TECHNICAL SPECIFICATION

StirLNG-1
Stirling Gas Liquefier for conditioning of LNG

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1. INTRODUCTION

Since more than sixty years Stirling Cryogenics has designed and manufactured gas liquefaction system, serving customers all over the world under all possible climatic conditions. This experience is used for our methane liquefiers called StirLNG. These have two specific fields of application:

- Production of LNG from a purified gas source such as pipe line or biogas.
- Re-liquefaction of boil off gas to compensate for losses in a cryogenic (storage) system (fuel stations, storage tanks, etc.).
- Re-liquefaction of boil-off gas on vessels. The StirLNG-1 is available in an adapted version specifically for maritime use.

In this quotation for the StirLNG you will find all technical information for this system and the different optional sub-systems to integrate the StirLNG into the customers main system.

We trust that this information demonstrates that our plant will be a valuable asset in meeting your methane liquefaction demand.

Thank you for your interest in our company and our products, we look forward to your valuable response.

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2. WORKING OF THE STIRLNG

2.1 Creation of cooling power

Creation of cooling power by the StirLNG is done by the so called reversed Stirling cycle which is based on the compression and expansion of helium gas in a closed cycle. The Stirling cycle efficiently produces cooling power at cryogenic temperatures by input of shaftpower from an electric motor.
For detailed information on this creation of cooling power we refer to our leaflet "The Stirling Cycle" available on our website.

2.2 Cooling power to LNG

One main advantage of the StirLNG is that the gas to be liquefied is not part of the cycle to create the cold. The gas will just flow through a cold heat exchanger in the StirLNG, where energy is extracted so the gas will cool down and then condensate against the cold surface.
This is a phase change at saturated equilibrium so there is no pressure change.

The (re-) liquefaction capacity of the StirLNG depends on the process conditions. Main parameters are the gas inlet temperature and pressure.
The influence of gas inlet temperature is obvious: with lower inlet gas temperature, the Cryogenerator needs to extract less energy and the liquefaction rate increases.

The influence of pressure is more complicated. The pressure of the gas determines the liquefaction temperature. At higher pressure the liquefaction temperature goes up. Higher liquefaction temperature results in a higher production rate, due to two reasons:

- First, less energy needs to be extracted to reach liquefaction temperature.
- Secondly, at higher temperatures the Stirling Cycle will generate more cooling power, while also using less input power.

Please refer to the production rate as function of pressure to determine the exact capacity.

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3. SYSTEM BACKGROUND

In this chapter different ways to integrate the StirLNG-1 into a complete system by the SYSTEM INTEGRATOR are discussed. In the drawings only one StirLNG-1is shown, but these can be multiple units to match the required liquefaction capacity.

The system integrator shall install the StirLNG-1 in a housing to protect it from ambient environment. This could be a simple shed or a container in which several StirLNG-1 can be placed.

3.1 Sources of heat

Conditioning of the LNG in a storage vessel is required for two different reasons.

1. Always present is the heat loss of the vessel by radiation and conduction, determined by the size and construction of the vessel. This heat loss needs to be compensated to keep the pressure and liquid temperature in the vessel stable.

2. Depending on the use of the vessel, the second source can be vapor return caused while transferring LNG to the next user in the chain. The receiving vessel will need to blow out gas, while the supplying vessel will need to take in gas. Usually this results in an increase of the gas pressure in the vessel supplying the LNG.

Both mentioned reasons will result in an increase of pressure inside the tank, but they will also increase the temperature of the LNG. As a high temperature might not be acceptable for the receiving party and allowed pressure increase in the tank is limited, the system will have to vent methane gas to stay within operating parameters.

This vent gas (“LNG gas” = Methane) is valuable (both economic and environmental) and should not be wasted.

The solution is so called “Conditioning” of the LNG, meaning that the temperature of the liquid is kept low while keeping pressure at saturation equilibrium.

This is done by extracting heat from the system, using one or more StirLNG Cryogenerators. This prevents the need for venting. Extracting the heat can be done in two ways: re-liquefaction of gas or cooling the (liquid) LNG. Either way has its pro’s and con’s; final choice depend on possibilities and requirements of the system integrator.

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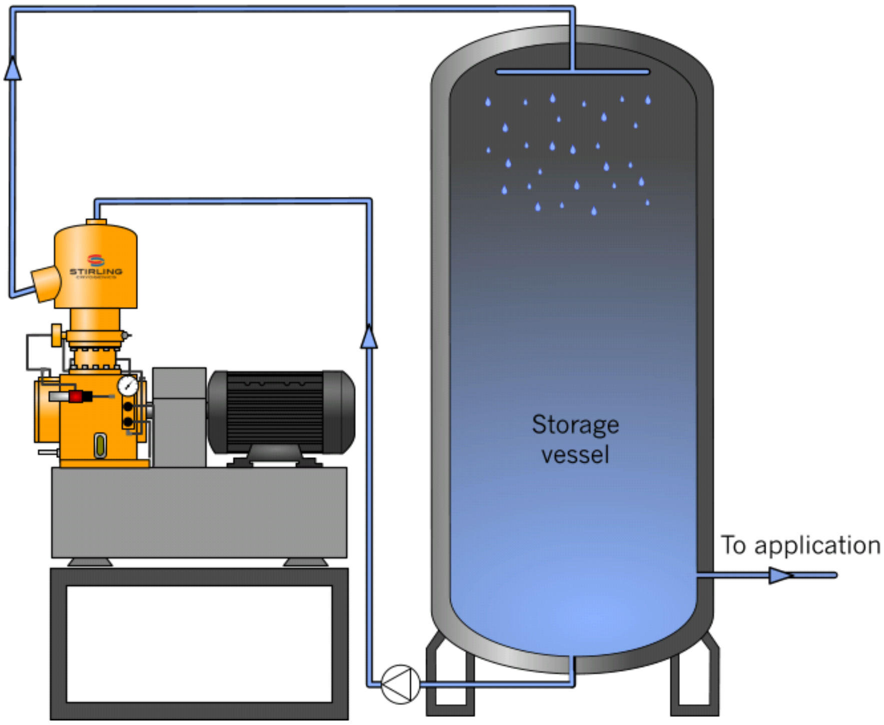
3.2 Cooling of LNG

In this first configuration (liquid) LNG is taken from the bottom of the vessel and is pumped through the cold heat-exchanger of the StirLNG, refer to Drawing 1.



Drawing 1, Conditioning of LNG by cooling of the liquid.

The liquid will cool a few degrees and is sprayed in the gas volume at the top of the tank. The amount of cooling will be the same as with re-liquefaction, it is just transferred in a different way. Cooling the liquid methane means preventing it from evaporating. Spraying of the liquid will reduce pressure build-up. As the liquid is below the saturation temperature inside the tank, the gas will condensate on the surface of the droplets.
This is an effective method of liquefying gas in a vessel, used widely in the cryogenic industry when tanks containing 'warm' liquid are filled with colder liquid from the supplying truck.

Once the gas pressure is at equilibrium with the liquid temperature, the LNG can be cooled down further by this method of cooling the liquid directly.
Cooling of liquid can be a continuous process, until the system control decides that a low enough pressure or temperature is reached and the StirLNG can be stopped.

One advantage of this set-up is that the StirLNG can be placed anywhere because the system contains a pump to overcome height. In this way it is independent of level of LNG or distance to the vessel.

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3.3 Re-liquefaction

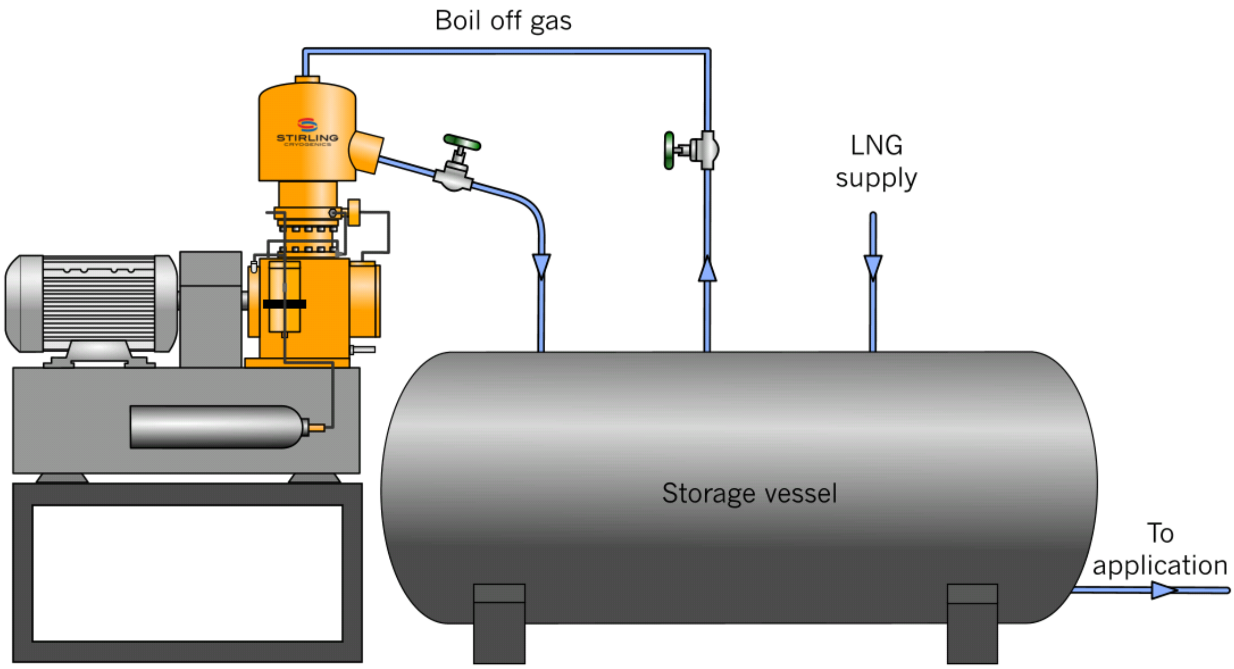
Re-liquefying the gas from the top of the tank is the second method of conditioning. The methane gas is fed to the StirLNG and re-liquefied at its equilibrium saturated temperature.
Pressure of the gas will slowly drop because of the liquefaction, which means that also the liquid will be cooled in time, be it that this will be a slow process.

The LNG produced by the StirLNG flows out downwards by gravity, meaning it shall be placed on top of the collection vessel. The infrastructure of the total set-up will determine whether it is possible to place the StirLNG on top of the main storage vessel or not, resulting in different ways to integrate the StirLNG.

3.3.1 Re-liquefaction directly into the main storage

The methane gas (boil off and/or vapor return) is fed from the tank to the StirLNG.
The simplest approach is to put the StirLNG above the main storage vessel so by gravity the liquid can flow into it directly, refer to Drawing 2.

This set-up is limited by the height of the main storage vessel. In case installation on top of the vessel is not possible, refer to 3.3.2.



Drawing 2, *Conditioning of LNG by liquefaction of boil-off gas directly.*

Re-liquefaction can be a continuous process, until the system control decides that a low enough pressure is reached and the StirLNG can be stopped.

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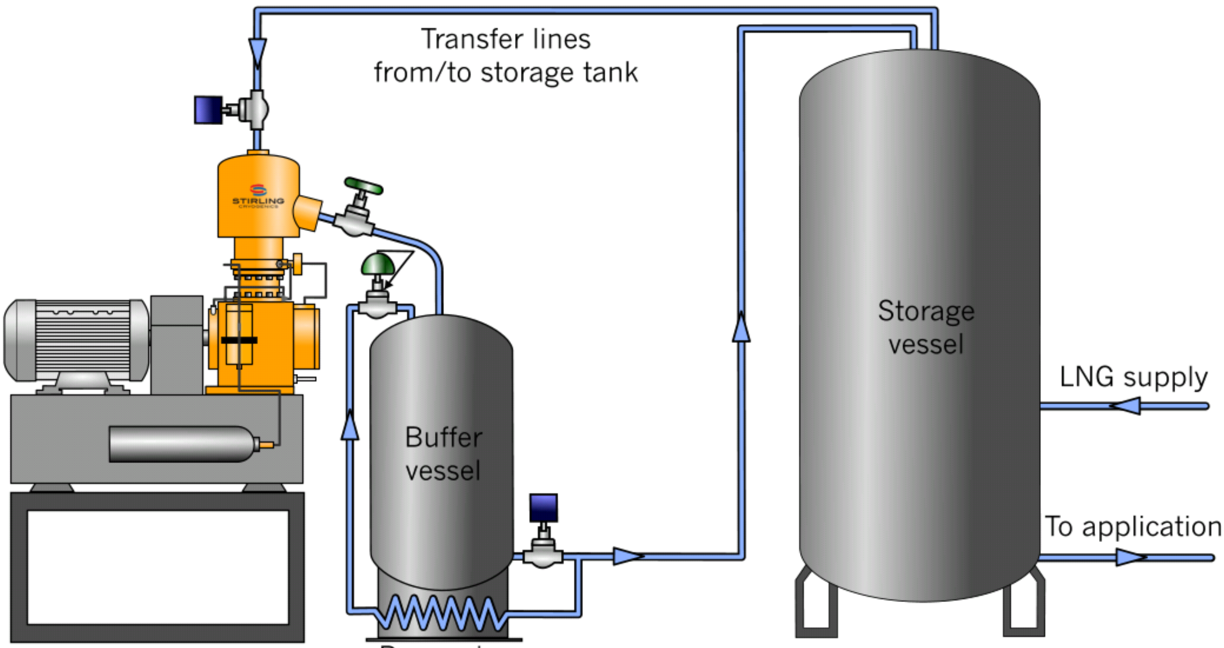
3.3.2 Through a transfer vessel

If the StirLNG cannot be installed above the main storage vessel a transfer vessel has to be used, refer to Drawing 2. This can be small in size and is only intended to store a small amount of liquid (200 up to 500 liters) until transfer.

Transferring is done batch wise when the transfer vessel is full, refer to Drawing 3.
The StirLNG is stopped and a cryogenic valve in the feed line is closed while another in the (bottom) connection is opened. The pressurizer evaporates some liquid to build up gas pressure which will push out the liquid into the actual main storage. When the transfer vessel is almost empty, the valves are reset, the StirLNG started and the transfer vessel will fill up again. This cycle repeats until the main vessel is full and the system control stops the StirLNG.



Drawing 3, Conditioning of LNG by liquefaction of boil-off gas through an intermediate vessel.

Using a transfer vessel, re-liquefaction cannot be continuous. During the transfer, re-liquefaction will be stopped while a part of the liquid will be evaporated to achieve the pressure build up. This will thus result in a loss of re-liquefaction capacity per day.

The influence of this effect depends on the final total system set-up.
This has to be considered by the system integrator when designing this set-up.

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4. TECHNICAL SPECIFICATIONS

This technical specification below describes the functionality for the StirLNG-1 Cryogenerator only. Further system components such as vessels, valves, piping and pumps are to be designed and supplied by the system integrator. These components will have effect on the final net production of LNG of the system since they will have losses consuming a part of the liquefaction capacity available from the StirLNG-1.

4.1 Specifications StirLNG-1

4.1.1 General design specifications StirLNG-1

Methane liquefaction rate	Depending process conditions, refer to the graph Appendix 2
Power consumption	Depending process conditions, refer to the graph Appendix 2
Maximum gas pressure	20 bar(g)
Electricity supply	3 Ph 400 V (+/- 5%), 50 Hz (+/- 2%), OR 3 Ph 480 V (+/- 5%), 60 Hz (+/- 2%), Others upon request
Ambient operating conditions	Between 5°C and 45°C (40 to 110F) The Cryogenerator can be stored (protected from the elements) between -15°C and 85°C (-4 to 185F). Below freezing provisions need to be made to prevent freezing of the cooling water.
Ambient humidity	20 – 95%
Explosion proof classification	ATEX, Zone 2
Dimensions	See enclosed drawing (dimensions in mm) Appendix 1
Weight	~550kg (1200 lbs)

(dimensions and weights are subjected to scope of supply)

4.1.2 Cooling water specifications StirLNG-1

Water quality	Flow rate	Pressure drop
0% anti-freeze/inhibitor	1000 l/h	2.4 bar
10% anti-freeze/inhibitor	1100 l/h	3.2 bar
20% anti-freeze/inhibitor	1200 l/h	3.7 bar
30% anti-freeze/inhibitor	1300 l/h	4.4 bar

Inlet pressure	Specification
Minimum	Depends on pressure drop and flow rate, refer to paragraph above
Maximum	6 bar(g)

Temperature	Specification
Nominal*	15 ºC
Range	0-25 ºC

* The cryogenic cooling capacity is specified at 15 ºC. The cooling water temperature affects the cryogenic cooling capacity.

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Cooling water quality	Specification
The machine requires drinking (potable) water quality. Drinking water is not regarded as an oxidizing liquid, therefore do **not** use deionized, distilled, demineralized or reverse osmosis water. Drinking (potable) water with the next specification:	
Acidity	between pH 7 and 9
Chlorine (Cl)	< 200 mg/l
Iron (Fe)	< 0.5 ppm
Manganese (Mg)	< 0.5 ppm
Hardness (CACO3)	< 5 °D
Sediment	< 600 ppm

4.1.3 Methane feed gas specification

Methane feed gas specifications to the StirLNG-1:

- Main stream CH4
- CxHy (C2 to C4) < 10%
- CxHy (C5+) < 1 ppm
- CO2 < 50 ppm @ atm. pressure, refer to Note 1
- H2O < -70ºC dew point
- H2S < 3,3 ppm
- Oil content < 0,01 mg/m3
- Particles < 0,1 micron
- N2/O2 < 10%, refer to Note 2

NOTES:

Note 1:
The 50 ppm CO2 stated above is not a specific requirement for the StirLNG, but (possibly) for the entire LNG logistic chain:
50 ppm is the maximum solubility of CO2 in LNG at atmospheric pressure. At higher pressures, the solubility increases and thus more CO2 can be allowed in the feed-gas to the StirLNG. However, it must be considered that when, down-stream in the logistic chain, the LNG pressure is decreased, solid CO2 will deposit. This will collect in vessels and potentially block or damage valves and pumps. Therefore, the lowest pressure in the logistic chain determines the maximum CO2 content of the feed-gas.

Note 2:
Oxygen and nitrogen will be liquefied only partially in the LNG flow, dependent on their solubility. The remainder needs to be vented from the liquefaction heat-exchanger. This will be a mixture of methane/oxygen/nitrogen gas that needs to be processed. This venting will have minor effect on liquefaction rate, but it will increase the rate of gas consumption against liquid production, depending on the quantity of N2/O2.

Note 3:
In case of re-liquefaction of boiled-off methane gas, or when cooling a liquid flow, the gas the composition will, generally, be correct for use.

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4.2 Capacity of the StirLNG-1

The capacity of the StirLNG for conditioning depends on the inlet temperature of the gas or liquid and the pressure. The capacity can be found in the graph attached.

To increase LNG production capacity, several StirLNG 's can be put in parallel. The gasflow will be divided and combined with manifolds. Technically there is no limit to the amount of StirLNG's to be combined.

4.3 StirLNG-1 Set up

Refer to the drawing for the size of the StirLNG-1 and its connection positions.

Installation of a Cryogenerator is relatively simple. It involves placing the Cryogenerator at its position and connecting it to the several interfaces:
- Methane gas inlet line
- LNG outlet line
- Cooling water lines
- Signal cables to the control box.
- Power cables from mains supply to the electric motor via a star/delta switch or frequency convertor.

The Cryogenerator can be placed in a hazardous area for which its components are suited. Recommended installation footprint is approx. 3 x 3 meter, refer to the drawing.

The control box, optionally supplied by Stirling Cryogenics, must be placed in the non-hazardous area. From here wiring for signals are directed to the Cryogenerator termination box.

Feed of power to the Cryogenerator electric motor is part of the customer preparation according local regulations.

Installation by a Stirling Cryogenics engineer is offered separately and is recommended for users not familiar with this equipment.

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5. SCOPE OF SUPPLY

Stirling Cryogenics offers the following scope of supply and options for the StirLNG-1:

Standard:

The standard delivery consist of the following:

- One basic 1-cylinder Cryogenerator, model SPC-1, suitable for Methane (re-)liquefaction, including safety switches, signal connection box and motor coupling.
- ATEX Zone 2 certified
- Cryogenerator base frame with cushion feet
- Internal helium gas and water lines
- Connections for water and helium supply
- Gas and liquid counter couplings, suitable for cryogenic use, loose delivered, to be welded on your lines
- Documentation (in English):
    - Pre-installation manual
    - Operating and maintenance instructions
    - CE declaration of conformity or incorporation (depending on which is applicable)

Additions:

The below mentioned components ARE required for proper operations. They can either be delivered by us or by the customer themselves.

Certification:

The standard StirLNG-1 will be certified according ATEX Zone 2 classification. Optionally the unit can be executed and certified according

2a) ATEX Zone 2 (standard incl. with Cryogenerator)
2b) ATEX Zone 1
2c) NEC 500, Class 1, Div. 2
2d) NEC 500, Class 1, Div. 1
2e) Others upon request

Electrical motor:

Optionally the unit can be equipped with a motor according above mentioned area class:

3a) ATEX Zone 2 motor
3b) ATEX Zone 1 motor
3c) NEC 500, Class 1, Div. 2 motor
3d) NEC 500, Class 1, Div. 1 motor
3e) Others upon request

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Start-up / Power supply:
In order to (smoothly) start up the Cryogenerator and to reduce the starting current, electrical equipment is required. This is not included in the standard StirLNG-1. Optionally the unit can be equipped with:

4a) Start/delta switch. This unit will be either CE or UL compliant, non-explosion proof, to be placed in the safe area.
4b) Frequency converter. This unit will be either CE or UL compliant, non-explosion proof, to be placed in the safe area.

Note: In case of 60Hz power supply we strongly advice to use a frequency converter to run the Cryogenerator at 50Hz and reduce wear and tear.

Control panel:
The Cryogenerator is standard equipped with safety switches and a termination box (see notes page 14). The unit must be controlled by a PLC control panel, that can optionally be provided by Stirling Cryogenics. This control panel will contain a Siemens PLC with touch screen and other required equipment. This panel will be non-explosion proof and is to be placed in the safe area. 10 Meter wiring (according the applicable certification) between the Cryogenerator and Cryogenerator is included.

5a) Control panel CE (non-Ex)
5b) Control panel UL (non-Ex), NEC 500, Div. 2 Cryogenerator
5c) Control panel UL (non-Ex), NEC 500, Div. 1 Cryogenerator. This additions includes 10mtr. wiring and conduits between cooler and panel according NEC 500, Div. 1 requirements. Price might vary upon physical dimensions and/or lay-out.

Options:

The following options can be ordered for the StirLNG-1:

Support frame:
Our standard support frame for the Cryogenerator with a height of 465mm.

Note: Please be aware that, in order for proper operation, the Cryogenerator needs to be connected to a vessel, into which the formed LNG flows by gravity. Therefore the cooler needs to be above the vessel.

500 liter transfer vessel:
Either ASME or PED certified, horizontal transfer vessel. Including:

- Pressure build up unit
- Level sensor
- One pressure transmitter
- 2 automated valves
- Connection for gas inlet and liquid outlet incl. bayonet coupling
- Liquid and gas connection for Cryogenerator including 2 x 1,5mtr. hoses and hand valves.

7a) Maximum operating pressure 10 barg (145 psig)
7b) Maximum operating pressure 20 barg (290 psig)

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Water chiller:
This option will supply a stand-alone water chiller to provide cooling water to the Cryogenerator, suitable for the conditions specified. The water chiller will be non-explosion proof and needs to be placed in the safe area. 20mtr. connection lines are included. The water chiller will be either CE or UL/ASME.

Cylinder of Helium gas:
The Cryogenerator needs to be filled with helium gas during installation, min. purity of 99,99%. Only after maintenance the unit needs to be refilled.
This option will supply a European certified 200 bar, 50L gas cylinder of Helium including suitable pressure regulator.

Consumable parts and tools:
Consumable parts for xxx hours of operation (several packages are available) + required tools.

Site services:
Commissioning, start-up assistance and installation can be provided by a Stirling Cryogenics certified Engineer, at customers site for the duration, and according conditions, as specified in the commercial quotation.

Training maintenance Engineer:
1 Week of training at the manufacturer in The Netherlands for operations and maintenance. Lodging, breakfast and lunch is included. Travel expenses are at customer's account.

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Remote monitoring:
All StirLNG PLC Control Panels (Siemens based) include local control of the system through a Touch Screen. Besides this local accessibility, DHI also offers 3 different options for remote monitoring and on/off control.

a) 2nd Touch Screen, either wired or remote by WIFI (intranet or internet)
An extra Touch Screen which can be positioned in e.g. the customers' control room. From this Touch Screen, the customer can remotely read out all system information and can manually stop and start the StirLNG as required.

The 2nd Touch Screen shall be connected over the customers' intranet. The maximum of extra displays is 2. The display can also be taken over by a pc on the local network

b) Integration in the customers' control system through OPC Server
In this option, the customer is able to read out all relevant I/O signals of the StirLNG through an OPC server. The customer can incorporate these data in his own control system, e.g. to monitor operation and store data.

From the customer system control, the StirLNG can be stopped and started as required. Several communication protocols (Profibus, Modbus, Ethernet/IP, etc.) are available upon request

c) Over internet on a mobile device or PC through an EWON modem
A modem will be added to the StirLNG Control, which the customer shall connect to the Internet through a local router. Through a password the customer can now have access using any computer, smartphone or mobile, with a maximum of 2 logins (VPN connection) . On this device the customer can monitor the StirLNG and start and stop it as required.
To notify the operator in case of an alarm, the internal modem will send an SMS message to up to 5 phone numbers.

This option also allows the Stirling Cryogenics Service Centre to access the StirLNG for support and to read the stored data. In case of a Service contract, this option is mandatory to allow maximum system uptime.

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Not included in the delivery are:

- Housing/enclosure for the Cryogenerator
- Lines for liquid and gas
- Main power box and fuses
- Any of the lines, pumps and vessels described in this specification unless quoted separately
- Commissioning, site installation & site acceptance test, unless explicitly mentioned

Notes:

- The Cryogenerator is standard equipped with safety switches and a termination box. However, the Cryogenerator requires a control system to start and stop, and to safeguard the proper functioning of the cryogenic system, protecting it from internal and external faults (no oil pressure, no water flow, etc.). This control can be supplied by Stirling Cryogenics as option (see point 5) or will have to be integrated in the customers control system.
  In this case, Stirling Cryogenics will provide a Siemens S7 software block containing the required control logic plus the electrical diagram for the customers' hard-ware.

- Service interval is 6,000 operating hours (5,000 for 60 Hz operation).

- The Cryogenerator can operate with a 60Hz motor (with a lower Helium pressure) but with a reduced MTBM of 5,000 operating hours and increased wear and tear. Therefore we recommend either a 50Hz motor or the use of a frequency converter.

- The StirLNG-1 will be tested at the factory for its performance using liquid Nitrogen. Customer can witness the final 2 days of Factory Acceptance Test at their own cost. Additional factory acceptance test/requirements need to be discussed and might be subject to additional charges.

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6. INSTALLATION AND MAINTENANCE

Installation, commissioning and maintenance of the plant must be done by a Stirling Cryogenics service engineer or by our certified representative to qualify for the warranty. The plant room must be prepared by the customer according to Stirling Cryogenics Site Preparation Instructions and must comply with local legislation. Local, qualified technicians, made available by and on account of the customer, will carry out electrical and plumbing work, as well as construction/civil work prior and during installation.

Stirling Cryogenics has a pool of field engineers available to assist during the installation and commissioning at site. This will charged at actual according the applicable tariff sheet.

Stirling Cryogenics also offers training courses at our facilities in Son, The Netherlands, to improve the knowledge of plant operators and technicians.

During the warranty period, maintenance must be performed by a technician trained by Stirling Cryogenics at Son or by a Stirling Cryogenics engineer. If non-qualified personnel carry out maintenance or repair, the warranty will be null and void.

We recommend to include in your order a set of consumable parts and tools to cover the initial requirements.

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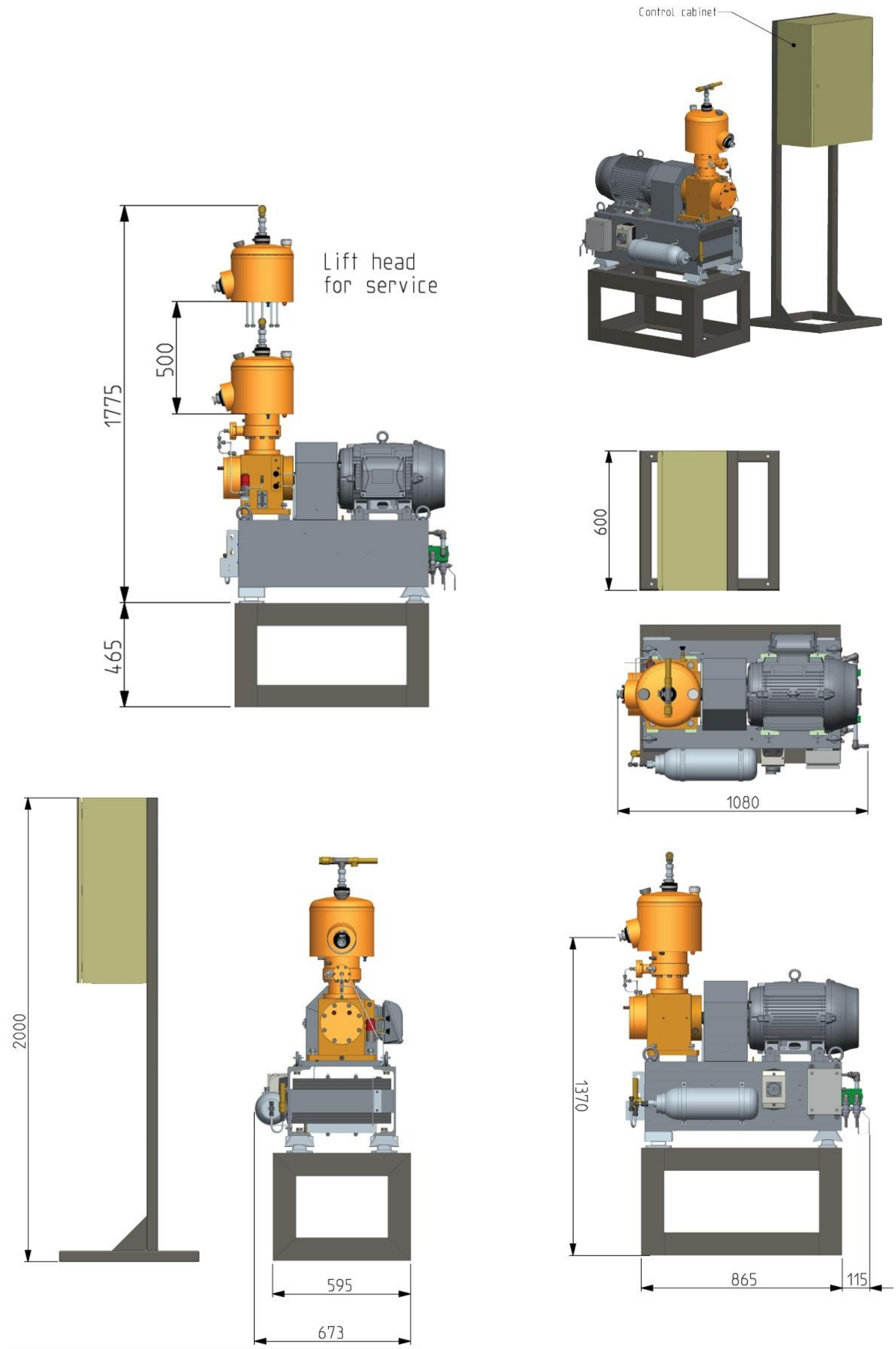
APPENDIX 1



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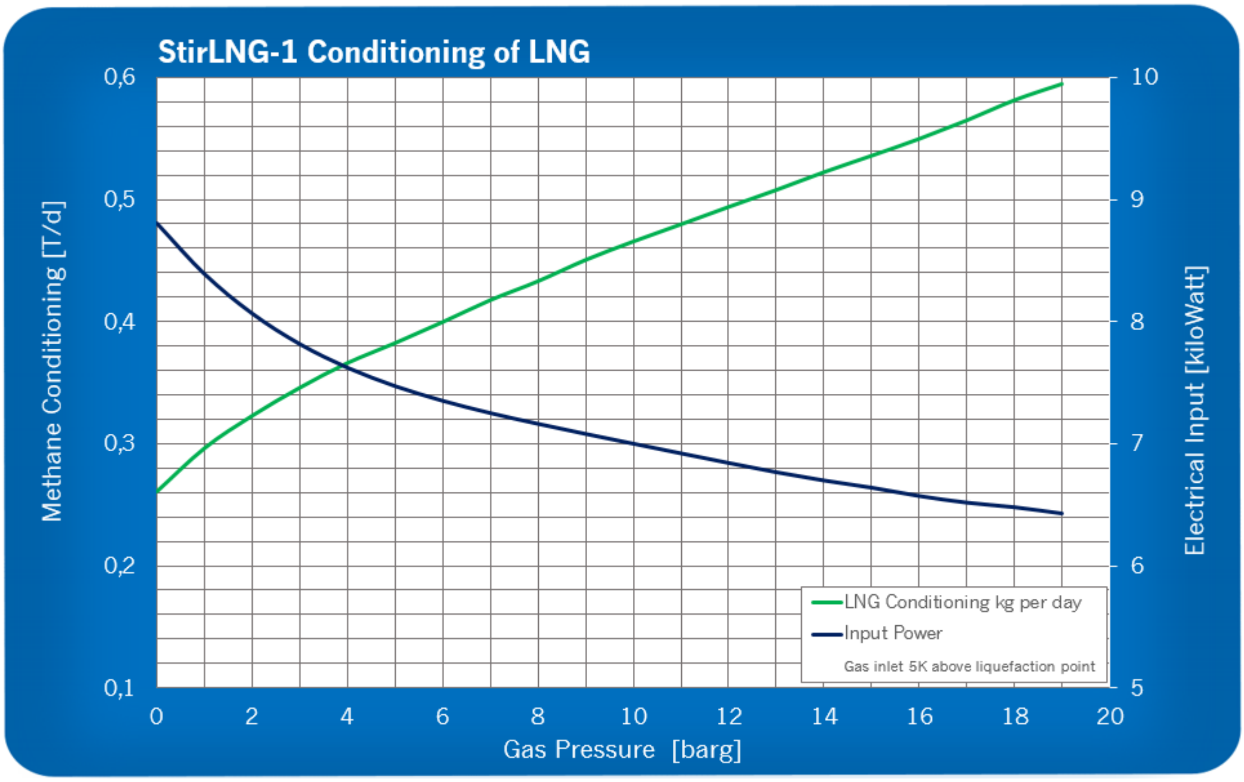
APPENDIX 2



Gas Pressure	Temp. Liquid	CO_2(1)	Cooling Power	Electrical Input	Capacity based on pure methane				
Barg	K	PPM	W	kW	Nm³/hr	kg/hr	l/hr	T/day	Gal/day
0	111	66	1550	8,9	14,9	10,7	25,4	0,26	161
2	126	230	1820	8,1	18,7	13,4	33,5	0,32	213
4	135	486	1980	7,7	21,2	15,2	39,4	0,36	250
6	141	800	2080	7,4	23,1	16,6	44,4	0,40	282
8	146	1213	2170	7,2	25,0	18,0	49,3	0,43	313
10	151	1837	2250	7,0	26,8	19,2	54,1	0,46	343
12	155	2562	2315	6,9	28,5	20,5	58,9	0,49	374
14	158	3287	2360	6,7	30,2	21,6	63,7	0,52	404
16	161	4217	2410	6,6	31,9	22,9	68,9	0,55	437
18	164	5412	2460	6,5	33,7	24,2	74,4	0,58	472
20	167	6944	2505	6,4	35,5	25,4	79,9	0,61	507

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