TECHNICAL SPECIFICATION

StirLNG-4
Stirling Cryogenics gas liquefier for LNG conditioning

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Stirling Cryogenics is a registered trade name of DH Industries BV
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cool to excel.

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 3 specific fields of application:

- Production of LNG from a purified gas source such as pipe line or biogas to make it suitable for transport and/or to use it as fuel.
- 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-4 is available in an adapted version specifically for maritime use.

In this technical specification for the StirLNG-4 you will find all technical information for this system and the different optional sub-systems to integrate the StirLNG-4 into the total system.

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

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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.

3. SYSTEM BACKGROUND

In this chapter different ways to integrate (by e.g. the System Integrator) the StirLNG-4 into a total system are discussed. In the schematics only one StirLNG-4 is shown, but these can be multiple units to match the required liquefaction capacity.

The StirLNG-4 needs to be installed in a housing to protect it from ambient environment. This can be a simple shed or a container in which several StirLNG-4 can be placed.

3.1 Sources of heat

For two different reasons conditioning of LNG in a storage tank is required as venting of (BOG) gas is economically and environmentally not preferred.

Reason 1:
Continuous heat loss is present due to radiation and conduction through the insulation, determined by the size and construction of the tank. This heat loss, causing the LNG to evaporate, needs to be compensated to keep the pressure and liquid temperature in the tank stable.

Reason 2:
Depending on the use of the tank, the second source of heat loss can be vapor return while transferring LNG. Difference in the LNG conditions and losses during the transfer, usually results in an increase of the gas pressure in the tank from which the LNG is transferred.

Both mentioned reasons will result in an increase of pressure inside the tank, which will also increase the temperature of the LNG. A high liquid temperature or gas pressure might not be acceptable for the receiving party. Also the maximum pressure of a specific tank construction is limited. Therefore, the LNG tank system will have to reduce the methane gas increase to stay within operating parameters without the need of venting gas.

The solution to prevent (BOG) gas venting is called “Conditioning” of LNG, meaning that the temperature of the liquid is kept low while keeping pressure at saturation equilibrium.

Conditioning is based on extracting heat from the LNG storage system, using one or more StirLNG liquefiers.

Extracting heat can be done with two different concepts:

a) Through cooling the LNG before it evaporates.
b) By re-liquefying the (BOG) gas as it is being formed.

Either concept has its specific benefits; the choice depends on (physical) possibilities, circumstances and requirements of the total LNG tank system.

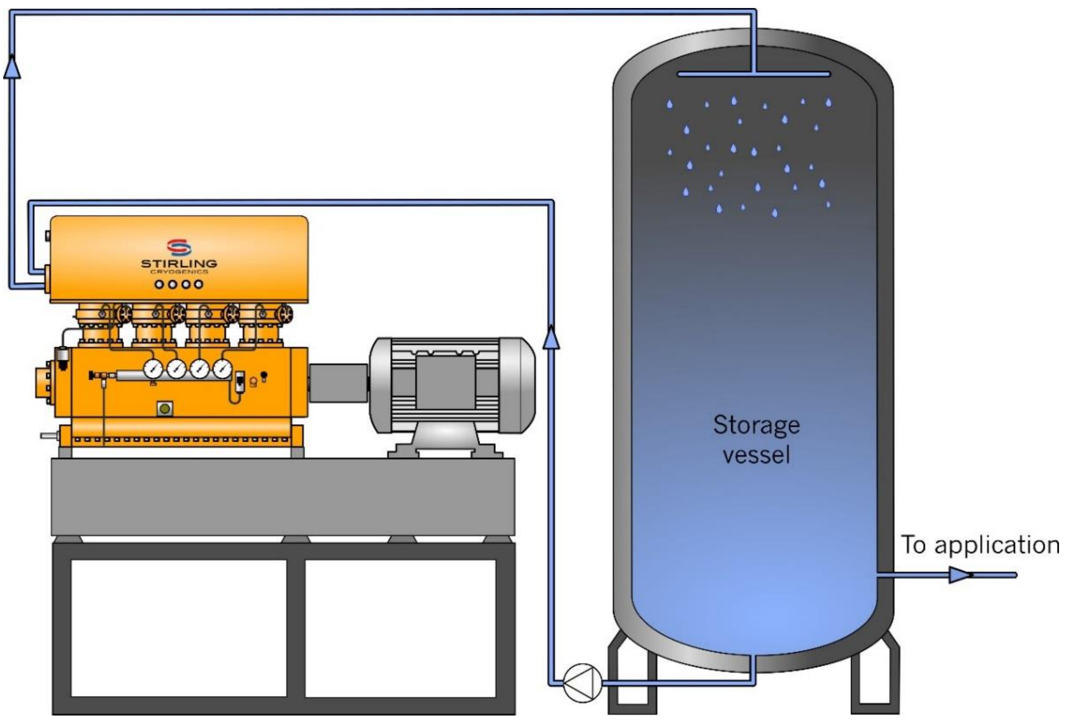
In the next paragraphs these concepts are described in more detail.

3.2 Direct Liquid Cooling (LC)

The concept of Liquid Cooling is based on an effective method of reducing pressure in a storage tank called “Spraying”. This method is widely used in the cryogenic industry when tanks contain ‘warm’ liquid. Pressure and temperature are reduced by filling and spraying with colder liquid supplied from a delivery truck, or by using spray pumps in larger tanks making use of the relatively cold liquid at the bottom of the tank.

Spraying can be done only during a limited period of time as the amount of ‘cold’ in the liquid is limited. Once all of the LNG in the storage tank is at the same temperature, spraying cannot function anymore.

With the StirLNG LC concept, LNG is taken from the bottom of the tank and pumped through the heat-exchanger of the StirLNG-4. Here energy is extracted due to which the LNG will cool down a few degrees. Via the spray nozzles the ‘colder’ liquid is sprayed into the gas area at the top of the tank and by this process the tank pressure reduces (ref. Drawing 1).



Drawing 1, Liquid Cooling concept

Cooling of LNG can be a continuous process. A control system will monitor the temperature and pressure and stops the StirLNG-4 when the storage tank reaches a pre-set level.

Advantages of the Liquid Cooling concept:

- the StirLNG-4 can be placed anywhere because the system contains a pump to overcome height and/or distance between the storage tank and the StirLNG-4.
- the composition of the LNG or the BOG has no effect on the cooling capacity of the StirLNG-4 (for more information we refer to the re-liquefaction concept in paragraph 3.3).

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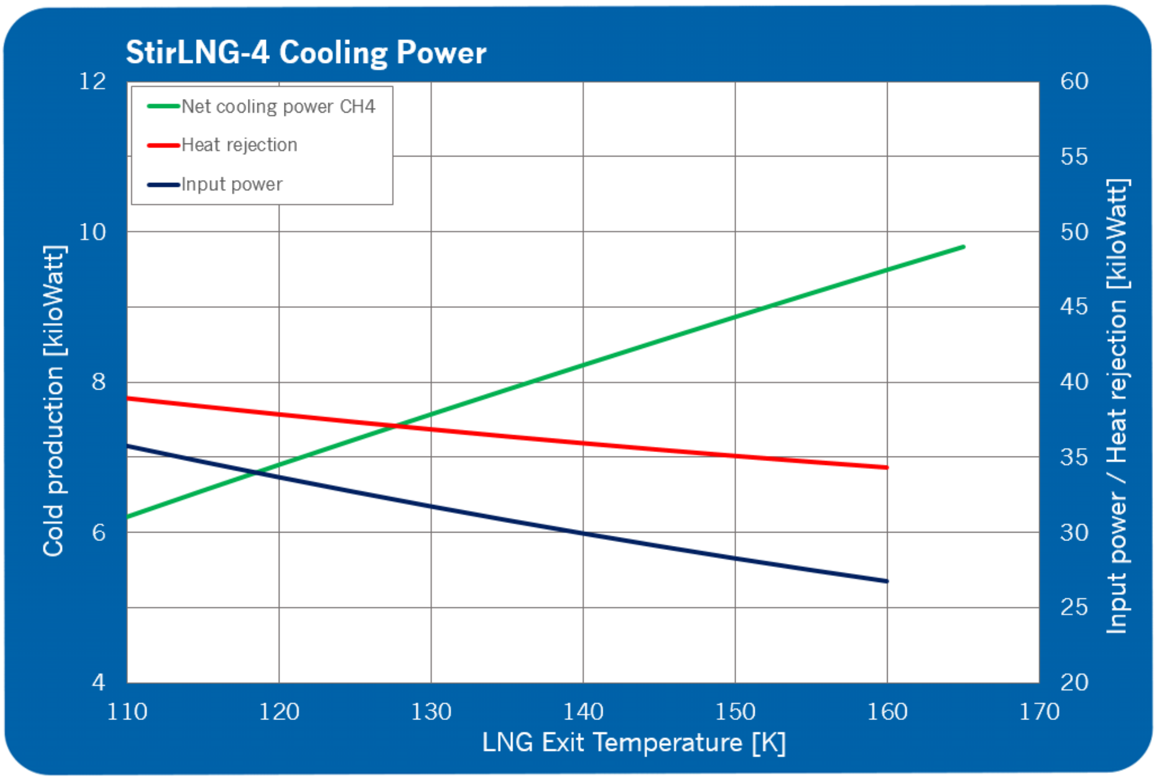
3.2.1 Cooling capacity of the StirLNG-4 (in LC mode)

The next graph and table show the cooling capacity in liquid cooling (LC) mode of a single StirLNG-4 as function of the LNG exit temperature. The following conditions apply:

- The cooling capacity is brut cooling capacity in W into the LNG flow.
  Net cooling power available will be less due to heat input and flow losses of the VJ lines as well as pump labor and inefficiency depending flow pressure drop. The amount has to be determined by the system designer.
- Temperature difference (dT) of the LNG in and out of the liquefier will depend of the flow chosen by System Integrator.
- Data is based on a cooling water temperature of 15°C, with a flow of 4,000 ltr/hr and 20% glycol. Other water temperatures will have an effect on these capacity numbers and are available upon request).

LNG Exit Temp	Cooling Power	Electrical Input
K	W	kW
111	6250	35,4
126	7350	32,3
135	7950	30,7
141	8400	29,6
146	8750	28,8
151	9050	28,0
155	9300	27,5
158	9500	26,9
161	9700	26,5



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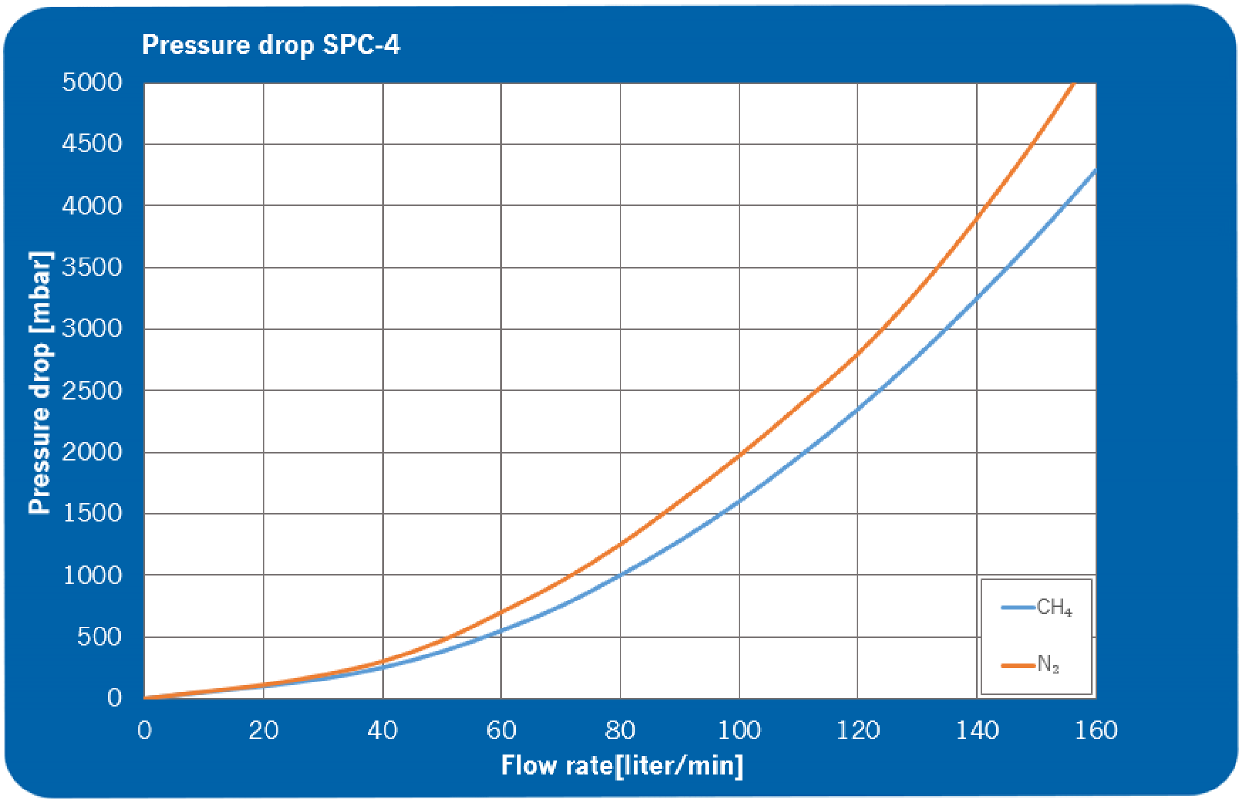
3.2.2 Heat exchanger pressure drop



The above graph shows the pressure drop over the heat-exchanger of one StirLNG-4.
The system designer is responsible to determine the total pressure drop over the total piping system including the StirLNG-4 heat exchangers. This pressure drop is required to determine the heat input by labor and inefficiency of the pump(s), which will influence the final cooling capacity available to the LNG tank.

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3.2.3 Capacity calculation example

As example 2x StirLNG-4 are chosen to cool the liquid flow at the outlet of the StirLNG-4 to 136K, preventing warmer LNG in the storage tank from evaporating. The cooling capacity per StirLNG-4 is 7,990 W, 15,980 W in total. Since there are system losses, not all this cooling power will be available in the spray entering the storage tank. Two main losses need to be considered:

- Insulation heat losses by the insulated piping. For this example 500 W is taken.
- Pumping losses by the LNG pump. In order to determine these, a flow needs to be chosen, which will determine the dT across the liquefier. For this example a total flow of 80 l/min is assumed.
  - StirLNG-4 losses:
    Each liquefier will see a flow of 40 l/min. As per the graph, this results in a dP of 300 mbar in the HX. The flow friction per StirLNG-4 is the multiplication of dP and V, being 20 W.
    Total for 2 liquefiers: 40 W
  - Pipe losses:
    The 80 l/min flow has to pass all piping and spray nozzles, for this a dP of 2 bar, resulting in a friction loss of 270 W is assumed.
  - Efficiency of the pump:
    Assumed to be 50%: Total of 310W results in 465 W flow losses.

Total losses:
500W + 465 W is 965 W, which results in a total available net cooling power of 15980 – 965 = 15,015 W.

It is the responsibility of the System Integrator to perform this determination for the particular design at hand.

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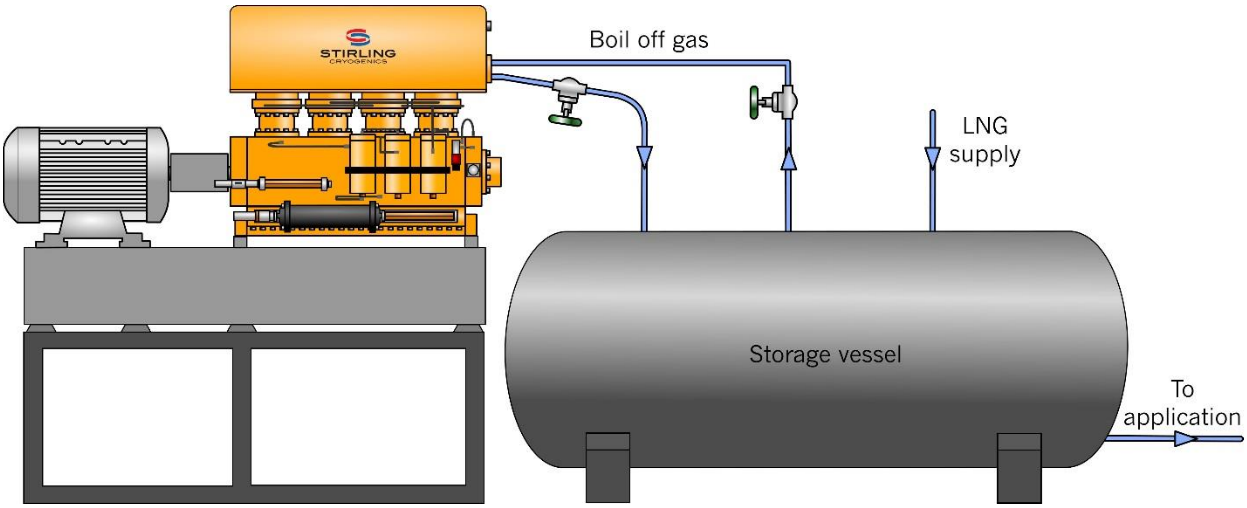
3.3 Re-liquefaction of BOG (RL)

In this concept the BOG is fed to the StirLNG-4 and re-liquefied at its equilibrium saturated temperature (depending on the actual pressure of the storage tank). Because gas is converted in much denser liquid, the gas pressure will slowly drop. With reducing pressure the LNG will get colder, meaning that also the storage tank content will be cooled in time.

The LNG produced by the StirLNG-4 flows out downwards by gravity, meaning it is required to be placed above the LNG (storage) tank. The configuration of the total system will ultimately determine the final location of the StirLNG-4.



Drawing 1: *Re-liquefaction of BOG concept*

Cooling of LNG can be a continuous process. A control system will monitor the temperature and pressure and stops the StirLNG-4 when the storage tank reaches a pre-set level.

Note:
The presence of other composition components might affect this temperature. Especially N2 is of importance since this will lower the liquefaction temperature of the mixture, resulting in a lower cooling capacity of the StirLNG-4.

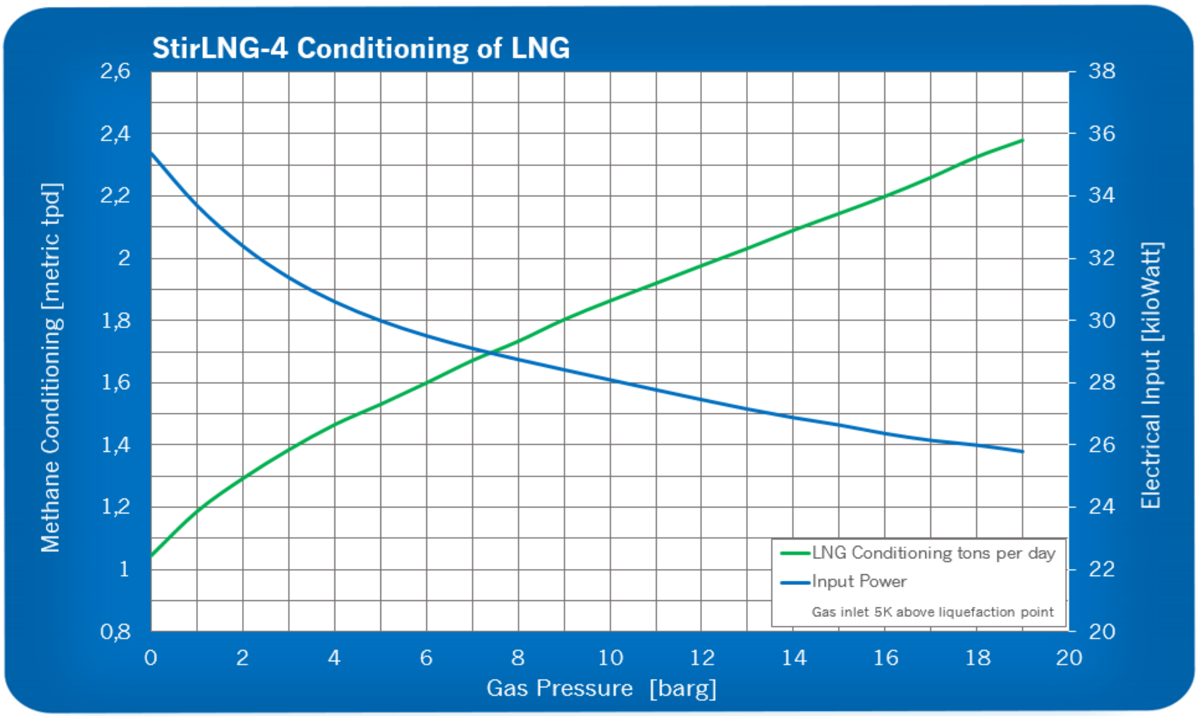
Even though the quantity of N2 in the LNG may seem low, due to the fact N2 evaporates faster, the content in the BOG is much higher. As example, 0.5 mol% of N2 in the LNG in an atmospheric tank will produce BOG with a content of 12 mol% N2. This result in a liquefaction temperature that drops from 112 to near 90K, affecting the liquefaction capacity in kg/h by 16%.

Advantages of the Re-liquefaction concept:

- higher net cooling capacity (no pump needed)
- No maintenance for pump needed

3.3.1. Cooling capacity of the StirLNG-4 (in RL mode)

The next graph and table show the single StirLNG-4 cooling capacity in re-liquefaction (RL) mode under following conditions:



Gas Pressure	Temp. Liquid	CO_2(')	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	6250	35,4	60,2	43,2	102,3	1,0	648
2	126	230	7350	32,3	75,4	54,1	135,4	1,3	858
4	135	486	7950	30,7	85,0	61,0	158,3	1,5	1004
6	141	800	8400	29,6	93,4	67,0	179,3	1,6	1137
8	146	1213	8750	28,8	100,9	72,4	198,9	1,7	1261
10	151	1837	9050	28,0	107,8	77,3	217,6	1,9	1380
12	155	2562	9300	27,5	114,6	82,2	236,7	2,0	1501
14	158	3287	9500	26,9	121,4	87,1	256,4	2,1	1626
16	161	4217	9700	26,5	128,4	92,2	277,3	2,2	1758
18	164	5412	9900	26,1	135,8	97,4	299,4	2,3	1898
20	167	6944	10050	25,7	142,3	102,1	320,6	2,4	2033

CONDITIONS:

- Guaranteed values will be the cooling power on the cold head of the Cryogenerators.
- The above mentioned data is based on pure Methane. The actual re-liquefaction capacity might be lower, based on the composition of the boil off gas. Especially Nitrogen will lower the re-liquefaction point (hence cold head temperature) and therefor will reduce the available cooling power. Upon request we can provide the specific re-liquefaction capacity based on the specified BOG composition.
- Data is based on a cooling water temperature of 15°C, with a flow of 4,000 ltr/hr and 20% glycol. Other water temperatures will have an effect on these capacity numbers and are available upon request).

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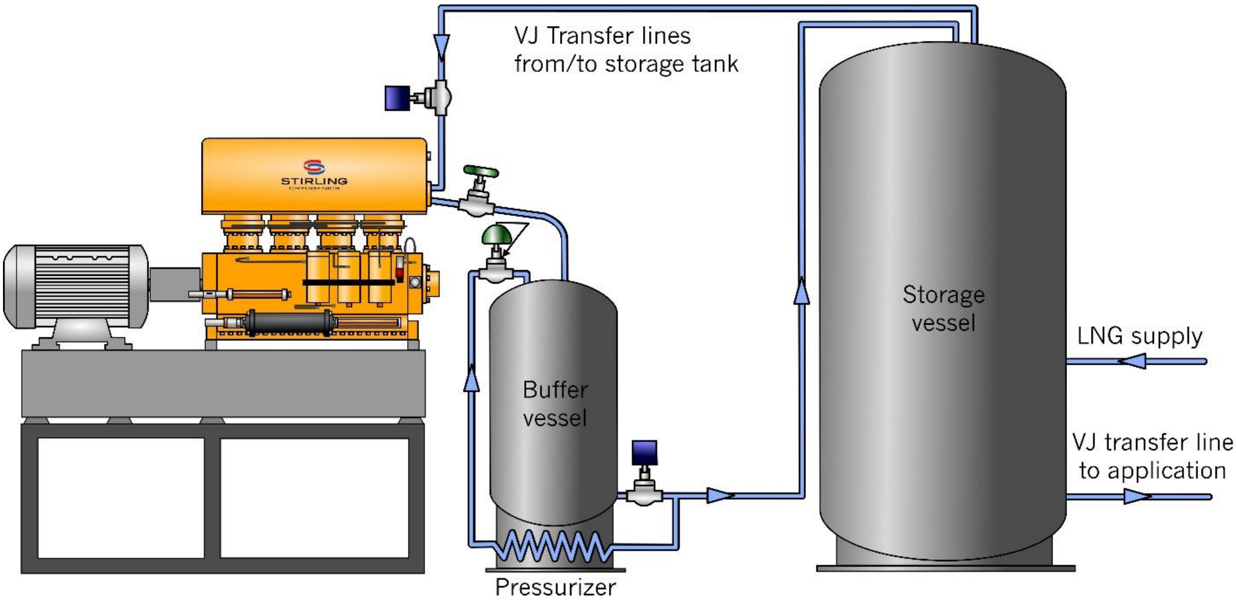
3.3.2 Through a transfer vessel

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 re-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.

4. TECHNICAL SPECIFICATIONS

This technical specification below describes the functionality for the StirLNG-4 only. Other system components such as vessels, valves, piping and pumps are to be designed and supplied by the system integrator. These components will influence the final net production capacity of LNG of the system since these will create losses and consume a part of the liquefaction capacity available from the StirLNG-4.

4.1 Functional specifications StirLNG-4

Methane liquefaction rate	Depending process conditions, refer to §3.2 and §3.3
Power consumption	Depending process conditions, refer to §3.2 and §3.3
Maximum process pressure	20 bar(g)
Electricity supply	3 Phase 400 V (+/- 5%), 50 Hz (+/- 2%), OR 3 Phase 480 V (+/- 5%), 60 Hz (+/- 2%), Others upon request
Ambient operating conditions	Standard between 5°C and 45°C (40 to 110°F)
Ambient humidity	20 – 95%
Preferred cooling water flow	4.000 L/hr @ 15ºC per StirLNG-4 (1060 gal/hr @ 68ºF); 20% glycol (other water temperatures upon request)
Explosion proof classification	ATEX, Zone 2
Dimensions	See enclosed drawing (dimensions in mm) in Appendix 1
Weight	1,400 kg per StirLNG-4

(note: dimensions and weights are subjected to the final scope of supply)

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4.2 Methane feed gas specification

The required methane feed gas specification to the StirLNG-4 is:

- Main stream CH_4
- CxHy (C_2 to C_4) < 10%
- CxHy (C_5^+) < 1 ppm
- CO_2 See table 3.3.1., refer to Note 1
- H_2O < -70ºC dew point
- H_2S < 3,3 ppm
- Oil content < 0,01 mg/m^3
- Particles < 0,1 micron
- N_2/O_2 < 10%, refer to Note 2

Note 1.)
The CO_2 stated level stated in the table is not a specific requirement for the StirLNG-4, but for the entire LNG logistic chain at that given pressure.
It must be considered that when, down-stream in the logistic chain, the LNG pressure is decreased, solid CO_2 will deposit. This deposit will collect in vessels and potentially block or even damage valves and pumps. Therefore, the lowest LNG temperature in the logistic chain determines the maximum CO_2 content of the feed gas.

Note 2.)
Non-condensable gases might 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 non-condensable gases.

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4.3 Installing a StirLNG-4 liquefier

Installation of a StirLNG-4 liquefier is relatively easy. It involves locating the StirLNG-4 at its (final) position and connecting it to all 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 either a star/delta switch or frequency convertor).

The StirLNG-4 can only be installed in a hazardous area depending on the ATEX or NEC configuration. Recommended installation footprint is approx. 3 x 3 meter.

The control box, optionally supplied as part of the StirLNG-4, must be located in a non-hazardous area.

Electric power availability and connections is part of the customer site preparation (according to local regulations).

Installation of the StirLNG-4 is mandatory required to be performed by one of our service engineers.

Note:
Each StirLNG-4 liquefier will be tested at the factory for its performance using liquid Nitrogen.
A customer can witness the standard Factory Acceptance Test (max. 2 days) at their own cost.
Additional factory acceptance test(s) and/or special requirements need to be discussed upfront and might be subject to additional charges.

(see Appendix 1 for StirLNG-4 dimensions and connection positions).

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STIRLING CRYOGENICS

5. SCOPE OF SUPPLY

Standard configuration:

1) The standard delivery consist of:

- One basic 4-cylinder Cryogenerator, model SPC-4, suitable for Methane (re-)liquefaction, including safety switches, signal connection box and motor coupling.
- ATEX Zone 2 compliant
- ATEX Zone 2 motor
- 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, separately delivered, to be welded on customer lines
- Documentation (in English):
  - Pre-installation manual
  - Operating and maintenance instructions
  - CE declaration of conformity or incorporation (depending on which is applicable)

Options

2) Certification:

The standard StirLNG-4 will be certified according ATEX Zone 2 classification. Optionally the unit can be executed and certified according:

2a) ATEX Zone 2 (standard incl. with each StirLNG-4)
2b) ATEX Zone 1
2c) NEC 500, Class 1, Div. 2
2d) NEC 500, Class 1, Div. 1
2e) Others upon request

3) Electrical motor:

The standard StirLNG-4 will be equipped with a ATEX Zone 2 motor. Optionally the unit can be equipped with another motor type according specified area class:

3a) ATEX Zone 2 motor (standard incl. with each StirLNG-4)
3b) ATEX Zone 1 motor
3c) NEC 500, Class 1, Div. 2 motor
3d) NEC 500, Class 1, Div. 1 motor
3e) Others electrical motors upon request

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4) Start-up / Power supply:

In order to (smoothly) start up the StirLNG-4 and to reduce the starting current, electrical equipment is required. This is not included in the standard StirLNG-4 configuration. The unit must be equipped with either:

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

Note: In case of 60Hz power supply a frequency converter is mandatory to be part of the standard StirLNG-4 configuration.

5) Controls:

The StirLNG-4 is standard equipped with safety sensors and a termination box. In addition, the StirLNG-4 requires a Control Panel to start and stop, and to safeguard the proper operation, protecting it from internal and external faults (no oil pressure, no water flow, etc.).

Each Control Panel/Unit (in a IP 54 cabinet) is non-explosion proof and has to be placed in a non-hazardous area. Start & stop signals need to be provided by the customer's control system. Error signals can be provided by the Control Panel/Unit (Ethernet communication by Profibus or other protocols can be made available on request). Our control units are delivered with a Siemens PLC (S7-1200 version 12) and other required components;. Also max. 10m of wiring is included. The Control Unit has no User Interface.

- 5a) Control panel CE (non-Ex. proof)
- 5b) Control panel UL (non-Ex. proof), NEC 500, Div. 2
- 5c) Control panel UL (non-Ex. proof), NEC 500, Div. 1 (incl. conduits between cooler and panel according NEC 500, Div. 1 requirements).
- 5d) Control unit CE (non-Ex. proof)

Both the Control Panel and the Control Unit have an option for data logging to enable fast troubleshooting and reduce downtime. They can (optionally) be supplied with an industrial VPN router for easy remote access. This offers the possibility to troubleshoot machines remotely without going on site.

When the StirLNG-4 control need to be part of the customers control system, it is also possible to deliver the system without a Control Panel/Unit. On request we can provide more details.

6) Support frame:

Our standard support frame for the StirLNG-4 is delivered with a height of 830mm.
Other heights are available on request.

7) 500 liter horizontal transfer vessel:

- Either ASME or PED certified
- 1 explosion proof level sensor, 1 pressure transmitter and 2 automated valves
- Connection for gas inlet and liquid outlet incl. bayonet coupling
- Liquid and gas connection for the StirLNG-4 including 2 x 1,5m hoses and hand valves
  - 7a) Maximum operating pressure 10 barg (145 psig)
  - 7b) Maximum operating pressure 20 barg (290 psig)

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8) Suitable for outdoor placement:

Each StirLNG-4 liquefier can be made suitable for outdoor placement with temperature conditions in the range of -5°C to + 45°C (23°F to 113°F).

For this option, the StirLNG-4 will be supplied with:

- Additional stainless steel components and a special surface coating for corrosion protection
- IP 65 enclosures for electrical equipment

When placed outside, the customer needs to provide a canopy (e.g. for rain, snow or debris protection) for the StirLNG-4 and other equipment (if applicable).

For more extreme outdoor conditions (in the range of -5°C to -20°C) , suitable pre-cautions and/or modifications need to be applied; this specific StirLNG-4 configuration needs to be designed case-by-case.

9) 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 non-hazardous are (20m connection lines are included). The water chiller will be either CE or UL/ASME.

10) Cylinder of Helium gas:

The StirLNG-4 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 contains a European certified 200 bar, 50L gas cylinder of Helium including suitable pressure regulator.

11) Consumable parts and tools:

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

12) Training Maintenance Engineer:

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

Not included in the StirLNG-4 Scope of Supply are:

- Any housing/enclosure for the StirLNG-4
- Piping for liquid and/or gas
- Main power (connection) box, cables 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

Stirling Cryogenics is a registered trade name of DH Industries BV
For more information on the Stirling Cryogenics product range, please contact:
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6. SERVICE AND MAINTENANCE

Service

With our Service Agreements we cover all required (preventive) maintenance to ensure a reliable operating of the StirLNG-4. Depending on customer's personal needs, the service concept can be individualized and tailored to the specific requirements.

With this approach we offer a choice of options for planning and performing maintenance. Whether you're prioritizing high levels of product safety, want to keep a tight hold on your maintenance costs at all times, or wish to optimize your total cost of ownership.

Maintenance

Each StirLNG-4 reliquefier requires preventive (minor) maintenance only after each 6,000 operating hours. Specific Consumable parts sets are available for this maintenance (please see our price quotation).
At 36,000 operating hours each StirLNG-4 reliquefier requires a more extensive (major) maintenance.

All maintenance inspections can be done at site by our Service engineers.

As an option, also customer technicians can be trained to perform this maintenance but they need to be officially certified. A (regular) training at our premises is mandatory in this case.

Maintenance inspection	Interval [operating hours]	Duration (on site)
Preventive (minor) maintenance	every 6,000 hours	8 hours
Extensive (major) maintenance	36,000 hours	16 hours

Note: the StirLNG-4 liquefier has to be shut down (to be warmed up) at least 24 hours before commencing with each maintenance

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APPENDIX 1
General sizes of the StirLNG-4