



STIRLING

CRYOGENICS

Liquefaction of Hydrogen

Stirling Cryogenics B.V.

- Main product lines:
 - Range of Stirling Cryogenerators:
on-site production of 18 to 200K cooling power
 - Range of CryoFans:
Several types of gas pumps for closed cycle transmission of cooling power

Liquefaction of Hydrogen

- Two liquefaction concepts:
 - Inside Stirling Cryogenerator cold head with H_2 gas pre-cooling at 80K
 - Inside LH_2 vessel by flow of cold He from Stirling Cryogenerator with H_2 gas pre-cooling at 80K

Stirling Hydrogen Liquefaction System Features

- The range of capacities we offer is from 5.5 up to 200 kg/day in one system, large capacities by multiple systems
- Smaller systems up to 44 kg/day can be placed in a plant room, but can also be offered as containerized system
- Larger systems are offered containerized as standard
- To allow for future growth, systems can be supplied for current size but already built for future extension, allowing later addition of Cryogenerators and hence capacity extension
- Cryogenerators can be stopped and started regularly, allowing to stop part of them in case less GH_2 is available with less wind power.
With increasing GH_2 production, more Cryogenerators are started.
- Cool-down time to liquefaction from warm start is 20 minutes, shorter after short stops
- In smaller systems, liquefaction capacity can be varied by rpm depending GH_2 supply

Hydrogen Liquefaction Capacity

- Table of liquefaction capacity to para LH₂ per SPC-4T

	Liquefaction pressure [bar(g)]					
	0	1	2	3	4	5
T_{Liquid} [K]	20.2	22.9	24.7	26.1	27.2	28.3
P_{1st stage} [W]	775	955	1080	1115	1170	1225
P_{2nd stage} [W]	270	340	395	415	445	460
\dot{m} [kg/d]	17	22	25,2	26,1	27,7	29,2
\dot{V} [L/d]	240	324	387	415	455	497

T_{Liquid} : Equilibrium temperature of the para-LH₂ produced at given pressure

P_{1st}, P_{2nd} : Cooling powers at first stage and second stage of the Stirling Cycle at T_{Liquid}

\dot{m} , \dot{V} : Massflow and volume flow of the para-LH₂ produced at liquefaction pressure

Input P_e : 37 kW @ 20K; 15 kW for water chiller

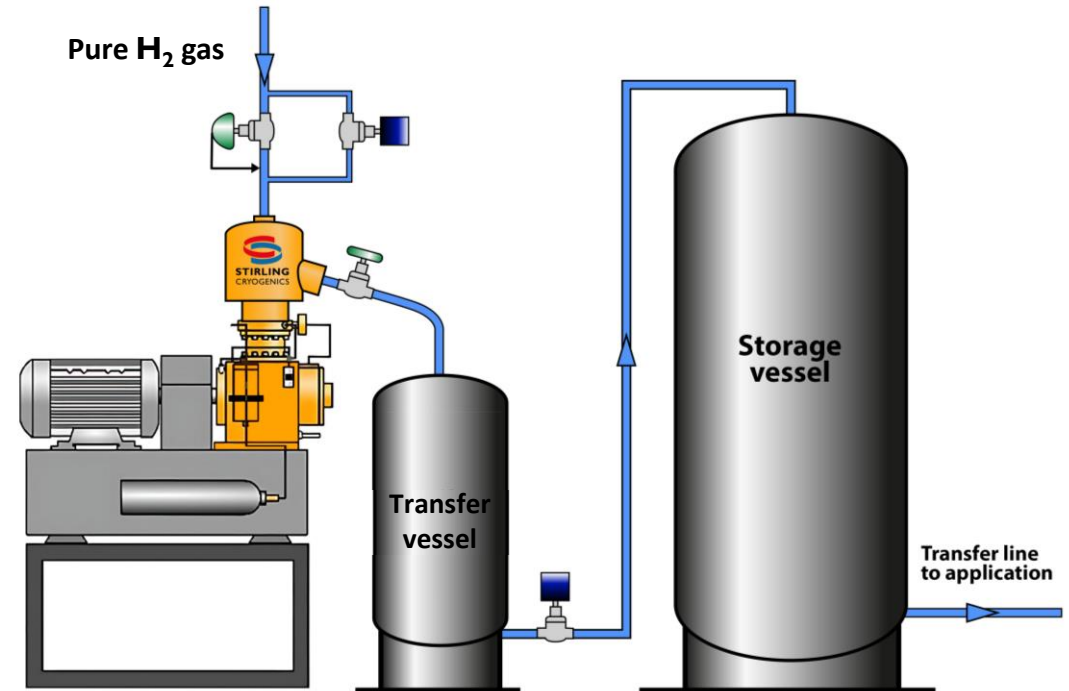
→ For 1 barg, this results in a power to kg LH₂ ratio of 57 kWh/kg

Stirling Hydrogen Liquefaction Capacity

- The table shows cooling capacities at the first and second cooling stages of the 4-cylinder Cryogenerator, type SPC-4T
- Liquefaction temperature depends on liquid pressure required while Stirling cooling power depends on liquefaction temperature
- Thus, higher liquefaction pressure results in higher production capacity and better power to kg ratio
- Ortho-para conversion will create heat and back-flow of evaporated GH_2 . This flow is fed back to the Cryogenerator and re-liquefied, reducing the net liquefaction rate. The table shows the final net liquefaction rate after O-P conversion.
- Catalyst are integrated causing the O-P conversion to be immediate. This assures the delivered LH_2 is fully para hydrogen.
- Since the Cryogenerators are in contact with H_2 , they will be built according ATEX.

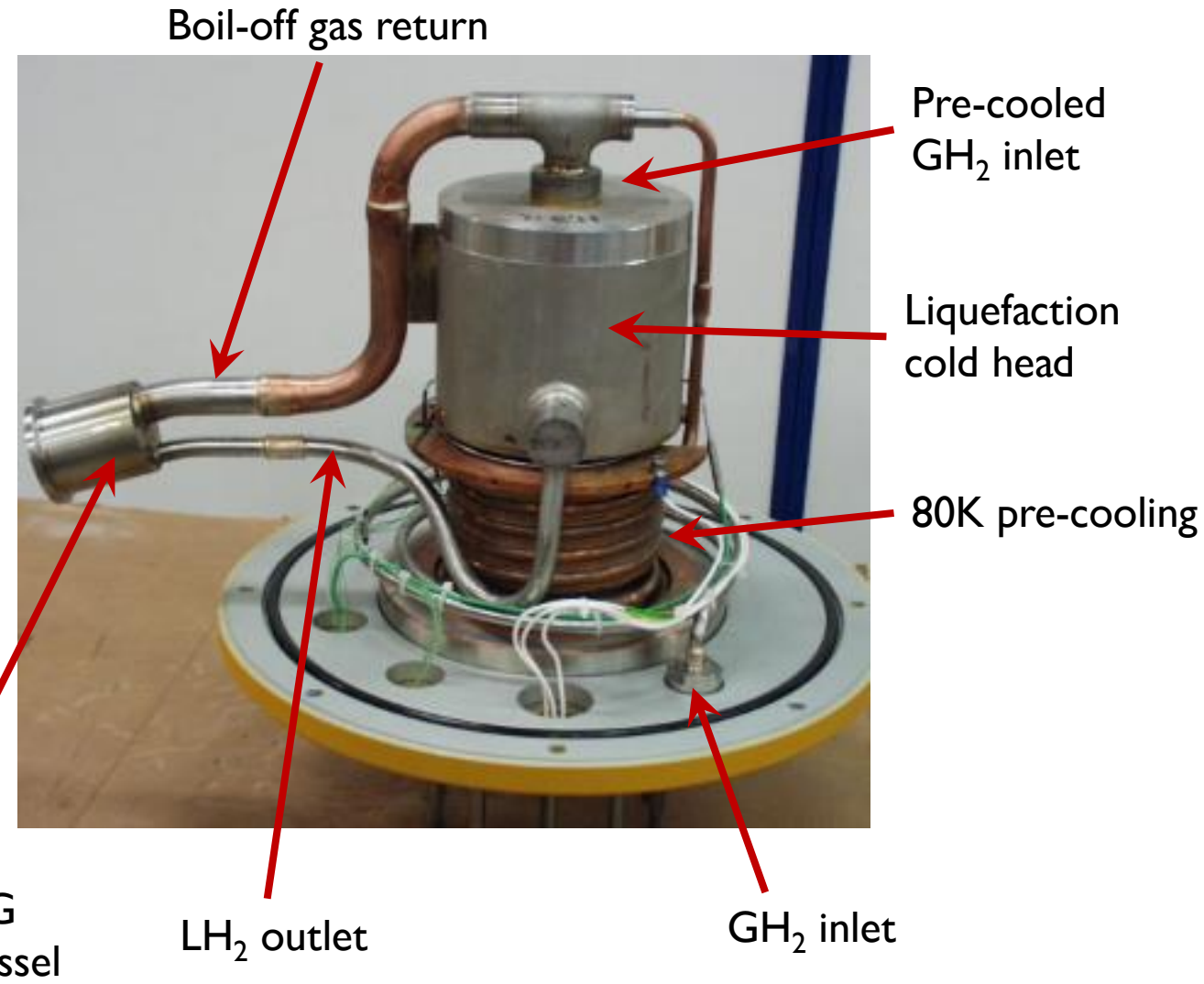
Hydrogen Liquefaction inside Stirling Cold-head

- H₂ gas is fed from a source to the Cryogenerator and pre-cooled at 80K in the first stage
- Liquefaction by the second stage cold head
- Ortho-para conversion by catalyst
- Para LH₂ produced is stored in a transfer vessel
- When full, closes and bottom valve opens and feed gas pressure is raised
- LH₂ is pressurized via a by-pass valve and transferred to the storage vessel



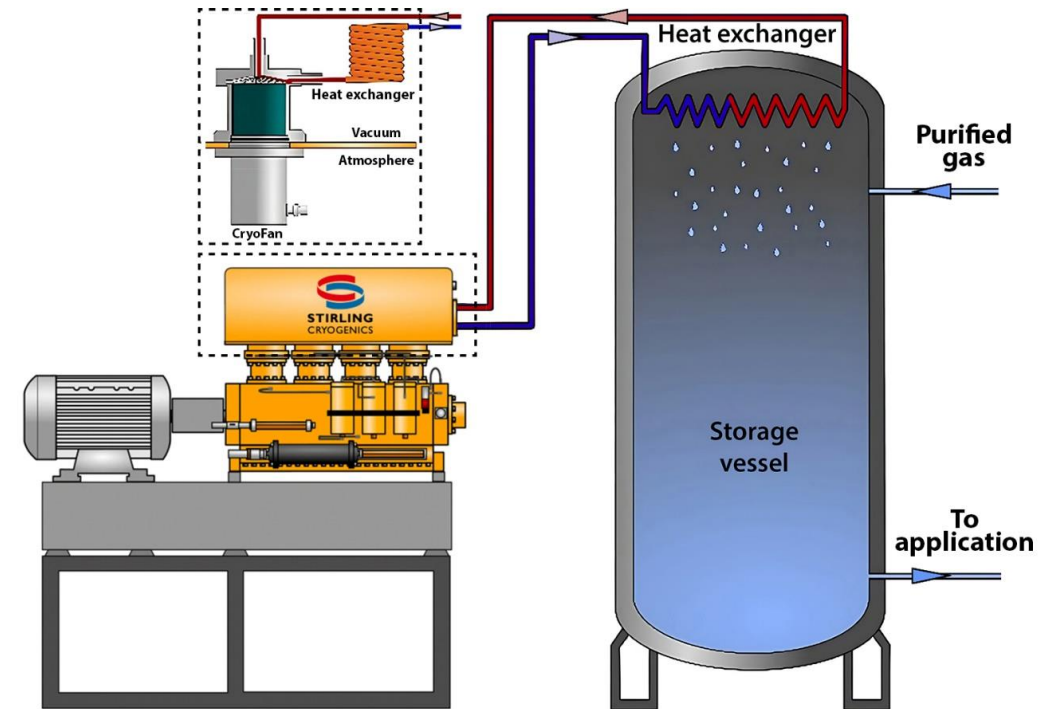
Hydrogen Liquefaction inside Stirling Cold-head

- 1-Cylinder, 2-Stage Cold Head for GH₂
Pre-cooling of inlet gas at first stage
- Liquefaction of cooled gas in second stage
- Re-liquefaction of boil-off gas
- Two phase flow pipe connection
- Liquid produced drops in transfer vessel
- From here batch-wise push over to main vessel



Hydrogen Liquefaction inside a vessel

- In case it is preferred to liquefy the H₂ gas inside the vessel, e.g. for classification reasons, this can be achieved by a flow of cold He coming from the Cryogenerator.
- The He flow is driven in a loop by a Stirling CryoFan, thermally connecting the Cryogenerator with the heat-exchanger to be cooled.
- Heat-exchangers inside of the LH₂ vessel will pre-cool the H₂ gas @ 80K and liquefy @ 20K.
- An additional heat-exchanger can be placed in the liquid, to cool this and prevent evaporation.
- With the Cryogenerator in a safe area, no ATEX is required.



Large Set-up Hydrogen Liquefaction by He loop



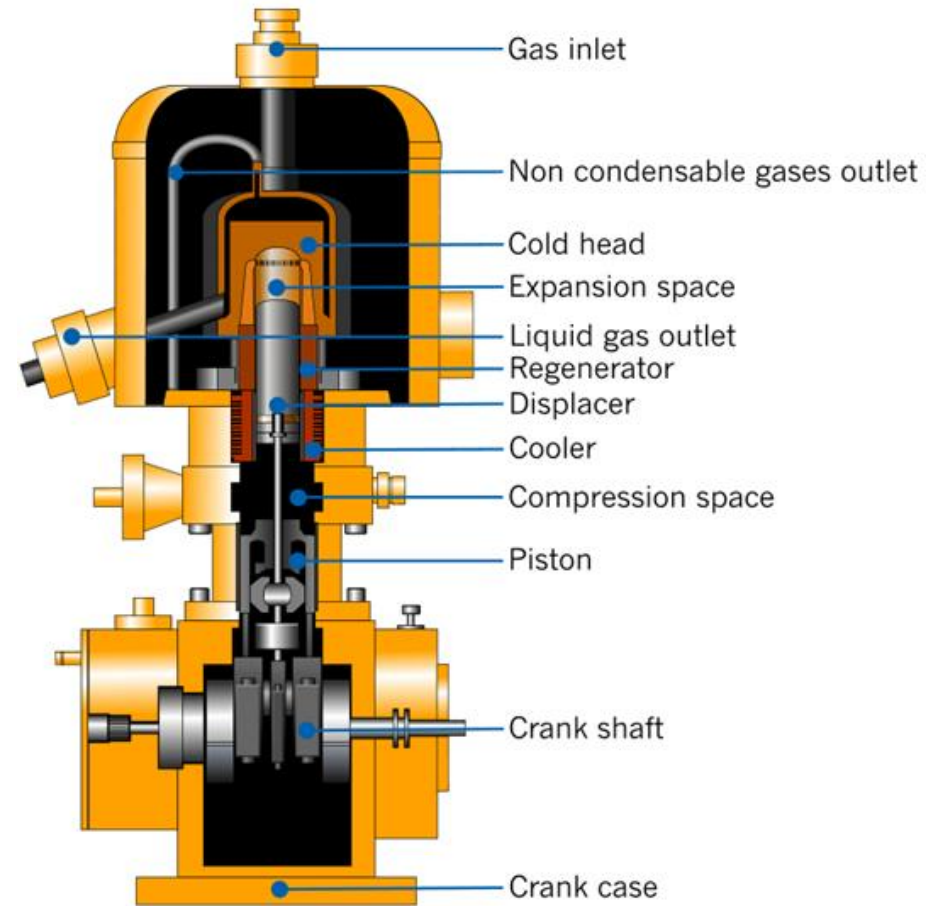
- 6x 4-Cylinder, 2-Stage Cryogenerators each a CryoFan
- Individual start/stop and connection to the main flow by valves

Hydrogen Liquefaction

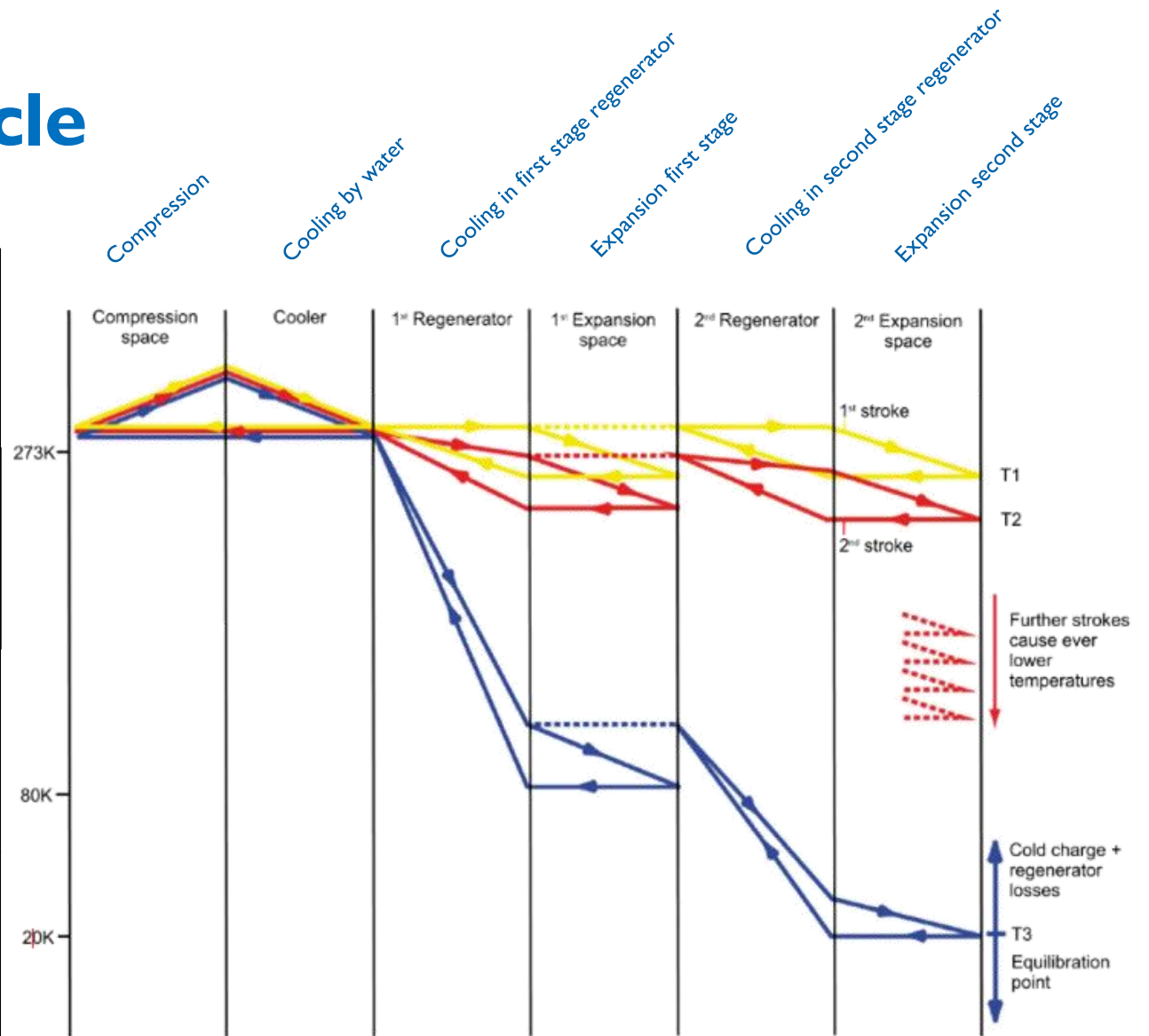
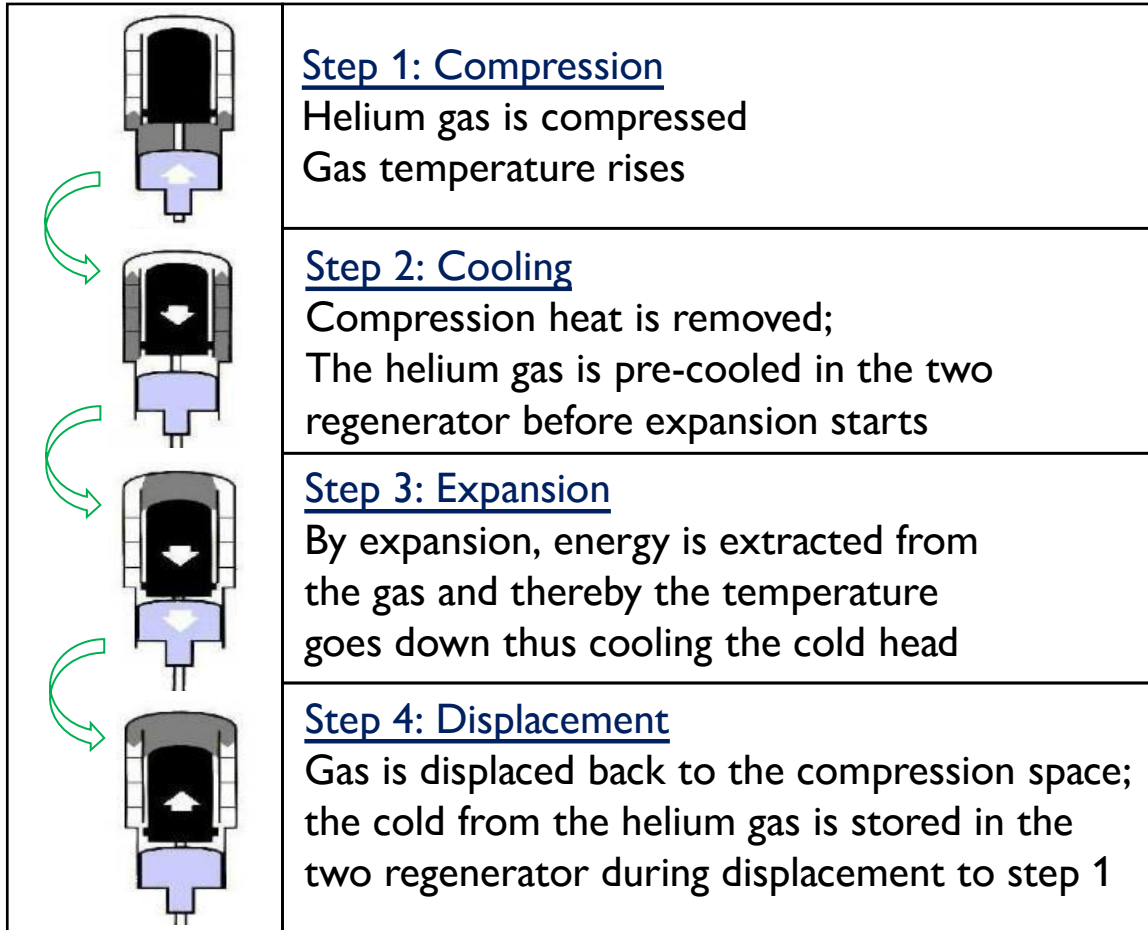
- Picture of two stage, 4-cylinder Cryogenerator type SPC-4T
- Vacuum insulated cold head.
- At the front the boil-off gas inlet and liquid outlet connections



Stirling Thermodynamic Cycle




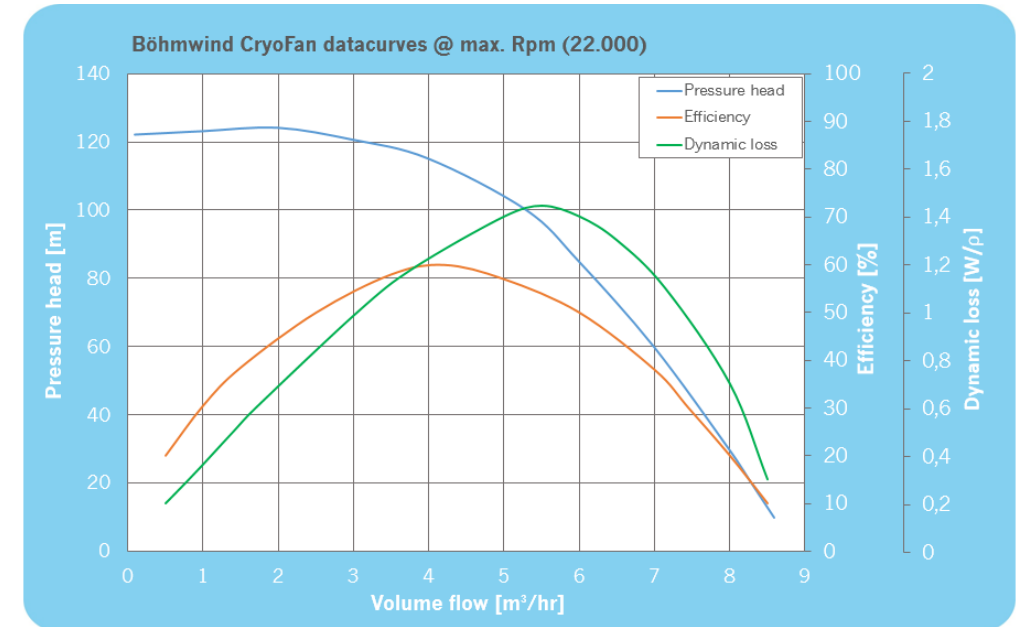
Stirling Thermodynamic Cycle



Range of CryoFans for cold He Loops

- Example: CryoFan type Böhmwind
- Max static pressure 30 barg
- Static heat loss 6W @ 40K
- 4,2 m³/h @ 112 m pressure head; 60% efficiency

Cryofan model	Mistra I	Cierzo	Noorden wind	Böhm wind	Bise	Chinook	Nevol	Nodin	Tramontana	Yeti
										
Motor power [W]	5	12	80	80	340	120	340	340	2400	3600
Impeller [mm]	20	25	31	42	56	75	75	85	140	240
Max Efficiency [%]	56	62	53	60	81	71	71	72	90	70
Head [m]	1,5	20	35	112	170	200	200	260	800	850
Flow [m ³ /hr]	0,07	0,24	1,85	4,2	7,6	34	34	45	300	500



For further information, please visit our website

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