

STIRLING

CRYOGENICS

Re-liquefaction of Hydrogen / Zero Boil-off System

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

Re-Liquefaction of Hydrogen

- Two liquefaction concepts:
 - Inside Stirling Cryogenerator cold head via a transfer tank
 - Inside LH₂ vessel by flow of cold He from Stirling Cryogenerator

Stirling Hydrogen Re-Liquefaction System Features

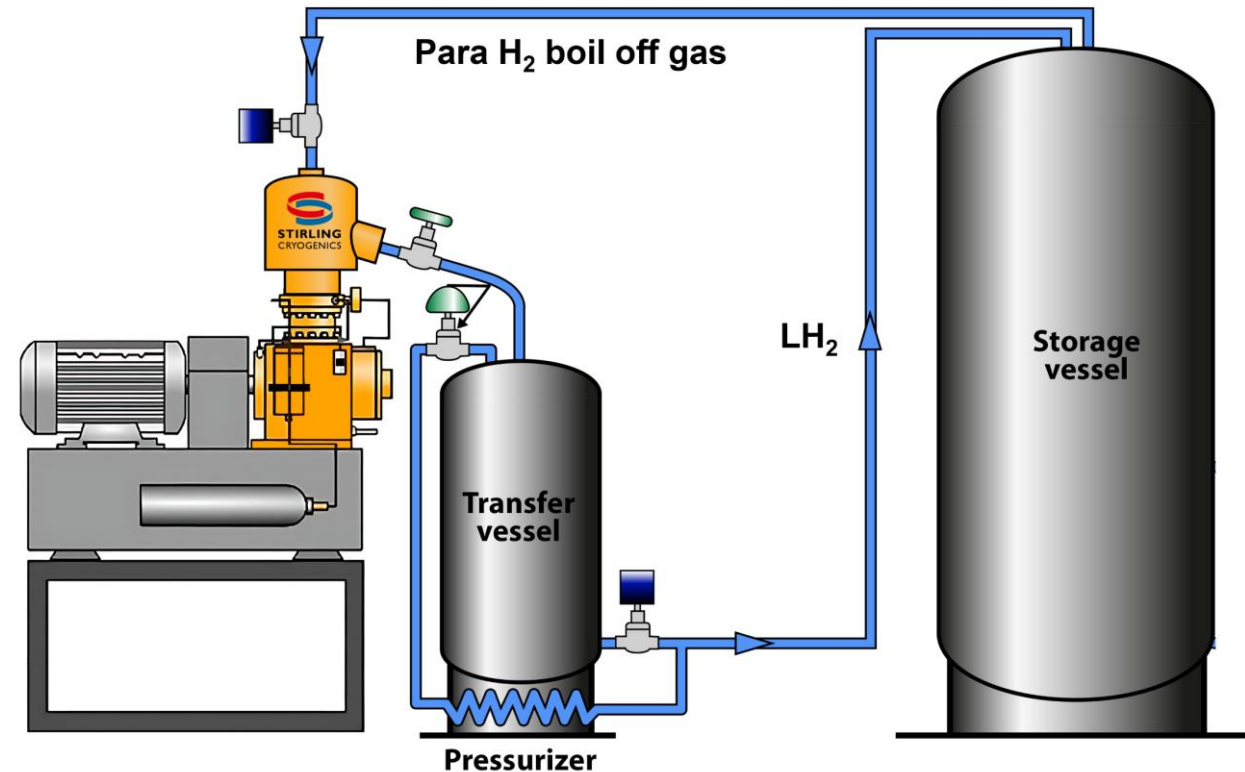
- The range of capacities we offer is from 12 up to 350 kg/day in one system, large capacities by multiple systems
- Smaller systems up to 100 kg/day can be placed in a plant room, but can also be offered as containerized system
- Larger systems are offered containerized as standard
- To allow for future 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 boil-off is generated
With increasing GH_2 boil-off, 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 boil-off

Hydrogen Re-Liquefaction Capacity

- Capacity is based on 100% para hydrogen boil-off gas at 30K, so heated 7K in the transfer lines
- Vessel pressure at 1 barg / liquefaction temperature is 22.8 K
- dH is $542.8 - 27.6 = 515.2$ kJ/kg
- Available cooling power per SPC-4T is 300W at the second stage
- Depending re-liquefaction concept and piping geometry etc, re-liquefaction capacity is ~50 kg/day, requiring 37 kW input power plus 15 kW for water chiller
- The SPC-1T will do ~12 kg/day, requiring 10 kW input power plus 4 kW for water chiller
- → This results in a power to kg LH₂ ratio of 25 kWh/kg

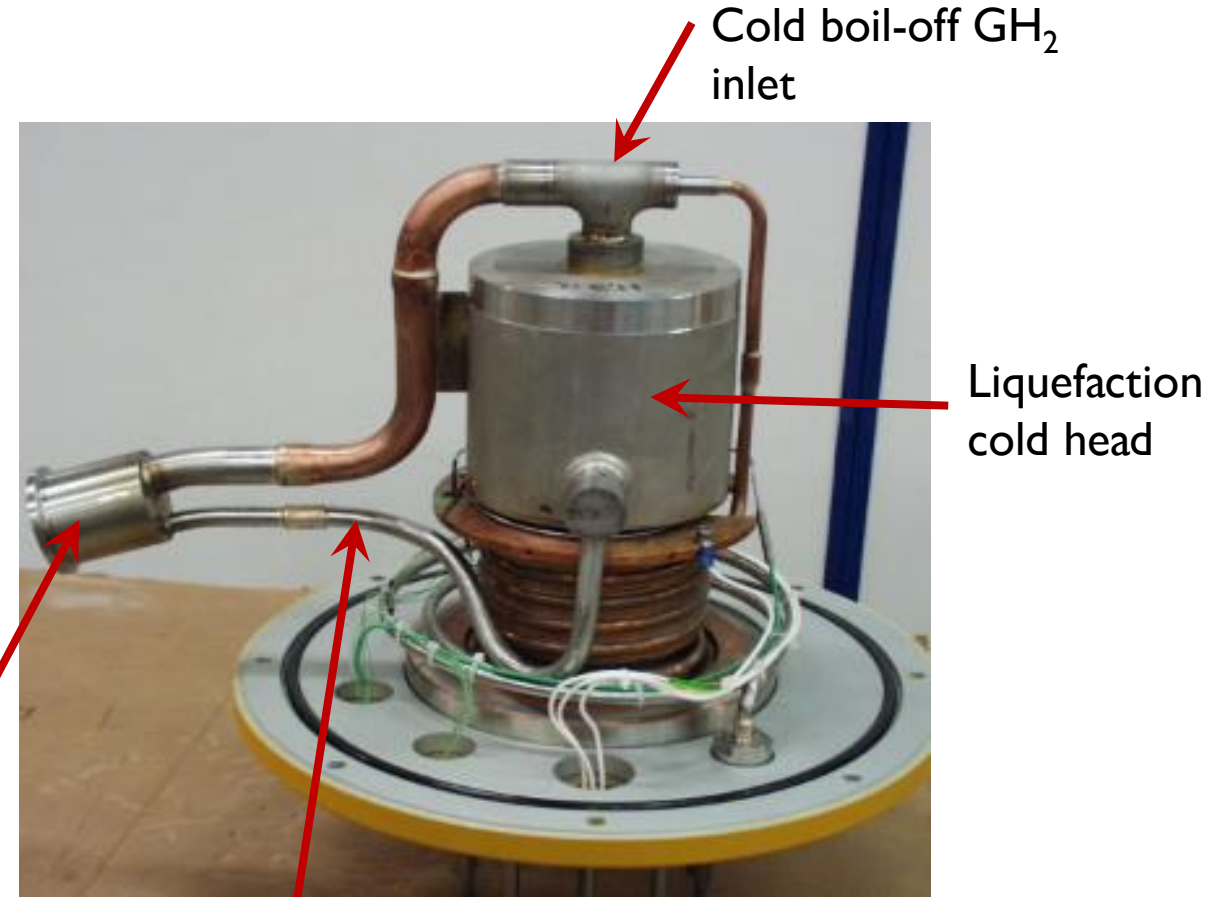
Hydrogen Re-Liquefaction in Stirling Cold-head

- Boil-off gas, being 100% para H₂ from the storage vessel is fed to the Cryogenerator
- Re-liquefaction by second stage cold head, no 80K pre-cooling required
- LH₂ produced is stored in a transfer vessel
- When full, gas feed valve closes and bottom valve opens
- LH₂ is pressurized and transferred to the storage vessel



Hydrogen Re-Liquefaction inside Stirling cold head

- 1-Cylinder, 2-Stage Cold Head for LH₂
- Re-liquefaction of boil-off gas in second stage cold head
- Two phase flow pipe connection to transfer vessel
- Liquid produced drops in transfer vessel
- From here batch-wise push over to main vessel

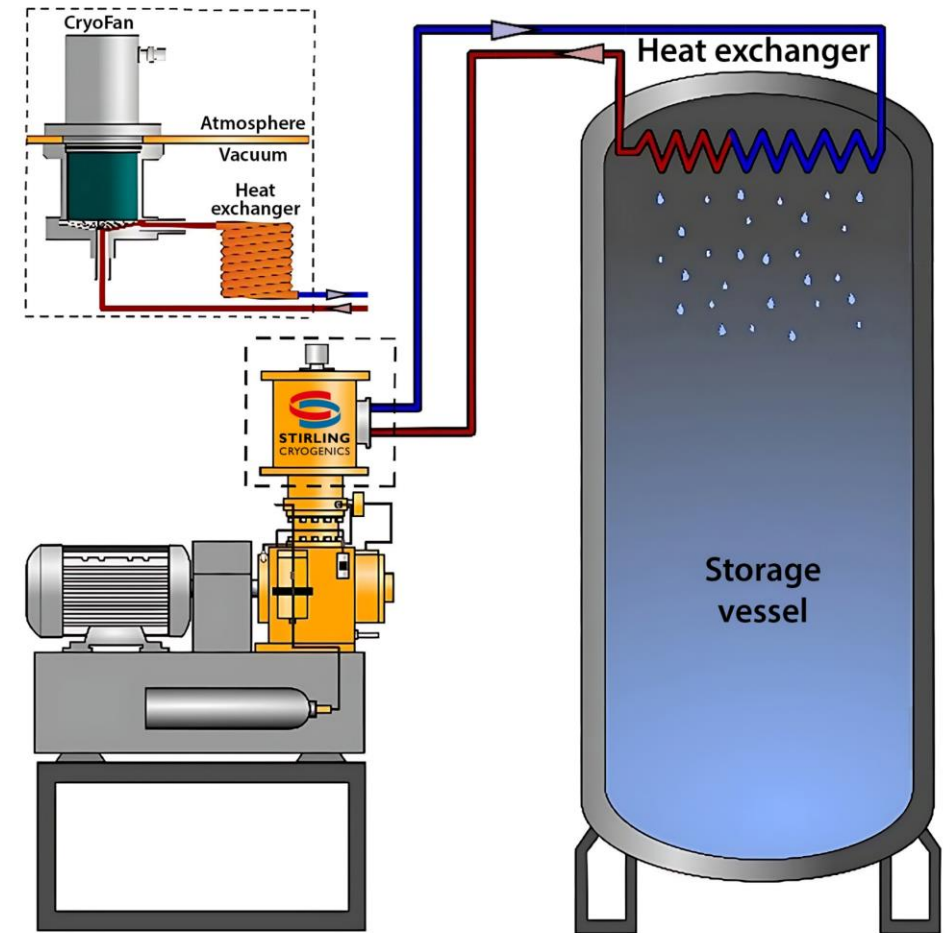


Two phase LH₂ / BOG
connection to LH₂ vessel

LH₂ outlet

Hydrogen Re-Liquefaction in a vessel

- In case it is preferred to re-liquefy the H_2 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.
- A heat-exchanger @ 20K inside of the LH_2 vessel will re-liquefy the GH_2 .
- A second 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.

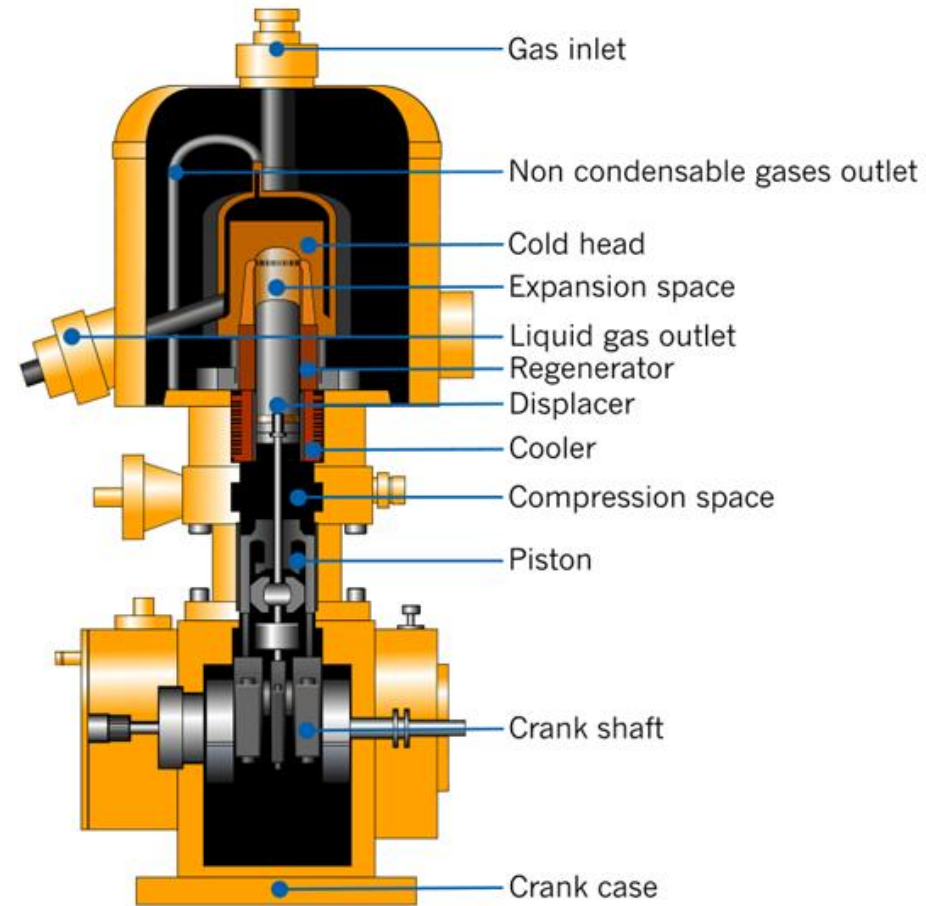


Large Set-up Hydrogen Re-Liquefaction

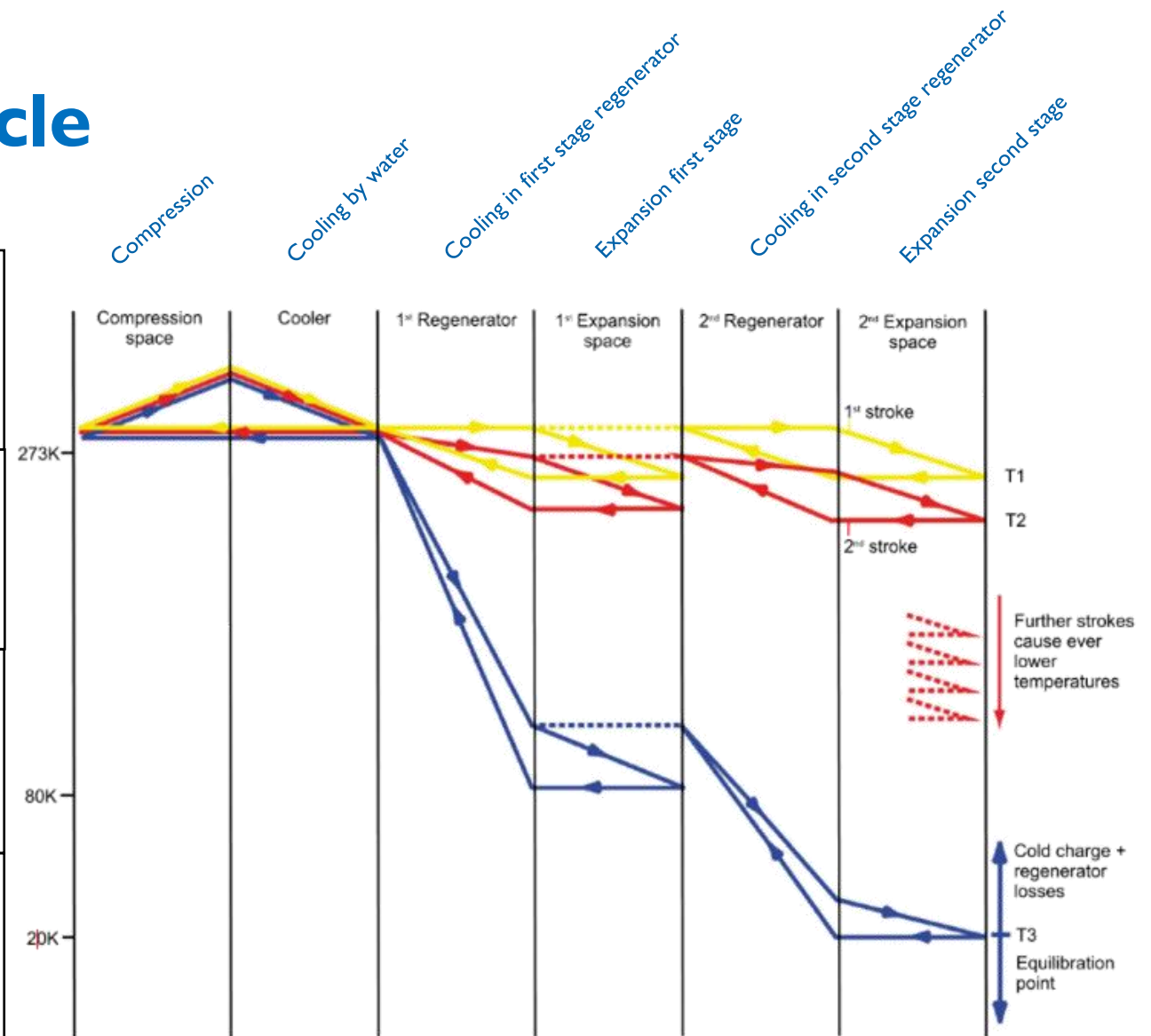
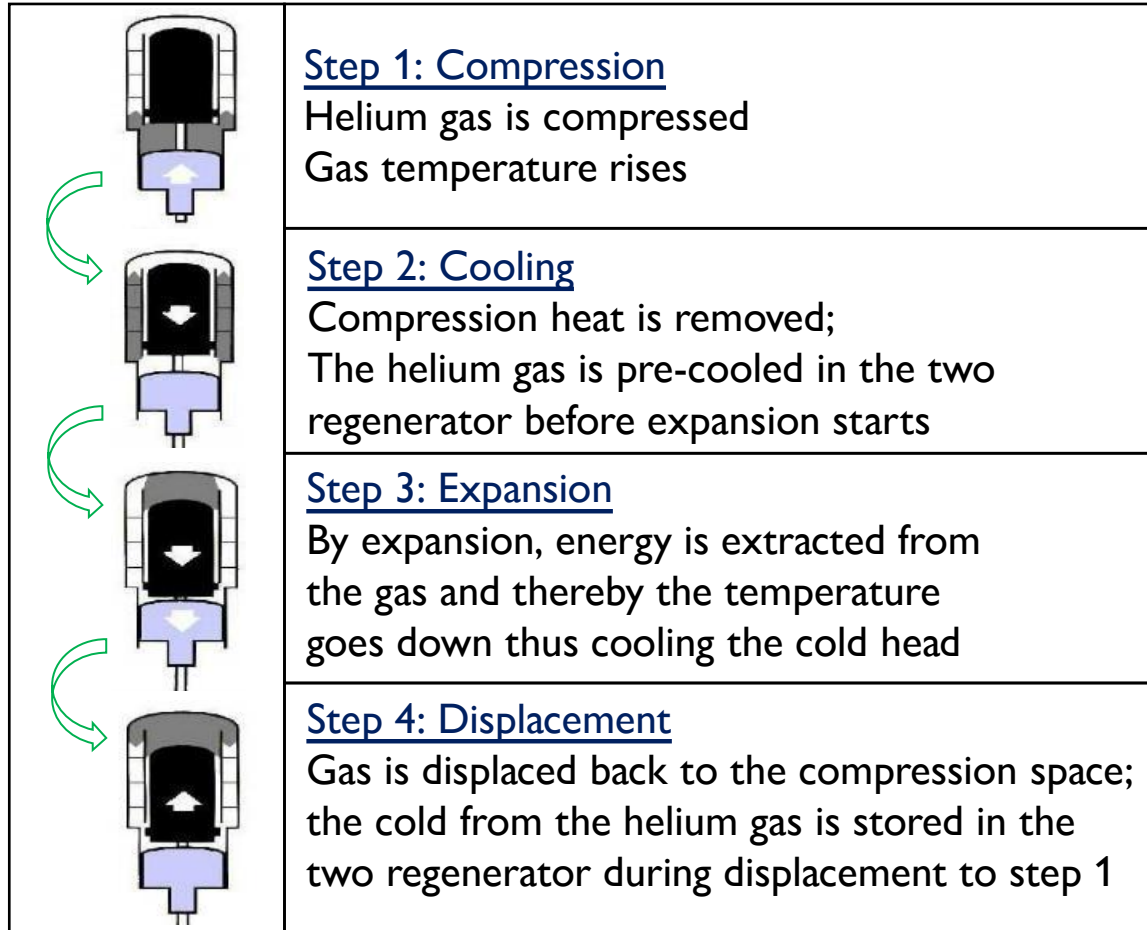


- 6x 4-Cylinder, 2-Stage Cryogenerators each a CryoFan
- Individual start/stop and connection to the main flow by valves

Stirling Thermodynamic Cycle



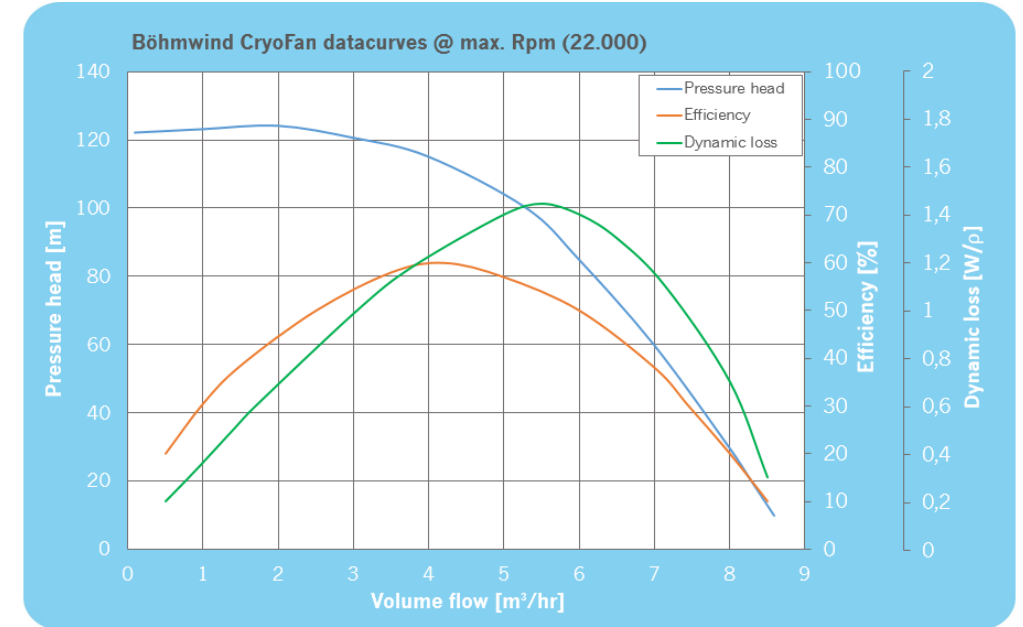
Stirling Thermodynamic Cycle



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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