Small scale boil off gas (BOG) re-liquefaction systems

As presented by Francesco Dioguardi
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DH Industries BV

- Based in Eindhoven, The Netherlands
- Successor of Philips Cryogenics, in business since 1955
- Main product brands:
  - Stirling Cryogenics: Several types of Cryogenerators to produce on site cooling power
  - CryoZone: Several types of pumps and circulators for cryogenic gases and liquids
StirLNG-4
CONDITIONING OF LNG
Why conditioning of LNG?

To prevent (a) LNG storage (cargo or fuel) from venting (pressure control):

- Safety, environmental & economic
- Keep LNG “cold” = value
- To maintain the composition of the LNG (mixture)
- Conditioning can be done by:
  - Re-liquefying the (excess) boil off gas
  or
  - Cooling the liquid

*Both methods will decrease the tank pressure*
Conditioning of LNG

- Liquefaction temperature of LNG increases with increasing pressure.
- Reducing the pressure of a system will cool down the liquid & reducing liquid temperature will reduce pressure (as gas and liquid want to stay in equilibrium).
THE STIRLING CYCLE
to create cryogenic cooling power
Stirling thermodynamic cycle

- Stirling Cryogenerator interior

- Gas inlet
- Non condensable gases outlet
- Cold head
- Expansion space
- Liquid gas outlet
- Regenerator
- Displacer
- Cooler
- Compression space
- Piston
- Crank shaft
- Crank case
Stirling thermodynamic cycle

**Step 1: Compression**
Helium gas is compressed
Gas temperature rises

**Step 2: Cooling**
Compression heat is removed;
The helium gas is pre-cooled in the regenerator before expansion starts

**Step 3: Expansion**
By expansion, energy is extracted from the gas and thereby the temperature goes down thus cooling the cold head

**Step 4: Displacement**
Gas is displaced back to the compression space; the cold from the helium gas is stored in the regenerator during displacement to step 1
Cooling capacity

- StirLNG-4
EASY PROCESS INTEGRATION
Easy process integration

- Internal cold generation by He gas: methane is not part of process
- Simple integration: at the LNG process side, the Stirling Cryogenerator is only a heat-exchanger.
- Small enough & efficient to fit maritime BOG size re-liquefaction
- Capacity range 0.25 to > 10 ton/day.
Easy process integration

- The liquefier works as a simple heat exchanger either for gas or liquid
- No compression of LNG
- No contamination of LNG
- High efficiency
- Scalable, flexible and redundant
Conditioning by re-liquefaction of BOG

- Cold boil-off gas, directly from the tank, is fed to the Cryogenerator
- Gas is re-liquefied and fed back to main storage vessel
- No pumping required
- Driving force is pressure difference and gravity
- T of liquid will decrease with lower head pressure
Conditioning by liquid sub-cooling

- Liquid from the tank is pumped through the HX of the liquefier, decreasing its temperature
- Colder liquid re-enters the tank reducing overall T and pressure
ADAPTATIONS
FOR MARITIME USE
Adaptation for Maritime usage

- Modifications made for maritime application:
  - To assure functionality during role and pitching
  - Allow static inclination during (un)loading
  - Vertical motion due to waves
  - Vibrations
  - Corrosion
  - Remote operating
  - Modifications to meet regulations (ABS, USCG, UL etc.)
Adaptation for Maritime usage

- Corrosion prevention for maritime circumstances
- Lubrication system and LNG outlets of StirLNG-4 adapted for 22,5° dynamic roll and pitch, refer to videos
- Static tilting up to 15° each direction
- Free directional positioning on ship
- For USCG: separation of Cryogenerator and motor by bulk head with rotating seal
- ABS Certified, other notified bodies upon request
ABS Type Approval

Amongst others 22,5° Roll & pitch test

- Link to roll test clip
- Link to pitch test clip

Note:
Units are in operation during these tests to proof their full functionality
Adaptation for Maritime usage

USCG requirement:
- Bulk head seal
- Motors in safe area
FIRST MARITIME PROJECT
DESIGN AND PRODUCTION
2200 M$^3$ LNG Bunker Barge

- Based on conceptual design developed by GTT
- Single cargo tank of Mark III Flex technology with BOR 0.38%/day
- Cold LNG delivery ensured by 6 Stirling StirLNG-4 cryocooler units
StirLNG on board LNG Barge
StirLNG on board LNG Barge

Design Parameters 6 x StirLNG-4 units:

- **Capacity:**
  6 x ~ 900 kg/day = ~5,400 kg/day @ 0 barg and 0.5% N2

- **Power consumption:**
  6 x ~38 kW = ~ 228kW (+ water chillers)

- **Operations:**
  Each StirLNG-4 has its own controller and can start and stop on its own

- **Dimensions and weight:**
  lxwxh = 7,850 x 3,000 x 1,700mm (25.8’ x 10’ x 5.6’)
  ~ 8,500 kg (18,800 lbs)
Re-liquefaction concept

Boil off gas → LNG → Liquid return
Factory Acceptance Test
Factory Acceptance Test

Each StirLNG-4 was tested for:

- **Capacity:**
  With LN2 at 4.8 barg (same liquefaction T as the expected BOG)

- **Vibrations:**
  at 5 points per unit, in 3 directions

- **Temperatures:**
  at 5 points per unit

- **Error test:**
  Each individual unit was error tested by simulating or initiating fault conditions.

Result: All units successfully passed.
FIRST MARITIME PROJECT INSTALLATION
Installation at Conrad
Installation at Conrad
Installation at Conrad
For further information, please visit our Maritime website