Innovations in Natural Gas Liquefaction Technology for Floating LNG

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LNG Prospects

- Land-based
- FLNG
Air Products LNG Technology and Equipment

- 85 LNG heat exchangers / 40 years
- 24 turboexpanders
- Integrated offering with several high efficiency refrigeration process cycles
Air Products Liquefaction Processes for FLNG Applications

Train Capacity, MTA

0  1  2  3  4  5+

N2: AP - N
Pre-Cooled N2: AP - HN
Pre-Cooled MR: AP - C3MR, TM / AP - DMR, TM / AP - HMR, TM

MR: AP - SMR, TM

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N2 Recycle

- ~ 1 MTPA
- No HC refrigerant
- All Vapor
Dual Mixed Refrigerant

- High Efficiency
- High Capacity

Natural Gas

Warm Mixed Refrigerant

Cold Mixed Refrigerant

MRV

MRL

LNG
Wound Coil Heat Exchanger

- Natural gas liquefied in wound coil tubes
- Refrigerant flows down over outside of tubes
Wound Coil Exchangers for Safety and Reliability

- Liquefying hydrocarbons can cause high thermal stresses due to inherent refrigerant/load imbalances
- Wound Coil Exchangers proven to withstand thermal stresses
- Dual containment – high pressure hydrocarbons contained in tubes within a pressure vessel shell. Containment important to FLNG safety
WCHE for Floating LNG

FLNG vessel subject to motion

Exchanger design verification
• Mechanical strength
• Process flow effects
WCHE Mechanical Design Verification for FLNG

- Pressure vessel design
  - Considered North Sea 100 year storm conditions for strength, with 25 year service life for fatigue
  - Exchanger design meets fatigue criteria set by DNV
  - Design method certified by DNV

- Internal bundle support system
  - Tested cyclic loads due to wave motion, based on North Sea 100 year storm conditions
  - Demonstrated resistance to wear or distress that would impair function
Wound Coil Exchangers for FLNG: Process Effects

• Flow through tubes
  – Pressure driven, not affected by ship motion

• Liquid flow through shell-side distributors
  – Performance insensitive to motion, as verified by computational fluid dynamics and experimental testing

• Flow on shell-side of exchanger
  – Motion may affect how liquid flows over the tube bundle
  – Liquid distribution may affect heat transfer performance
  – Effects are mitigated by proper bundle design, using Air Products’ enhanced design tools
Development of Enhanced Wound Coil Exchanger Design Tools

Fundamental Fluid Flow Experiments & Analysis
Institute of Thermophysics, Russia

Enhanced Wound Coil Exchanger Design Tools
Fundamental Fluid Flow
Experiments & Analysis

• Laboratory measurements provide inputs to hydraulic flow model
  – Experiments performed with water, water-surfactant mix, and hydrocarbons
  – Experiments give hydraulic behavior under tilt conditions
Development of Enhanced Wound Coil Exchanger Design Tools

Fundamental Fluid Flow Experiments & Analysis
Institute of Thermophysics, Russia

Pilot Plant Test Bundle
Liquid Flow with Bundle Oscillations
Heriot-Watt University, Scotland

Develop Model

Enhanced Wound Coil Exchanger Design Tools

Verify Model
Pilot Scale Experiments
Liquid Flow with Bundle Oscillations

• Testing performed at Heriot-Watt University in Scotland
• Flow distribution data under static tilt and oscillation (pitch/roll)
Validation of Model

- Model validated by comparison to Heriot-Watt pilot scale data
Development of Enhanced Wound Coil Exchanger Design Tools

- Fundamental Fluid Flow Experiments & Analysis
  Institute of Thermophysics, Russia

- Pilot Plant Test Bundle
  Liquid Flow with Bundle Oscillations
  Heriot-Watt University, Scotland

- Dynamic Simulations & CFD
  Effect of Motion on Heat Transfer

Develop Model
Verify Model
Determine Performance

Enhanced Wound Coil Exchanger Design Tools
FLNG Exchanger Design

Key Motion Variables

- Static tilt
- Pitch/roll
- Oscillation period
- Exchanger elevation

Key Design Variables

- Duty and temperatures
- Bundle geometry
- Shell-side flow
Design for FLNG Motion

• Exchangers are typically designed for full production at maximum ship motions expected majority of the year (e.g. ~99% occurrence probability)
  – Typical design point: Pitch/roll of 3 degrees or less

• For higher ship motion:
  – Have analyzed for ship motions up to 6 degrees pitch/roll and these can be accommodated with small impact
  – At larger motion, heat exchangers continue to operate with possible reduction in production or increase in power requirement
Sensitivity to Static Tilt

Typical FLNG Vessel
Sensitivity to Oscillation Period

% LNG Production, Relative to No-Tilt Period, sec

Typical FLNG Vessel
Summary

• Air Products offers a robust wound coil exchanger design and a selection of process cycles for FLNG

• Air Products has developed a detailed approach to understanding impact of motion on the heat exchanger:
  – Both experimental and theoretical
  – Includes the significant inputs and design parameters
  – Effects are quantified

• For typical FLNG motion
  – Effects are mitigated by proper bundle design, using Air Products’ enhanced design tools
Thank You