ARCTIC LNG PLANT DESIGN: TAKING ADVANTAGE OF THE COLD CLIMATE

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“Are Today’s Proven Baseload LNG Liquefaction Processes Acceptable for Cold Climates?”

To Answer:

- Current & future baseload LNG locations
- LNG liquefaction processes
- Characteristics of arctic climates
- How each process performs in arctic climates
- Summary
Air Products Baseload LNG Trains
Industry Arctic Plants

In Development
AP-C3MR™ Process

Heat Rejection

Natural Gas

C₃ Pre-cooling

Precool Temperature

Mixed Refrigerant (MR)

LNG

C₃

MRV

MRL

LNG-17
AP-DMR™ Process

Warm Mixed Refrigerant (WMR)

Natural Gas

Precool Temperature

Cold Mixed Refrigerant (CMR)

LNG
What Makes an Arctic Location Different?

● Periods with Very Short and Very Long Daylight
● Extreme winds
● Winter precipitation does not melt until summer
  – Ice accumulation from sea spray and fog
● Sea contains ice and may freeze over
  – Problem for shipping
● It’s Cold!
  – Cold cooling medium for process heat sink
  – Cold air to gas turbine drive
Yearly Air Temperature Trend

Avg Daily T

High-Low T

Temperature (°C)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Borneo
Qatar
Yamal
Yearly Seawater Temperature Trend

Temperature (°C)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

-50 -40 -30 -20 -10 0 10 20 30 40 50

Borneo
Qatar
Yamal

Ice Covered
Ice Free
Ice Covered
Process Temperatures Yearly Range

Process $T = \text{Cooling } T + \Delta T_{\text{Approach}}$

- **Borneo**
  - Air Cooling
  - Seawater Cooling

- **Qatar**
  - Air Cooling
  - Seawater Cooling

- **Yamal**
  - Air Cooling
  - Seawater Cooling
Case Study
Arctic Climate

- Compare two LNG Liquefaction Processes
  - AP-C3MR™ and AP-DMR™

- Generic Arctic Location, Ambient -20°C to +22°C

- Compressors
  - 2 x Frame 7 Mechanical Drive Gas Turbine
  - Each GT drives 50% compression string
  - Design compressors at average T
    - Rate for other conditions

- Air Cooling
Case Study
Arctic Climate (cont)

- Unlimited Feed Rate
  - Maximize LNG using all available gas turbine power
What is Effect of Cold Ambient?

- LNG Production depends on
  - How much power is available
  - How effectively the power is used
What is Effect of Cold Ambient?

- \[ \text{LNG} = \frac{P_{\text{Avail}}}{P_{\text{Spec}}} \]

- LNG = production (t/hr)
- \( P_{\text{Avail}} \) = Available power (kW)
- \( P_{\text{Spec}} \) = Liquefier spec power (kWh/tonne)

Colder air \( T \) raises LNG production by
- Increasing \( P_{\text{Avail}} \)
- Improving (lowering) \( P_{\text{Spec}} \)

\[ \text{LNG} \uparrow = \frac{\text{kW}}{\text{SP}} \uparrow \]
DMR Production

Production (mtpa) vs. Ambient Temperature (°C)

Baseline

Total Increase = 75%

½ Gas Turbine

½ Spec Power
C3MR Production

Total Increase = 45%
¾ Gas Turbine
¼ Spec Power
C3MR vs. DMR
Air Cooled Arctic Case Study

Production (mtpa) vs. Ambient Temperature (°C)
C3MR for Colder Ambient T

-80
-60
-40
-20
0
20
40
60
-20 -15 -10 -5 0 5 10 15 20 25

Process T (°C)

Ambient T (°C)

Feed T
C3 Precool T

C3 compressor recycles
Keeps C3 compressor suction P above vacuum
C3 Precooling Load

C3 compressor
recycles

Keeps C3 compressor
suction P above
vacuum

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LNG-17
17 April 2013
DMR for Colder Ambient T

Process T (°C) vs Ambient T (°C)

- Feed T
- DMR Precool T

DMR Precooling Load

-80 -60 -40 -20 0 20 40 60
-20 -15 -10 -5 0 5 10 15 20 25

17 April 2013
So what have we learned?

- For winter-to-summer temperature range, compare arctic to tropical/desert climate
  - Ambient air: very wide for arctic
  - Seawater: similar or smaller

- Air cooled
  - For moderate air T range, C3MR and DMR produce equal LNG
    - Approx 30°C for this case study
  - With large air T range, DMR produces more LNG than C3MR
    - Based on 3 key assumptions
3 Key Assumptions

1. Plant is air cooled

2. Available refrigeration power limits production
   – Entire value chain can process extra feed
   – Gas fields, pipeline, slug catcher, AGRU, dehydration, storage, carriers . . .
   – Additional CAPEX used only part of year

3. Customers’ needs match plant production
   – Vary seasonally
   – Supply and demand are synchronized

● If all three are true, then DMR liquefaction will produce more yearly LNG
C3MR vs. DMR
Yearly Production Range
Seawater Cooled Arctic Case Study

Seawater Temperature Range

Production (mtpa)

Seawater Temperature (°C)

Year Round Production
C3MR = DMR
C3MR vs. DMR - Fixed Feed
Yearly Production Range
Air Cooled Arctic Case Study

Year Round Production
C3MR = DMR
Where does each process produce most annual LNG?

<table>
<thead>
<tr>
<th>Climate</th>
<th>Cooling Media</th>
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AP-DMR™ > AP-C3MR™
Where does each process produce most annual LNG?

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\[ AP-DMR^{TM} = AP-C3MR^{TM} \]

\[ AP-DMR^{TM} > AP-C3MR^{TM} \]
DMR and C3MR – Other Factors

- Type of precooling equipment
  - Coil Wound Heat Exchanger (DMR) vs. Kettle evaporators (C3MR)

- Equipment Count & Footprint

- Operating considerations

- Experience and reference list

- CAPEX

- These are very project specific, and must be evaluated for each project
Summary

● Arctic compared to desert and tropical climates
  – Colder - gives more production
  – Ambient air T range: wide summer-to-winter
  – Seawater T range: similar summer-to-winter

● When selecting liquefaction process for arctic, DMR produces same LNG as C3MR, unless:
  – Air Cooling with wide T variation, and
  – Excess value chain capacity installed, and
  – Extra production can be sold seasonally
Conclusion

*Both AP-C3MR™ and AP-DMR™ are viable liquefaction processes for arctic climates*
Thank you