LNG physics

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Co-financed by the European Union
Trans-European Transport Network (TEN-T)
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a) The vapor compression refrigeration cycle
b) Simplified schematic of refrigeration cycle
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The reversed Carnot refrigeration cycle
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Temperature-entropy diagram of the reversed Carnot refrigeration cycle.
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Temperature-entropy (T-s) diagrams of Ericson and Stirling cycles
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The reversed Carnot cycle with finite heat transfer temperature difference
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The internal reversible cycle

\[ Q_H = Q_L + W_{\text{rev}}, \quad \text{COP}_{\text{rev}} = \frac{Q_L}{W_{\text{rev}}} = \frac{T_L}{T_H - T_L} \]

The external reversible cycle

\[ Q_{H'} = Q_{L'} + W_{\text{irrev}}, \quad \text{COP}_{\text{irrev}} = \frac{Q_{L'}}{W_{\text{irrev}}} = \frac{T_{L'}}{T_{H'} - T_{L'}} \]

The entropy generation can be expressed as:

\[ \Delta W = T_H \Delta S_{\text{irrev}} \]
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a) The reversed Carnot cycle between heat source and heat sink with varying temperatures.
b) The reversed Carnot cycle based on average equivalent temperatures.
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Closed cycle cryogenic refrigerator
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Ideal Linde-Hampson liquefaction process
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Ideal expander liquefaction process.
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Different components in cryogenic systems

Compressor

Expander

Throttle valve

Separator

Splitter

Expander

Condenser

Multi-stream heat exchanger
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The exergy efficiency of any refrigeration or cryogenic liquefaction system is defined as follows:

\[
\eta_{ex} = \frac{\text{minimum power required by a reversible system}}{\text{actual power supplied}}
\]

\[
\eta_{ex} = 1 - \frac{\sum \text{exergy loss in each component}}{\text{actual power supplied}}
\]

For the processes or equipment (control volume) where there is no work transfer involved, the concept of exergy efficiency can also be determined. Instead, the actual power supplied is replaced by exergy expenditure as follows:

\[
\eta_{ex} = 1 - \frac{\sum \text{exergy loss in each component}}{\text{exergy expenditure}}
\]

\[
\eta_{ex} = 1 - \frac{\sum \dot{m}_{in} e_{in} - \sum \dot{m}_{out} e_{out} + \sum \dot{Q}_{i} \left(1 - \frac{T_{0}}{T_{i}}\right)}{\text{exergy expenditure}}
\]
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Utilization of input exergy in a nonideal Linde-Hampson methane liquefier at heat exchanger effectiveness 90%, compressor efficiency 50%, $P_2 = 25\,\text{MPa}$, $P_1 = 0.1\,\text{MPa}$.
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Utilization of input exergy in a nonideal Kapitza methane liquefier at compressor efficiency 50%, $P_2 = 4\text{MPa}$, and $P_1 = 0.1 \text{MPa}$. 
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Propane-precooling mixed refrigerant cycle for natural gas liquefaction
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(a) Exergy loss distribution in mixed refrigerant unit.
(b) Exergy loss distribution in propane-precooling unit.
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Exergy loss distribution in the C3/MRC natural gas liquefaction system.
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N2-CH4 expander natural gas liquefaction.
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Effect of methane mole fraction in N2-CH4 mixture on the total power consumption of the liquefaction process.
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Exergy loss distribution in N2-CH4 expander natural gas liquefaction cycle. (a) Single expander cycle with propane precooling unit, (b) Duel expander cycle.
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Cascade refrigeration cycle operating with refrigerant mixtures. (C – Compressor; HX – Heat exchanger; SP – Separator; V – Valve; WC – Water cooler)
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Temperature profiles in the cascade refrigeration cycle operating with mixed refrigerants.
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Exergy loss distribution in the cascade refrigeration cycle.

- Compressor loss: 37.50%
- Throttling loss: 11.04%
- Cycle HXs loss: 21.88%
- Water cooler loss: 29.58%
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