Work Output of Multicomponent LNG Mixtures in Two-Phase Expanders

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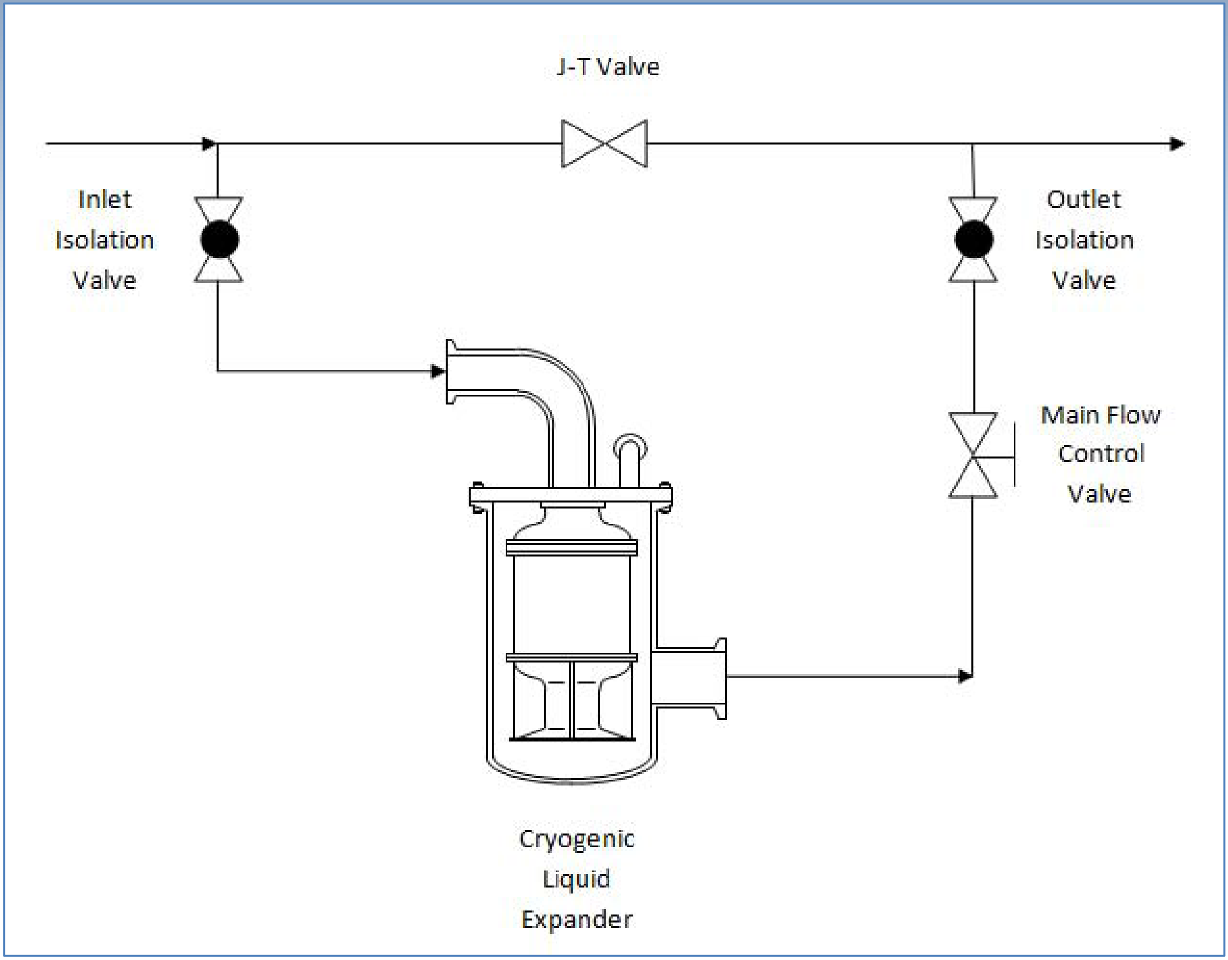
EBARA

Typical Installation Schematic for an LNG Expander



Numerical Experimentation with NIST REFPROP

• By doing numerical experiments using properties from the NIST REFPROP tables, it is possible to clarify the thermodynamics of mixtures and 2-phase systems.

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NIST
National Institute of Standards and Technology

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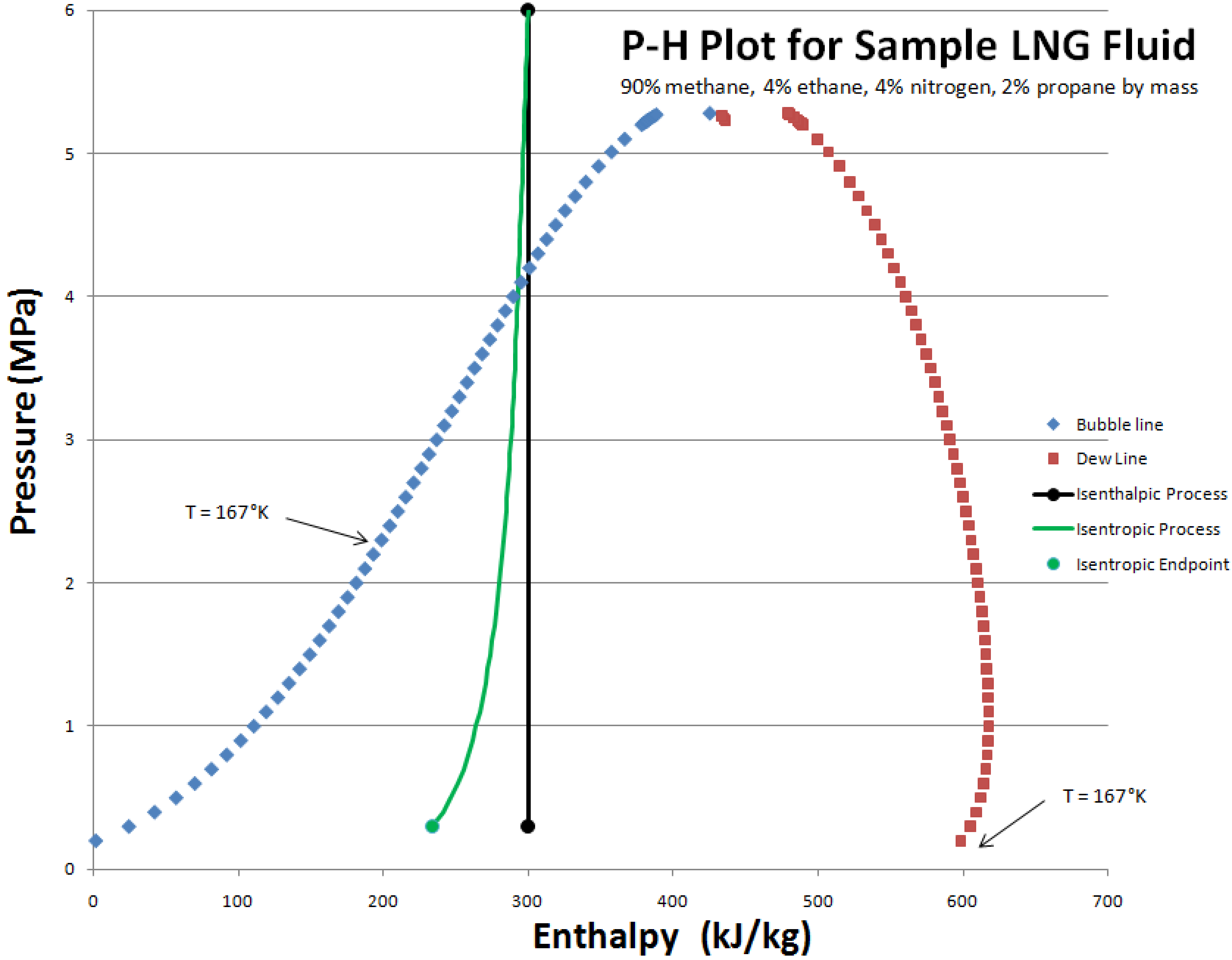
• The NIST tables for LNG components are based on equations developed by the European Gas Research Group (GERG-2008).



P-H Plot for Sample LNG Fluid
90% methane, 4% ethane, 4% nitrogen, 2% propane by mass
Pressure (MPa)
Enthalpy (kJ/kg)
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700
T = 167°K
T = 167°K
Bubble line
Dew Line
Isenthalpic Process
Isentropic Process
Isentropic Endpoint

Expander Process vs Throttling Process

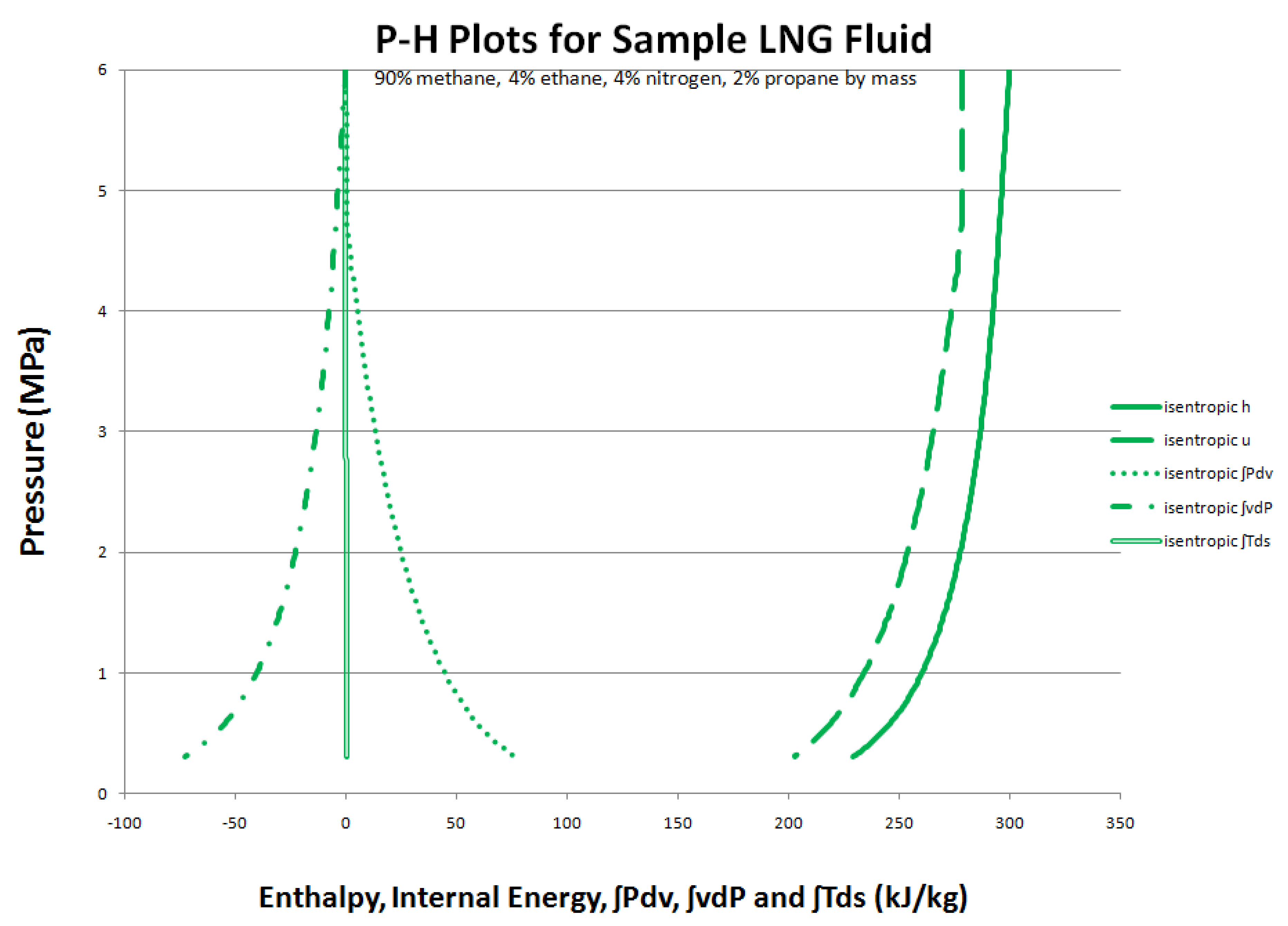
- An isentropic expansion process (green) and an isenthalpic expansion process (black) show two possible fluid paths starting at
  h = 300 kJ/kg and P = 6 MPa
  and ending at P = 0.3 MPa.
- The isentropic curve represents a 100% efficient (ideal) process. Expanders approximate this curve, usually at about 85% efficiency.
- The isenthalpic line represents the effect of using a throttling valve to reduce LNG pressure. This constant enthalpy process is known as a Joule-Thomson process.

Calculation of Liquid Fractions For This Example

- Joule Thomson process → liquid fraction of 0.43
- Single-phase expanders operate only up to the beginning of the 2-phase region. After that, a Joule-Thomson valve is needed to continue the expansion to the desired ending pressure.
- Single-phase expander → liquid fraction of 0.442
- Two-phase expander → liquid fraction of 0.51
- Isentropic process → liquid fraction of 0.57
- These specific numbers are applicable only to this example fluid and conditions

Work Output of 2-Phase Expander

- Is there a way to predict the maximum possible work output from a 2-phase expander?
- Reversible, steady-flow work is $\Delta h = \int v \, dP$
- Similarly, for reversible boundary work, $\Delta u = - \int P \, dv$
- Reversibility => $\int T ds = 0$
- Trace these integrals from initial to ending point….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Pressure (MPa)
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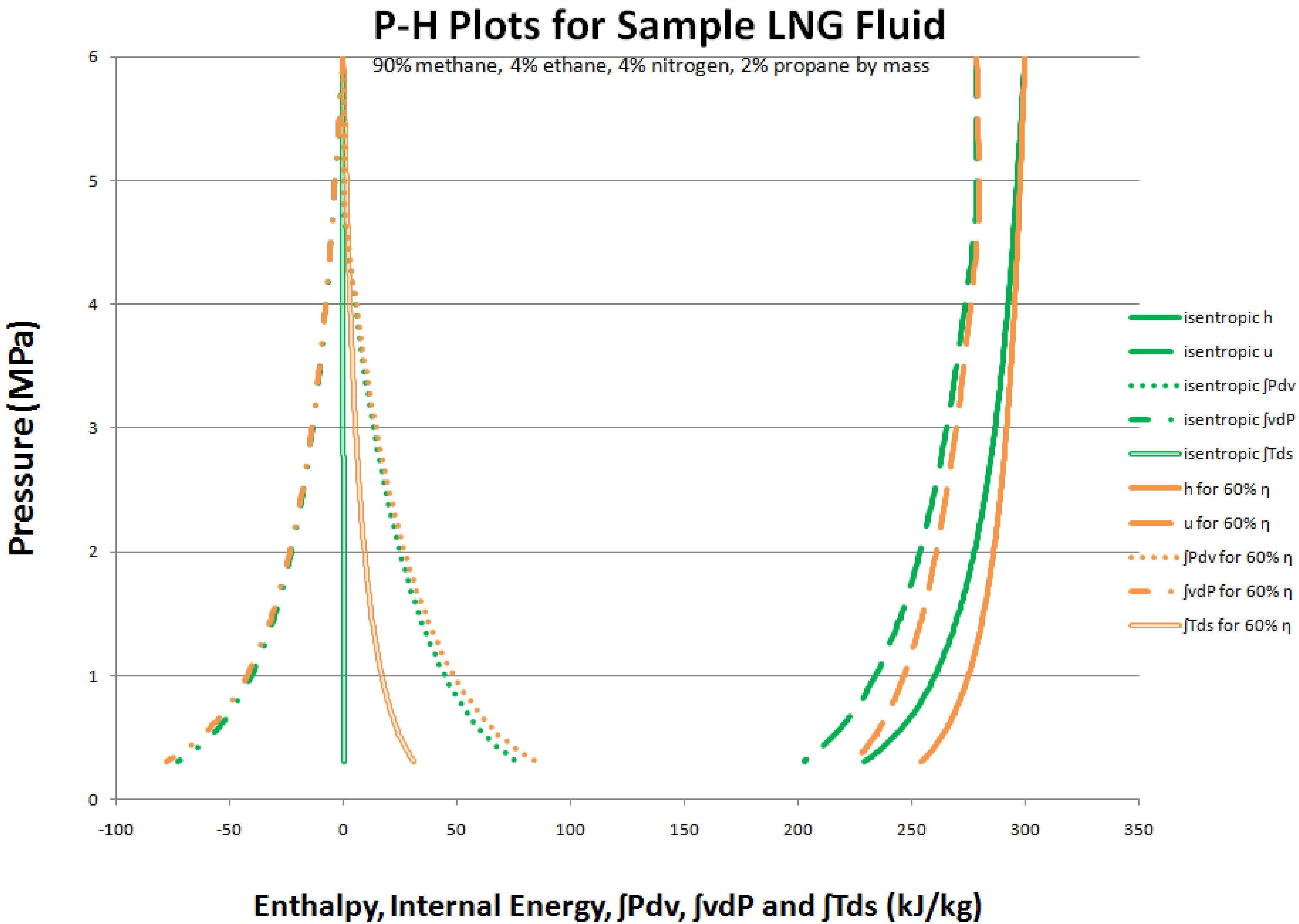
2
3
4
5
6
-100
-50
0
50
100
150
200
250
300
350
isentropic h
isentropic u
isentropic ∫Pdv
isentropic ∫vdP
isentropic ∫Tds
Enthalpy, Internal Energy, ∫Pdv, ∫vdP and ∫Tds (kJ/kg)



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6
-100
-50
0
50
100
150
200
250
300
350
Enthalpy, Internal Energy, ∫Pdv, ∫vdP and ∫Tds (kJ/kg)
isentropic h
isentropic u
isentropic ∫Pdv
isentropic ∫vdP
isentropic ∫Tds
h for 60% η
u for 60% η
∫Pdv for 60% η
∫vdP for 60% η
∫Tds for 60% η

Gibbs Relation

- For a process that is not 100% efficient, we can see what is happening via one of the Gibbs equations:
  $\Delta h = \int v\, dP + \int T ds$

- For an expansion, $\Delta h < 0$, $\int v\, dP < 0$ and $\int T ds > 0$
  so $\int T ds$ reduces the available Δh

- $\int T ds > 0$ => the process is *not* reversible, thus $\int v\, dP$ gives a measure of the available work *only* in the case of an isentropic process