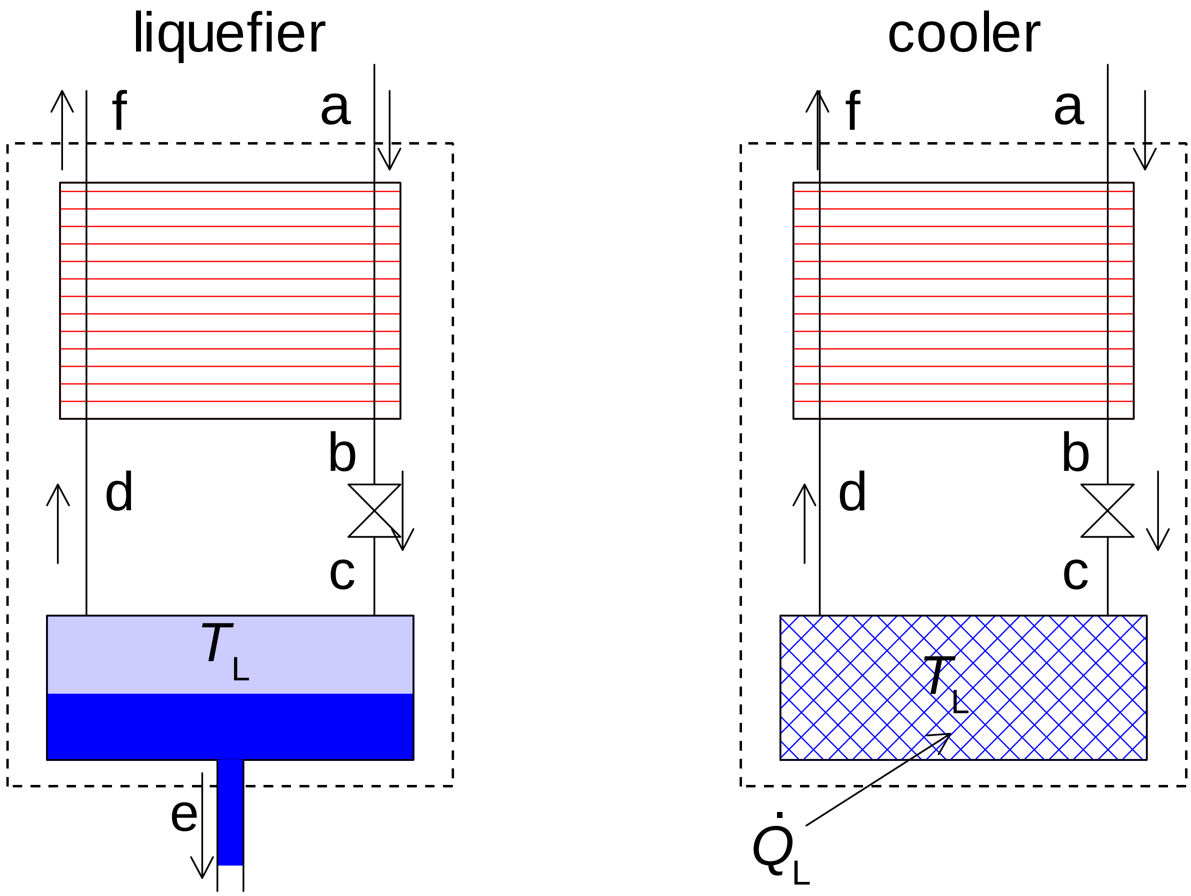
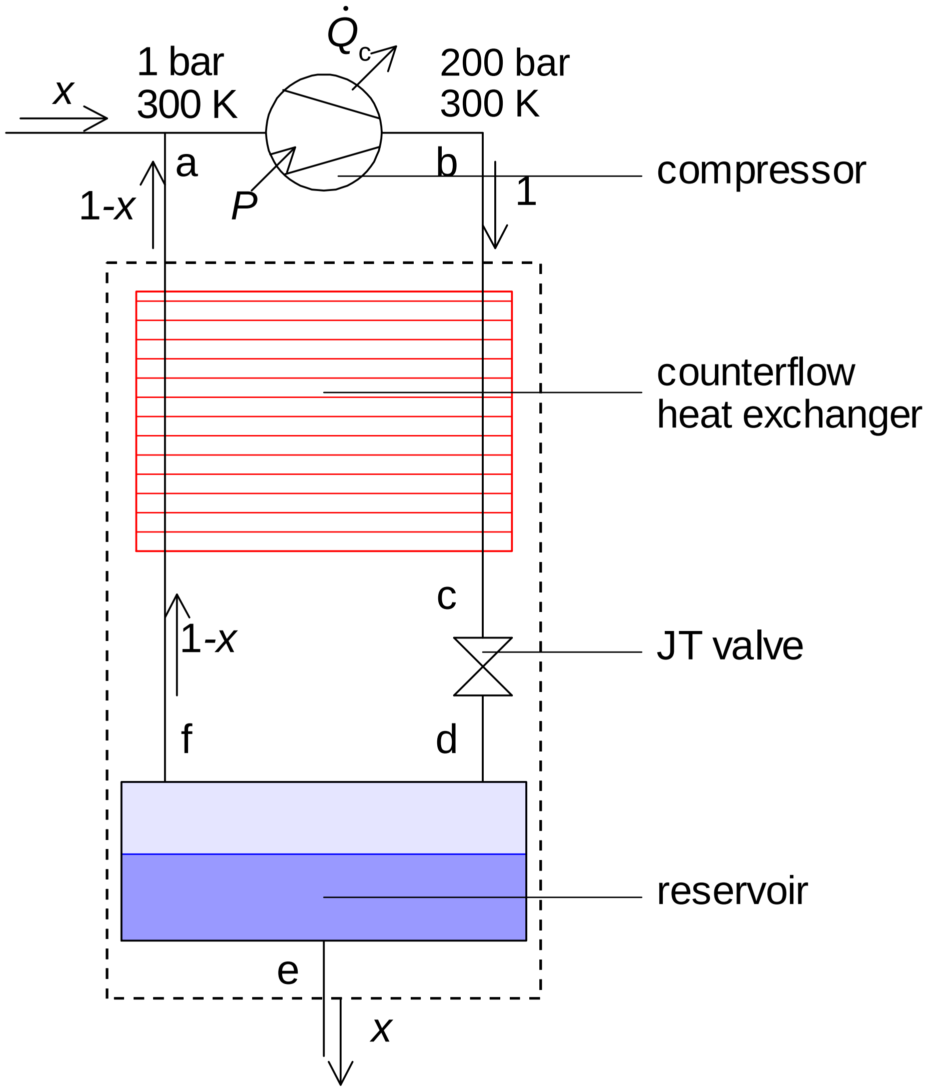
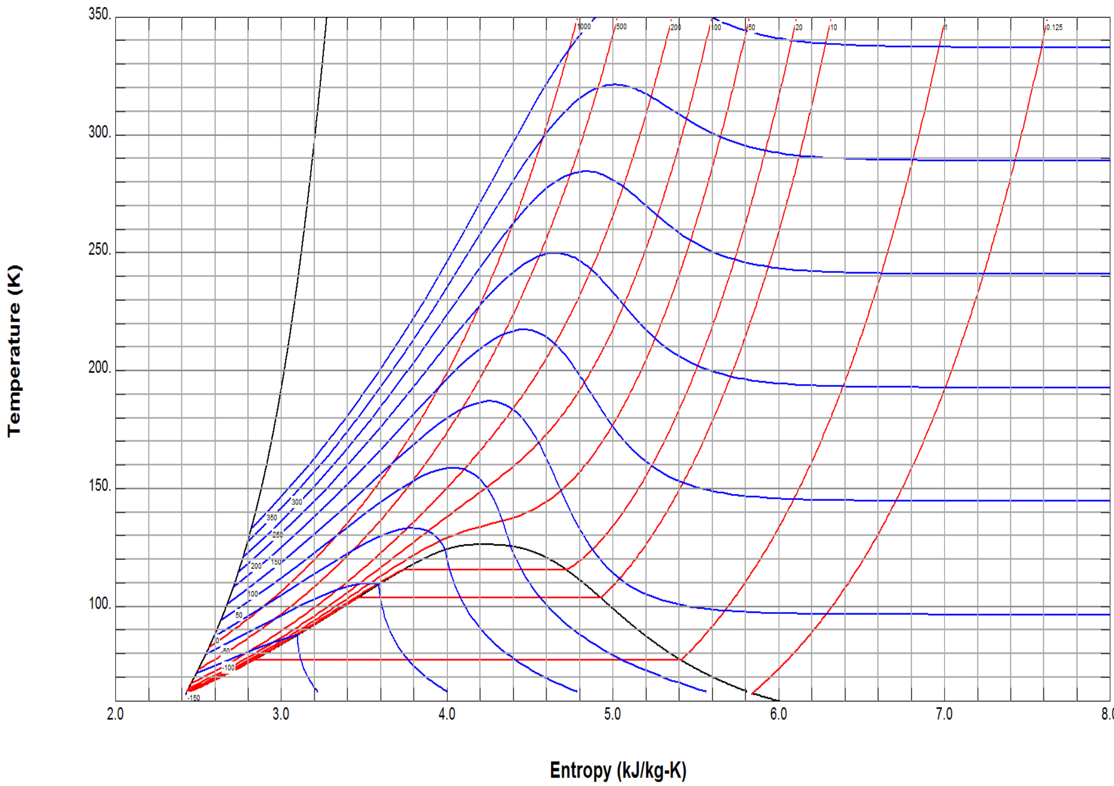
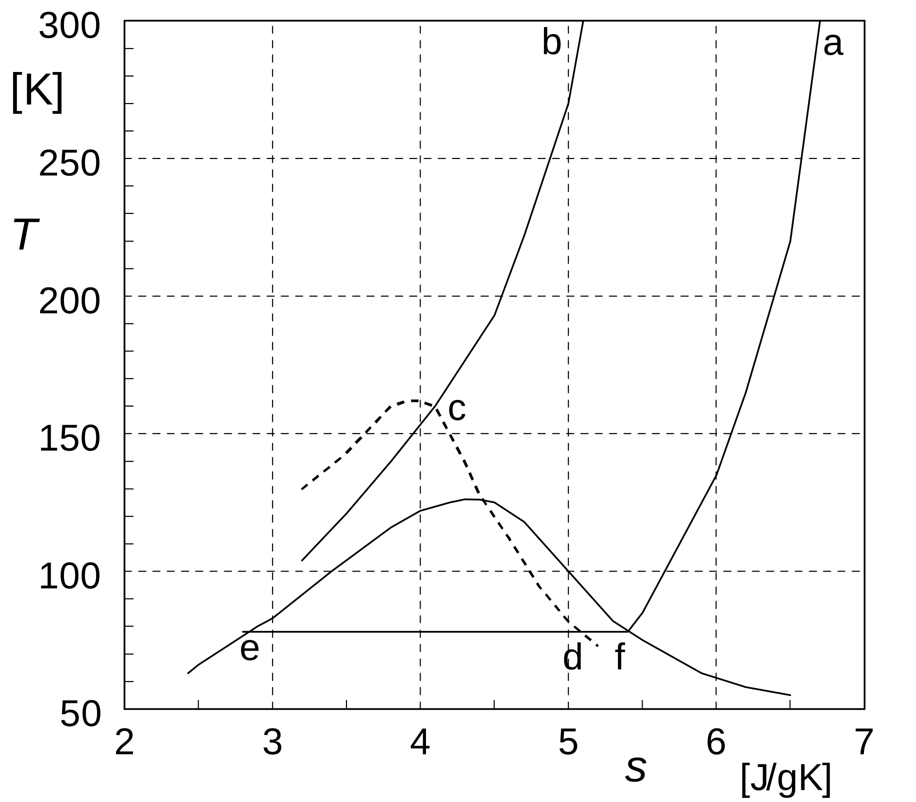

liquefier
f
a
b
d
c
T_L
e
cooler
f
a
b
d
c
T_L
$\dot{Q}_L$

Joule-Thomson liquefier

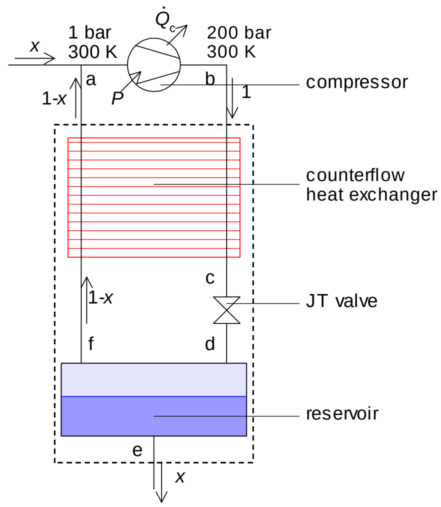


Ts diagram of 4He





300
[K]
250
T
200
150
100
50
2
3
4
5
6
7
s
[J/gK]
a
b
c
d
e
f



$$h_{\mathsf{b}} = x h_{\mathsf{e}} + (1 - x)\, h_{\mathsf{a}}$$

or

$$x = \frac{h_{\mathsf{a}} - h_{\mathsf{b}}}{h_{\mathsf{a}} - h_{\mathsf{e}}}$$

liquefaction if $x > 0$. As $h_{\mathsf{a}} > h_{\mathsf{e}}$ this means

$$h_{\mathsf{a}} > h_{\mathsf{b}}$$

e.g.

$$x = \frac{310 - 280}{310 - (-120)} = 0.070$$

compressor power

first law

$$P = \dot{Q}_{\mathsf{c}} - \overset{*}{m}\left(h_{\mathsf{a}} - h_{\mathsf{b}}\right)$$

second law

$$\dot{Q}_{\mathsf{c}} = \overset{*}{m} T_{\mathsf{a}}\left(s_{\mathsf{a}} - s_{\mathsf{b}}\right) + T_{\mathsf{a}}\dot{S}_{\mathsf{c}}$$

so

$$P = \overset{*}{m}\left[T_{\mathsf{a}}\left(s_{\mathsf{a}} - s_{\mathsf{b}}\right) - \left(h_{\mathsf{a}} - h_{\mathsf{b}}\right)\right] + T_{\mathsf{a}}\dot{S}_{\mathsf{c}}$$

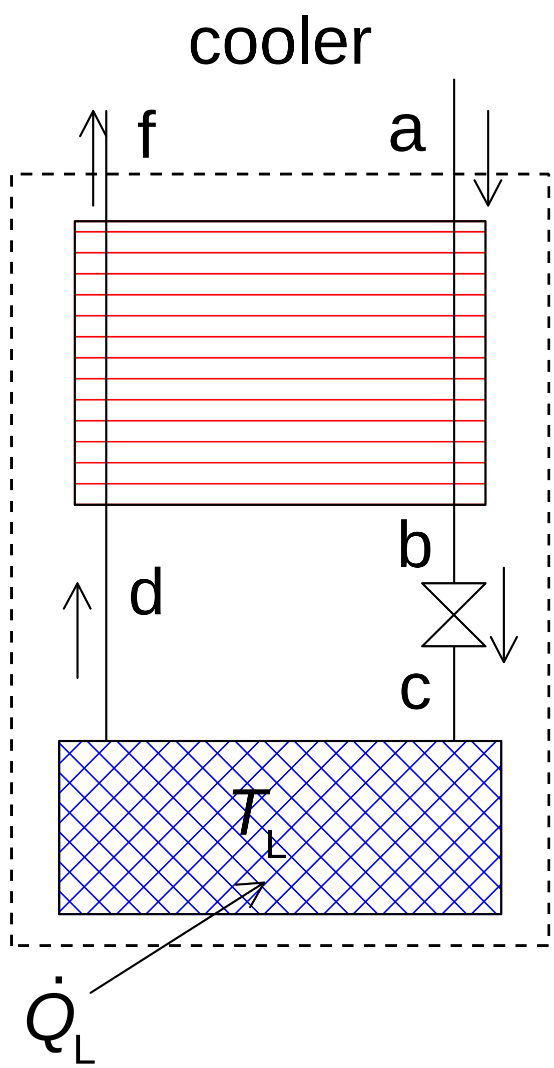
$T_{\mathsf{a}}\dot{S}_{\mathsf{c}}$ is the dissipated power due to friction, heat exchange, eddy-currents, Joule heating, hysteresis
reverisible case $\dot{S}_{\mathsf{c}} = 0$

$$\frac{P_{\mathsf{min}}}{\overset{*}{m}} = T_{\mathsf{a}}\left(s_{\mathsf{a}} - s_{\mathsf{b}}\right) - \left(h_{\mathsf{a}} - h_{\mathsf{b}}\right)$$

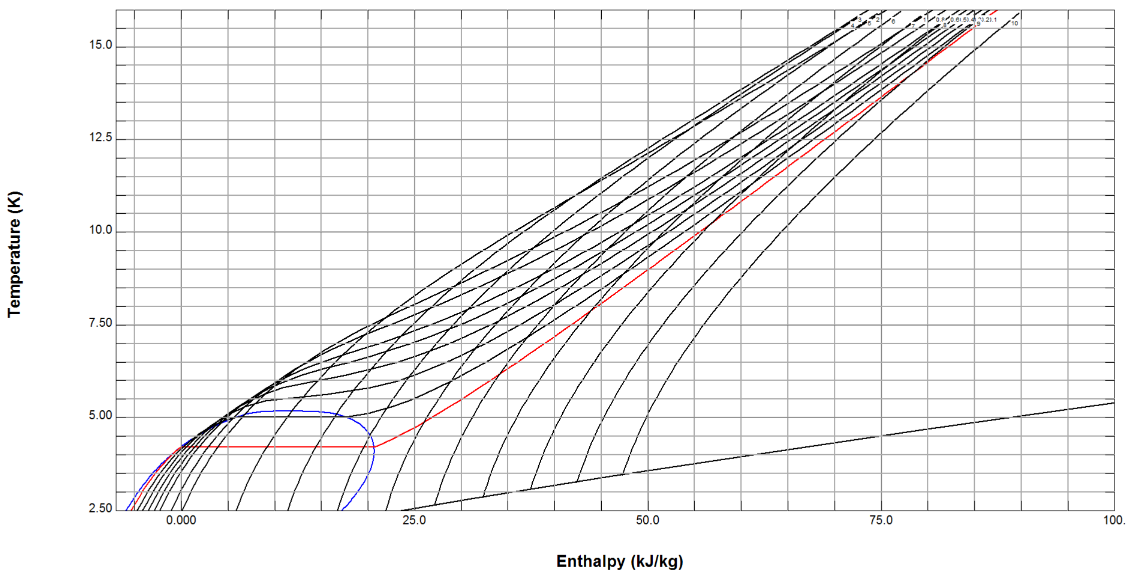
so

$$\frac{P_{\mathsf{min}}}{\overset{*}{m}} = 300\left(6.8457 - 5.1630\right) - \left(310 - 280\right) = 475\ \frac{\mathsf{J}}{\mathsf{g}}$$

Basics of JT cooling



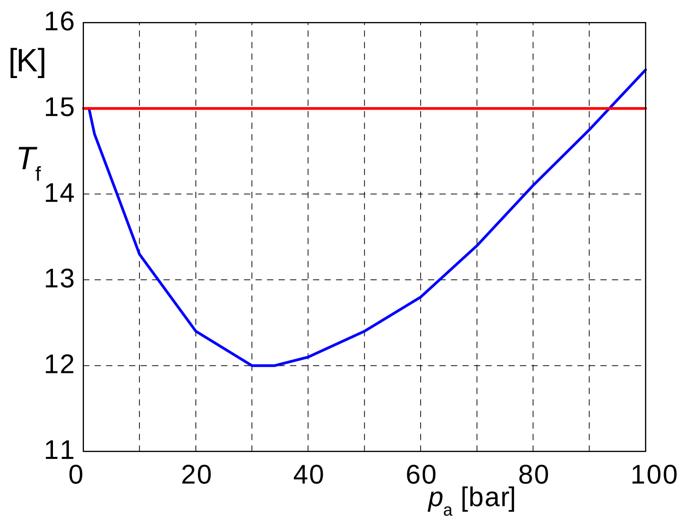
Th diagram of ^{4}He



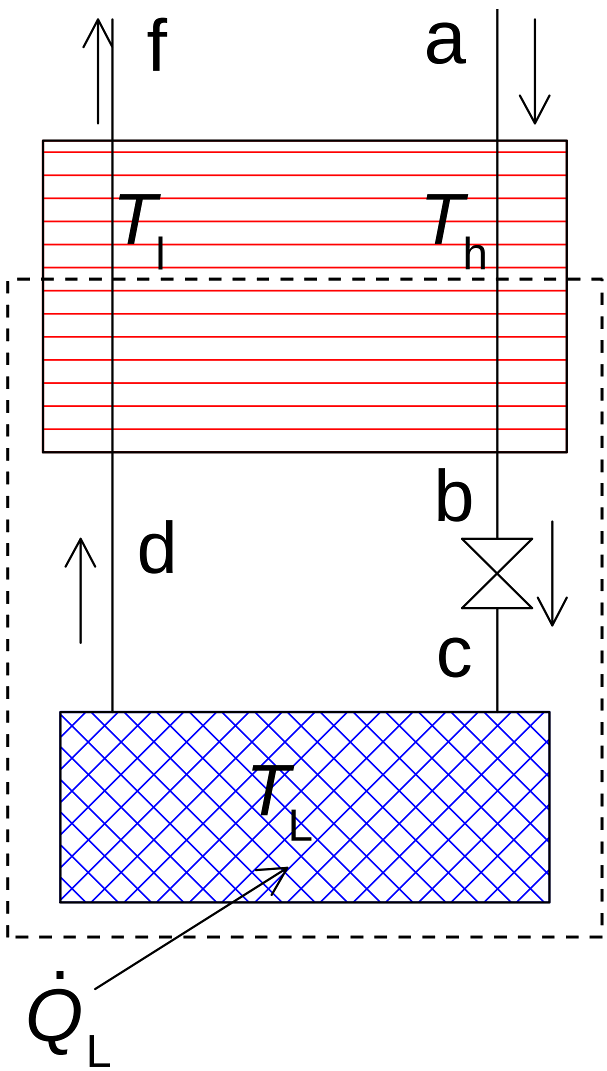
Th diagram of ^{4}He; isobars at 1 (red), 2, 4, 6, 8, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 bar.

if $\dot{Q}_{\mathsf{L}} = 0$ then $h_{\mathsf{a}} = h_{\mathsf{f}}$

exit temperature for $T_{\mathsf{a}} = 15$ K and $p_{\mathsf{f}} = 1$bar



usually $T_{\mathsf{a}} \neq T_{\mathsf{f}}$ even with a perfect heat exchanger

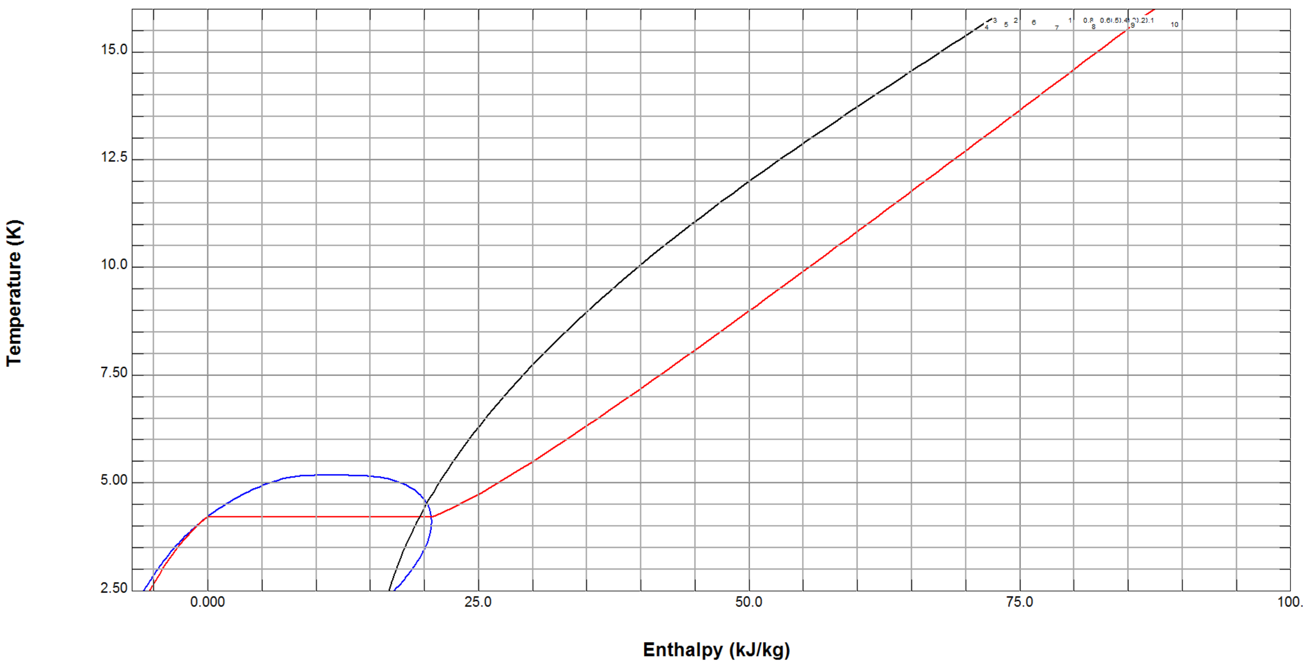


definition of "the" temperatures T_l and T_h

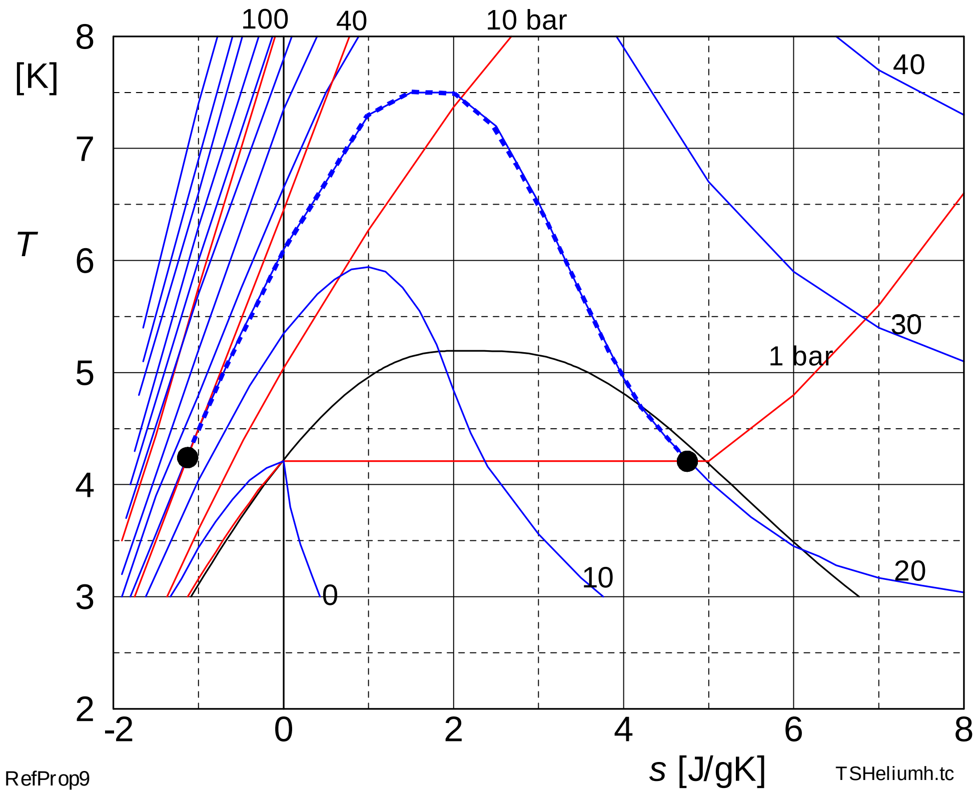
$$\overset{*}{m} h\left(T_\mathsf{l}, p_\mathsf{f}\right) = \int \rho v h \mathsf{d} A_\mathsf{l}$$

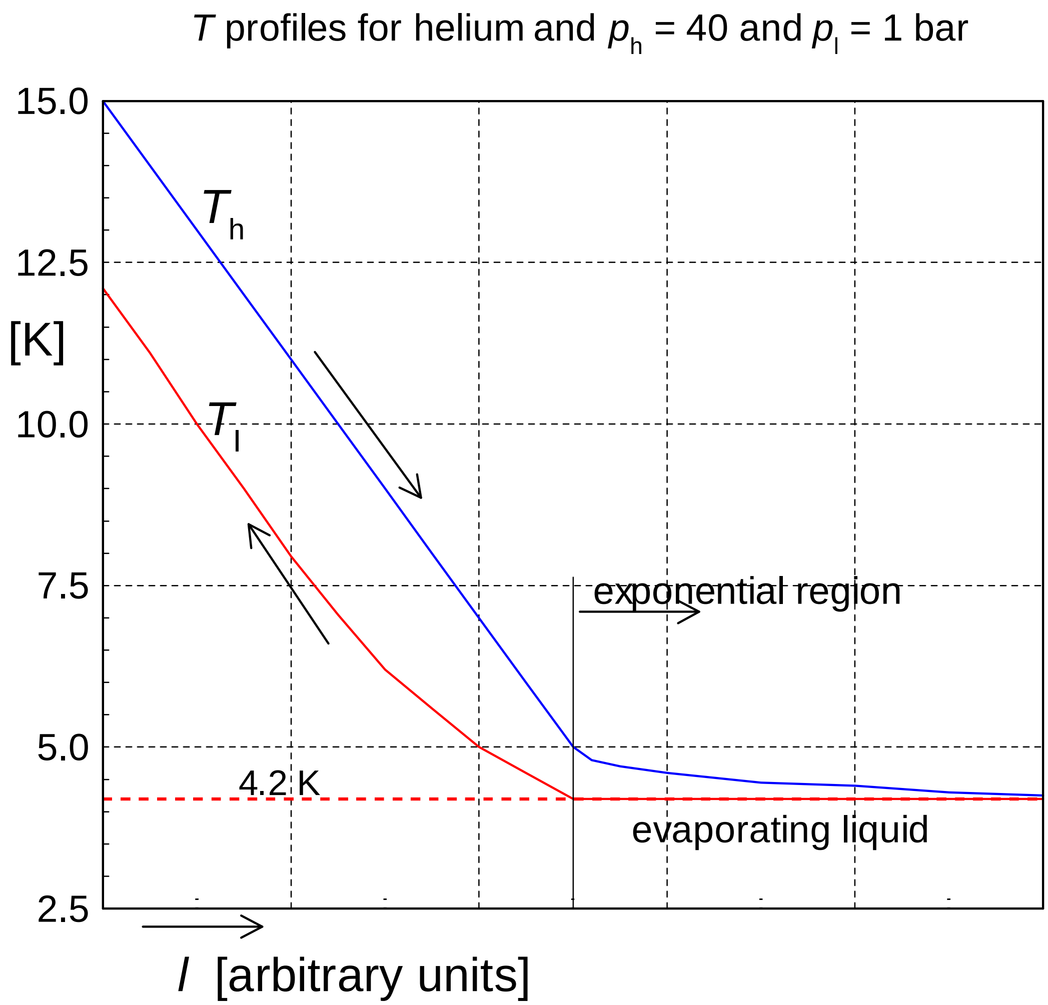
$$h\left(T_\mathsf{h}, p_\mathsf{a}\right) = h\left(T_\mathsf{l}, p_\mathsf{f}\right)$$

40 bar



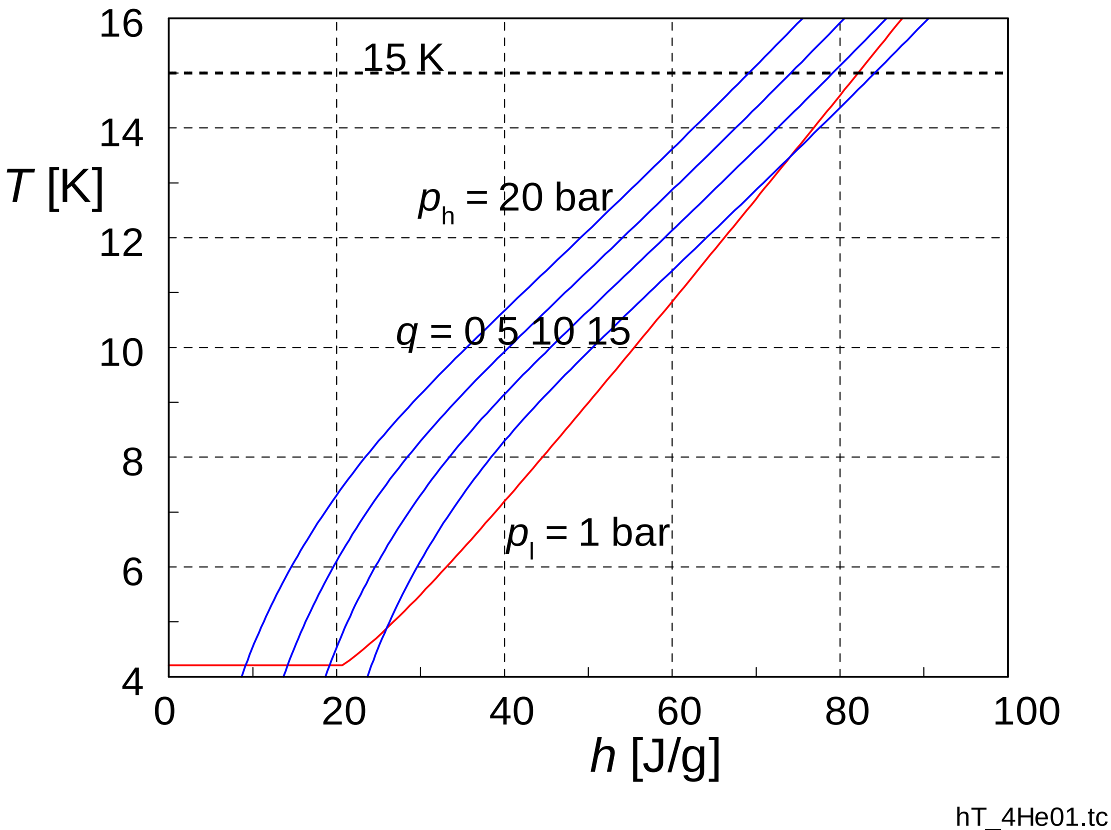
Temperature (K)
15.0
12.5
10.0
7.50
5.00
2.50
0.000
25.0
50.0
75.0
100.
Enthalpy (kJ/kg)

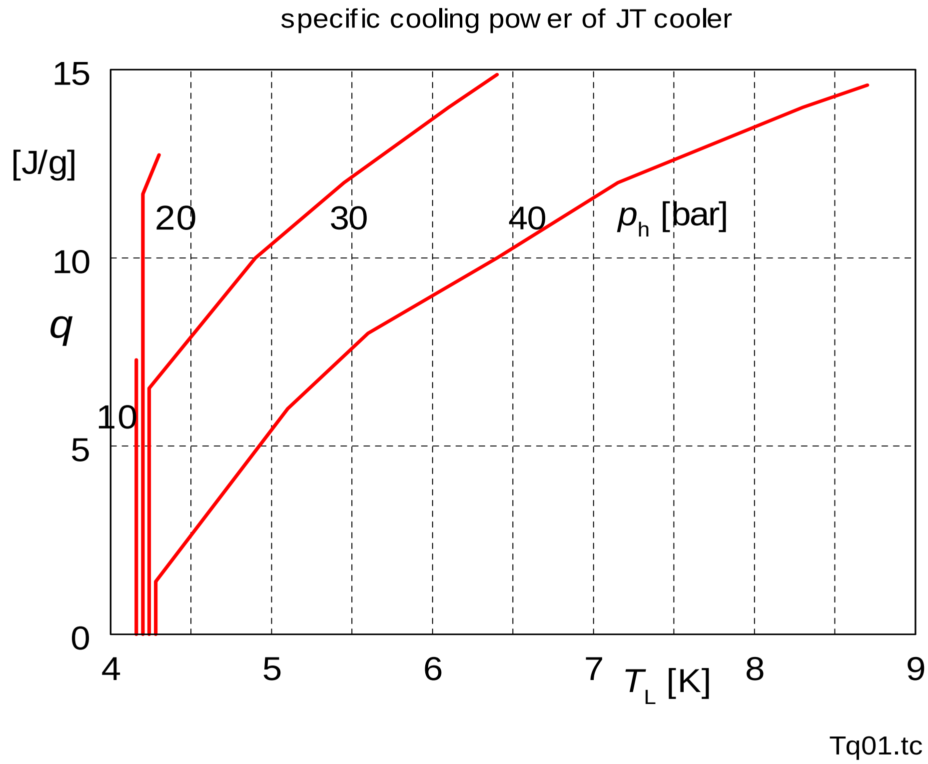

100
40
10 bar
8
7
6
5
4
3
2
[K]
T
40
30
1 bar
20
10
0
-2
0
2
4
6
8
s [J/gK]
RefProp9
TSHeliumh.tc



T_l and T_h can be regarded as cold-end temperatures as functions of the length of the HEX now with heat load and $p_\mathsf{h} = 20$ bar

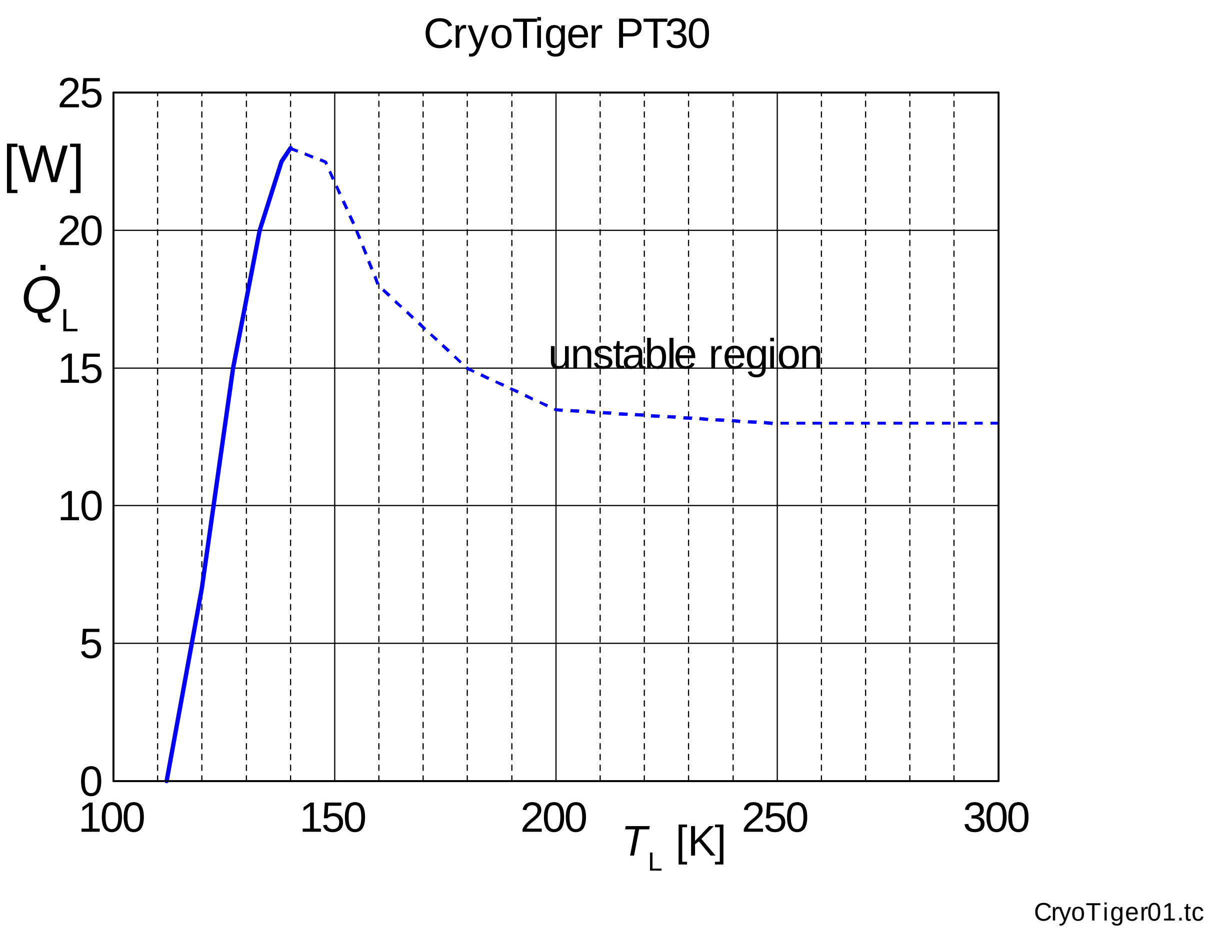
$$q + h_\mathsf{h} = h_\mathsf{l}$$

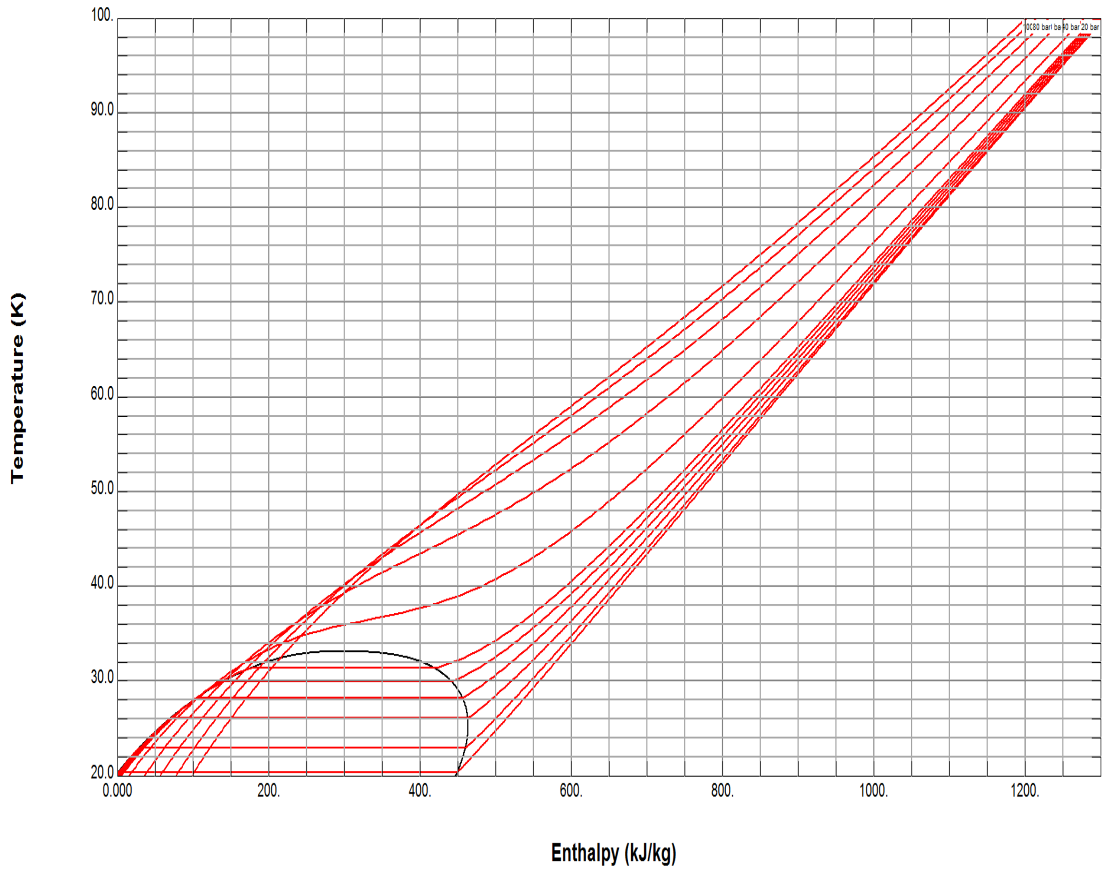




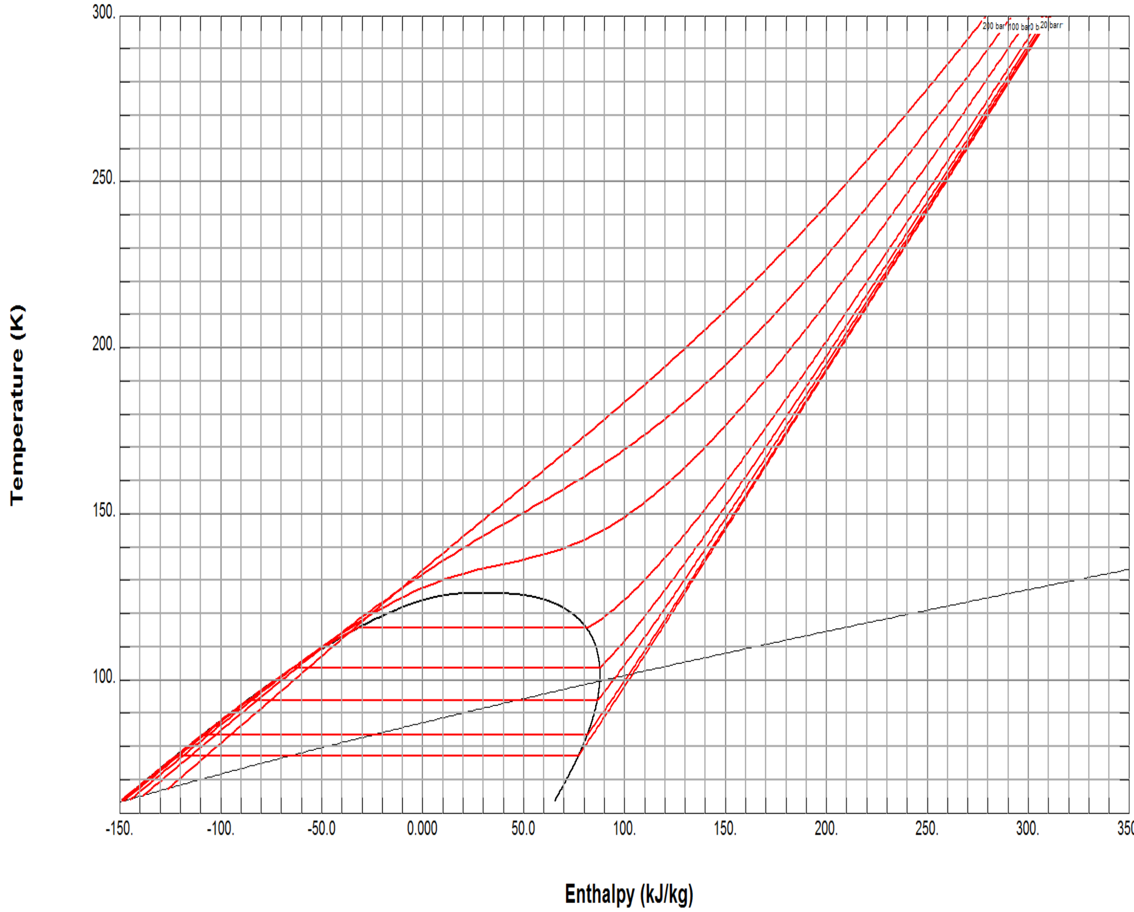
specific cooling pow er of JT cooler
15
[J/g]
20
30
40
p_h [bar]
10
q
10
5
0
4
5
6
7
T_L [K]
8
9
Tq01.tc

gas mixtures are used to reduce the pressure level and increase the efficiency





Th-diagram of hydrogen with isobars at 1, 2, 4, 6, 8, 10, 20, 40, 60, 80, 100 bar.



Th-diagram of nitrogen with isobars at 1, 2, 5, 10, 20, 50, 100, and 200 bar