Problem 2   Liquefied natural gas

2.1
In the boiling point the pressure of methane is 1 atm. Then
P = 1 atm = 1.01325 bar   Log(1.01325) = 3.99 – 443/(T – 0.49)
T = 111.68 K

2.2
The energy density is proportional to the moles of methane.
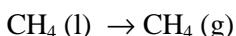liquefied methane
$d(CH_4)$ = 16 800 tn/40 000 m^3 = 420 kg/m^3
gaseous methane
$d(CH_4)$ = (300.10^5 Pa).(16.10^{-3} kg/mol)/(8.314 J/mol.K.298K) = 193.74 kg/m^3
ratio (CH_4 (l)/CH_4 (g)) = 420/193.74 = 2.17

2.3
The reaction is:
CH_4 (l) → CH_4 (g)
If pressure inside it is kept constant then:
T = - 159 °C = 114 K   log(p) = 3.99 – 443/(114-0.49) = 0.0873
A phase diagram show that:
U_L = 0.1 kJ/mol and U_G = 7.35 kJ/mol at Log(p) = 0.0873
Now ΔU vap = U_G – U_L = 7.35 – 0.1 = 7.25 kJ/mol and
ΔH vap = ΔU vap + R.T. $Δn_g$ = 7.25 kJ/mol + 8.314 ·10^{-3} kJ/mol.K. 114 K. (1-0) = 8.20 kJ/mol

2.4
heat leakage = 50 kW.(1000J.s^{-1}/W).15 days.(24.3600s/day) = 6.48x10^{10} J
$n(CH_4$ evaporated) = 6.48x10^{10}/8.20x10^3 = 7.90244x10^6 mol
$n(CH_4$ total) = 16800 ton.(1000 000 g/ton).(1 mol/16 g) = 1.05x10^9
% evaporated = (7.90244x10^6/1.05x10^9).100% = 0.753 %

2.5
In this case the volume is constant then
m CH_4 = 16 800 ton/3 = 5 600 ton
n CH_4 = 5 600 ton.(1 000 000 g/ton).(1 mol/16 g) = 3.5x10^8 mol
Q = ΔU
Q = 50 kW.(1000J.s^{-1}/W).9 month.(30.5 days/month).(24.3600s/day) = 1.186x10^{12} J
Let α the fraction of methane evaporated, then a phase diagram show that:
U_L initial conditions (114 K and Log(p) = 0.0873) is 0.1 kJ/mol
U_G final conditions (Log(p =16.4) = 1.215) is 7.9 kJ/mol
U_L final conditions (Log(p=16.4) = 1.215) is 2.9 kJ/mol
Now
Q = 1.186 ·10^{12} = ΔU = U_{final} - $U_{initial}$ = (3.5 ·10^8 mol).(7.9α + 2.9(1- α) – 0.1)kJ/mol. (1000J/1kJ)
3.3886 = 5.0α + 2.8   → α = 0.1177

2.6
Maximum temperature is the critic temperature at the critic pressure. Phase diagram show that:
Log(critic pressure) = 1.7, Pc = 50.12 bar and Log(p) = 3.99 – 443(T-0.49) = 1.7 Tc = 194 K

Solution proposed by
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