Note Title 12.04.2016

Compression process

$\dot{W} = \dot{m}(h_2 - h_1)$

$P_1 \rightarrow P_2$

$\frac{\dot{W}}{\dot{m}} = w$ ~ specific work

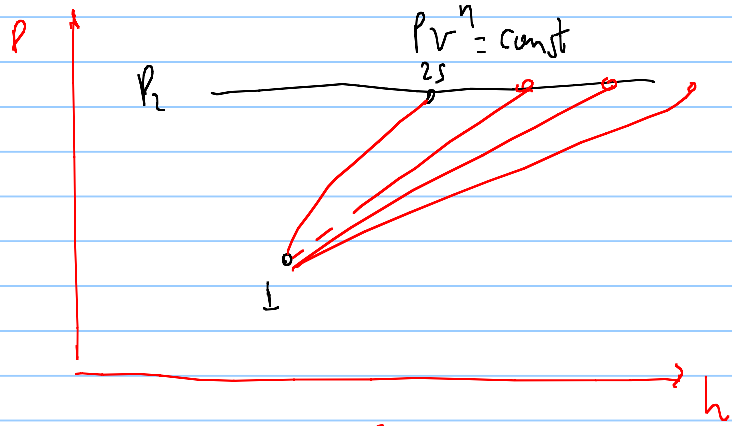
$(h_{2s} - h_1) \rightarrow$ smallest specific work required to compress from 1 to 2

T_{2s} is the smallest outlet temperature that i can get when compressing from 1 to 2

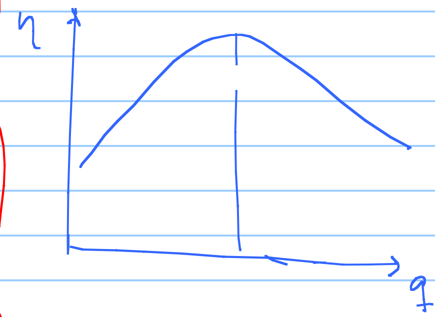
is difficult to relate it with $q, \Delta p$

$\eta_{adiabatic} = \frac{\Delta h_s}{\Delta h_{real}}$

assume polytropic process



example for pump



$\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \frac{T_2}{T_1}$ ~ η_p polytropic efficiency → $f(n)$

$r_p^{\frac{n-1}{n}} = \frac{T_2}{T_1}$

$r_p = \frac{P_2}{P_1}$

resembles a bit for liquids $\Delta h \simeq C_p(\Delta T)$

if a polytropic process : $\Delta h_p = T_1 \, Z_{av} \, R \, \frac{n}{n-1} \left(r_p^{\frac{n-1}{n}} - 1 \right)$

$\left(\frac{T_2 - T_1}{T_1}\right)$

calculated assuming a politropic process

$\frac{Z_1 + Z_2}{2}$

$\frac{\bar{R}_u}{M_g}$ ~ molecular weight of the gas

$\eta_p = \frac{\Delta h_s}{\Delta h_p}$

$$\Delta h_s = Z_{av} \cdot T_1 \, R \cdot \frac{k}{k-1} \left[r_p^{\frac{k-1}{k}} - 1 \right] \qquad k = \frac{C_v(T)}{C_p(T)}$$

adiabatic coefficient, exponent

$$\boxed{\frac{n-1}{n} = \frac{k-1}{k \, \eta_p}}$$

polytropic efficiency

polytropic exponent

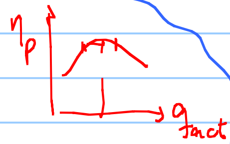
$$k = 1.3 - 0.31 \left(\gamma_g - 0.55 \right)$$

HC

η_p for radial compressors $\{$ 0.6 − 0.77

η_p for axial compressors $\{$ 0.8 − 0.85

we are going to use for class exercise $\eta_p = 0.73$

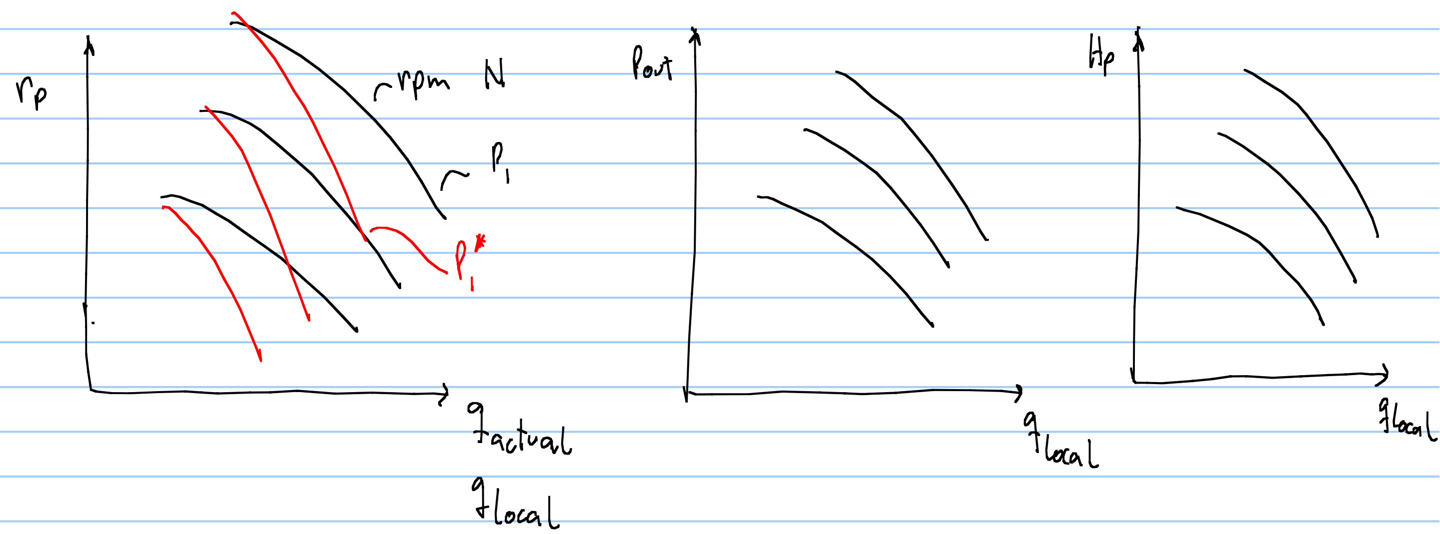


$q_{sc} \cdot \rho_{sc}$, $q_{act} \cdot \rho_{act}$

$$P = \dot{m} \, \Delta h_p$$

polytropic head $H_p = \dfrac{\Delta h_p}{g} \rightarrow [m]$ $\qquad \dfrac{\Delta P}{\rho} = h \, [m]$

Performance curves $\quad f(P_1, T_1, \gamma_g, k)$

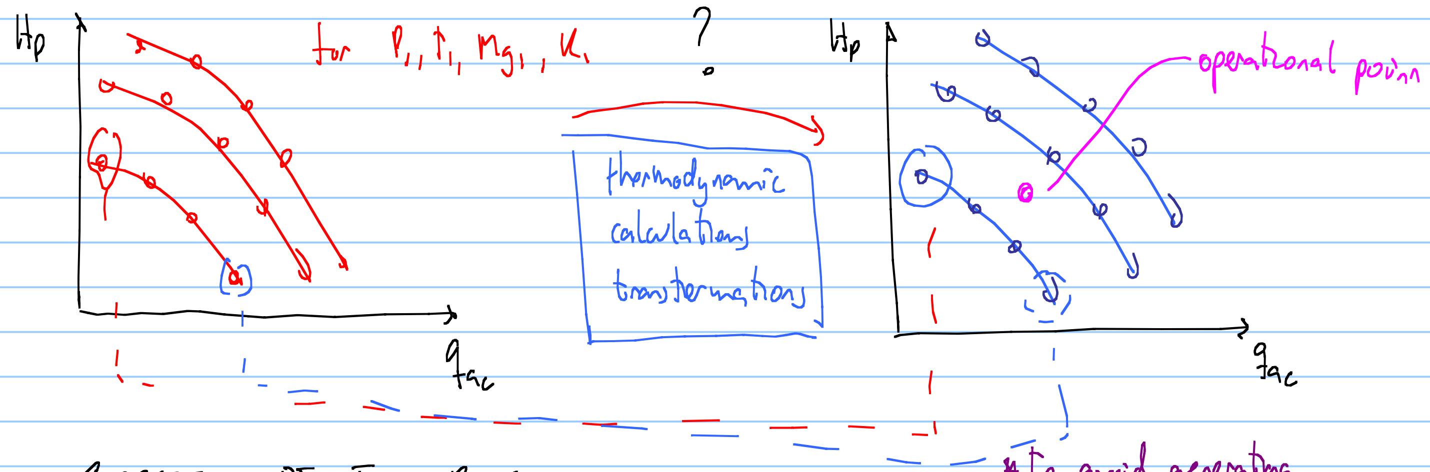


Usually compressor performance curves are measured for a specific set of inlet conditions P_1, T_1 → use a particular fluid M_g, K

P_1: 1.01325 bar, T_1: 15.6 °C

only for the exercise. *

$P_1^*, T_1^*, M_{g1}^*, K_1^*$



* to avoid generating performance map for every year.

- CORRECTION OF FLOW RATE :

$$\phi = \frac{\dot m}{\rho_{0,1}\, a_{0,1} D^2} \Rightarrow \underset{(TEST)}{\phi_T} = \underset{(ACTUAL)}{\phi_a} \Rightarrow \frac{\dot m_T}{\rho_T\, a_T \cancel{D^2}} = \frac{\dot m_a}{\rho_a\, a_a \cancel{D^2}}$$

$$\Rightarrow \frac{q_T \cdot \cancel{\rho_T}}{\cancel{\rho_T}\; a_T} = \frac{q_a\, \cancel{\rho_a}}{\cancel{\rho_a}\; a_a} \Rightarrow q_a = q_{TEST} \times \frac{\sqrt{K_a R_a T_a}}{\sqrt{K_{TEST} R_{TEST} T_{TEST}}}$$

$$\Rightarrow \boxed{q_{ACTUAL} = q_{TEST} \sqrt{\frac{K_a}{K_{TEST}}} \times \sqrt{\frac{M_{TEST}}{M_a}} \times \sqrt{\frac{T_a}{T_{TEST}}}}$$

- CORRECTION OF PRESSURE RATIO :

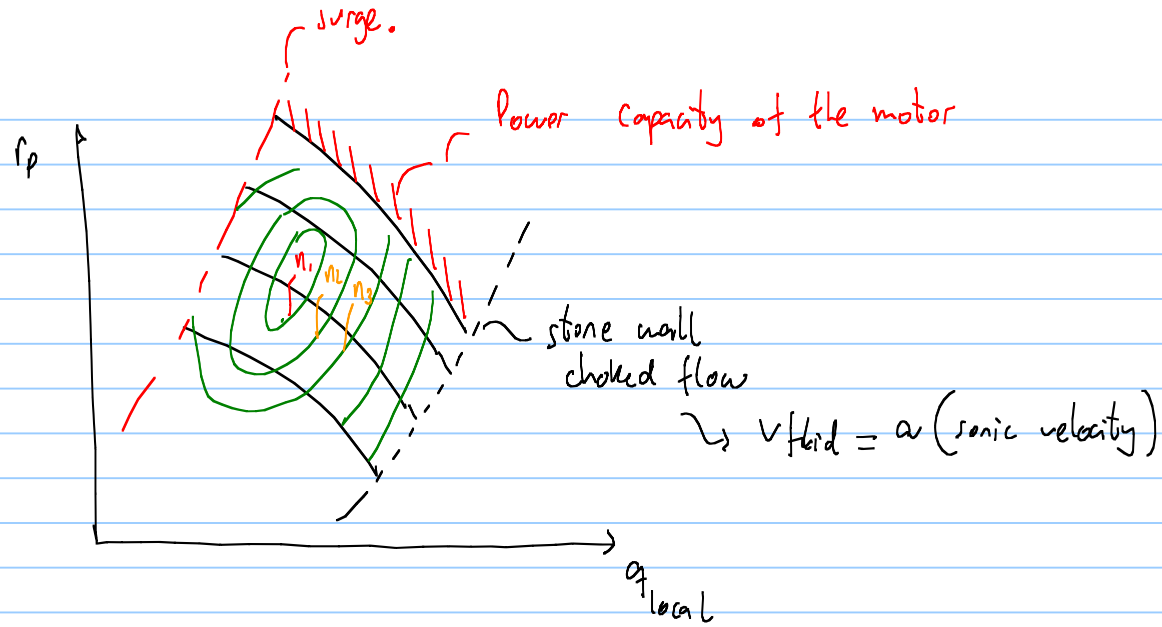
THE POLYTROPIC HEAD REMAINS THE SAME...

$$\boxed{H_{P_{TEST}} = H_{P_A}}$$

$$\left[\frac{R T_1 Z_1 n}{n-1} \left[r_p^{\frac{n-1}{n}} - 1 \right] \right]_{TEST} = \left[\frac{R T_1 Z_1 n}{n-1} \left[r_p^{\frac{n-1}{n}} - 1 \right] \right]_{ACTUAL}$$

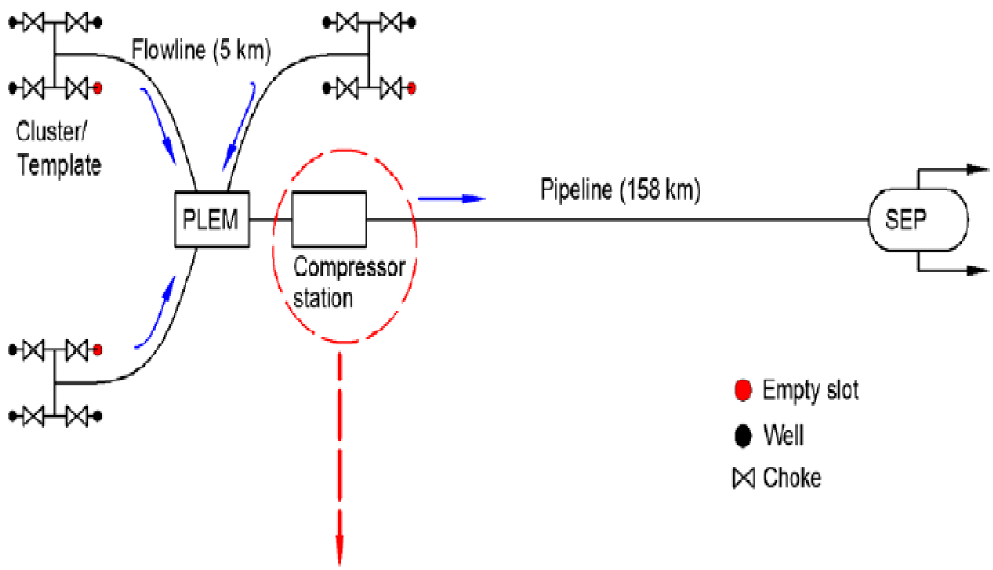
$$\frac{n-1}{n} = \frac{k-1}{k \cdot \eta_p}$$

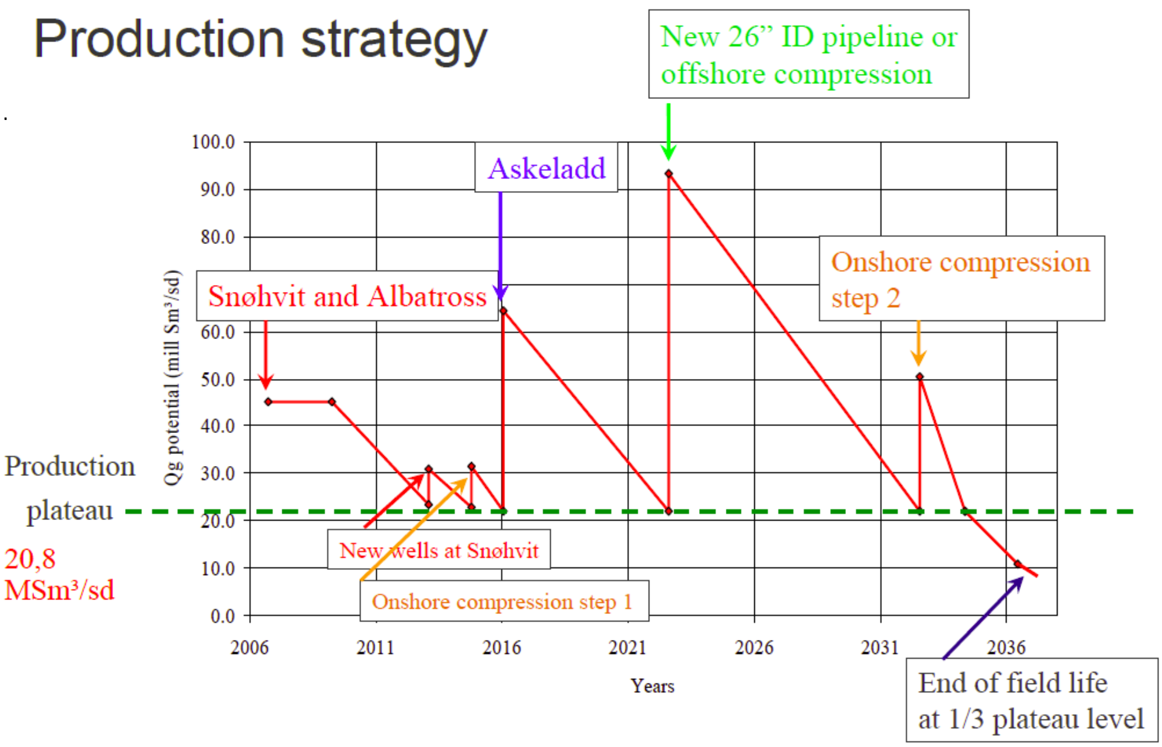
THEN ...
$$\boxed{r_{p_a} = \left[\frac{M_a}{M_T} \frac{T_T}{T_a} \frac{Z_a}{Z_T} \frac{\frac{n_T}{n_T - 1}}{\frac{n_a}{n_a - 1}} \left[r_{p_T}^{\frac{n_T - 1}{n_T}} - 1 \right] + 1 \right]^{\frac{n_a}{n_a - 1}}}$$



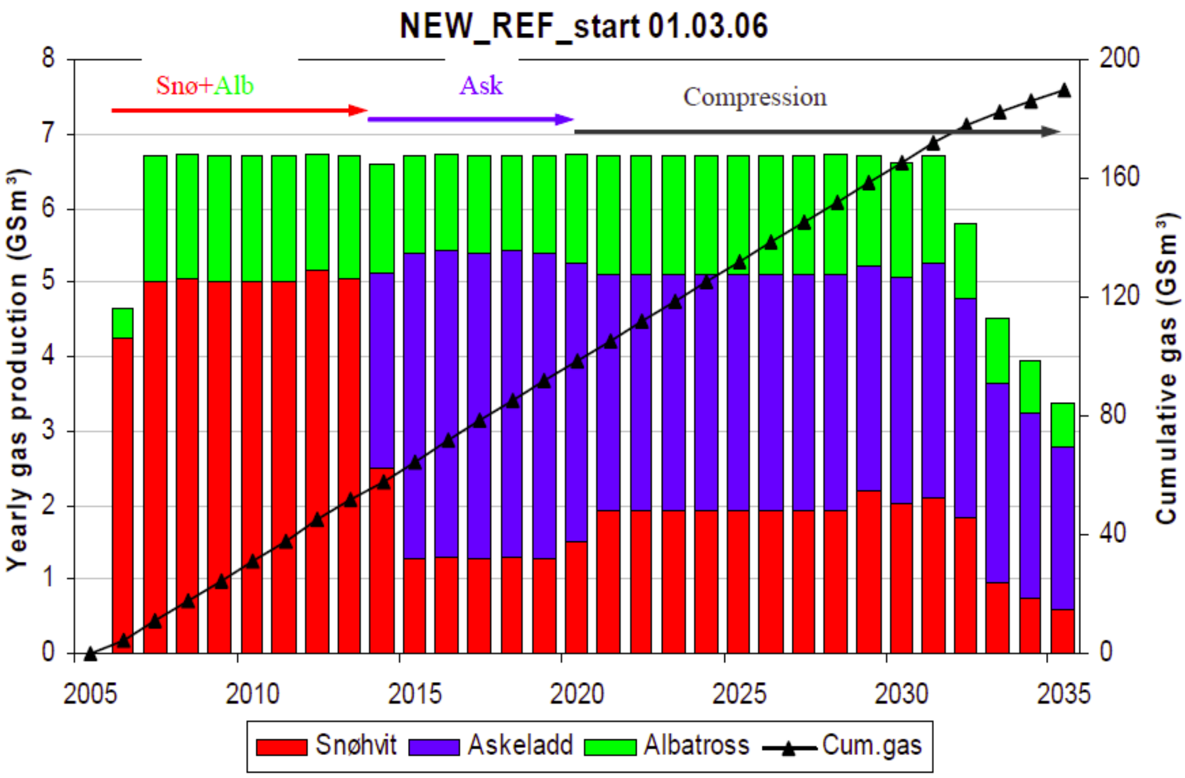
Class exercise

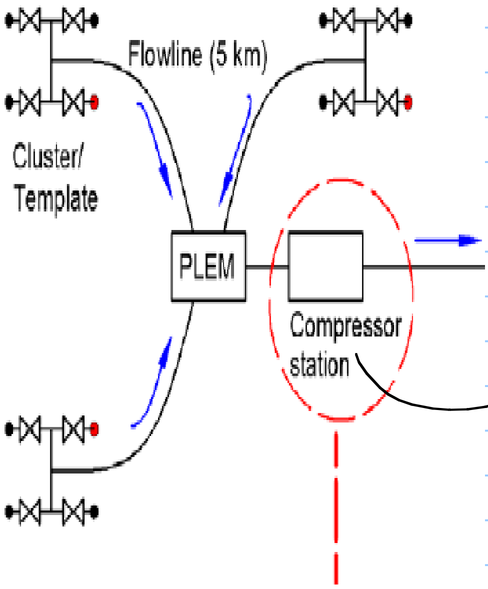
Snøhvit

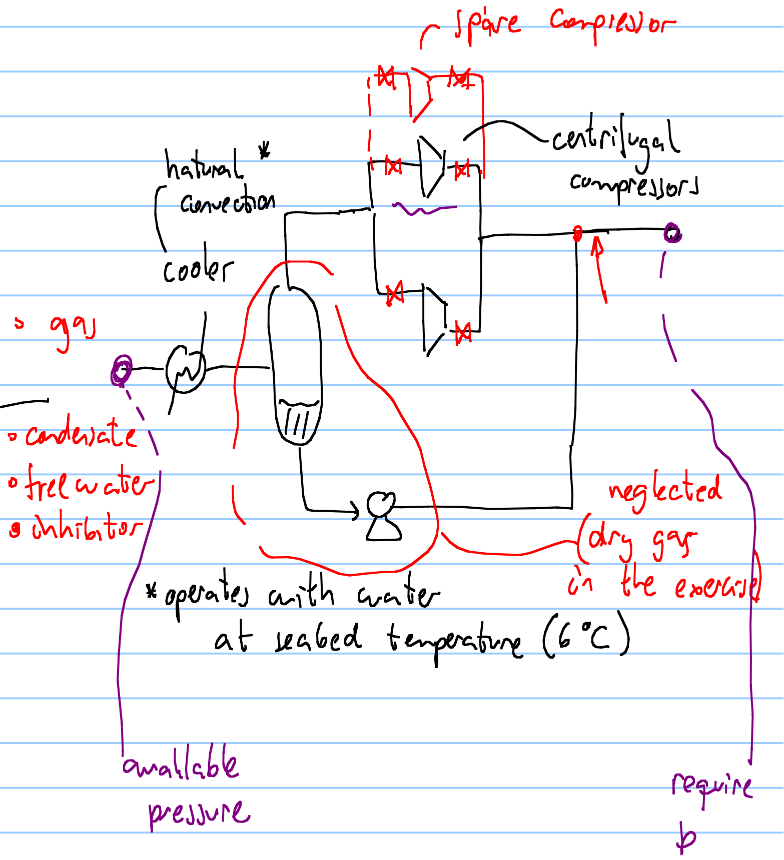




Production profile (20,8mill. Sm³/sd – 6,7 GSm³/år)





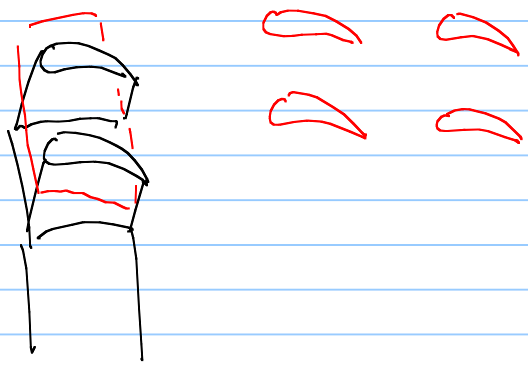


Δp needed is high

a) a side note: other option for boosting

$\Delta p \leq 40$ bara

WGC wet gas compressor



assumptions/requirements for the exercise:

- $\eta_p = \text{const} = 0.7$
- $T_{discharge} \leq 150°C$ — seals integrity; avoid vaporization of inhibitor; to avoid structural problems in discharge pipeline — operational constraints; general compressor constraints → later specific compressor constraints with the performance curve.
- $T_{inlet} = 67°C$ compressor station
- Cooler is operating with $T_{amb} = 6°C$ $\quad \underbrace{\Delta T_{MAX} = 27°C}$
- Power of each compressor unit: 11 MW. Max total = 22 MW.
- $P_{suc} \geq 20$ bara

$$r_p^{\frac{n-1}{n}} = \frac{T_2}{T_1} \qquad T_2 = T_1 \, r_p^{\frac{n-1}{n}} \; ✓ \; ?$$

T in absolute units K, °R

$$B_g(P,T) = \frac{q_{g\,local}}{q_{\bar{g}}} \qquad q_{g\,local} = q_{\bar{g}} \cdot B_g(P,T)$$

for this class $z_{av} \approx z_1$

$q_{sc} \cdot \rho_{sc}$ $\quad \frac{m^3}{d} \; \frac{kg}{m^3} \; \frac{kg}{d} \; \frac{1d}{(24h} \; \frac{1h}{3600s)}$

$J = \frac{W}{s}$ $\quad \Delta h = \frac{kJ}{}$

$P = \Delta h_p \cdot \dot{m}$

$\frac{kJ}{\cancel{kg}} \quad \cancel{kg}/s \qquad \frac{kJ}{s} \quad \frac{kW}{100} = [MW$

Debugging:

$$\Delta h_p = \underset{\sim}{T_1 \, Z_{av}} \, R \, \frac{n}{n-1} \underbrace{\left(r_p^{\frac{n-1}{n}} - 1 \right)}$$

? [K] $\frac{kJ}{kg\,K}$ $= \frac{kJ}{kg}$

$\bar{R} = 8314 \frac{J}{kgmol\,K}$

$8.314 \frac{kJ}{kgmol\,K}$

max = 22 MW

$P_{comp_1} + P_{comp_2}$

$T_{dis} \le 150°C$

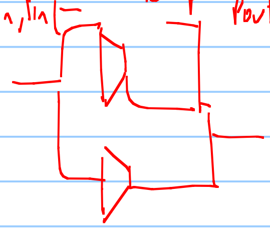
$P \geq 20$ bar

year	P_{suc} (bara)	Pplem req [bara]	Tsuc [C]	rp [-]	deltap [bar]	np [-]	n [-]	Tdis [C]	zsuc	zdisc	Bg @suc [m^3/Sm^:	qg_local [m^3/d]	Δhp [J/kg]	m [kg/s]	Power [MW]	Hp test [m]	([m
21	76.6	78.6	67	1.03	1.94	0.70	1.49	69.81	0.93	0.93	14.5E-3	289.3E+3	4126.15	156.0	643.6E-3	219.4E+0	
22	67.1	78.6	67	1.17	11.43	0.70	1.49	85.05	0.94	0.94	16.7E-3	332.7E+3	26754.95	156.0	4.2E+0	49.2E+0	
23	57.1	78.6	67	1.38	21.45	0.70	1.49	104.60	0.94	0.95	19.8E-3	394.5E+3	56384.84	156.0	8.8E+0	562.3E+0	
24	45.8	78.6	67	1.71	32.75	0.70	1.49	133.02	0.95	0.97	24.9E-3	497.1E+3	100283.54	156.0	15.6E+0	3.0E+3	
25	31.9	78.6	67	2.46	46.68	0.70	1.49	184.44	0.97	0.99	36.3E-3	724.1E+3	181242.31	156.0	28.3E+0	12.0E+3	
26	3.9	78.6	67	20.06	74.65	0.70	1.49	638.81	1.00	1.02	304.1E-3	6.1E+6	908936.00	156.0	141.8E+0	60.3E+9	
	#VALUE!	78.6	67	#VALUE!	#VALUE!	0.70	1.49	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	156.0	#VALUE!	#VALUE!	#
	#VALUE!	78.6	67	#VALUE!	#VALUE!	0.70	1.49	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	156.0	#VALUE!	#VALUE!	#

year 25

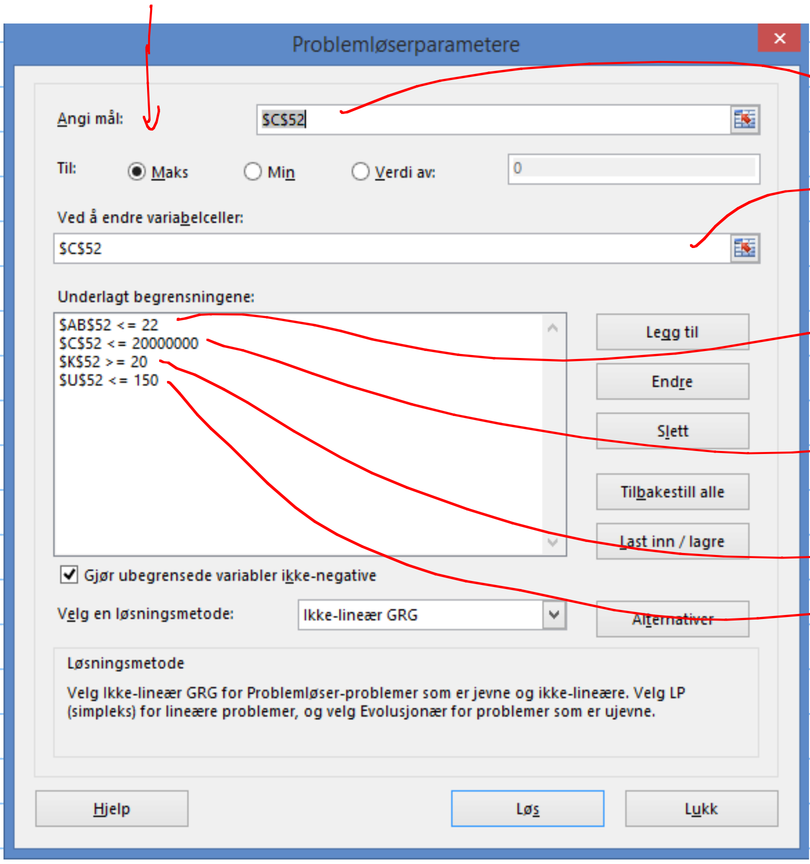
$\Delta h_p \cdot \dot{m}$

$\dot{m}_T \, \Delta h_p$



$\frac{\dot{m}_T}{2} \cdot \Delta h_p + \frac{\dot{m}_T}{2} \Delta h_p$

Instead of reducing manually the field rate, I set up the solver to modify it automatically while honouring all operational constraints.



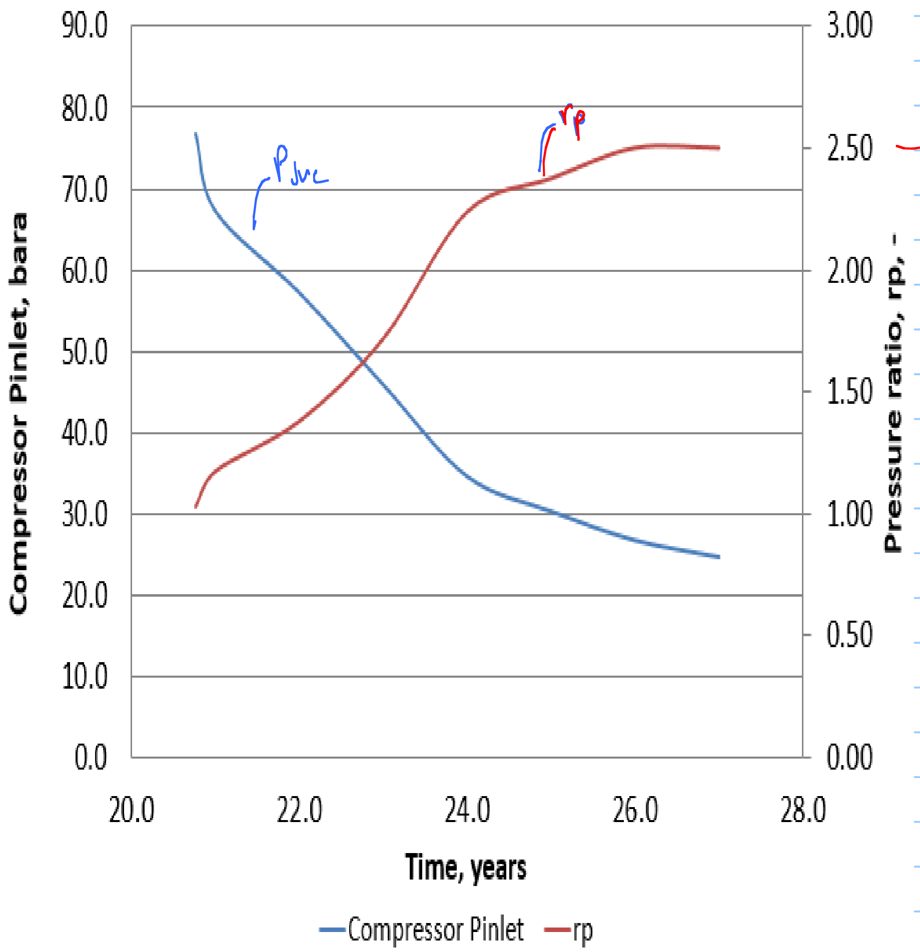
field rate

total power ≤ 22 MW

$q_f \leq 20E6\ Sm^3/d$

$P_{suc} \geq 20$ bara

$T_{dis} \leq 150°C$

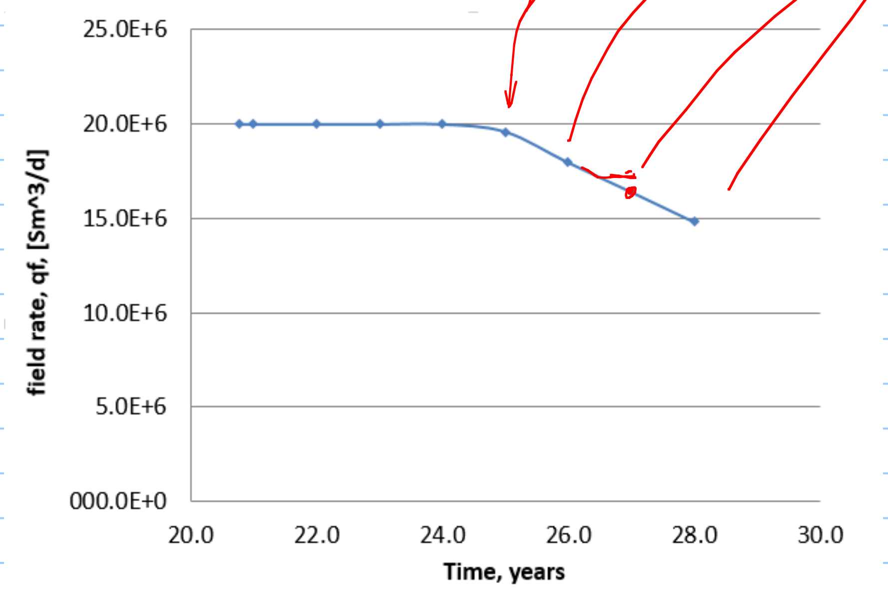


1.0 → 3

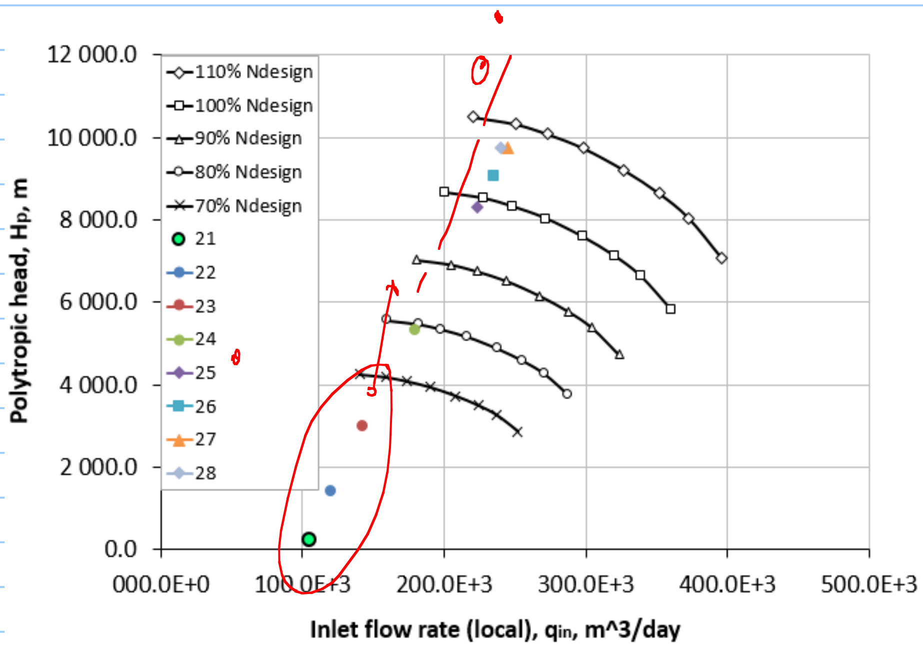
-3 years with plateau, no issues
-year 4 activate cooling to avoid excesive outlet temperature, compressor operating at maximum power, not possible to deliver plateau rate
-Year 5 , compressor operating at maximum power, not possible to deliver plateau rate
-years 6 and 7, reduce further the rate to avoid excessive outlet temperature, compressor operating at power less than maximum

activate cooling

$P = 22\,MW$ $\quad P = 22\,MW$ $\quad T_{dis} = 150°C$ $\quad P \leq 22\,MW$



In the last two years outlet temperature is th limiting condition. I could produce more gas but then the cooler efficiency has to be improved.



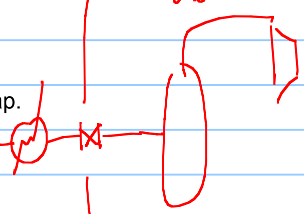
I have to move the points in the first 3 years inside the compressor map.

One solution is to choke at the inlet of the compressor.

In that way the compresor rp increases, i.e. the point goes up in the compression map.

I want to choke as less as possible, just to get the points inside the operation map.

additional valve choke



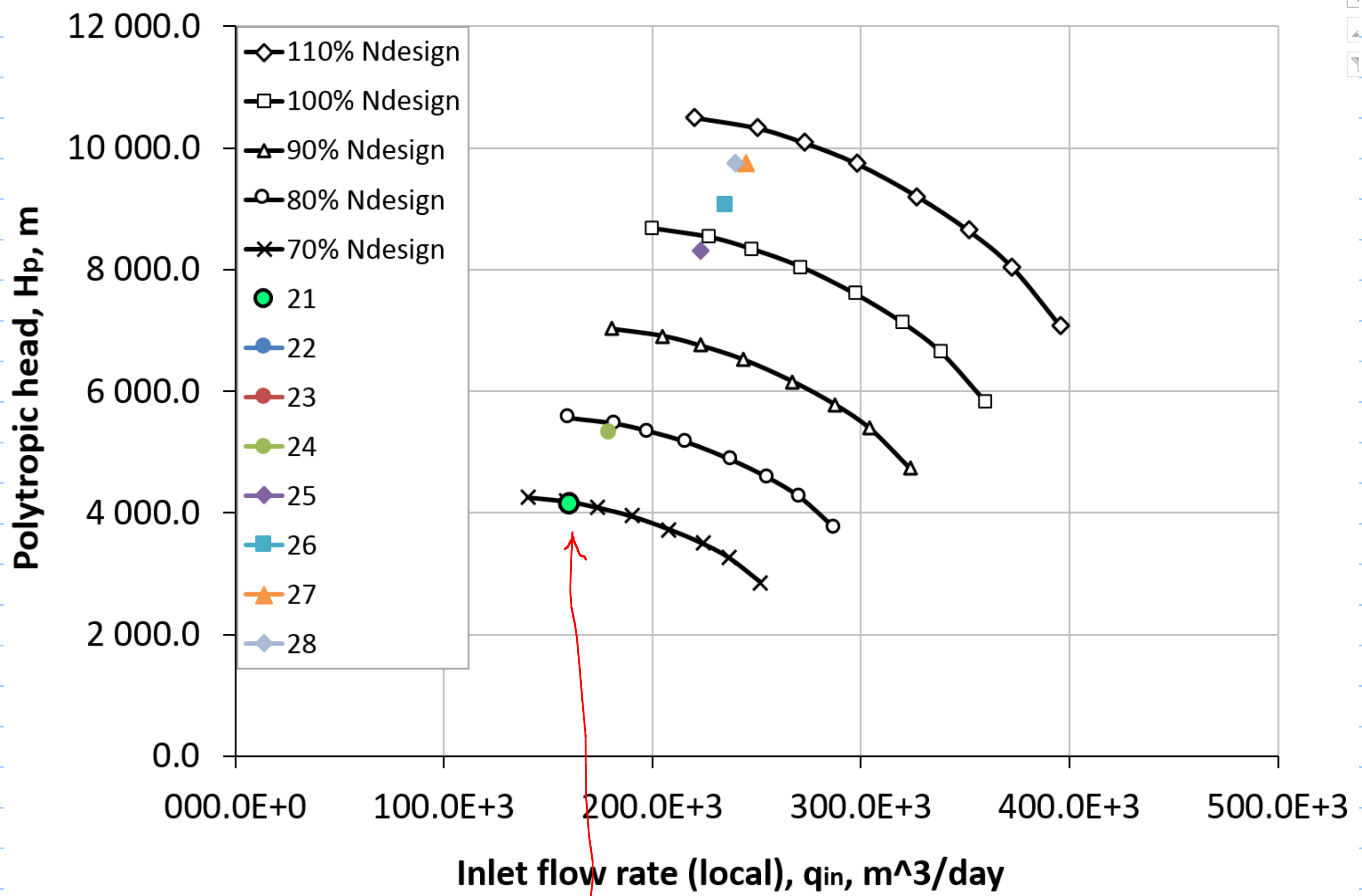
additional pressure drop to increase rp

Δp_{comp}

Modification of the excel sheet:

6	Pplem req	deltap comp choke	psuc	Tsuc	rp	deltap	np	n	Tdis	zsuc	zdisc	Bg @suc	qg_local	Δhp	m	Power	Hp test	qact test	qact test single comp
0	[bara]	[bar]	[bara]	[C]	[-]	[bar]	[-]	[-]	[C]			[m^3/Sm^3]	[m^3/d]	[J/kg]	[kg/s]	[MW]	[m]	[m^3/d]	[m^3/d]
	78.6	25.5	51.1	67	1.54	27.44	0.70	1.49	118.63	0.95	0.96	22.2E-3	443.2E+3	77954.84	156.0	12.2E+0	4.1E+3	320147.2	160073.6
	78.6	16	51.1	67	1.54	27.43	0.70	1.49	118.59	0.95	0.96	22.2E-3	443.1E+3	77893.47	156.0	12.1E+0	4.1E+3	320043.8	160021.9
	78.6	6.3	50.8	67	1.55	27.75	0.70	1.49	119.40	0.95	0.96	22.3E-3	446.0E+3	79145.59	156.0	12.3E+0	4.2E+3	322156.9	161078.4
	78.6	0	45.8	67	1.71	32.75	0.70	1.49	133.02	0.95	0.97	24.9E-3	497.1E+3	100283.54	156.0	15.6E+0	5.3E+3	359050.0	179525.0
	77.2	0	34.6	40	2.24	42.69	0.70	1.49	134.84	0.95	0.97	30.3E-3	592.6E+3	143884.32	152.9	22.0E+0	8.3E+3	446143.4	223071.7
	71.8	0	30.3	40	2.37	41.55	0.70	1.49	142.88	0.96	0.98	34.8E-3	624.0E+3	156933.95	140.2	22.0E+0	9.1E+3	469712.2	234856.1
	66.7	0	26.7	40	2.50	40.02	0.70	1.49	150.00	0.96	0.98	39.6E-3	649.3E+3	168531.01	128.1	21.6E+0	9.7E+3	488769.3	244384.6
	61.6	0	24.7	40	2.50	36.96	0.70	1.49	150.00	0.96	0.98	43.0E-3	636.9E+3	168880.65	115.7	19.5E+0	9.8E+3	479422.0	239711.0

The deltap of the inlet choke is changed manually for the first three years until all three points are inside the operational compressor map:



All points overlapping one on top of the other.