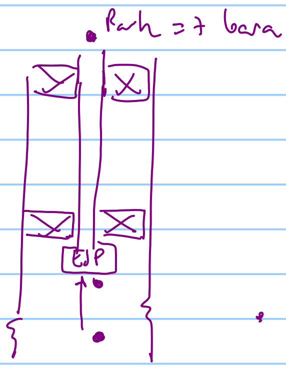
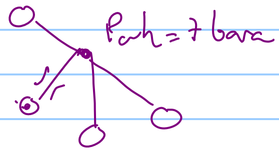
http://folk.ntnu.no/stanko/Courses/TPG4230/2017/Class_files/20170404/

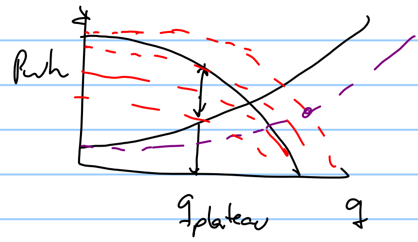




30	[bara]		Required pressure at pump intake			36										Max power [hp]	950		
p_R	WC	Average density	Effective viscosity	q_{tot}	p_{wf}	q_o	q_w	p_{suc}	f	p_{disc}	Δp_{ESP}	Δh_{ESP}	$p_{wh\ calc}$	$p_{wh\ given}$	Hydraulic Effic	Pump power	qmin	qmax	
bara	[-]	kg/m^3	Pa s	Sm^3/d	bara	Sm^3/d	Sm^3/d	bara	[hz]	bara	bara	m	bara	bara	[-]	[hp]	[m^3/d]	[m^3/d]	
231	0.10	910	0.138	1700	110	1530	170	75.7	53.0	188	113	1264	7.0	7	0.452	658.6	1121	1994	
215	0.10	910	0.138	1700	94	1530	170	59.6	55.3	188	129	1445	7.0	7	0.455	748.5	1169	2079	
200	0.10	910	0.138	1700	79	1530	170	44.6	57.4	188	144	1613	7.0	7	0.456	833.4	1213	2156	
175	0.10	910	0.138	1470	70	1323	147	36.0	56.5	187	151	1693	7.0	7	0.438	786.6	1194	2124	
150	0.10	910	0.138	1120	70	1008	112	36.0	54.1	185	149	1673	7.0	7	0.401	647.4	1144	2033	
125	0.10	910	0.138	771	70	694	77	36.0	52.5	184	148	1656	7.0	7	0.344	513.3	1110	1973	

Snøhvit, B2 Tanzania — what can we do to prolong plateau?

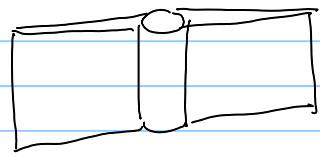
- Increase available pressure $P_{wh\,avail}$
- decrease required pressure $P_{wh\,req}$



methods to increase available pressure:

- $q = C_R (P_R^2 - P_{wf}^2)^n$ Increase reservoir deliverability: acidizing — injecting chemical to improve permeability of near wellbore region $

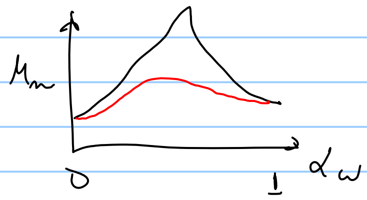
- fracturing. increase wellbore-formation exposure $



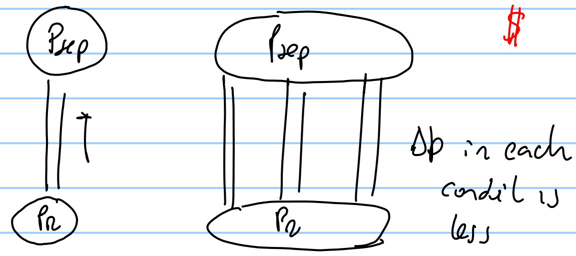
- multi-laterals $
- multi layer (perforate in another segment)
- Inflow control devices. ↳ reduce the flow of other phases that affect the flow of the main phase $

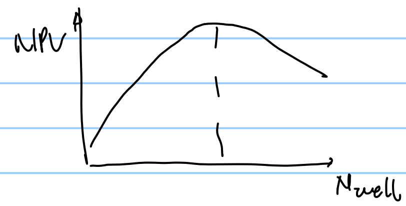
- pressure support in reservoir: water injection, gas injection $

- tubing:
  - increase tubing ID
  - install artificial lift { ESP, PCP, jet pump, gas lift }
  - reduce μ of fluid → demulsifiers
    - → diluent
    - → lighter API oil



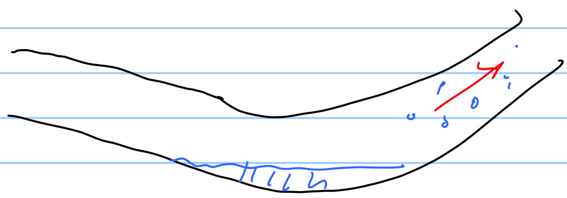
  - increase the number of wells





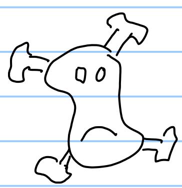
reducing required pressure

- changing size (ID) of transportation flowlines and pipelines ↑ID ↑$



WARNING! Be careful with liquid accumulation in gas/liquid flow.

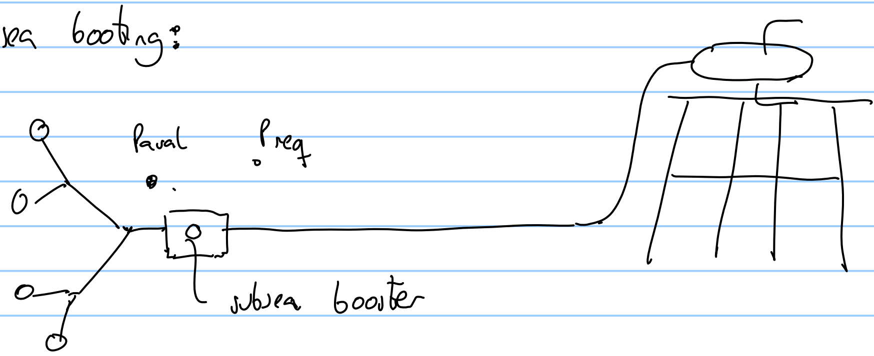
- a parallel pipeline !
- reduce μ_m → inject demulsifiers, diluent.
- reduce separator pressure



~ Big change in topside/processing facilities

- subsea processing: separation of oil, gas, water to avoid unnecessary transportation losses. from seabed to topside

• Subsea boosting:



2 types of booster : • single phase liquid, gas → requires separation before

• multiphase → oil, gas, water

two types of boosting principles

Positive displacement

• gives higher Δp

• don't tolerate solids

• lower rates

Rotordynamic

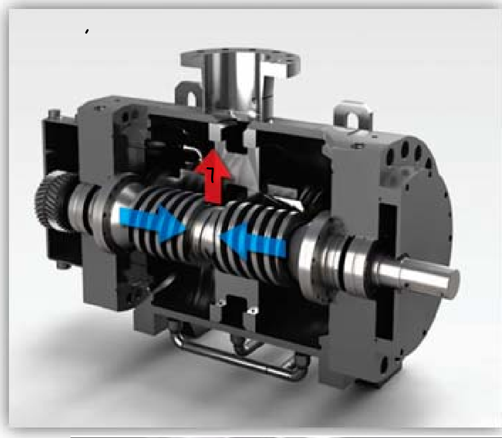
• gives medium → low Δp

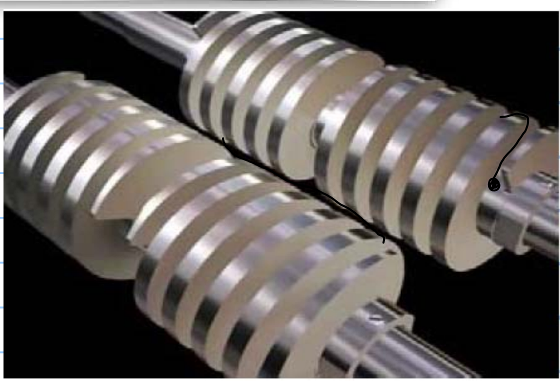
• have some tolerance to solids.

• medium and high rates.

multiphase boosters

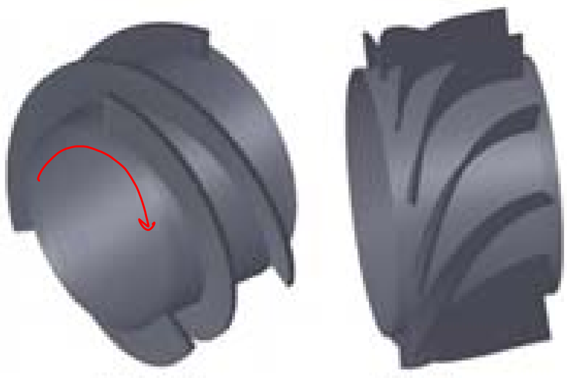
twin screw pump





HAP helico-axial pump.

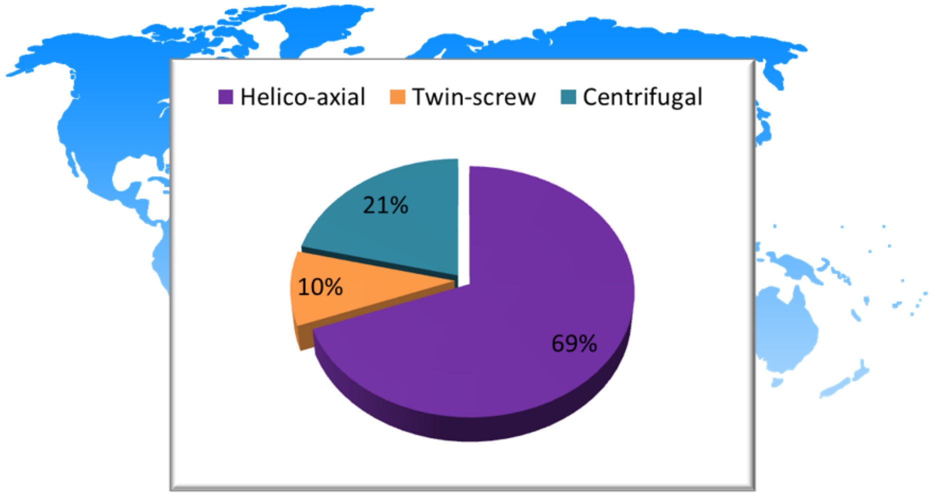
Framo. OneSubsea



(a) Impeller (b) Diffuser

Subsea multiphase boosting around the world

52 subsea pumps in 23 locations in the World



From http://www.offshore-mag.com/

- gas-liquid mixture is possible to model it as a single fluid with average properties.

wet gas compressor → lots of gas with some liquid.

counter-rotating wet gas compressor.

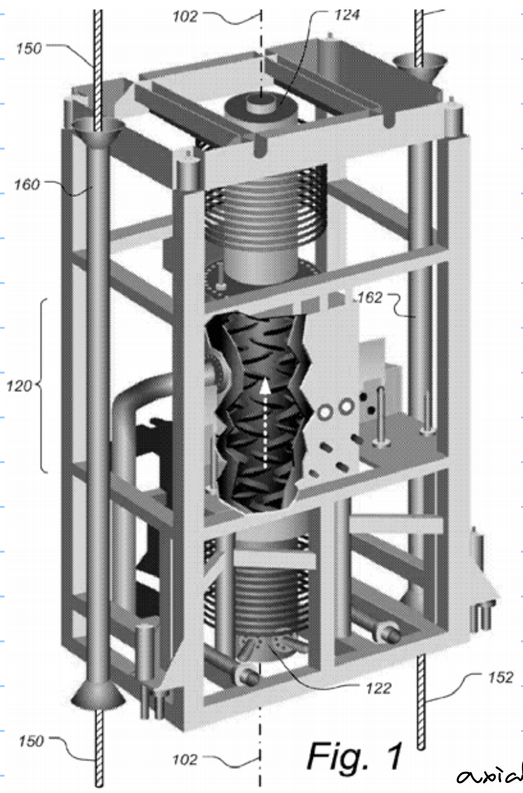


Fig. 1

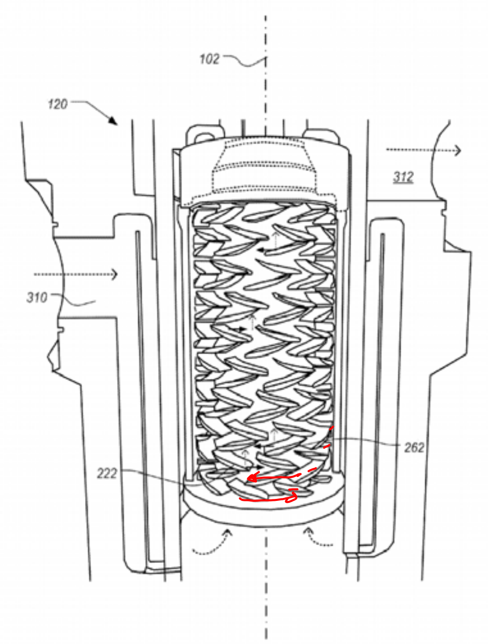


Fig. 3A

axial impellers {HAP / WGC gives a lower ΔP

usually requires more stages than centrifugal for same Δp!

mixed flow

0 0.1 0.5 1 GVF gas volume fraction

$$\frac{q_g}{q_o + q_w + q_g}$$

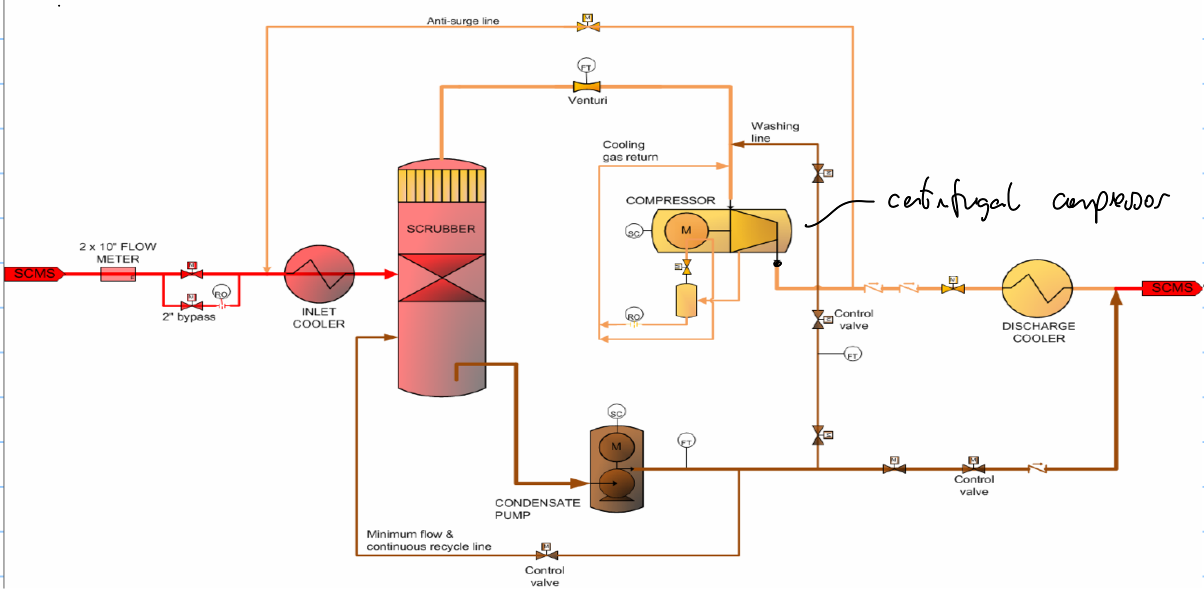
@ local conditions booster inlet

radial centrifugal impellers → high ΔP

Single phase subsea boosters ~> separation before !

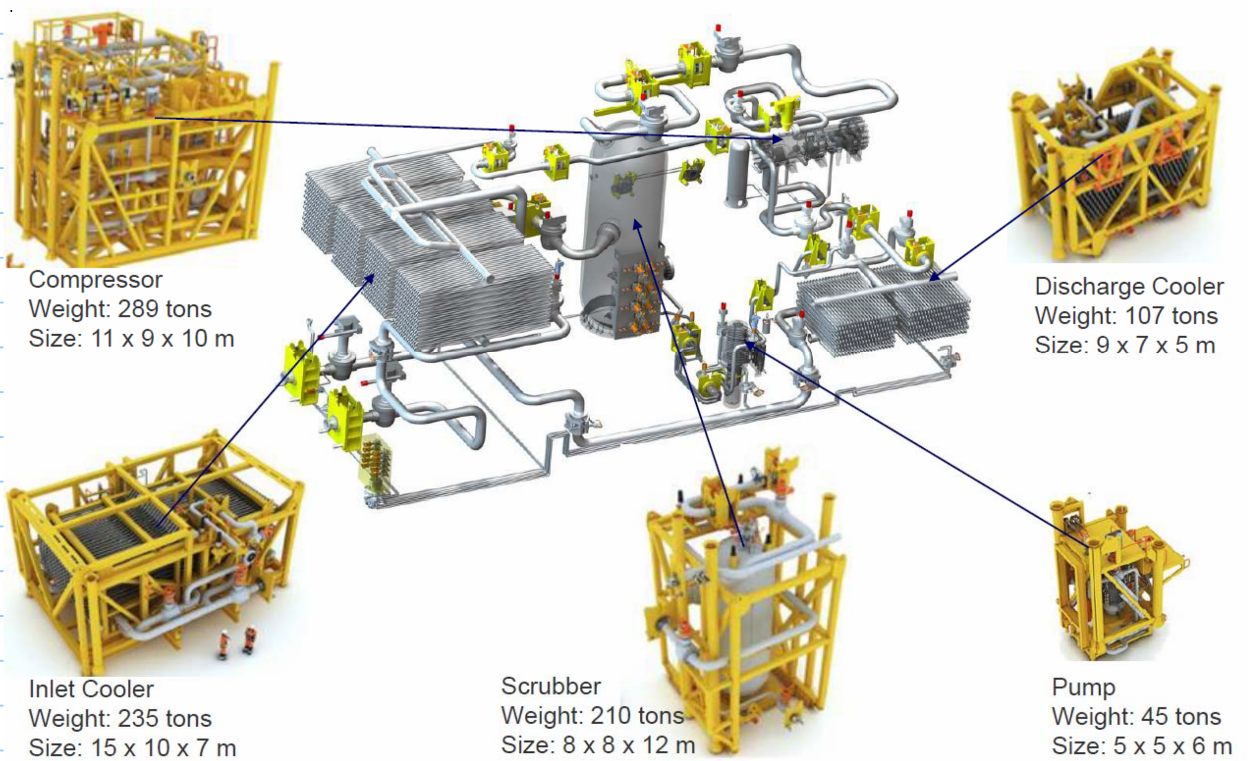
Aasgard subsea compression
dry compressor +
separation station

Process Flow Diagram



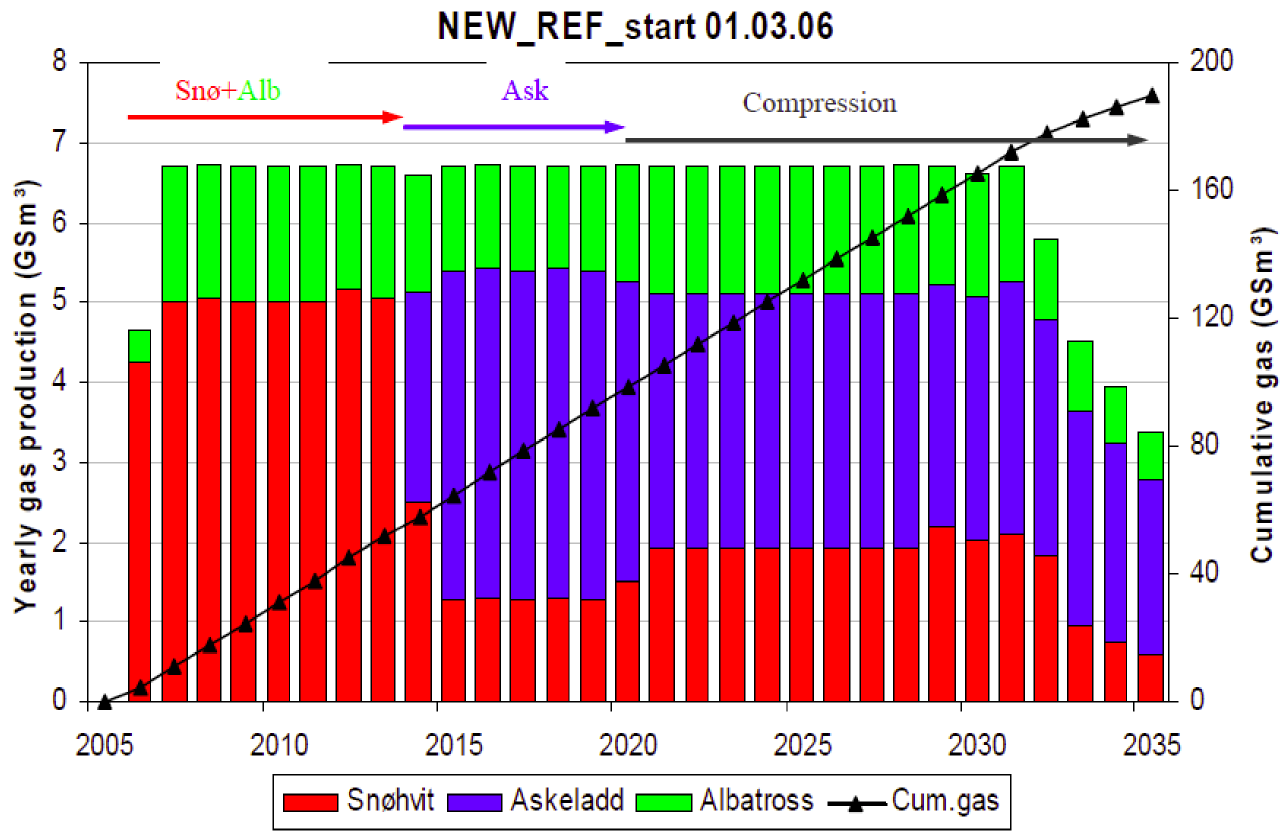
centrifugal compressor

Process Modules- Sizes and Dry Weights



In particular, the Snøhvit field:

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



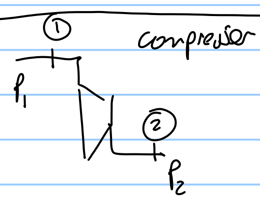
Refreshment in compressors

$$\dot{w} = \dot{m}\,\underbrace{(h_2 - h_1)}$$

if I compress ideally:

$$\frac{T_{2s}}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = r_p^{\left(\frac{k-1}{k}\right)}$$

$$k = \frac{C_p(T)}{C_v(T)} = k\ f(T)$$



$S_1 = S_2$

in reality the process is not isentropic!

the compression process is represented using a polytropic expansion

$pv^{n} = \text{const}$

polytropic exponent

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

the real compression power required is given by:

for liquids

$\approx c_p (T_2 - T_1) = h_2 - h_1$

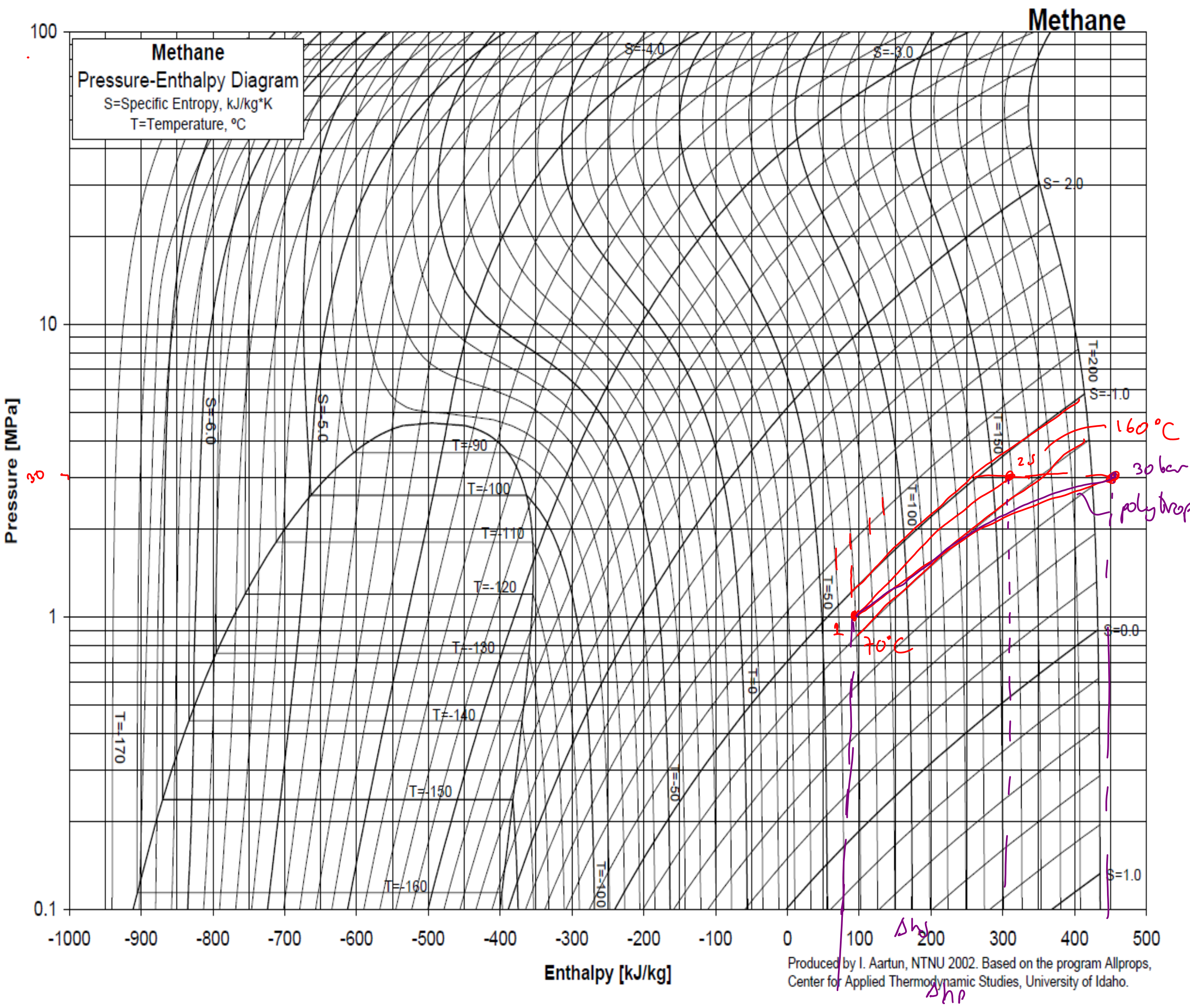
polytropic enthalpy difference

$$P_{comp} = \frac{\dot{m}\,\Delta h_p}{\{\eta_p \times \eta_m\}} = \frac{\dot{m}}{\eta_p \eta_m} \cdot \underbrace{z_{av} \cdot \bar{R} \cdot \frac{n}{n-1}\left(r_p^{\frac{n-1}{n}} - 1\right) T_1}_{\Delta h_p}$$

$\left(\frac{n-1}{n}\right) = \left(\frac{\kappa - 1}{\kappa \cdot \eta_p}\right)$

$\bar{R} = \frac{R_u}{MW_{gas}}$

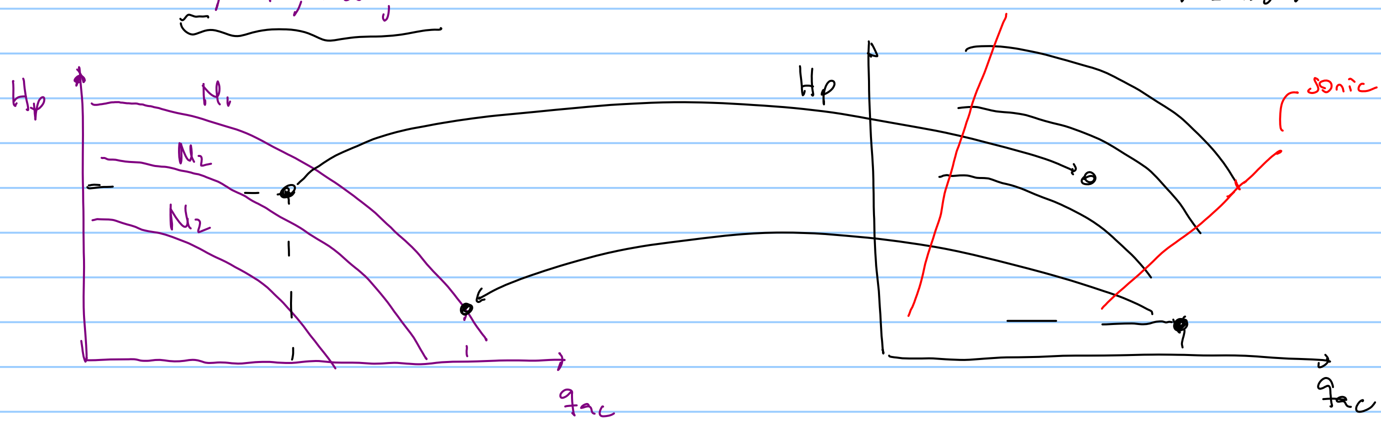
$z_{av} = \frac{z_1 + z_2}{2}$



$H_p = \frac{\Delta h_p}{g}$ ~> polytropic head

for P_1^*, T_1^*, M_w^*, k^*

test the compressor at $P_1 = 1.01325$ bara
$T_1 = 15.56°C$
$MW = 28.97$
$K = 1.3$?



to calculate compressor performance for other conditions different than test apply the following corrections:

$$q_{act} = q_{test} \sqrt{\frac{K_{ac}}{K_{tes}}} \cdot \sqrt{\frac{MW_{TEST}}{MW_{ac}}} \cdot \sqrt{\frac{T_{ac}}{T_{test}}} \qquad q^{TEST}$$

$$H_p^{corrected} = \frac{MW_{Test}}{MW} \cdot \frac{T_1}{T_{1TES}} \cdot \frac{K}{K_{TES}} \cdot H_p^{test}$$

Compressors constraints:

- discharge $T \leq 150°C$
  - integrity pipeline
  - avoid vaporization glycol hydrate inhibitor
  - avoid damaging compressor seals

another assumption $\boxed{\eta_p = \text{const} \approx 0.7}$

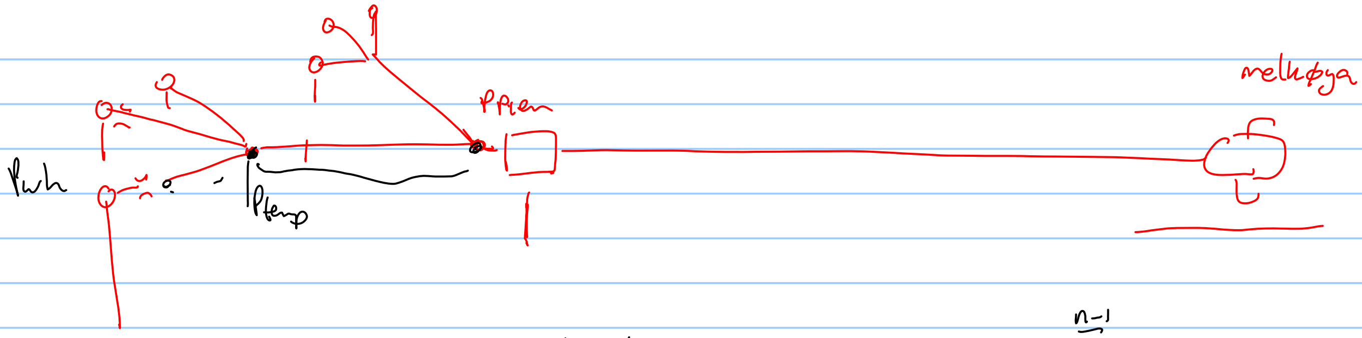
in reality $\eta_p = f(q_{act})$

- Power $\leq P_{max}$ (11 MW)
- $P_{suc} \geq 10$ bara — to activate seals
- operational speed 9350 – 6800 rpm

$q_{min} \leq q \leq q_{max}$

surge. flow back and forth in machine (unstable)

↳ sonic velocity in machine passages $M = 1$



estimate T_{outlet} $\qquad \frac{T_2}{T_1} = r_p^{\frac{n-1}{n}}$

estimate $\Delta h_p = z_{av} \cdot \bar{R} \cdot \frac{n}{n-1} \left(r_p^{\frac{n-1}{n}} - 1 \right) T_1$

calculate $H_p = \frac{\Delta h_p}{g}$

$\frac{8314}{\frac{kg}{kmol}} \frac{J}{kmol\,K} \cancel{K}$ $\quad \frac{J}{kg}$

calculate $q_{act} = \underbrace{B_g(P,T)} \cdot q_{sc}$

$B_g = z \frac{T}{T_{sc}} \frac{P_{sc}}{P}$

$H_p, q_{act} \longrightarrow$ convert to test conditions

plot in compressor map.