Example – effect of suction pressure

- Flooded Screw compressor in CBM service:

	fps	Both	SI
VI		4.6	
Speed		1200	
q_0	1 MMSCF/d		28.3 kSCM/d
$Vol_{revolution}$	0.0.053 ft^3		0.001503 m^3
P_{atm}	12 psia		82.7 kPaa
P_{suct0}	14.5 psig		100 kPag
P_{disch}	84 psig		579 kPag
T_{suct}	80°F		26.7 C
T_{disch}	205°F		96.1 C

- If suction pressure is changed with all other things held constant, how does input work required change?
  - Case 1 → suction pressure = 29.0 psig [200 kPag]
  - Case 2 → suction pressure = 0 psig [0 kPag]

Suction pressure example (fps)

$$W = \frac{cons}{\eta_{total}} \cdot P_{suction} \cdot q_{std} \cdot \left(\frac{\rho_{std}}{\rho_{suction}}\right)\left(\frac{k}{k-1}\right)\left((R_c)^{\frac{k-1}{k}} - 1\right)\frac{Z_{avg}}{Z_{suct}} = \left(\frac{cons \cdot P_{std}}{T_{std} \cdot Z_{std}}\right)\left(\frac{T_{suct} \cdot Z_{avg} \cdot q_{mmscf/d}}{\eta_{total}}\right)\left(\frac{k}{k-1}\right)\left((R_c)^{\frac{k-1}{k}} - 1\right)$$

Input (first four rows):

	Case 0	Case 1	Case 2
Suction pressure (psig)	14.5	29.0 (+55%)	0 (-55%)
Flow rate (MMSCF/day)	1.00	1.55 (+55%)	0.45 (-54%)
Compression ratios	3.62	2.34 (-35%)	8.00 (+120%)
Efficiency	73%	61% (-16%)	69% (-5%)
Work/MMSCF (hp)	95.2	71.3 (-25%)	179.8 (+88%)
Total work (hp)	95.2	110.6 (+16%)	81.3 (-14%)

- Work is a function of both
  - The amount of stuff you lift (mass flow rate)
  - How far you lift it(compression ratios)
- It is very easy to fool yourself about the relative magnitude of each of these

Suction pressure example (SI)

$$W = \frac{cons}{\eta_{total}} \cdot P_{suction} \cdot q_{std} \cdot \left(\frac{\rho_{std}}{\rho_{suction}}\right)\left(\frac{k}{k-1}\right)\left(\left(R_c\right)^{\frac{k-1}{k}} - 1\right)\frac{Z_{avg}}{Z_{suct}} = \left(\frac{cons \cdot P_{std}}{T_{std} \cdot Z_{std}}\right)\left(\frac{T_{suct} \cdot Z_{avg} \cdot q_{SCM/s}}{\eta_{total}}\right)\left(\frac{k}{k-1}\right)\left(\left(R_c\right)^{\frac{k-1}{k}} - 1\right)$$

		Case 0	Case 1	Case 2
Input	Suction pressure (kPag)	100	200 (+55%)	0 (-55%)
Input	Flow rate (kSCM/day)	28.3	43.9 (+55%)	12.8 (-54%)
Input	Compression ratios	3.62	2.34 (-35%)	8.00 (+120%)
Input	Efficiency	73%	61% (-16%)	69% (-5%)
	Work/MMSCF (kW)	71.0	53.2 (-25%)	134.1 (+88%)
	Total work (kW)	71.0	82.4 (+16%)	60.6 (-14%)

- Work is a function of both
  - The amount of stuff you lift (mass flow rate)
  - How far you lift it(compression ratios)
- It is very easy to fool yourself about the relative magnitude of each of these

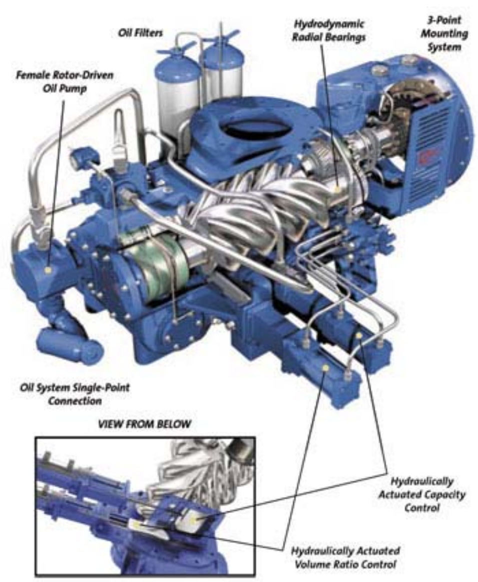
Adiabatic Heat of Compression

- It is often useful to try to predict a theoretical discharge temperature for a given:
  - Suction temperature (in absolute units)
  - Compression ratios
  - Gas composition

$$T_{disch} = T_{suct}\left(R_c\right)^{\frac{k-1}{k}}$$

Flooded Screw Compressor

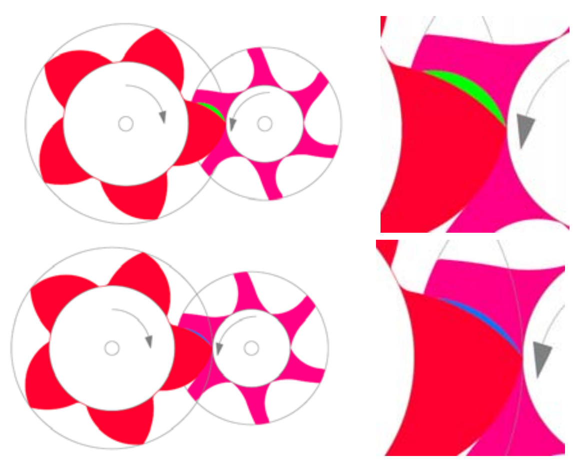
- First flooded screw made by Howden in 1957
- Male rotor is driven by engine or motor
- Female rotor driven by male rotor
- Oil flood
  - Prevents metal-to-metal contact between rotors
  - Seals area around rotors
  - Lubricates
  - Cools



15

Screw Compressor Operation

- The two rotors are different sizes and the female rotor has more lobes
- The compression chamber on the suction end is much bigger than on the discharge end
- The relationship is called the VI (Volume Index)
- Try to match VI to design disch pressure, if you miss it the compressor efficiency drops

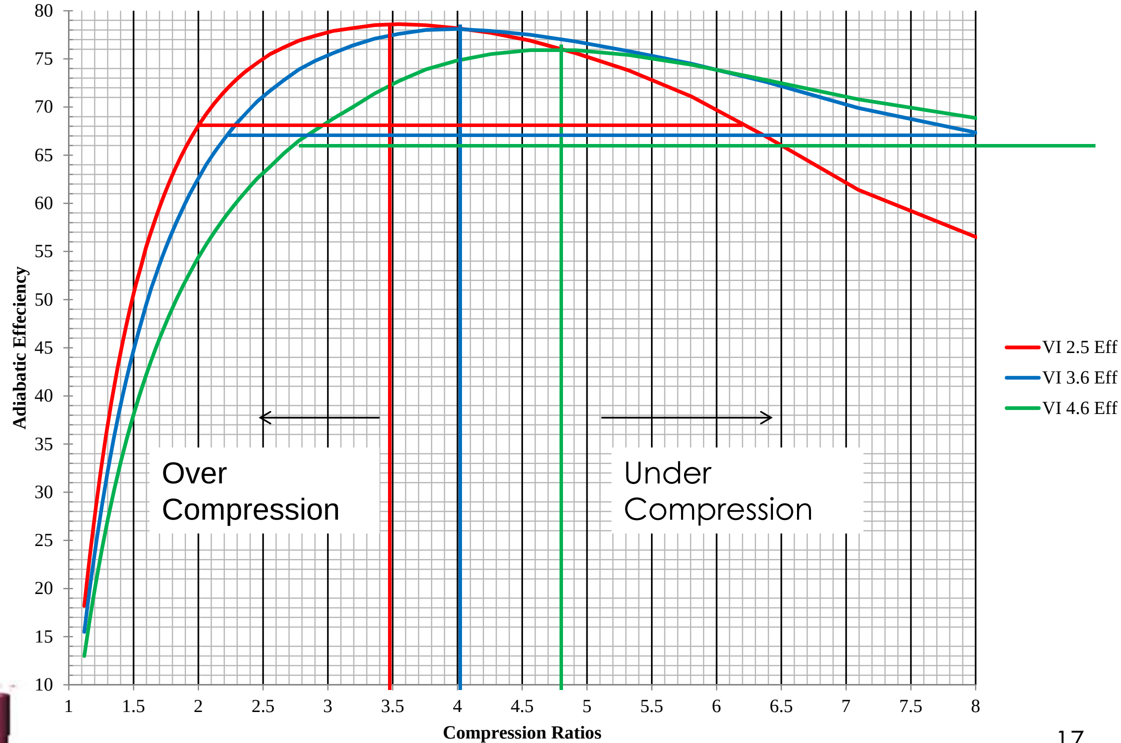


$$VI = \left(\frac{P_{disch}}{P_{suct}}\right)^{1/k}$$

$$P_{disch} = P_{suct} VI^{k}$$

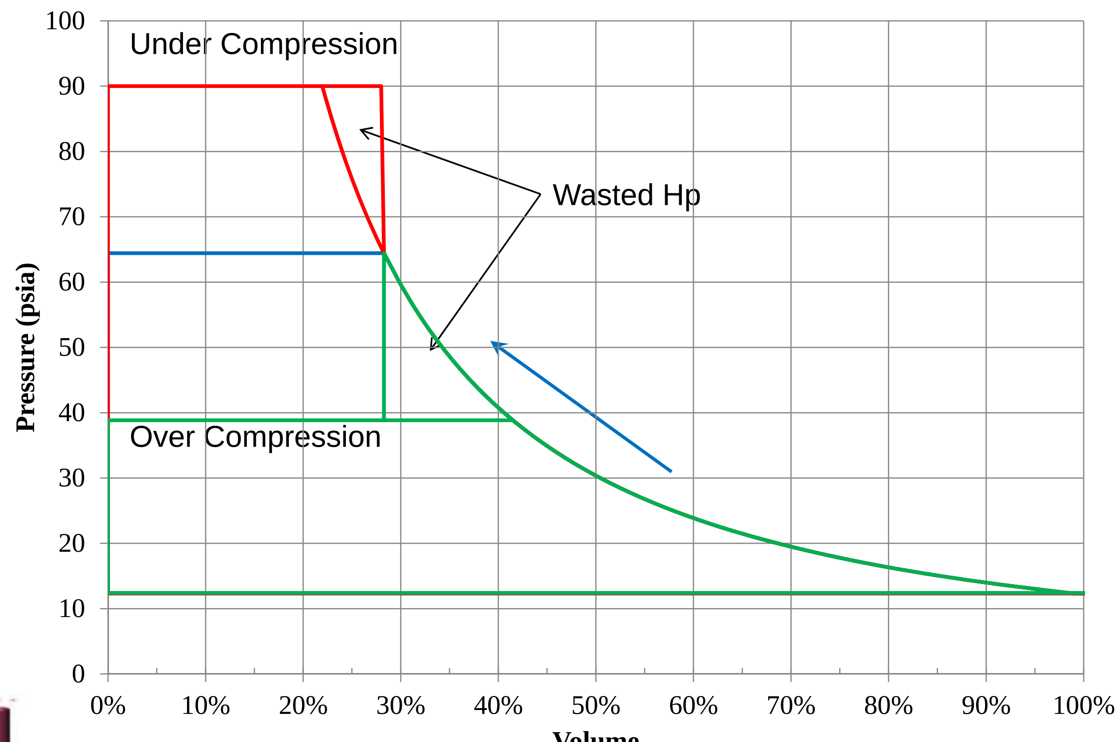
16

Adiabatic Effeciency vs. Compression Ratios



17

Screw Compressor P-V



18

Flooded Screw Compressor

- Initially used exclusively within plants
  - Process Derivative: Air conditioning service, compressing propane or ammonia
  - Air Derivative: Air compressors
- Plant packages do not have to be very flexible
  - Oil only has to be compatible with one fluid
  - Process fluid generally has very low water vapor content
  - dP across skid reliable enough to drive oil
  - Solids accumulation is rare
  - Generally set on rigid foundation so skids can be lighter

Flooded Screw Compressor

- In the early 90's we started moving screws to wellsites
  - Very large water vapor content
  - Not much control over either suction/discharge pressure/temperature or fluids
- Plant packages generally perform poorly in field use
  - Oil selection often not compatible with condensable hydrocarbon vapors
  - Oil temperature too cool to cook water off
  - Oil temp control too inflexible for highly varying service
  - dP across skid not reliable enough to drive oil consistently
  - Accumulated solids quite common and packages can't deal with them
  - Plant skids too light to be tail rolled or to be dropped in the dirt
- Packager vs. Screw manufacturer
  - Any manufacturer's screw will perform well if properly packaged
  - Packager is key and many of them don't understand field use

Flooded Screw Compressor Oil

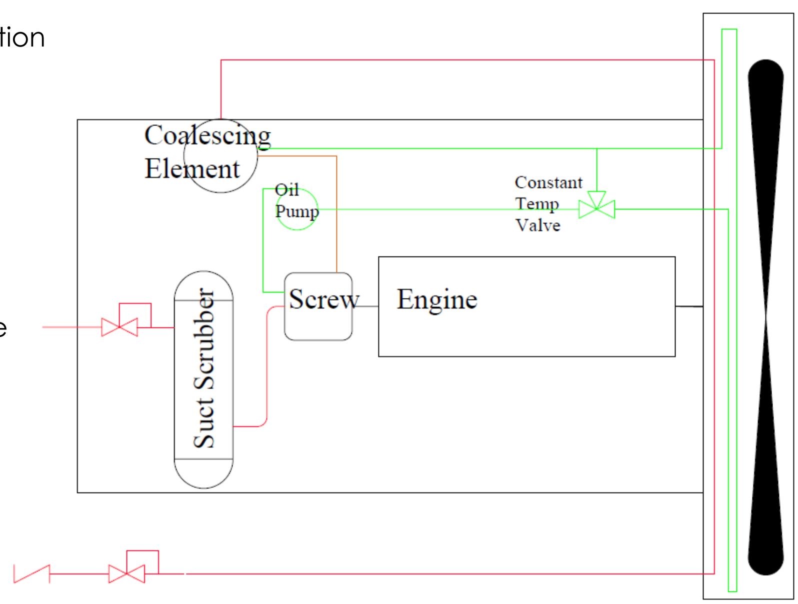
- Oil Selection
  - Mineral Oil: Least expensive, not compatible with liquid hydrocarbons
  - Synthetic Oil: Most expensive, generally has the best compatibility with liquid hydrocarbons and will perform slightly better with absorbed water
  - Semi-synthetic: Mixture of the other two and has intermediate properties
- Screw oil is hydrophilic and will absorb water vapor
- When the oil absorbs water it:
  - Becomes more viscous
  - Loses lubricity
  - Increases surface tension (allowing bigger droplets to fail to coalesce)
- You have to cook the water out of the oil like a reboiler
  - Adjust oil flow, cooling, and/or discharge pressure to achieve 205-215°F out of the screw
  - Higher temps can damage oil, lower temps don't cook water out

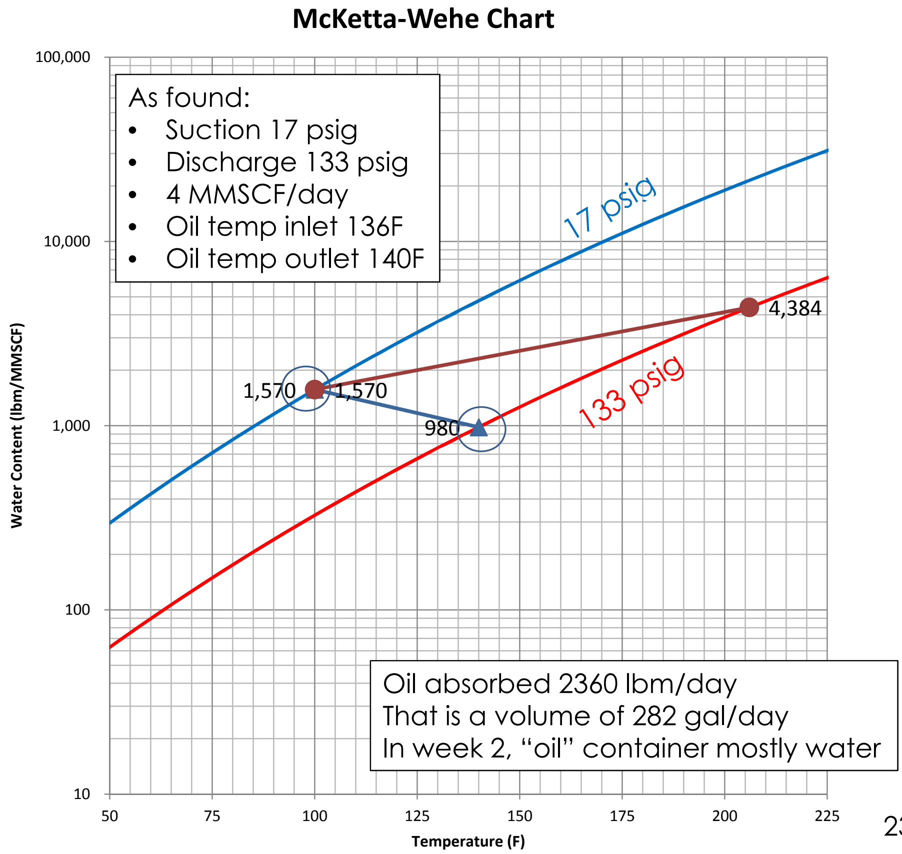
Temperature Control that everyone uses

Disch temp is a function of:

- Gas flow rate
- Oil flow rate
- Oil inlet temp
- Gas inlet temp

A "Constant Temperature Valve" gives you the right temp for exactly one set of conditions





Flooded Screw Temp Example

	Gas	Both	Oil
Atmospheric Pressure		12 psia 101.6 kPaa	
Gas Suction		0 psig 0 kPag	
Gas Discharge		50 psig 345 kPag	
Fluid	Methane		Semi-Synthetic
Flow Rate	500 MSCF/day		40 gpm
SG	0.6		0.81
Temp In	80°F		180°F
c_p	0.52669 BTU/lbm-R		0.45 BTU/lbm-R
k	1.28		-

- What is the discharge temperature of the compressor?

Flooded Screw Temp Example (fps)

$$\dot{m}_{gas} = q_{gasMSCFd} \cdot \rho_{gasStd} = 500000\frac{ft^3}{day} \cdot 0.046\frac{lbm}{ft^3} = 23000\frac{lbm}{day}$$

$$\dot{m}_{oil} = q_{oil} \cdot \rho_{water} \cdot SG_{oil} = 40\frac{gal}{min} \cdot 8.34\frac{lbm}{gal} \cdot 0.81 \cdot \frac{1440min}{day} = 389111\frac{lbm}{day}$$

$$T_{disch-gas} = (80+460)\left(\frac{50+14.73}{0+14.73}\right)^{(1.28-1)/1.28} = 773R$$

$$Q_{gas} = 23000\frac{lbm}{day} \cdot \left(0.52669\frac{BTU}{lbm \cdot R}\right) \cdot (773R - 540R) = 2.822 \times 10^6 \frac{BTU}{day}$$

$$T_{disch} = \frac{Q_{gas} + T_{gasIn} \cdot \dot{m}_{gas} \cdot c_{pGas} + T_{oilIn} \cdot \dot{m}_{oil} \cdot c_{pOil}}{\dot{m}_{gas} \cdot c_{pGas} + \dot{m}_{oil} \cdot c_{pOil}}$$

$$T_{disch} = \frac{2.822 \times 10^6 \frac{BTU}{day} + 540R \cdot 23000\frac{lbm}{day} \cdot 0.52669\frac{BTU}{lbm \cdot R} + 640R \cdot 389111\frac{lbm}{day} \cdot 0.45\frac{BTU}{lbm * R}}{23000\frac{lbm}{day} \cdot 0.52669\frac{BTU}{lbm \cdot R} + 389111\frac{lbm}{day} \cdot 0.45\frac{BTU}{lbm * R}} = 188.9F$$

Too Cool, can raise discharge to 220 psig or lower q_{oil} to 12 gpm or raise oil inlet to 197F

Or some combination

25

Flooded Screw Temp Example (SI)

$$\dot{m}_{gas} = q_{gasMSCFd} \cdot \rho_{gasStd} = 589\frac{m^3}{hr} \cdot 0.735\frac{kg}{m^3} = 434\frac{kg}{hr}$$

$$\dot{m}_{oil} = q_{oil} \cdot \rho_{water} \cdot SG_{oil} = 151.4\frac{L}{min} \cdot 1\frac{kg}{L} \cdot 0.81 \cdot \frac{0min}{hr} = 7536\frac{kg}{hr}$$

$$T_{disch-gas} = (26.7+273.15)\left(\frac{345+101.6}{0+101.6}\right)^{(1.28-1)/1.28} = 414.7K$$

$$Q_{gas} = 434\frac{kg}{hr} \cdot \left(2205\frac{J}{kg \cdot K}\right) \cdot (414.7K - 300K) = 109.7 \times 10^6 \frac{J}{hr} = 30.5kW$$

$$T_{disch} = \frac{Q_{gas} + T_{gasIn} \cdot \dot{m}_{gas} \cdot c_{pGas} + T_{oilIn} \cdot \dot{m}_{oil} \cdot c_{pOil}}{\dot{m}_{gas} \cdot c_{pGas} + \dot{m}_{oil} \cdot c_{pOil}}$$

$$T_{disch} = \frac{109.7 \times 10^6 \frac{J}{hr} + 300K \cdot 434\frac{kg}{hr} \cdot 2205\frac{J}{kg \cdot K} + 355.6K \cdot 7356\frac{kg}{hr} \cdot 1884\frac{J}{kg * K}}{434\frac{kg}{hr} \cdot 2205\frac{J}{kg \cdot K} + 7356\frac{kg}{hr} \cdot 1884\frac{J}{kg * K}} = 359.375K = 86.2C$$

Too Cool, can raise discharge to 1758 kPa or lower q_{oil} to 34 Lpm or raise oil inlet to 93C

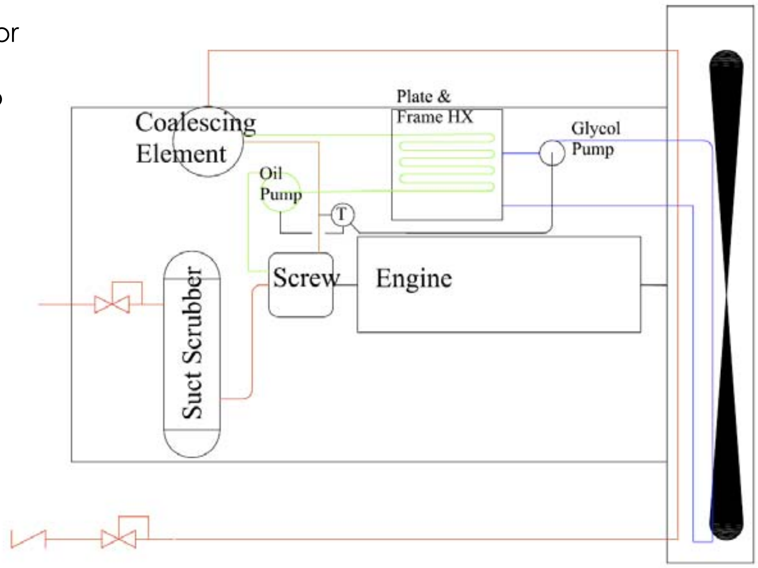
Or some combination

26

Temperature Control that Works

PLC looks at compressor discharge temp and:

- Adjusts glycol pump between zero and max speed, then
- Adjusts oil pump between min and max speed



Best Temperature Control (so far)

- Glycol Loop
  - Glycol goes through all coolers in series
  - Screw Oil is last
  - During start-up, the screw oil "cooler" acts as a "heater" dumping engine and process gas heat into screw oil
- Screw oil
  - Temperature controlled by PLC
  - T1 instrument activates (in sequence)
    - Cooler glycol bypass
    - Oil control valve