Low Pressure Operations

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Role of Low Pressure in Well Performance

- Low surface pressures can impact:
  - Inflow rate by lowering BHP
  - Liquid level by increasing gas velocity (to increase liquid-lifting capacity of the gas)
  - Liquid level by lowering dew point and increasing evaporation
- Liquid level is often the controlling factor in production rate from a "dry gas" well:
  - Water exerts 0.43 psi/ft (condensate is somewhat less)
  - 2-3/8 tubing holds 0.162 gal/ft
  - 1/2 bbl (130 ft) of water will increase sand face pressure >50 psi
- Low pressures can have a role in deliquification:
  - Small problems (<20 bbl/MMCF) it can be the whole answer
  - Large problems it can participate in the answer

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General Questions

- What constitutes low pressure operations?
  - As pressure drops below 50 psia, the flowing gas begins behaving less like an incompressible fluid and the flow stream's ability to act on the environment declines rapidly
  - By 2 atm (11-15 psig) the incompressible flow assumption is invalid and the gas acts very differently from high pressure gas
- Will piping ingest air during vacuum ops?
  - Probably. Can be reduced by plugging open-ended lines.
- Can ingested air cause the line to blow up?
  - No, you have to be between the LEL and UEL for an explosion.
  - If a well makes 100 MCF/d, you would have to ingest 0.650-2.000 MMCF/d of air which would be a very large hole (that couldn't sustain vacuum operations).
- Can ingested air cause corrosion problems?
  - The gathering companies claim that it can but their evidence is REALLY weak

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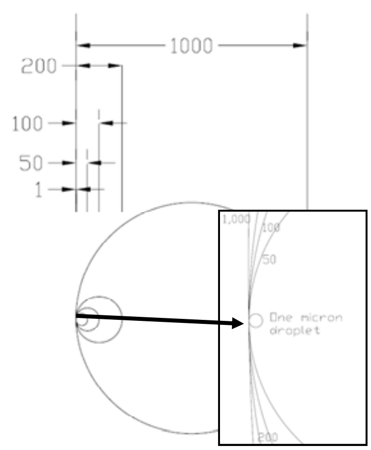
Water Droplets

- Coarse Spray
  - 201-1,000 microns (0.2-1 mm)
  - Terminal velocity as a raindrop 7 ft/s so it would tend to fall at separator velocities
  - Will sheet or pool at normal temps
- Fine Spray
  - 101-200 microns
  - Terminal velocity as drizzle 0.5 ft/s (won't tend to fall at sep velocities)
  - Will pool at normal temps
- Mist
  - 51 -100 microns
  - Terminal velocity as fog 0.05 ft/s
  - Will bead at normal temps
- Aerosol
  - 1-50 microns
  - Terminal velocity as cloud 0.003 ft/s
  - Will collect on a mirror at normal temps



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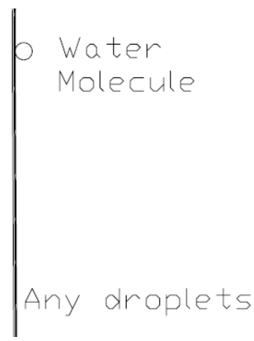
Water Vapor

- A water vapor molecule is 0.00038 microns
- If a one micron droplet was blown up to the size of the earth,
  - A water molecule would be 4 ft diameter
  - A methane molecule would be 6.4 ft diameter
- Any filter that can stop a water vapor molecule would not allow a methane molecule through



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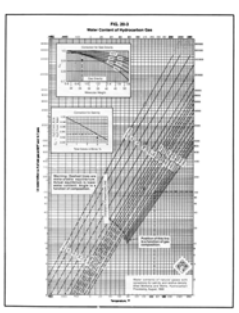
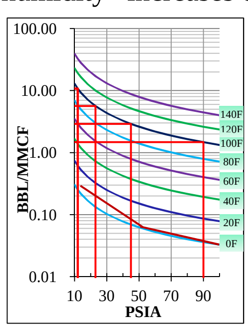
Evaporation

- Whenever there is a coherent gas/liquid interface, liquid will evaporate until the gas at the surface of the liquid is at 100% relative humidity
- As wellhead pressures diminish, the amount of water that gas can carry as "humidity" increases dramatically





- At 100°F
  - 90 psia holds 1.5 bbl/MMCF
  - 45 psia holds 2.9 bbl/MMCf
  - 23 psia holds 5.6 bbl/MMCf
  - 12 psia holds 10.7 bbl/MMCF

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Phase-Change Scale

- Produced water is usually at least 10,000 mg/L TDS
- Flashing a barrel of 10,000 mg/L water deposits 3.5 pounds of solids somewhere
  - NaCl turns into salt blocks (eventually soluble in hot water)
  - Bicarbonate (HCO3) turns into Nahcolite (NaHCO3) that is granite hard and barely soluble in strong acid

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Salt Inhibition

- Intent is to form soft, mobile "slurry" instead of rocks and gravel
- The flow stream must have enough energy to move slurry to some convenient location
- Salt inhibition does not work well in gas wells:
  - Surface injection tends to stick to the top of the pipe and not contact downhole liquids
  - Cap string injection doesn't mix well
- No injected chemical works very well in low pressure gas, but salt inhibitors are especially worthless
  - They can't prevent evaporation
  - When the liquid evaporates the inhibitor contributes to mass left

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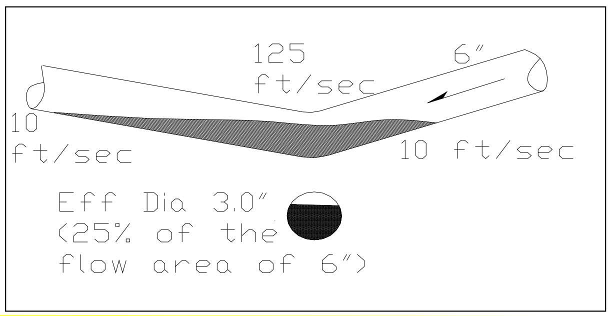
Water in Piping

- Standing liquid requires gas to do work
  - Gas wants to drag water surface along the pipe
  - Result is white caps on the water and big pressure drop
- Piping too big leaves water behind.



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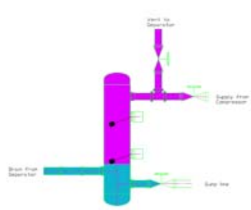
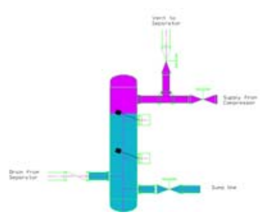
Considerations for Moving Water from Separator

- Separator Pressures
  - <15 psig, probably can't dump to an above-ground tank
  - <0 psig can't dump to a buried pit
- Options
  - Transfer Pump (auto-start required)
  - Remove separator
  - Blowcase





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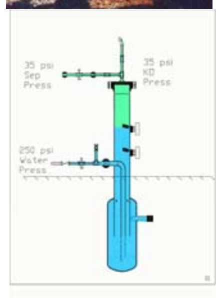
Wells with Downhole Pumps



- Where do you go with a pump discharge?
  - To Separator?
    - Minimum Separator pressure limited to water line pressure unless you have a blowcase or a pump
  - To water line?
    - Every pump makes some gas (some pumps make a lot of gas), you don't want it in your water system
    - Getting gas out of the water system can be a chore
- There seems to be fewer problems when the pump goes to the water system, but even these can be solved with a gas knock out

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Typical Compressor Types

	Eff	Limit	Max Ratio	Typical Use
Liquid Ring	40-50%	Disch Press	5	Deep vacuum to <5 psig
Eductor/Ejector	40-70%	Power fluid flow rate	10	Focus hp
Dry Screw	60-72%	Disch Temp	5	Control air
Centrifugal	65-75%	Disch temp	2.5/stage	Offshore (small foot print)
Flooded Screw	70-72%	Max suction	10-20	Varying Suction pressure
Recip	78-88%	Rod load or disch temp	4.5/stage	Varying discharge pressure

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Operating Principles Recip Compressor

- Recip compressors used since 1800’s (steam driven, air service)
- Pistons moving inside cylinders draw gas in, then raise gas pressure above required discharge
- Recip compressors are categorized by:
  - Number of “throws” (each throw has two compression chambers)
  - Number of stages
  - Separable or integral
  - High speed vs. low speed

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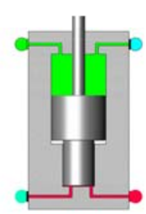
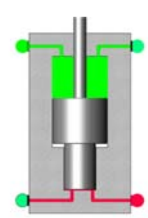
Recip Compressor Suction Pressure

- This cylinder is properly configured for:
  - 1st stage suction 40 psig, discharge 209 psig @ 272°F
  - 2nd stage suction 197 psig, discharge 760 psig @ 298°F
  - 130 MCF/d
  - It has the right clearance and spring stiffness for these conditions
- What happens if a half barrel of water comes into the wellbore and the suction pressure drops to 20 psig (39% at 5,300 ft elevation)?
  - 1st stage discharge 136 psig @ 345°F
  - 2nd stage discharge 760 psig @ 411°F
  - Machine is down on high discharge temp





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Flooded Screw Compressor

- First flooded screw made by Howden in 1977
- 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

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Flooded Screw

- 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 adsorbed 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

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Flooded Screw Temp Example

- Assume
  - Sea level (atmospheric pressure = 14.73 psia)
  - Methane (k=1.28, c_p=0.52669 BTU/lbm-R, q_{gas}=500MCF/d)
  - Semi-synthetic oil (SG=0.81, c_p=0.45 BTU/lbm-R, q_{oil}=40gpm, T_{in}=180°F)
  - Gas Suction = 0 psig at 80°F
  - Gas Discharge = 50 psig at ???

$$T_{gas-disch} = T_{gas-suct}\left(\frac{P_{disch}}{P_{suct}}\right)^{(k-1)/k} = (80+460)\left(\frac{50+14.73}{0+14.73}\right)^{(1.28-1)/1.28} = 770R$$

$$Q_{gas} = \dot{m}_{gas}c_{p-gas}\Delta T_{gas} = 500000\frac{ft^3}{day}\left(0.046\frac{lbm}{ft^3}\right)*\left(0.52669\frac{BTU}{lbm*R}\right)*(770R-540R)\left(\frac{day}{24hr}\right) = 116000\frac{BTU}{hr}$$

$$\Delta T_{oil} = \frac{Q_{gas}}{\dot{m}_{oil}c_{oil}} = \frac{116000\frac{BTU}{hr}}{40\frac{gal}{\min}*\left(6.84\frac{lbm}{gal}\right)\left(0.45\frac{BTU}{lbm*R}\right)\left(\frac{60\min}{hr}\right)} = 15.7F$$

$$T_{out} = T_{in} + \Delta T_{oil} = 180F + 15.69F = 195.7F$$

Too Cool, can raise discharge to 150 psig or lower q(oil) to 22 gpm or raise oil inlet to 190F

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Compressor Comparison

Recip		Flooded Screw	
Strengths	**Weaknesses**	**Strengths**	**Weaknesses**
Best use of Hp -1 stage best -2 stage 8% more hp -3 stage 15% more hp	Narrow suction range	Wide range of suction pressures	Moving oil requires energy (screw about same efficiency as 2-stage recip)
Operating staff thinks they understand them	Not tolerant of changing conditions	Changing cond have little impact	Operating staff uncomfortable
Few consumables	Valves high maint	No valves no rods	Oil is expensive
Some packagers do field machines well	Difficult to balance stages	No stages to balance	Packagers don't do field machines well
Rugged and Reliable	High temps	Very low temps	
	High maintenance	Low maintenance	
	Higher Purchase cost	Lower Purch cost	

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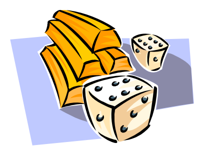
Decision

- Small Hp 2- or 3-stage recips are rarely the best choice for wellsite use
  - Can't afford personnel to optimize small units
  - Sub-optimized units prone to mechanical failures
- Suction
  - Above 40 psig single stage recip generally better
  - Below 40 psig flooded screw considerably better
- Ratios
  - Below 4 ratios single stage recip has better use of Hp
  - Screws work well up to nearly 20 ratios



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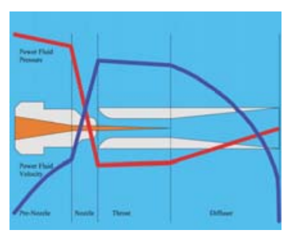
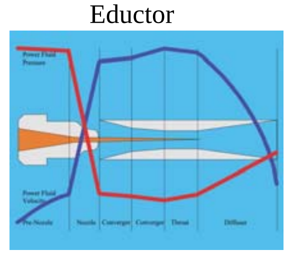
Eductors/Ejectors

- From the family of thermocompressors that includes Air Ejectors, Evacuators, Sand Blasters, Jet Pumps, and Eductors
- High pressure fluid entrains and boosts the pressure of suction fluid and the combined stream is left at an intermediate pressure
- Ratio of suction pressure to discharge pressure:
  - For an eductor, exhaust pressure limited to about 1.5-3 times suction pressure
  - For an ejector, ratio of exhaust to suction pressure can be as much as 10:1 in absolute terms (psia)
- Efficiency 30-70%
  - More ratios mean better efficiency, but
  - More ratios also means more power fluid required



Eductor



Ejector

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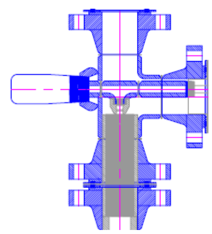
Casing Flow Control Case

- Uses friction in tubing to drive an ejector
- V-cone monitors tubing flow to stay above critical
- If above critical:
  - Flow cntl valve starts to open, sending power gas to Ejector Tee
  - If csg pressure > 45 #, BP regulator dumps extra
  - Compressor maintains exhaust at 5 psig
- Initial rate 25% higher than before installation (project had an 8 day payout)



Net Positive Suction Head (NPSH)

- Net Positive Suction Head is the amount of external pressure at the inlet to a pump.
- The *Required* NPSH (NPSH-r) is the amount of external pressure required to ensure the pump operates full of liquid.
- The *Available* NPSH (NPSH-a) is the amount of external pressure available at the pump suction.
- It generally doesn't matter if the NPSH comes from an actual hydrostatic head or an applied pressure (as long as the pump sees continuous-phase liquid).
- NPSH-r is very dependent upon fluid properties (mainly the boiling point, and vapor pressure)

Technologies that evolved from Artificial Lift

	Typical Capacity (BBL/day)	NPSHr (ft)	Failure method
PCP	4-600+	60-100	Heat of Compression
Beam Pump	20-500+	75-100	Gas Lock
Gas Lift	1,000+	200-500	Fall below critical rate
Jet Pump	10-45+	450-1,000	Cavitation
ESP	70-1,000+	150-2000	Cavitation

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Deliquification Technologies

	Typical Capacity (BBL/day)	NPSHr (ft)	Failure method
Velocity String	<100	0	Well capacity falls below critical
Tubing Flow Controller	<100	0	Well capacity falls below critical
Plunger	<20	0	Reservoir pressure falls below min required
Evaporation	<20	0	Scale plugging formation
HSP	<150	0	Wear

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Conclusion

- Low pressure operations are a pain in the posterior
  (But can be very profitable)
- Every solution to a problem will cause a new problem
  (That may be worse)
- Every symptom is masking another symptom
  (Which is masking still another symptom)
- What worked yesterday may not work tomorrow
  (But may work next month at a different pressure)
- NEVER say "we tried that and it didn't work"
  (Those words taste nasty when you have to eat them)
- Design for flexibility because you never know what the next problem will require

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Thank you for your attention.
Additional information can be found at
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