

Compression Options for Gas Storage Applications

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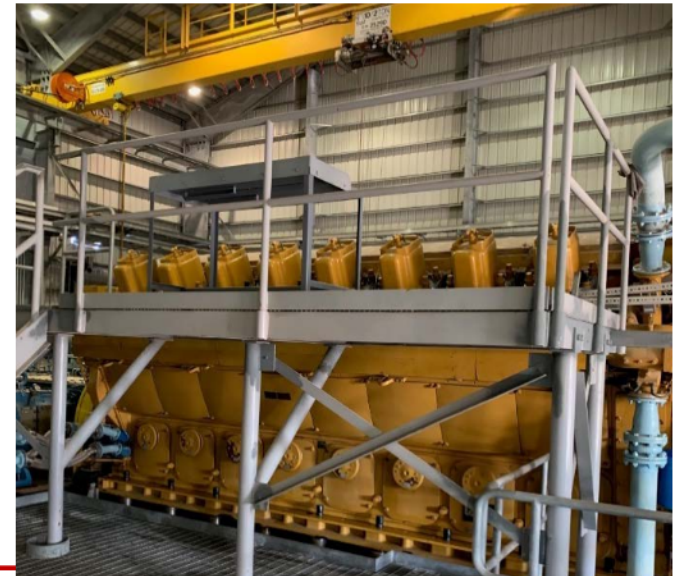
Compression Projects – Sr. Pipeline Engineer

Compression for Gas Storage: Then vs. Now

Markham Storage: KBV-6 two stage unit with G16 CM-34 CAT engine



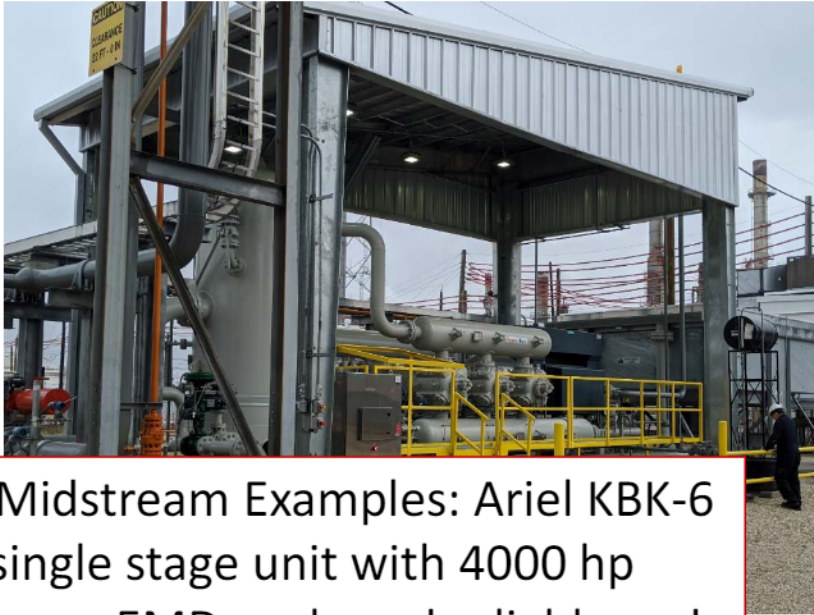
- Reliable unit with 7600 bhp gas engine drive.
- Reflected an older style of installing units with high capex: In building with overhead crane / block mounted / inlet air and exhaust ducts / lack of automation.
- Extensive cooling and piping / valves for engine Aux water, jacket water, gas cooling.
- Opex costs: oil usage, oil systems, low cost parts, valves.
- Recips need upstream and downstream scrubbers (for oil)



Compression for Gas Storage: Incorporating Midstream Lessons

- Avoid extensive compressor buildings – specifically for midstream in Texas – especially for non EMD units.
- Look for optimal sized units considering pipeline fluctuations and infrastructure (take-off points), moving away from > 5000 hp recip engines
- Consider commonality of midstream / storage equipment – Ariel KBx line, Solar compressors
- Engage power company early on, especially for large HP motor drive applications (> 2000 hp)
- Avoid shared VFD's or VFDs all together
- Add downstream cyclone scrubbers on recipis
- Lower capex through GCX lessons learned

Compression in KM Midstream: Recent Examples of Successful Projects



KM Midstream Examples: Ariel KBK-6 single stage unit with 4000 hp Siemens EMD packaged reliably and on time by Reagan Power



KM Midstream Examples: GCX Solar Turbines T-130 / T-250 with Enclosures / Pipeline compressors

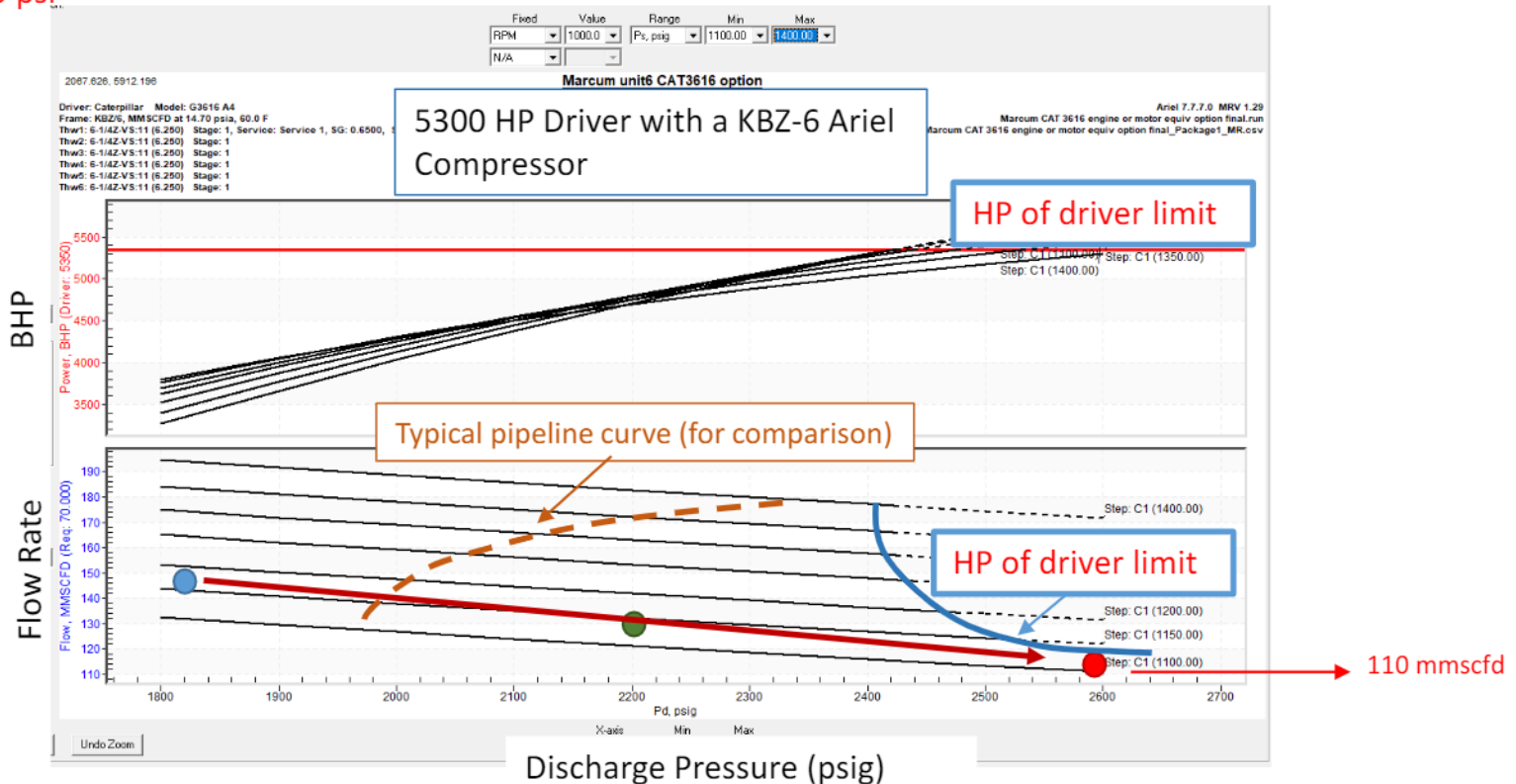


Reciprocating Compressor – Typical Curves for Storage Application

Curves shown below – assume KBZ-6 compressor with 1100 – 1400 psig suction pressures from pipeline with nearby booster station.

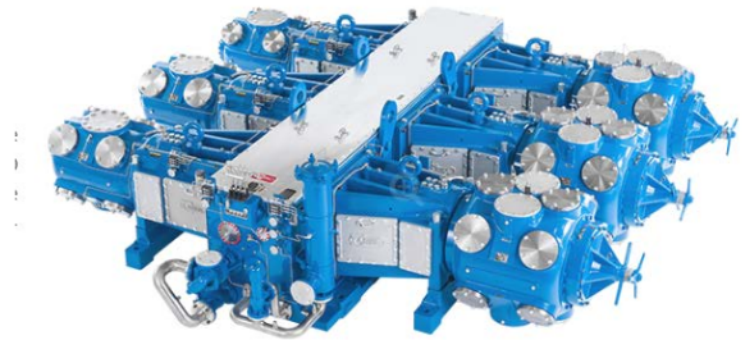
Blue Dot early storage = Use 6 cylinder compressor in single stage mode – LP injection up to 1800 psi (1.3-1.4x flow of late storage)

Green / Red Dots late storage as reservoir volume increases = Use compressor in two stage mode - HP injection at 2220-2600 psi



Reciprocating Compressors – High speed options configured for Single & Two Stage Mode

- High speed Recip compressors lend themselves to easy configuration of single stage and 2-stg mode. This will help to maximize flow at all reservoir pressures.
- However, single stage mode will provide significantly more flow for all cylinders if the pressure ratio can stay within ~ 1.5 - 2.3
- To accomplish single stage mode at high storage pressures ~ 2600 psi, consider a suction booster unit to maintain 1200-1400 psi suction header.
- Must still add automatic unloaders (VVCPs, SVU's, FVCP's) to manage HP at high injection pressures.
- Make sure you work with a packager that you trust on delivery and one who ensures high quality package.



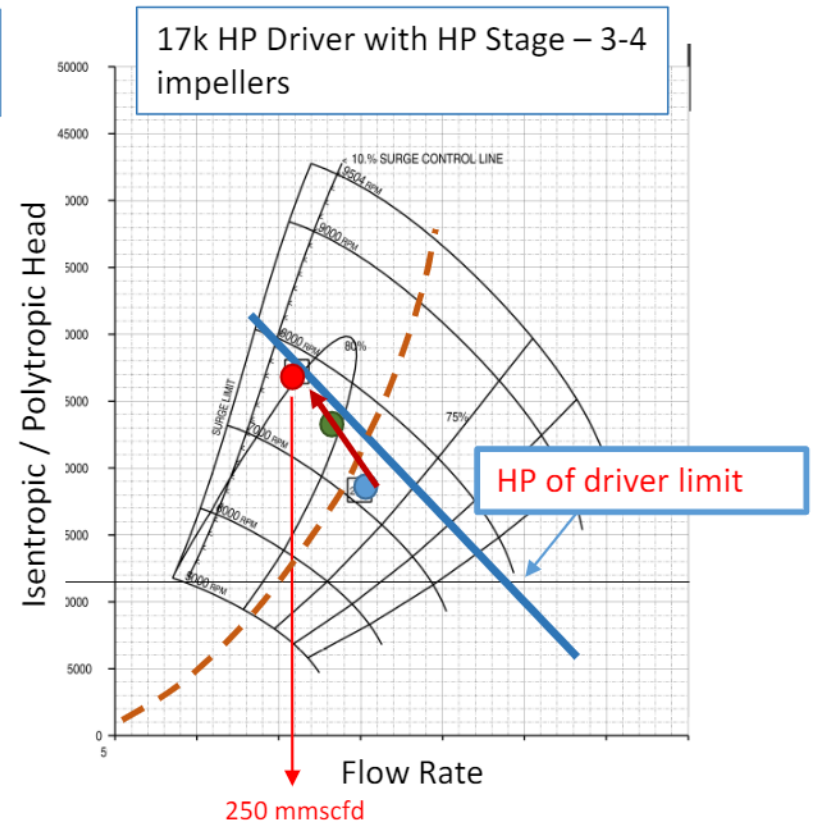
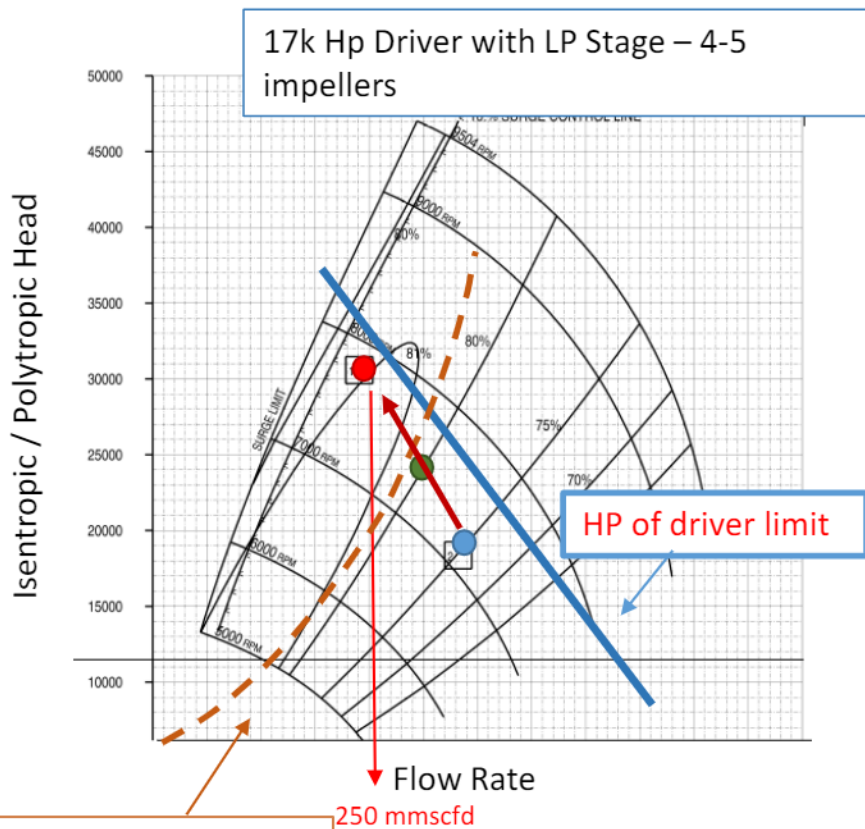
Centrifugal Compressor – Storage Application

Curve: Tandem Unit in Series / Parallel

Curves shown below – assume EMD 17.5k HP Solar tandem C51 / C41 compressors with 700-800 suction pressures from pipeline (no booster station required).

Blue = parallel – LP injection with tandem units in parallel at 1200 psi injection (2x flow)

Green / Red = In series - HP injection with tandem units in series at 2220-2600 psi injection



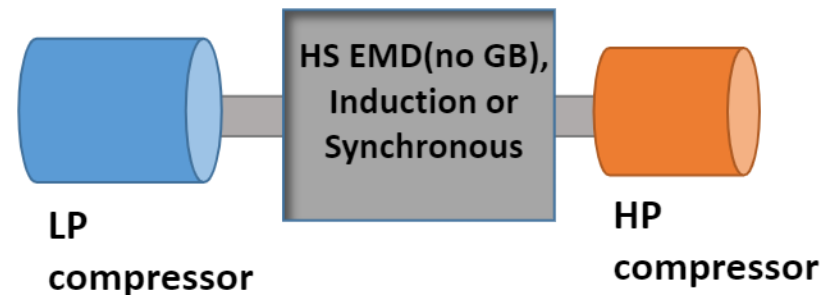
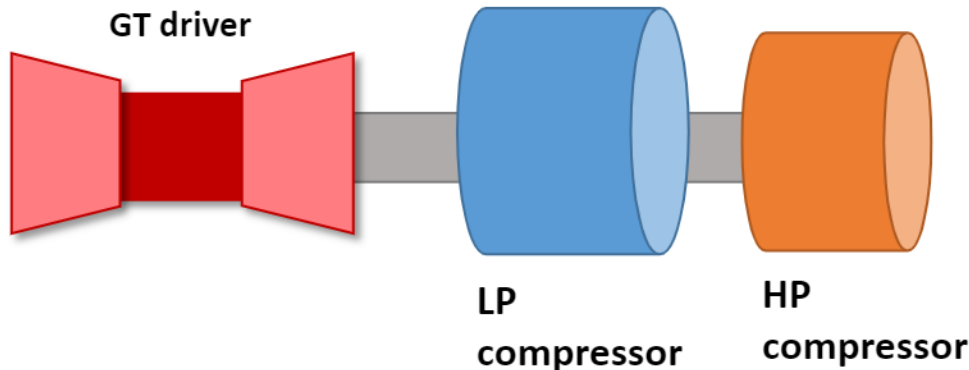
Typical pipeline curve (for comparison)

Centrifugal Compression – Tandem Options

Solar GT driven tandem, skid mounted



MAN HS electric motor driven tandem unit



Recips and Centrifugals in Gas Storage

- Important Considerations:
 - Existing units at storage field and in operating company fleet: both the good and bad actors
 - Non-attainment area?
 - Electric power availability – need high voltage lines within $\frac{1}{4}$ mile to make economics work,
 - Act early to engage power company!
 - Starting large motors – consider range of options including soft-starters or lower rated VFDs
 - OEM support for outages / repairs
 - Maintaining reservoir health and low oil injection

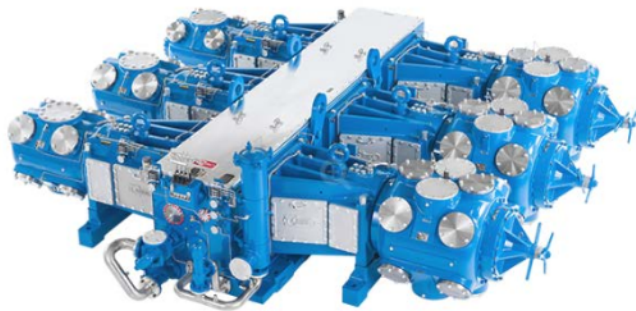
Markham Storage: 1 x 3616, 1 x CM34, 3 White Superiors – all gas engines.
+20kV lines within 1/4 mile



West Clear Lake – 5 x Electric Motor driven recips (non-attainment area), total = 32,000 hp

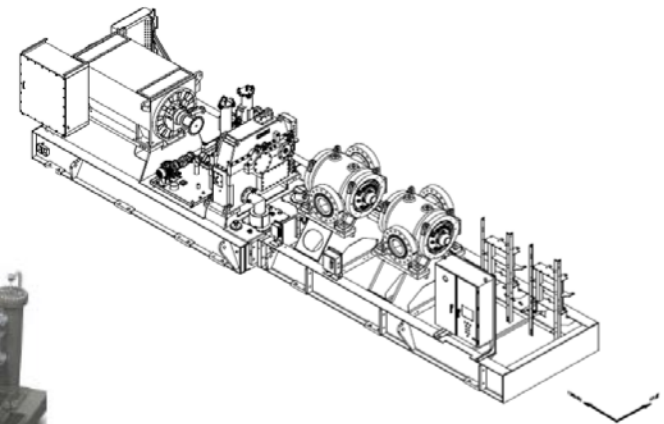
Recips and Centrifugals in Gas Storage

- Advantages:
 - Recips handle high pressure ratios easily, easily skid mounted, tend to have high operator familiarity, switching from single to 2-stage mode is not complicated, but good packaging is key.
 - Centrifugal tandem units can be skid-mounted, use less oil and have low vibrations / no pulsation issues, but somewhat more complicated / extensive systems especially for surge control.



Courtesy of Ariel

Courtesy of MAN



Courtesy of Solar Turbines

Finding the “Sweet” Spot for Driver Size and Common Gas Storage Compressors

- Bigger is not necessarily always better: 1x 20,000 hp vs 2 x 10,000 hp
- Larger motor will be:
 - Harder to start
 - Less turndown
 - Tends to be synchronous – not induction = More \$\$, less reliable, less available.
- Consider the KBZ-6 as an alternative to KBB /KBV frames. Can go up to 1000 RPM, 7500 hp, easily configurable.
- Ariel KBZ-6 with 7500 hp Motor or CAT 3616 or Waukesha 275 GL+ = Skid-mounted package, high reliability, single or two stage operation.
- For storage applications, centrifugal tandem units are actually fairly mainstream in Europe.
- Centrifugals offer good efficiency, low opex and can be skid-mounted. Avoid pulsation headaches and lower oil consumption. Must consider separate surge control valves and interstage piping / valves.

Special thanks to the KM Operations team at Markham Storage and West Clear Lake Storage for help with this presentation.

And for awesome pictures – thanks to Solar, MAN and Ariel !

Questions / Comments??