

Hydrogen compression & expansion

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KDR Compressors
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Key issues

Cost

Pressure ratio

Flow

Safety

Energy

Regulation and control

Cost



Mass produced air compressors

3 stage oil free piston machines.

40:1 compression ratio

500 to 5000 m³/hr

\$USD 500 / kw

5000 m³/ hr = 850 kw

\$USD 425,000

5000m³ / hr is the volume flow from a 25 MW
electrolyser. (assuming 5 kwhr / m³)

So compressor power 850kw /25000kw
= 3.5 % of electrolyser power.



c.. **VFD EMD – Gear - Compressor**

Typical electric drive natural gas pipeline compressor.

All up cost of compressor station

\$2500 / kw

Hydrogen likely to be more expensive.

1, More stages

2, More leaky

3, Less experience, less manufacturing volume.

4, Hydrogen flammability issues.

Turbo

Integrated High Speed EMD Compressor Products



GE ICL



Siemens
STC-ECO

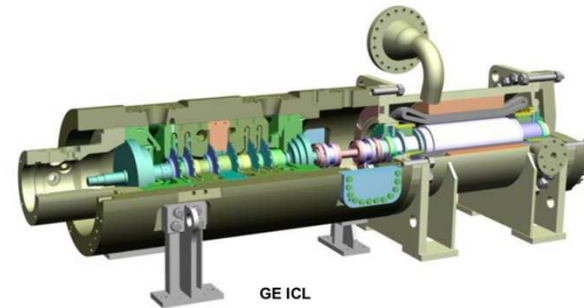
GE ICL

MAN
Hofim



All figures courtesy of Elliott Group, Solar Turbines Inc., Southwest Research Institute, and General Electric

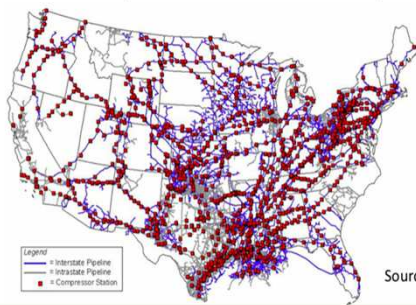
Technology Developments: Hermetically Sealed Direct Drive Compressors



GE ICL

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US Natural Gas Pipelines and Compression Stations



Background: Oil & Gas Compressors

- Compressors are used for natural gas gathering, transport, processing, storage, and distribution (fuel gas)
- US has approximately 1,700 midstream natural gas pipeline compressor stations with a total of 5,000-7,000 compressors
- US has approximately 13,000-15,000 smaller compressors in upstream and 2,000-3,000 compressors (all sizes) in downstream oil & gas and LNG applications.
- DOE estimates that 2-3% of US natural gas is utilized by oil & gas compressors (includes consumption and leakage)

Pressure ratio

Hydrogen hard to compress

A, Lots of it / kg ie $0.0893 \text{ kg} / \text{m}^3$

Compared to air @ $1.205 \text{ kg} / \text{m}^3$

= 13.4 times less dense than air.

B, High pressure compressors tend to have low compression ratios / stage.

So more stages. So more cost.

C, Main questions are.....

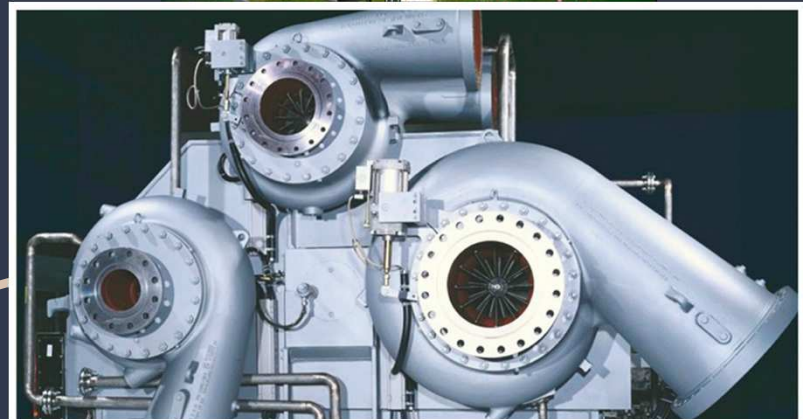
What is inlet pressure?

Better & cheaper for compressor if higher. But worse for electrolyser.

D, What is outlet pressure?

Better & cheaper for compressor if lower. But worse for storage density.

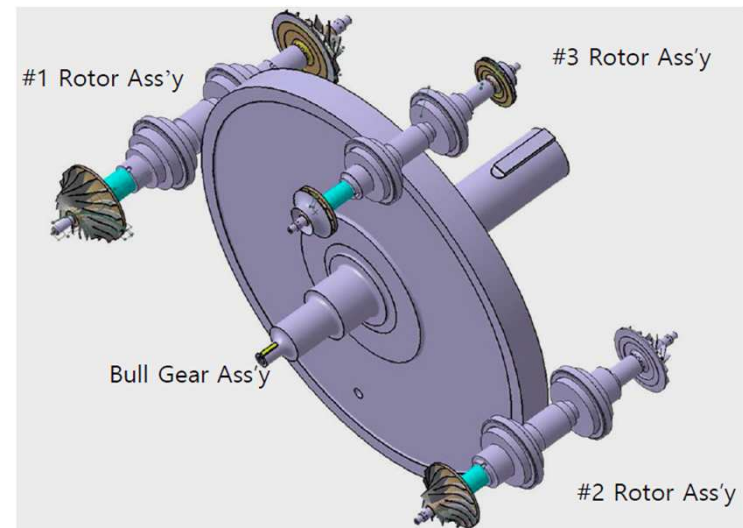
Flow



No limit to flow.

Compressor in a 737 engine compresses 400kg/sec of air @ a compression ratio of 30:1.

On hydrogen this is the atmospheric gas flow from a 5400 MW electrolyser.



Safety



The compressors were more than a bit player the Piper Alpha disaster.

An explosion and resulting oil and gas fires destroyed Piper Alpha on 6 July 1988, killing 167 men,^[3] including two crewmen of a rescue vessel;^[4] 61 workers escaped and survived. Thirty bodies were never recovered. The total insured loss was about £1.7 billion, making it one of the costliest man-made catastrophes ever.

At the time of the disaster, the platform accounted for approximately ten percent of [North Sea oil and gas](#) production. The accident is the worst offshore oil disaster in terms of lives lost and industry impact.^[5]

Wider flammability limits and lower ignition energy mean electrical systems more expensive to make safe.

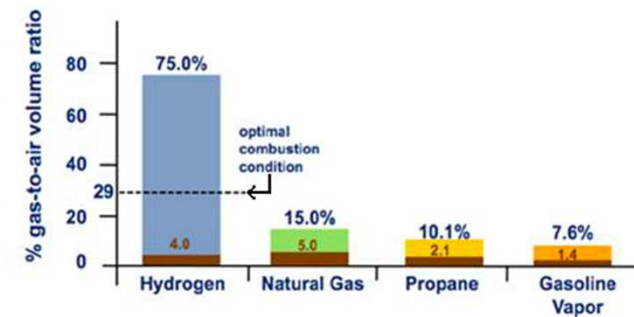


Figure 3. Flammability Range

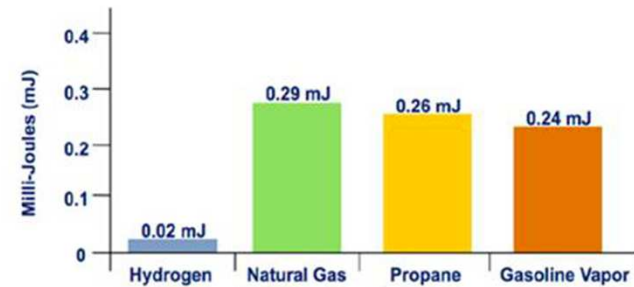
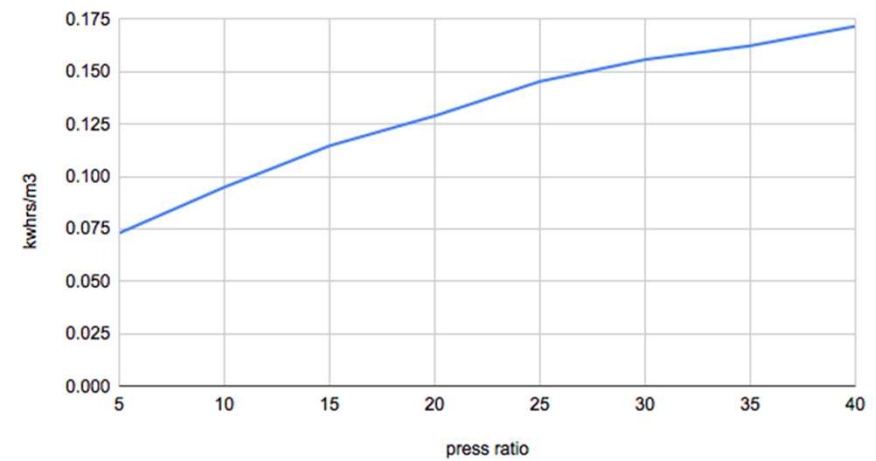


Figure 4. Minimum Ignition Energy

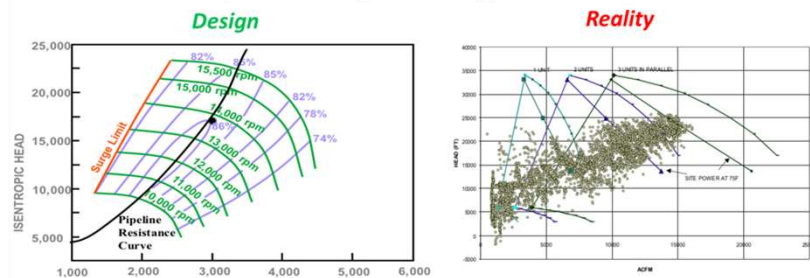
Energy

Energy needed to compress
kwhrs/m³ vs. press ratio



Regulation and control

Pipeline Operating Conditions



Pipeline compressors rarely operate near their design point:

- Reduced driver efficiency
- Reduced compressor efficiency
- Gas recycling or other flow control losses

All figures courtesy of Elliott Gorman, Solar Turbines Inc., Southwest Research Institute, and General Electric

Big compressors don't

A, Start easily.

B, Change speed easily.

C, Work very efficiently at part load.

D, Deal with changing pressure ratios very well.

E, Renewable energy sources obviously very variable which means flow from electrolyser may be too.

F, Turbos cannot maintain high pressure ratios at reduced speed.

D, Recip machines cannot slow much below 60% full speed.

E, Imples multiple machines needed.

F, Control complex.