Full Scale Natural Gas Compressor Loop Testing with Blended Hydrogen

Objectives

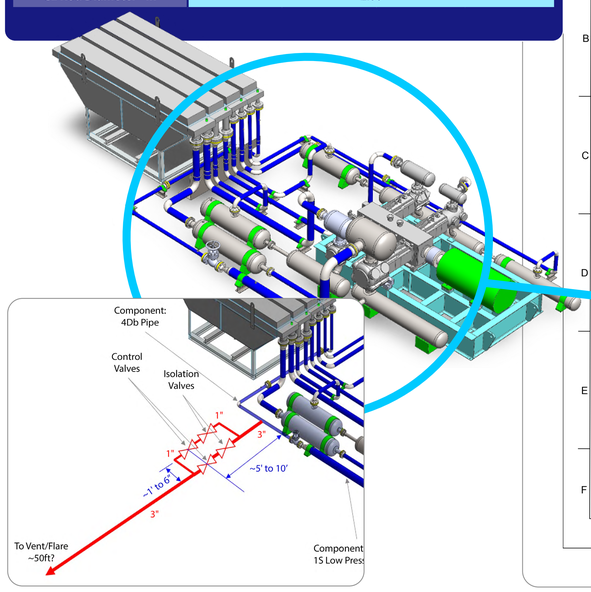
- Test up to 20% hydrogen in 5% increments in a full scale natural gas compressor loop
- Evaluate performance of various components, system characteristics, leakage and separation
- Create a best practice guidance document
- Identify key technology gaps in converting to hydrogen blends

Approach

- Design and modify a compressor loop, blending skid and separation skid for 20% hydrogen compatibility
- Perform modeling predictions: performance, pulsation, leakage, blowdown
- Test equipment: GCs, cameras, low leakage flanges, gas detectors, instrumentation
- Test loop characteristics at varying H2% (0-20%)
- Compare to modeling predictions
- Separation testing

Compressor System

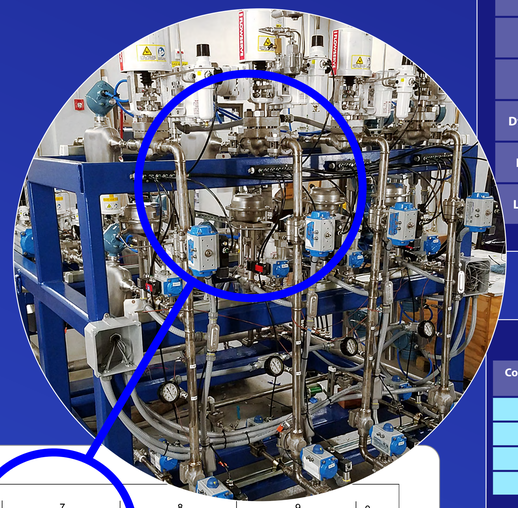
Compressor Model	Ariel JGT			
Driver Power - (HP)	700			
Number of Stages	4			
Number of Cylinders	4			
Operating Speed (rpm)	0-1500			
Stage No.	1	2	3	4
Cylinder Bore - (in)	15.75	9.75	7.375	4.625
Clearance HE / CE %	17.0/16.4	14.6/15.5	17.9/20.0	18.7/26.0
Stroke - (in)	4.5			
CE Rod Diameter - in	2.00			



Initial Blowdown Line Concept

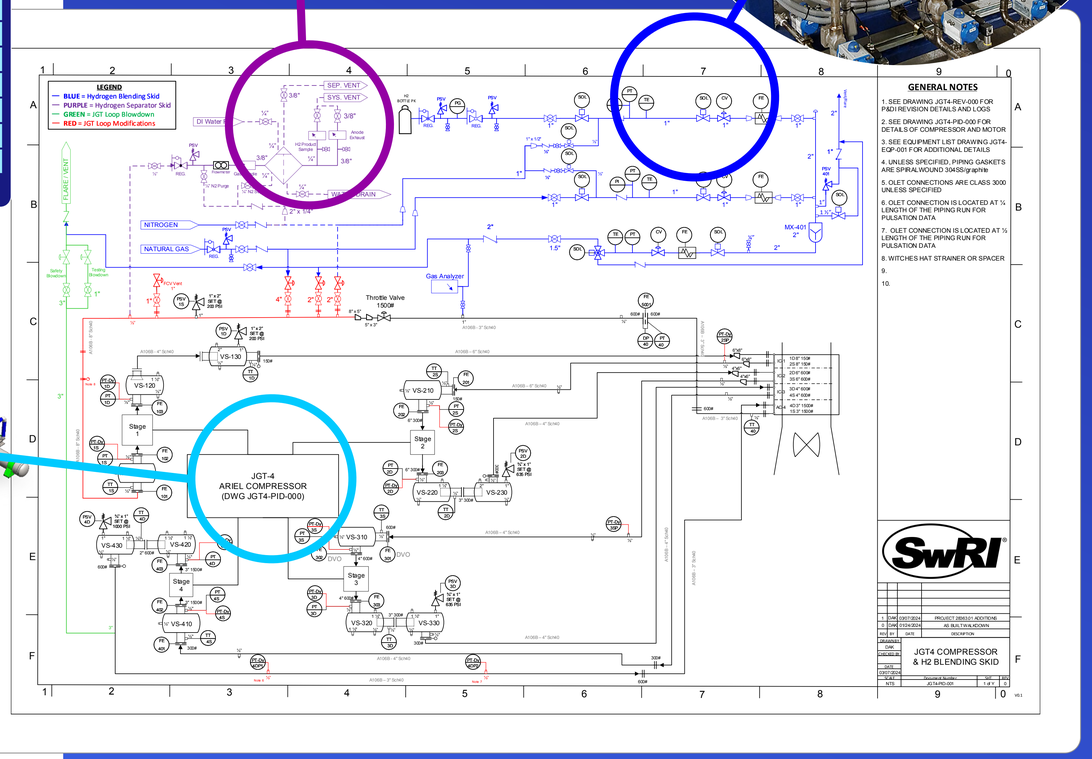
Separation System

- SKYRE H2RENEW
- PEM Technology
- >80% H2 Recovery
- 5 cell stacks



Blending Skid

- Hydrogen and Methane/NG
- Coriolis Meters
- Static Mixer



Gas Composition	100% NG / 0% H2	95% NG / 5% H2	90% NG / 10% H2	85% NG / 15% H2	80% NG / 20% H2
Mol.Wt.	16.55	15.82	15.09	14.37	13.64
Density (lbm/ft³)	0.1065	0.1018	0.0971	0.0923	0.0876
Sound Speed (ft/s)	1474	1510	1549	1591	1636
Specific Heat at Constant Pressure (Btu/lb °F)	0.5291	0.5475	0.5676	0.5898	0.6144
Ratio of Specific Heats	1.3023	1.3059	1.3096	1.3134	1.3174
J-T Coeff. (°F/psi)	0.0502	0.0463	0.0425	0.0388	0.03522
Dynamic Viscosity (lbm/ft-s)	7.773x10-6	7.770x10-6	7.766x10-6	7.761x10-6	7.755x10-6
LHV Mass basis (Btu/lbm)	20742	20939	21154	21392	21655
LHV Volume basis (Btu/ft³)	2200	2123	2047	1970	1894

Gas Composition Test 1: 0% Hydrogen

Compression Stage	Suction Pressure (PSI)	Suction Temp (°F)	Discharge Pressure (PSI)	Discharge Temp (°F)	Compressor Flow (MMSCFD)	Mass Flow (lb/hr)	Power Required (HP)
Stage 1	38.51	100.00	99.02	251.00	3.21	5845	192.50
Stage 2	96.41	120.00	209.07	242.00	3.19	5809	156.60
Stage 3	204.10	120.00	485.50	257.00	3.16	5754	170.10
Stage 4	476.50	120.00	1024.85	250.00	3.14	5718	150.70

Gas Composition Test 2: 5% Hydrogen

Compression Stage	Suction Pressure (PSI)	Suction Temp (°F)	Discharge Pressure (PSI)	Discharge Temp (°F)	Compressor Flow (MMSCFD)	Mass Flow (lb/hr)	Power Required (HP)
Stage 1	38.51	100.00	99.13	252.00	3.21	5587	5587
Stage 2	96.52	120.00	209.59	243.00	3.19	5553	5553
Stage 3	204.59	120.00	487.43	258.00	3.16	5500	5500
Stage 4	478.48	120.00	1024.85	249.00	3.14	5466	5466

Gas Composition Test 3: 10% Hydrogen

Compression Stage	Suction Pressure (PSI)	Suction Temp (°F)	Discharge Pressure (PSI)	Discharge Temp (°F)	Compressor Flow (MMSCFD)	Mass Flow (lb/hr)	Power Required (HP)
Stage 1	38.51	100.00	99.24	253.00	3.21	5330	191.50
Stage 2	96.62	120.00	210.09	244.00	3.19	5296	156.20
Stage 3	205.09	120.00	489.31	259.00	3.16	5247	170.40
Stage 4	480.35	120.00	1024.85	249.00	3.14	5213	149.20

Gas Composition Test 4: 15% Hydrogen

Compression Stage	Suction Pressure (PSI)	Suction Temp (°F)	Discharge Pressure (PSI)	Discharge Temp (°F)	Compressor Flow (MMSCFD)	Mass Flow (lb/hr)	Power Required (HP)
Stage 1	38.51	100.00	99.34	254.00	3.21	5072	191.00
Stage 2	96.73	120.00	210.58	245.00	3.19	5040	156.00
Stage 3	205.58	120.00	491.13	260.00	3.16	4993	170.50
Stage 4	482.18	120.00	1024.85	248.00	3.14	4961	148.50

Gas Composition Test 5: 20% Hydrogen

Compression Stage	Suction Pressure (PSI)	Suction Temp (°F)	Discharge Pressure (PSI)	Discharge Temp (°F)	Compressor Flow (MMSCFD)	Mass Flow (lb/hr)	Power Required (HP)
Stage 1	38.51	100.00	99.45	256.00	3.21	4815	190.60
Stage 2	96.84	120.00	211.06	246.00	3.19	4785	155.80
Stage 3	206.06	120.00	492.91	261.00	3.16	4740	170.60
Stage 4	483.96	120.00	1024.85	248.00	3.14	4710	147.70

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