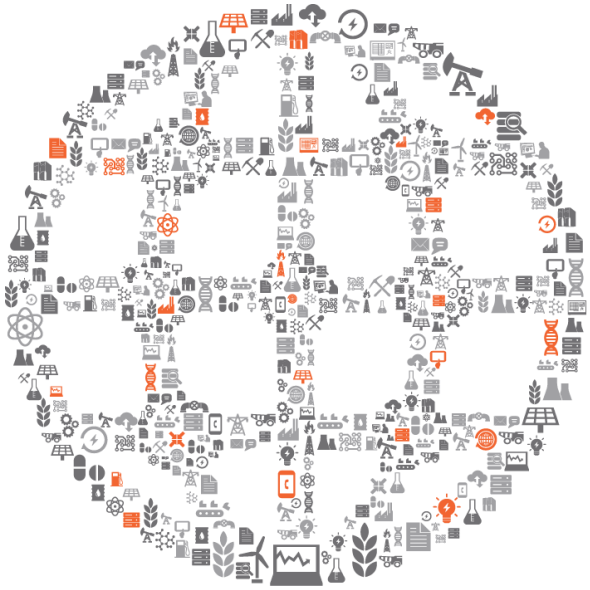

OSIsoft.

USERS CONFERENCE 2013

The Power of Data

THRIVING IN A WORLD OF CHANGE

VALERO
MEMPHIS REFINERY

Using PI ProcessBook to Monitor Centrifugal Compressor Performance

Presented by **Walter R. Fisher, PE**
Staff Mechanical Engineer

VALERO
MEMPHIS REFINERY

One of 14 refineries in Valero system; others in Texas, Louisiana, Oklahoma, California, Canada and Wales (UK)

10 Ethanol Plants in US Midwest

Products: Petroleum Fuels
Gasoline
Diesel Fuel
Jet Fuel

Centrifugal/Axial Compressor Population

5 Air Compressors
- One 30,000 hp Main Air Blower
- Four 400 hp Plant/Instrument Air Compressors

3 Hydrogen Compressors
- One 7300 hp
- Two 6000 hp

1 Hydrocarbon Gas Compressor
- One 6000 hp

2 Turbo Expander/Compressors
- Two 400 hp

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Centrifugal Compressor Operation is Critical to Plant Function

- Expensive – Unspared: Loss of Machine Means Unit Shutdown
- Limited Stable Operating Range – Surge or Choke
- Subject to Wear and/or Fouling

Business Challenge

Insure Maximum Availability of Compressors

Provide Operations Personnel with Easy-to-Understand Information

Solution

Monitor Compressor Performance and Condition Using PI System-Linked Excel Spreadsheets

Results and Benefits

Provides Graphic Representation of Compressor Operating Point on Curve

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Surge and Choke

Surge

Backflow Caused by Decay of Compressor Discharge Pressure at Low Flow Rates

Repeated Surges Shock Load Thrust Bearings and Rapidly Generate Heat in the Gas Path

Overstresses Axial Compressor Blades

Choke

Maximum Flow Limited by Shock Wave Internal to Machine

Particularly Damaging to Axial Machines with Cantilevered Blades

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Main Air Blower
30,000 hp
Axial Compressor

- Ingests Atmospheric Air
- Inlet Temperature Varies Widely Over the Year
- Sensitive to Both Surge and Choke

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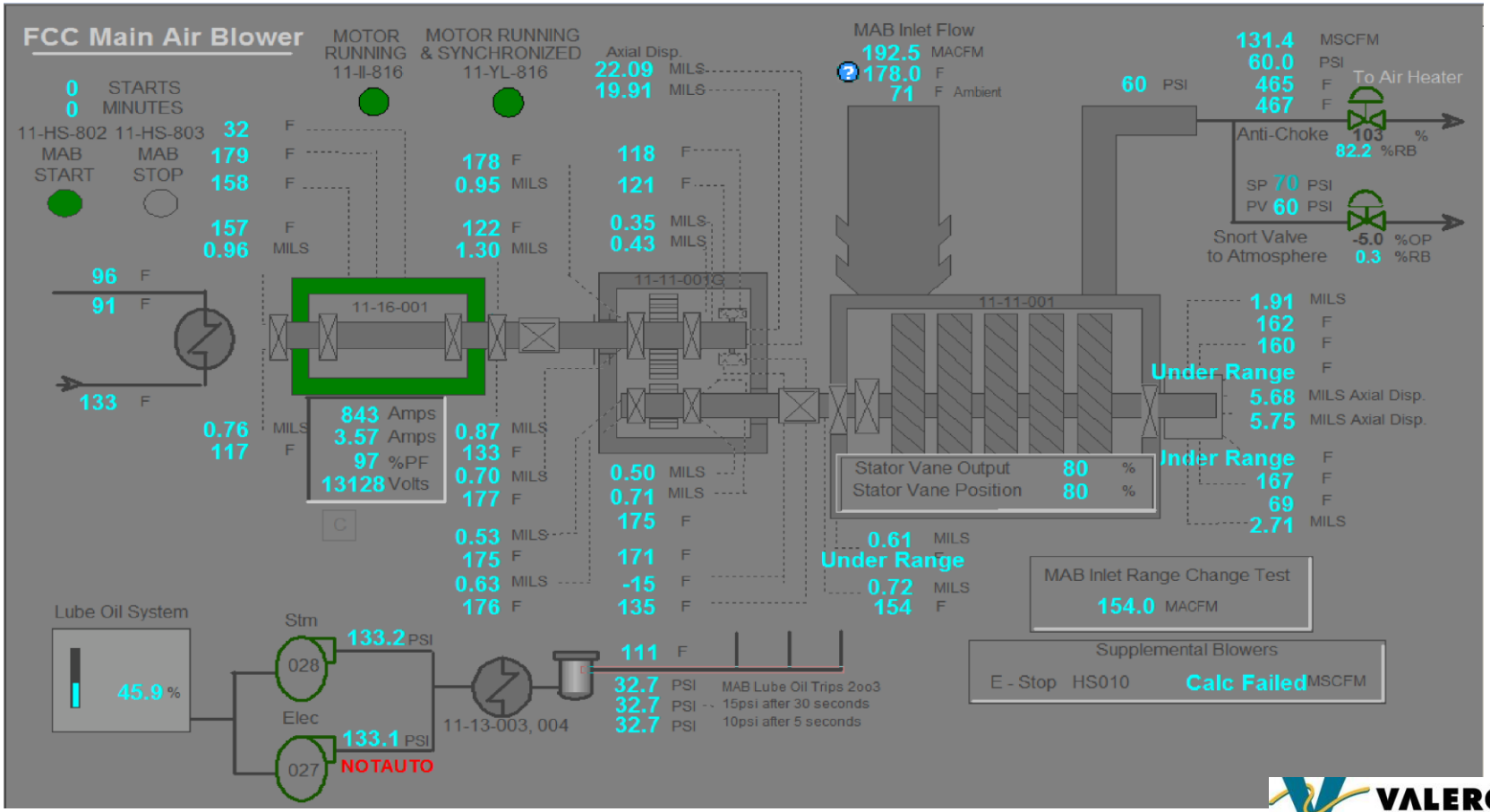

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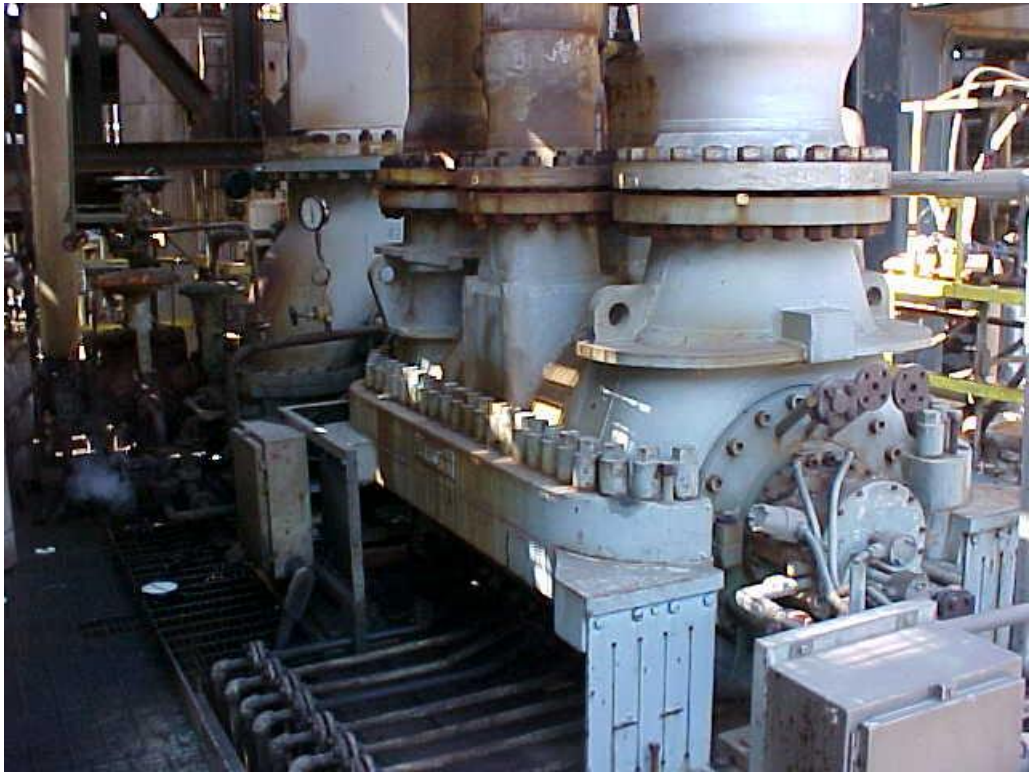
Wet Gas Compressor 6000 hp Turbine

Two Section Compressor

Variable Speed Drive via Steam Turbine

Suction Pressure and Temperature Vary due to Use of Air Coolers



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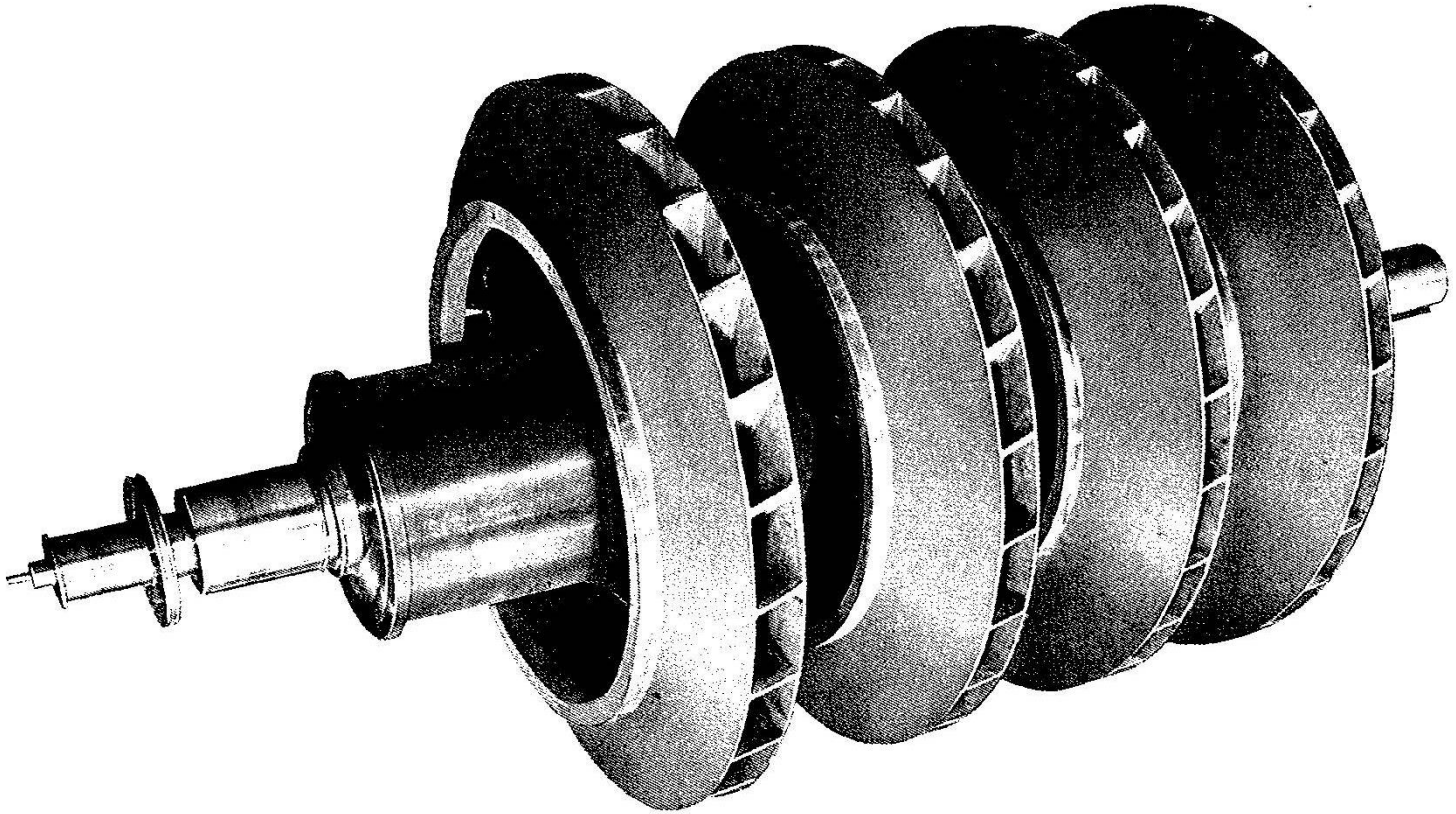

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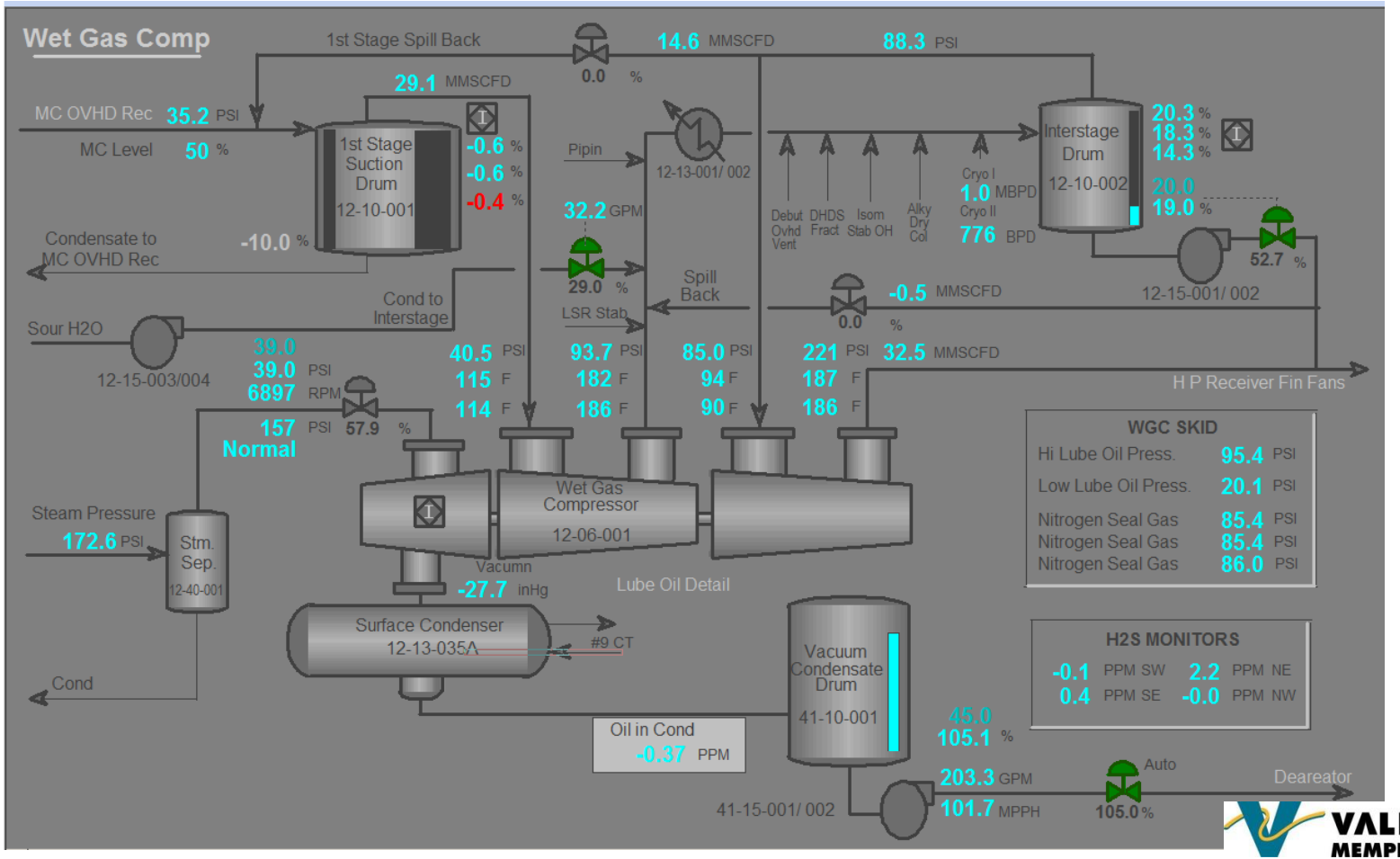

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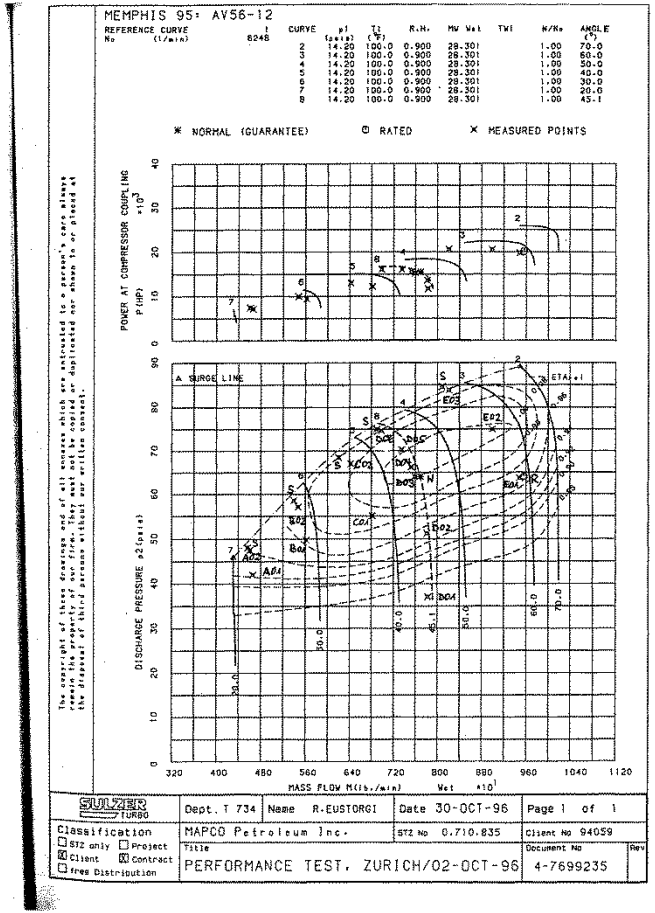
Main Air Blower

Performance Test Data Furnished by Manufacturer – not in Commonly Used Engineering Units

So….Hand-Drawn Curve Generated….

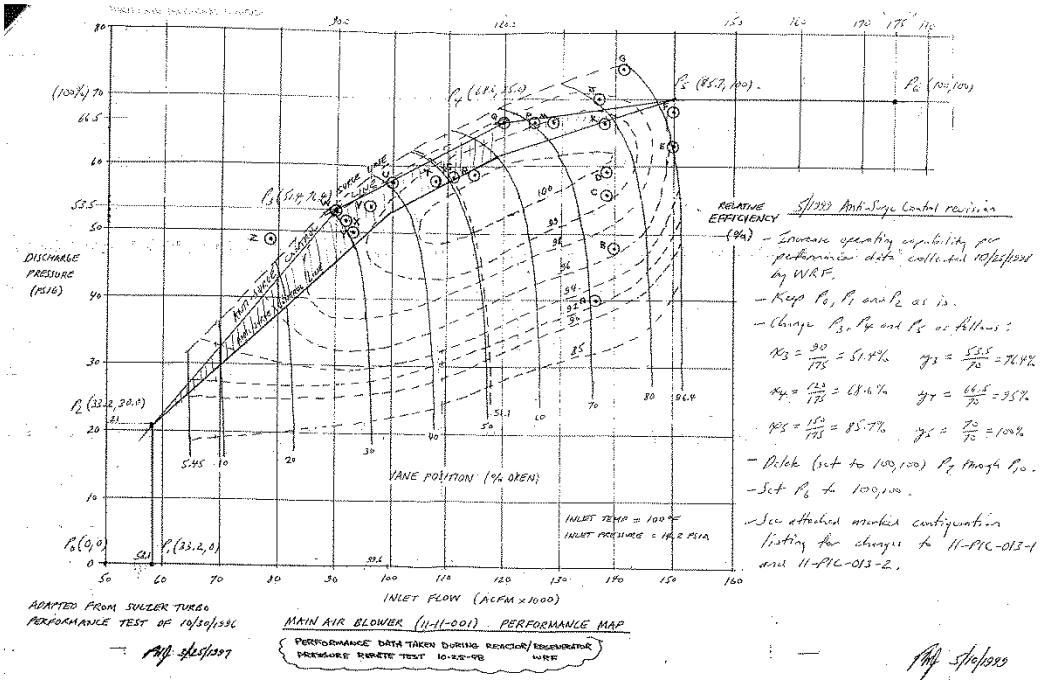


Hand-Drawn Blower Curve

Converted to Commonly Used Units

Curves like this are not very useful to an operator

So……PI System-linked spreadsheets were developed to give the operators and engineers a graphical indication of where the machine is operating:



VALERO MEMPHIS REFINERY

PI Data																			
MAB Inlet Flow		MAB Disch Flow	(corr)	Disch Press	Surge Line	Mass Flow - lb/min 20 °	30 °	40 °	50 °	60 °	70 °		psia	flow lbm/min	psig	100 F cu ft/min	60 F cu ft/min	0 F cu ft/min	scfm
11FI504.pv		11FC018.pv		psia									89.0	9550	74.3	143250	127015	110780	122695
190.0	MACFM	129.1	MSCFM	89.0	9550						9550		86.0	8500	71.3	127500	113050	98600	109205
													79.9	7400	65.2	111000	98420	85840	95072
MAB Inlet Temp		MAB Disch Press		86.0	8500					8500			73.0	6500	58.3	97500	86450	75400	83510
11TI503.pv		11PI017.pv		85.0						8750	9800		62.5	5550	47.8	83250	73815	64380	71304
90.0	F	59.5	psig	82.0						9200			46.0	4350	31.3	65250	57855	50460	55887
		MAB Disch Temp		80.0						9300	10000	20 °							
		11TI506.pv		79.9	7400				7400				46.0	4350	31.3	65250	57855	50460	55887
Date & Time:	13-Aug-13 13:04:26	472.3	F	75.0					8000	9500	10100		45.0	4360	30.3	65400	57988	50576	56016
				73.0	6500			6500					40.0	4370	25.3	65550	58121	50692	56144
				70.0				6800	8250	9600	10200		35.0	4380	20.3	65700	58254	50808	56273
K=	1.4	MAB Disch Flow		65.0				7050	8350	9650	10200				-14.7				
		(uncorrected)		62.5	5550		5550					30 °	62.5	5550	47.8	83250	73815	64380	71304
Polytropic Eff		45.9	MACFM	60.0			5700	7150	8400	9700	10200		60.0	5700	45.3	85500	75810	66120	73231
0.9				55.0			5775	7200	8450	9750	10200		55.0	5775	40.3	86625	76808	66990	74195
		MAB Inlet Flow		50.0			5825	7250	8500	9800	10200		50.0	5825	35.3	87375	77473	67570	74837
		calc from FT018		46.0	4350	4350							45.0	5850	30.3	87750	77805	67860	75159
		141.4	MACFM	45.0		4360	5850	7300	8550	9800	10200		40.0	5850	25.3	87750	77805	67860	75159
				40.0		4370	5850	7350	8600	9800	10200		35.0	5850	20.3	87750	77805	67860	75159
		Inlet Flow Error		35.0		4380	5850												
		25.6%										40 °	73.0	6500	58.3	97500	86450	75400	83510
													70.0	6800	55.3	102000	90440	78880	87364
		Surge SP											65.0	7050	50.3	105750	93765	81780	90576
		11PC013.sp											60.0	7150	45.3	107250	95095	82940	91860
													55.0	7200	40.3	108000	95760	83520	92503
		Discharge Press																	
		11PC013.pv											50.0	7250	35.3	108750	96425	84100	93145
													45.0	7300	30.3	109500	97090	84680	93788
													40.0	7350	25.3	110250	97755	85260	94430
												50 °	79.9	7400	65.2	111000	98420	85840	95072
													75.0	8000	60.3	120000	106400	92800	102781
													70.0	8250	55.3	123750	109725	95700	105993
Air Density									Current Flow Data										
P1	14.2	psia							Disch Flow	P disch			65.0	8350	50.3	125250	111055	96860	107278
T1	100	F							127031	58.5			60.0	8400	45.3	126000	111720	97440	107920
RH	0.9								Inlet Flow	corr			55.0	8450	40.3	126750	112385	98020	108562
MW wet	28.301								190042	140042			50.0	8500	35.3	127500	113050	98600	109205
													45.0	8550	30.3	128250	113715	99180	109847
									Stator Vanes	Snort	Plot Dummy		40.0	8600	25.3	129000	114380	99760	110490
Sp Vol	15.00	cu ft/lb							70.0	-5	200000.0								
Density	0.067	lb/cu ft										60 °	86.0	8500	71.3	127500	113050	98600	109205
									Surge Press SP										
Air Density									70.0				85.0	8750	70.3	131250	116375	101500	112417
P1	14.2	psia											82.0	9200	67.3	138000	122360	106720	118198
													80.0	9300	65.3	139500	123690	107880	119483
									Inlet Flow corr from FT18										
T1	60	F																	
RH	0.9								139090.5	icfm			75.0	9500	60.3	142500	126350	110200	122052
MW wet	28.301												70.0	9600	55.3	144000	127680	111360	123337
													65.0	9650	50.3	144750	128345	111940	123980
Sp Vol	13.30	cu ft/lb											60.0	9700	45.3	145500	129010	112520	124622
Density	0.075	lb/cu ft											55.0	9750	40.3	146250	129675	113100	125264
													50.0	9800	35.3	147000	130340	113680	125907
													45.0	9800	30.3	147000	130340	113680	125907
Air Density													40.0	9800	25.3	147000	130340	113680	125907
P1	14.2	psia																	
T1	0	F										70 °	89.0	9550	74.3	143250	127015	110780	122695
RH	0.9												85.0	9800	70.3	147000	130340	113680	125907
MW wet	28.301												80.0	10000	65.3	150000	133000	116000	128476
													75.0	10100	60.3	151500	134330	117160	129761
Sp Vol	11.60	cu ft/lb											70.0	10200	55.3	153000	135660	118320	131046
Density	0.086	lb/cu ft											65.0	10200	50.3	153000	135660	118320	131046
													60.0	10200	45.3	153000	135660	118320	131046
													55.0	10200	40.3	153000	135660	118320	131046
													50.0	10200	35.3	153000	135660	118320	131046
													45.0	10200	30.3	153000	135660	118320	131046
													40.0	10200	25.3	153000	135660	118320	131046

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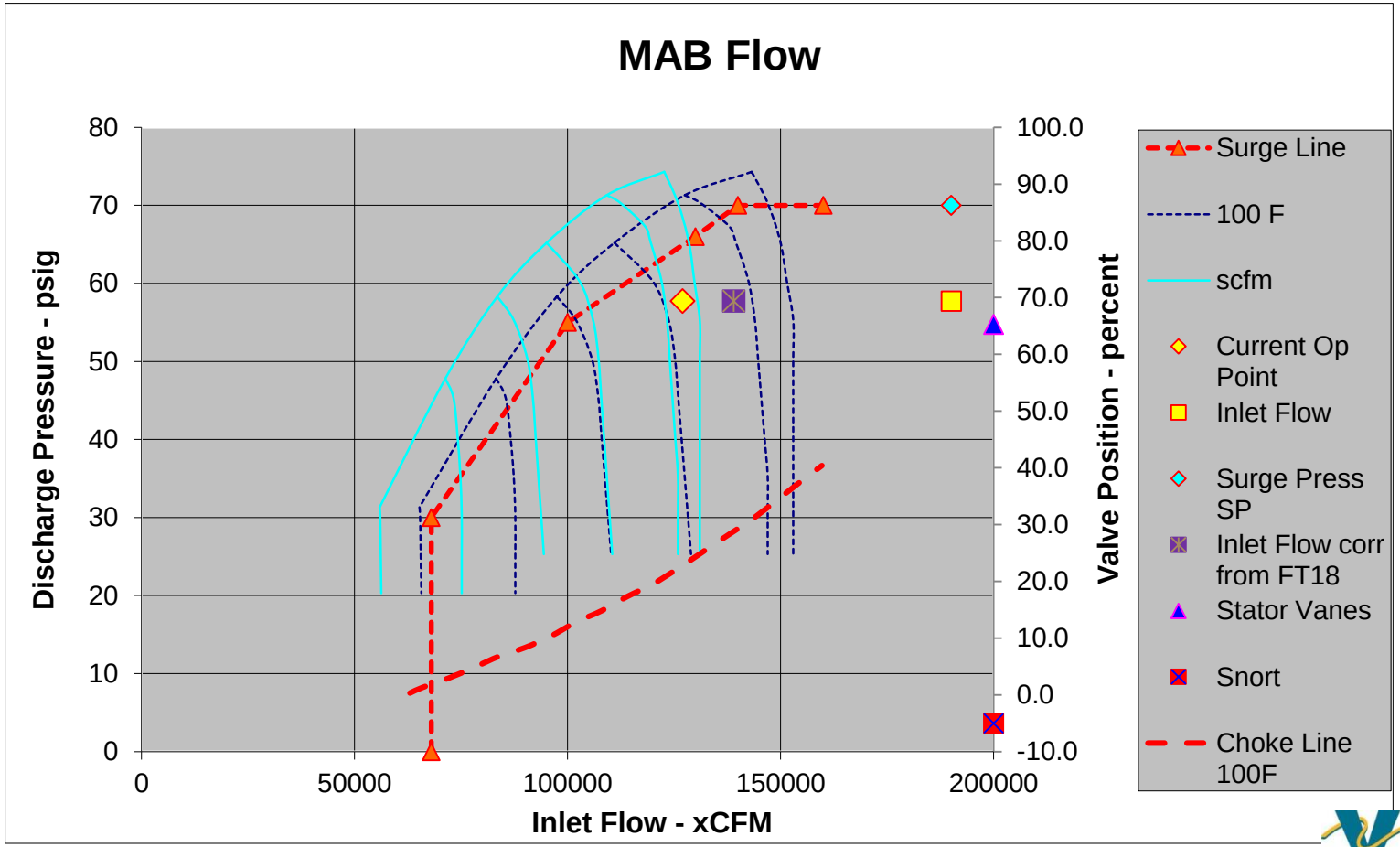

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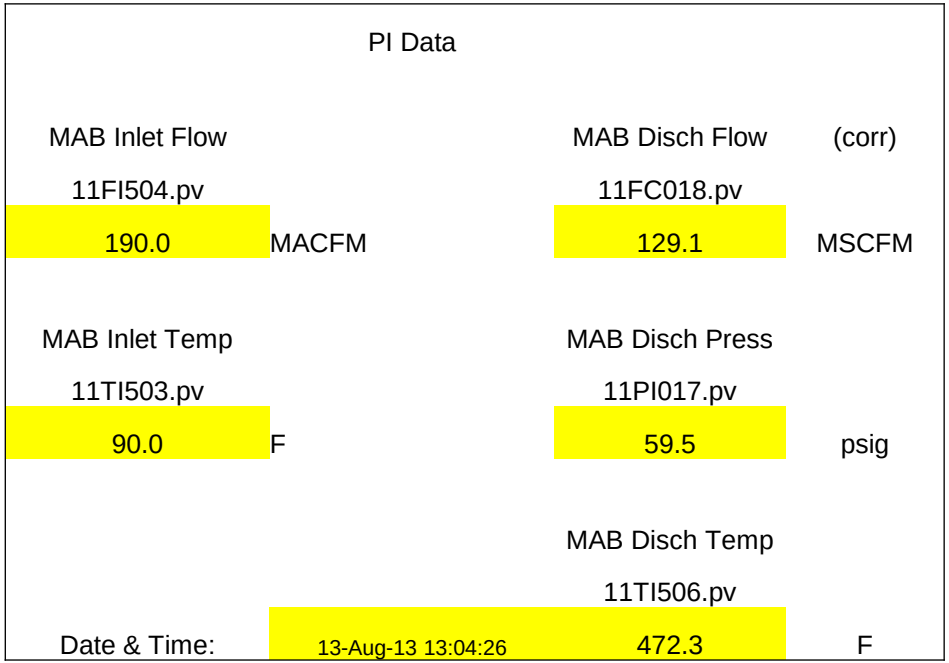
Spreadsheet Detail

Highlighted boxes are data extracted from the PI Server using Current Value functions.

PI System tag descriptor is placed above the data cell.

One value is extracted with a timestamp so printed copies will retain that information.



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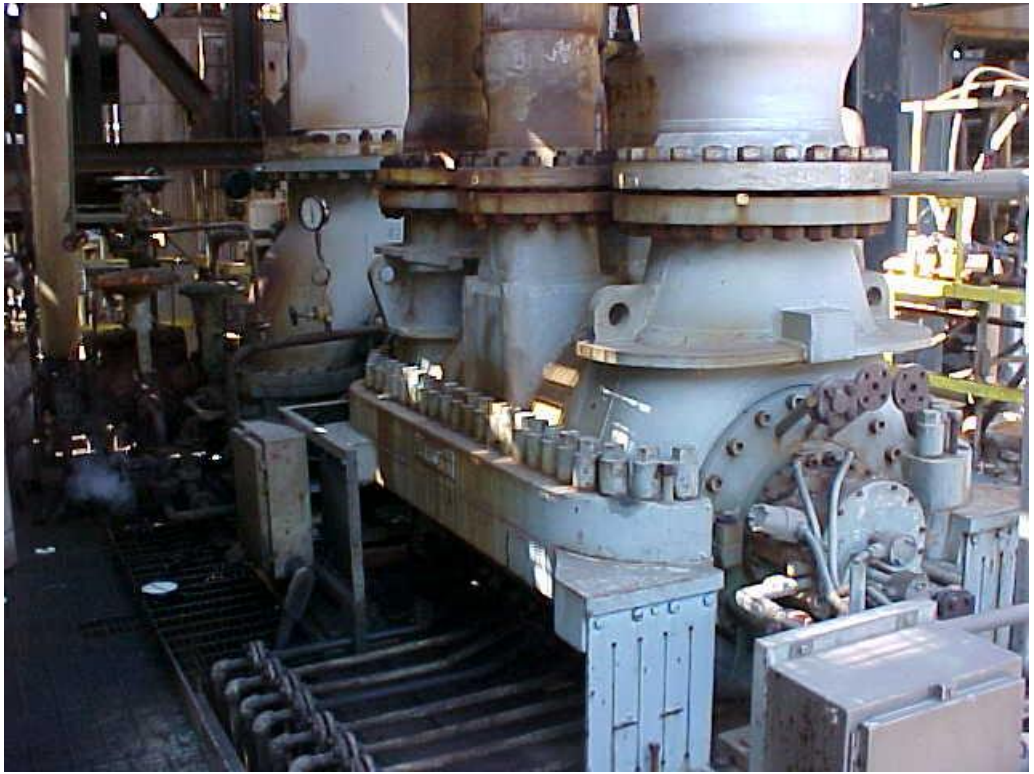
Wet Gas Compressor 6000 hp Turbine

Two Section Compressor

Variable Speed Drive via Steam Turbine

Suction Pressure and Temperature Vary due to Use of Air Coolers



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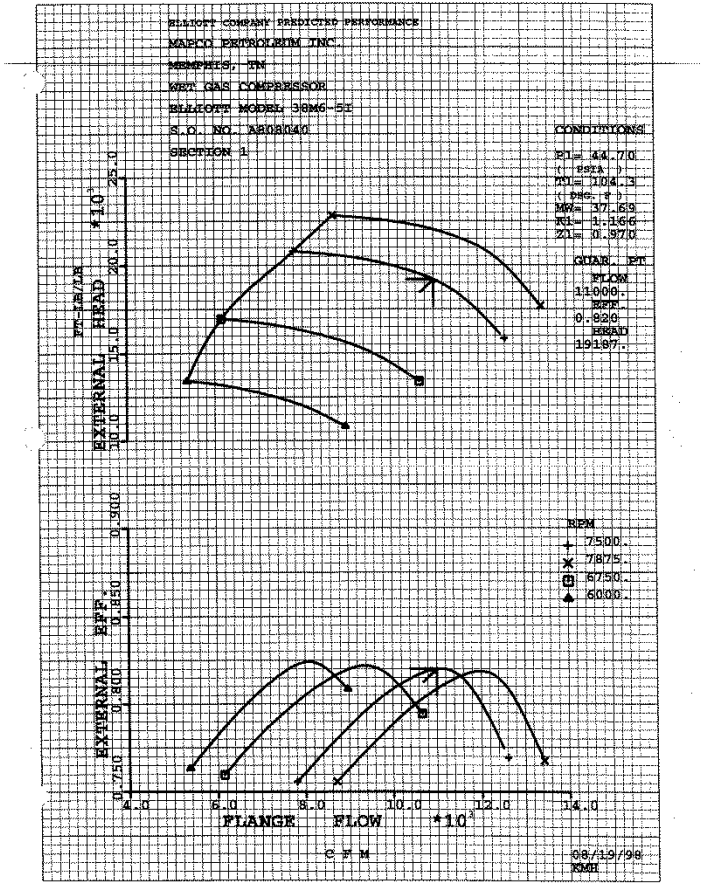
Wet Gas Compressor – Variable Speed

Vendor-supplied performance curve for first section.



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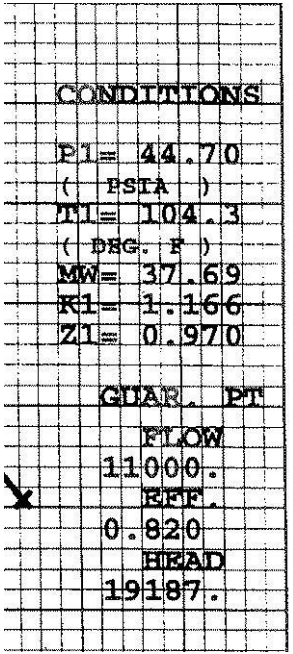
Wet Gas Compressor – Variable Speed

Curves are plotted for a given set of inlet conditions:

- MW
- Suction Pressure, P1
- Suction Temperature, T1
- Compressibility, Z1
- Polytropic Exponent, n

Guarantee is for One Point

But…..



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What if Inlet Conditions Change?

Recalculate Curves

- Polytropic Head

$$H_p = \frac{1544}{MW} T_1 \frac{n}{n-1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] Z$$

- Inlet Flow

$$V_i = V_s \frac{P_s}{P_i} \frac{T_i}{T_s}$$

Set up Excel spreadsheet

Import Pressures and Temperatures

Assume MW and other variables are constant

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Wet Gas Compressor 12-06-001

Operating Points Speed 12SI009.pv

S1 OP		7000 rpm				**Side Streams**			
						MCOH			
Inlet Flow	Suct Press	Suct Temp	Disch Press	Disch Temp		SHU Stab o/g	SHU Splitter o/g	Cryo I/G Scrubber	Total Side Stream Gas Flow-MCOH
12FI001.pv	12PI768.pv	12TI748.pv	12PI769.pv	12TI749.pv		15FI1257.pv	15FI281.pv	Drain (NorClsd)	
25.95	32.5	120.0	88.6	191.3	Section 1 calc	3.5	0.0	0	3.5
MMSCFD	psig	F	psig	F	Disch Flow	MMSCFD	MMSCFD	MMSCFD	MMSCFD
6260	Hext =19097		103.3		3212				**Corr S2 OP**
ACFM			psia		ACFM			Sec 2 suct + sidestreams =	3502 ACFM
				Sect 2 suct flow calc'd from Sect 1 disch flow =	3281				
S2 OP						**Interstage**		Sec 2 disch =	28.9 MMSCFD
					Section 2		Cryo DeC2 Bttms		Total Side Stream Gas Flow-Interstage
Disch Flow	Suct Press	Suct Temp	Disch Press	Disch Temp	calc	Sour Water			
12FI016.pv	12PI772.pv	12TI750.pv	12PI774.pv	12TI751.pv	Suct Flow	12FC022.pv	03FI137.pv		
43.11	79.0	118.3	222.2	212.8	5223	14.7	39.2		2.3
MMSCFD	psig	F	psig	F	ACFM	gpm	gpm		MMSCFD
2404	Hext =22899		236.9			0	2.3		221
ACFM			psia			MMSCFD	MMSCFD		ACFM

Plot dummies for speed

14000
6000

Compressor Curve - Design - Section 1

MW	37.69	Constant =	157504.7
k	1.166	k-1/k =	0.142
Z	0.97	k/k-1 =	7.024
		psig	
P1	30	psia=	44.7
T1	104.3	F	

Section 1 7875 rpm

Flow-ACFM	P1 79 design	H75 design	Delta P calc
8700	115	22800	70.3
10000	114	22500	69.3
11000	112	22000	67.3
12000	108	21000	63.3
13000	99	18800	54.3
13400	94	17500	49.3

Section 1 6000 rpm

Flow-ACFM	P1 60 design	H60 design	Delta P calc
5300	79	13400	34.3
6000	78.5	13200	33.8
7000	77	12700	32.3
8000	75	11900	30.3
9000	71	10700	26.3

Compressor Curve - Design - Section 2

MW	35.12	Constant =	139740.8
k	1.2	k-1/k =	0.167
Z	0.946	k/k-1 =	6.000
P1	79.9	psig psia=	94.6
T1	100	F	

Section 2 7875 rpm

Flow-ACFM	P2 79 design	H75 design	Delta P calc
3550	309	30500	214.4
4000	307	30000	212.4
4500	295	29000	200.4
5000	265	26000	170.4
5340	228	21700	133.4

Section 2 6000 rpm

Flow-ACFM	P2 60 design	H60 design	Delta P calc
2200	196	17700	101.4
2500	190	17200	95.4
3000	180	15900	85.4
3400	167	14000	72.4

Compressor Curve - Actual - Section 1

MW	37.69	Constant =	161886.8
k	1.166	k-1/k =	0.142
Z	0.97	k/k-1 =	7.024
		psig	
P1	32.5	psia=	47.2
T1	120.0	F	

Section 1 7875 rpm

Flow-ACFM	Delta P calc	P1 79 actual
8700	71.9	119
10000	70.5	118
11000	68.3	116
12000	64.0	111
13000	54.9	102
13400	49.9	97

Section 1 6000 rpm P1 60 actual

5300	35.3
6000	34.7
7000	33.0
8000	30.5
9000	26.8

Compressor Curve - Actual - Section 2

MW	37	Constant =	136975.0
k	1.2	k-1/k =	0.167
Z	0.946	k/k-1 =	6.000
P1	79.0	psig psia=	93.7
T1	118.3	F	

Section 2 7875 rpm

Flow-ACFM	Delta P calc	P2 79 actual
3550	219.3	313
4000	213.8	307
4500	202.9	297
5000	172.1	266
5340	132.7	226

Section 2 6000 rpm P2 60 actual

2200	100.6
2500	96.8
3000	87.4
3400	74.3

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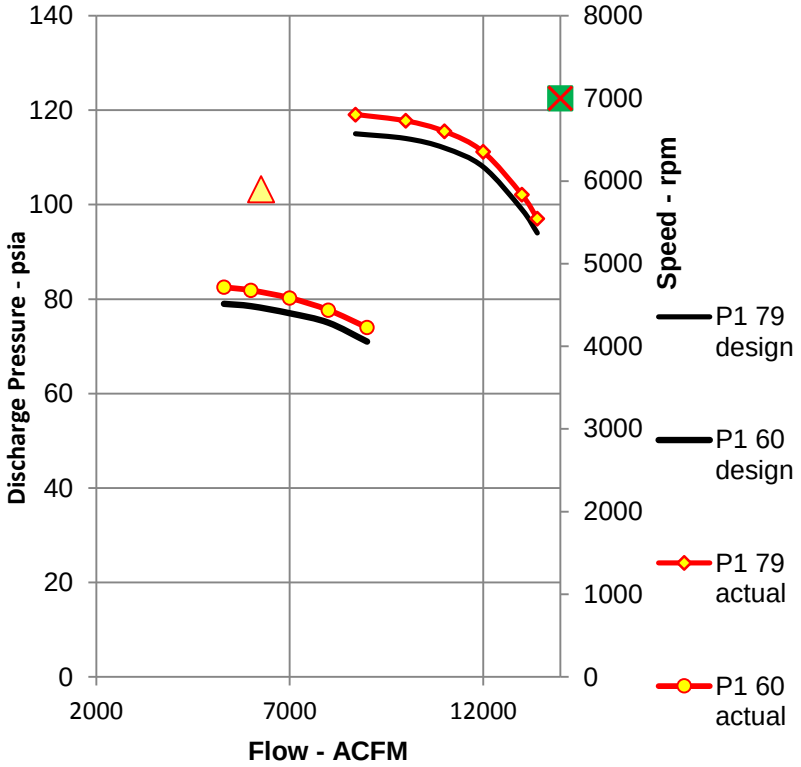
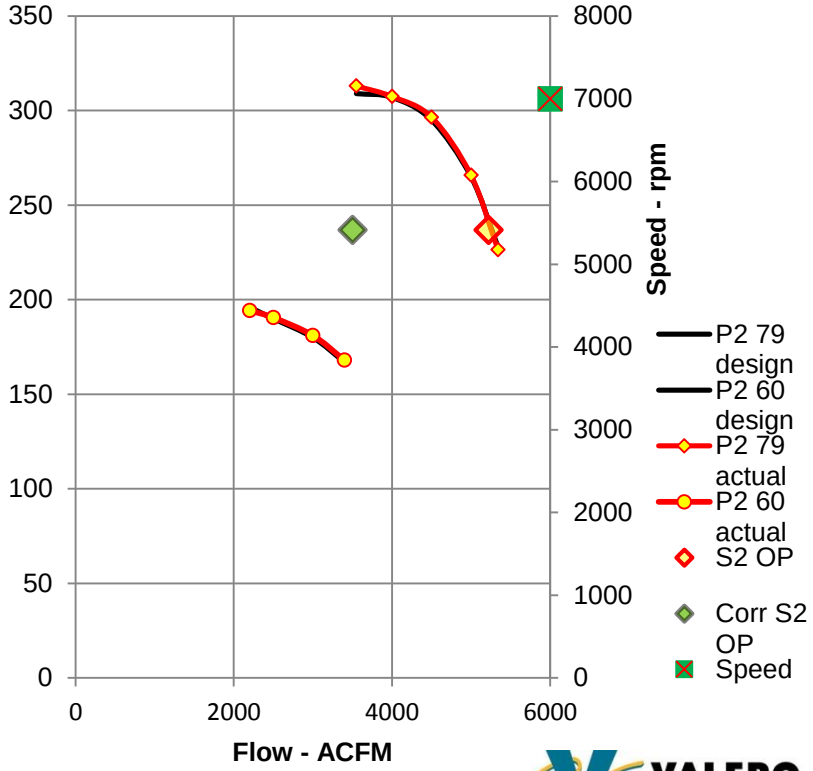
Section 1



Section 2



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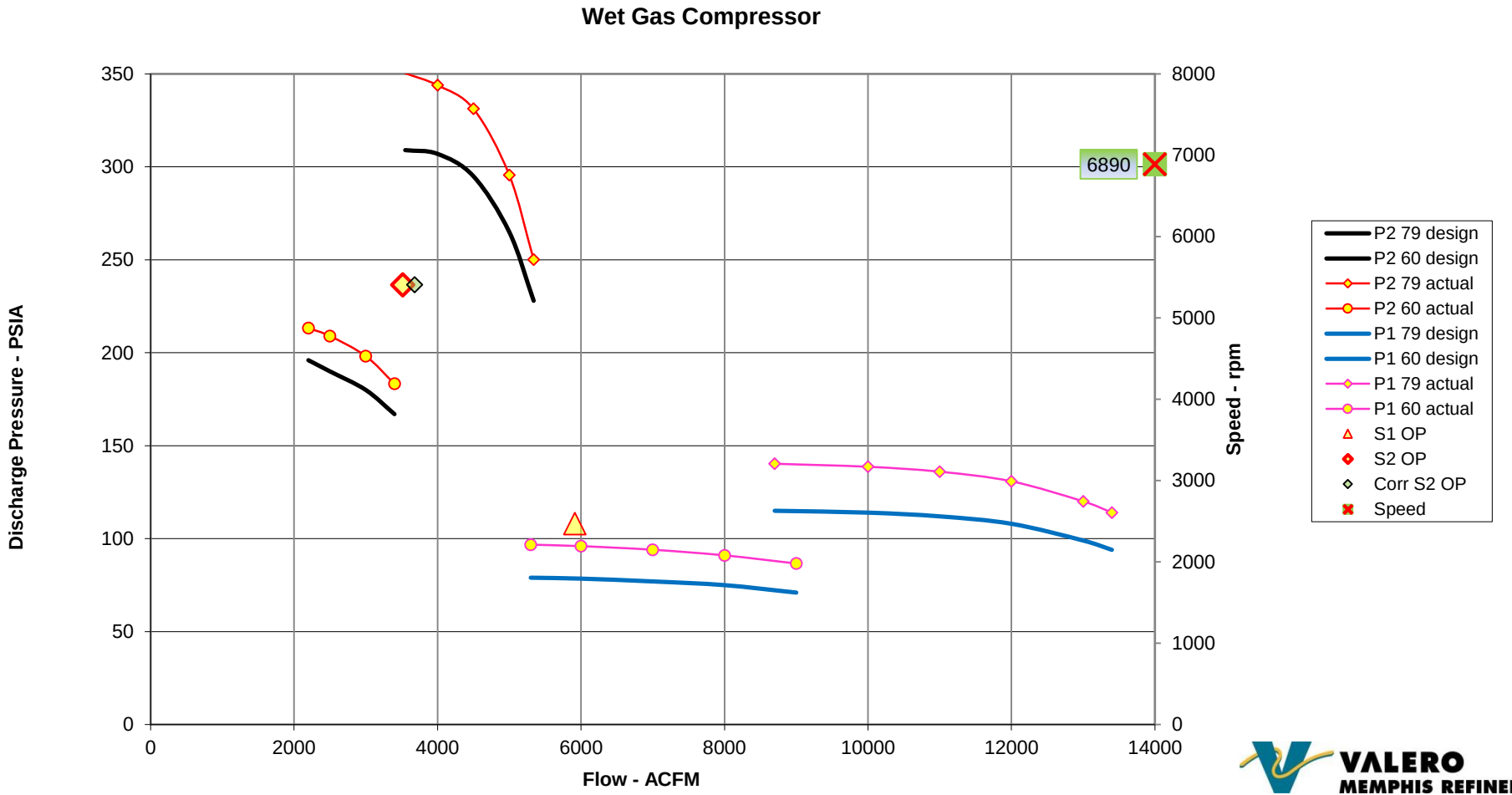

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Trending Capability

- PI ProcessBook allows trending of time-based data with simple points and clicks.
- PI ProcessBook screens can be configured to plot sets of data for evaluation.
- Alternative is to develop Excel spreadsheet using PI Sampled Data function to define start and end times.
- Typical plot would start at current time and sample backwards at set intervals to a defined point in the past.
- For repeated trending, set up data in a spreadsheet tab.
- Use Excel's Move or Copy command to copy the tab to the end of the workbook.
- The new tab will contain data starting from the current date and time.
- Convenient for collecting a set of trends on a daily, weekly or other basis.

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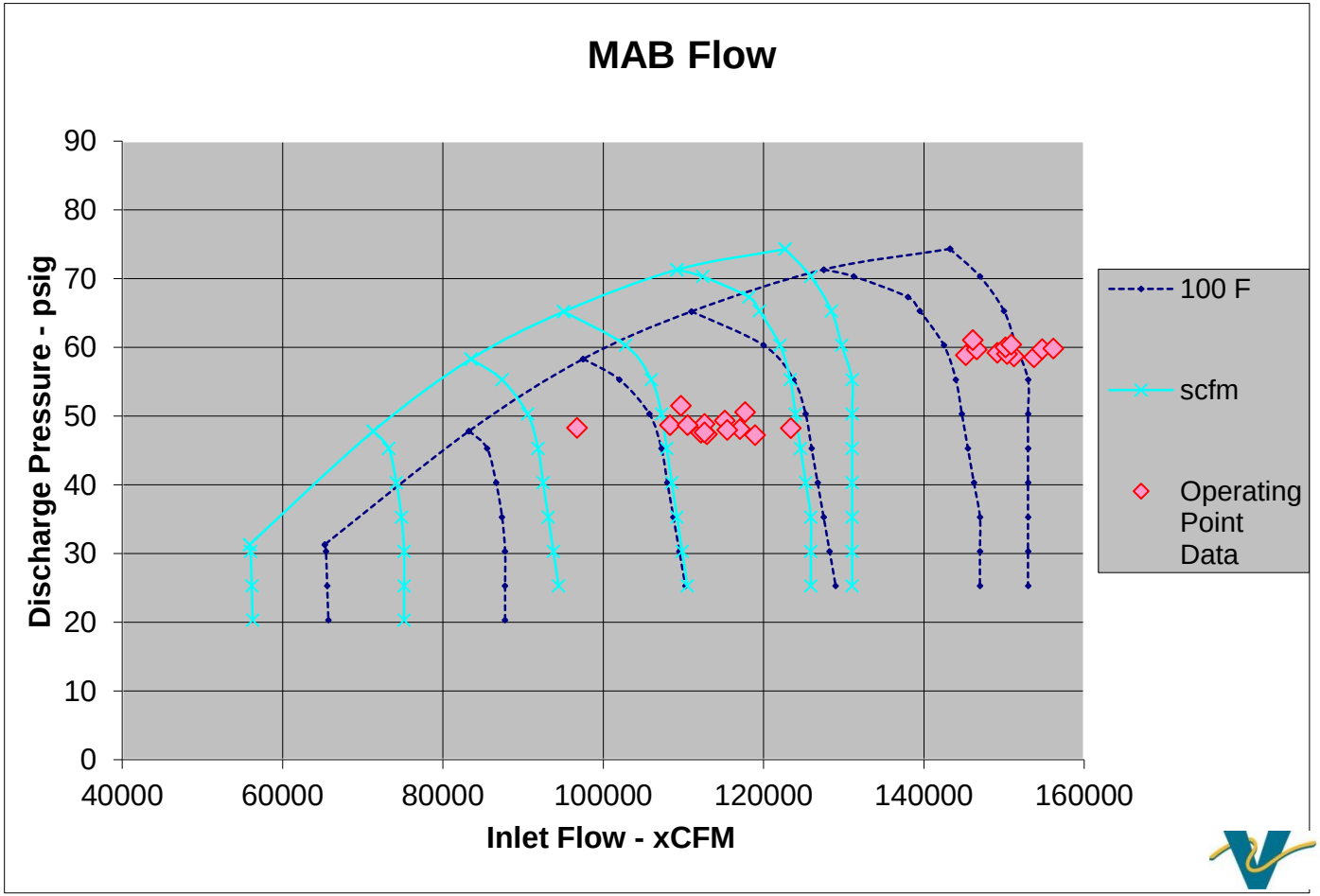
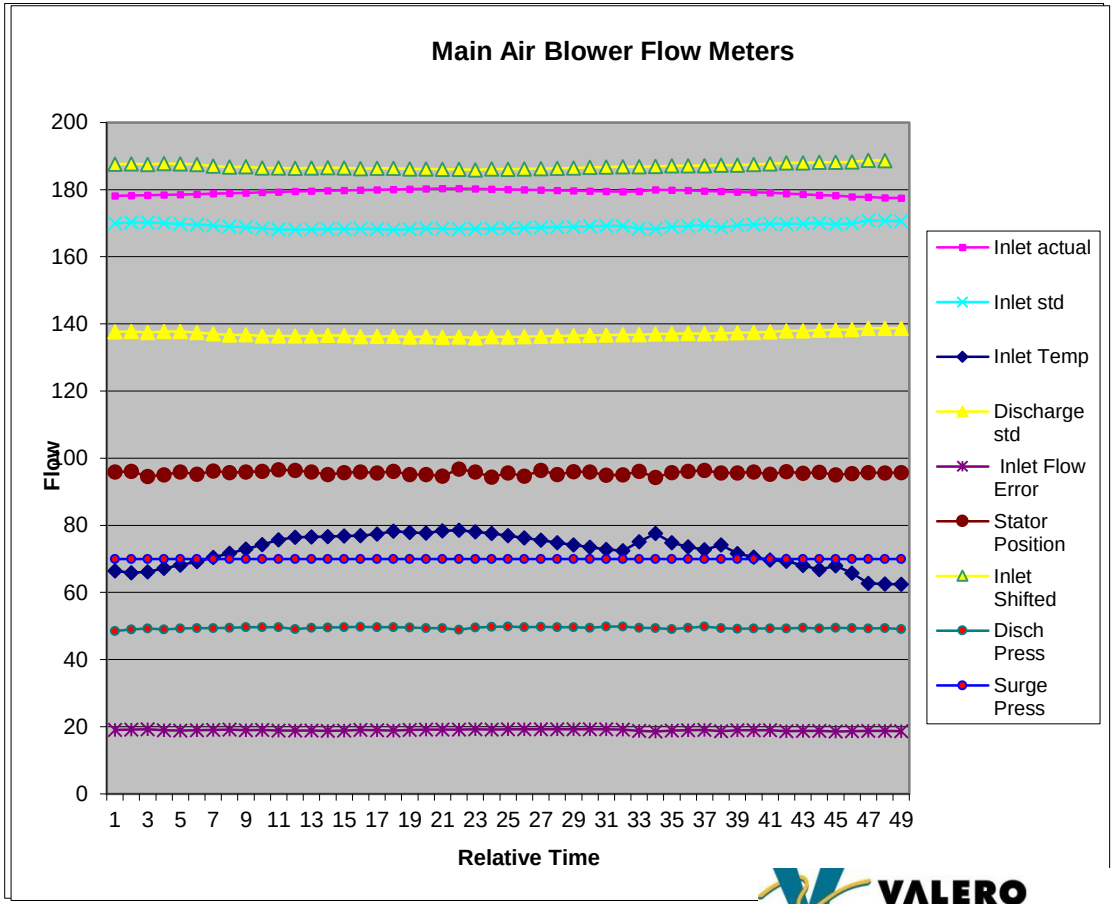


VALERO MEMPHIS REFINERY

Time	Inlet MACFM	Disch MSCFM	Inlet Temp F	Inlet MSCFM	Flow Error	Stator Position	Inlet Shifted	Disch Press	Surge Press
17-May-10 07:44:54	178.147	137.6254	66.46641	169.97	19.03	95.90166	50	48.49762	70
17-May-10 08:14:54	178.2407	137.7173	65.86054	170.26	19.11	96.0581	187.6	48.99006	70
17-May-10 08:44:54	178.3344	137.4481	66.18242	170.24	19.26	94.5672	187.7	49.27066	70
17-May-10 09:14:54	178.4281	137.7405	67.16165	170.02	18.98	95.02933	187.4	49.01955	70
17-May-10 09:44:54	178.5219	137.6898	68.14088	169.79	18.91	95.85323	187.7	49.238	70
17-May-10 10:14:54	178.6271	137.4704	69.18797	169.56	18.92	95.25277	187.7	49.33664	70
17-May-10 10:44:54	178.7673	137.0209	70.44014	169.29	19.06	96.15325	187.5	49.35038	70
17-May-10 11:14:54	178.9076	136.7257	71.69231	169.02	19.11	95.65051	187.0	49.42196	70
17-May-10 11:44:54	179.0478	136.7924	72.94448	168.76	18.94	95.8709	186.7	49.70242	70
17-May-10 12:14:54	179.188	136.43	74.28086	168.47	19.02	96.09872	186.8	49.6643	70
17-May-10 12:44:54	179.3283	136.4283	75.7205	168.15	18.86	96.53571	186.4	49.63969	70
17-May-10 13:14:54	179.4685	136.388	76.45275	168.05	18.84	96.3497	186.4	49.07106	70
17-May-10 13:44:54	179.6087	136.4347	76.56261	168.14	18.86	95.83942	186.4	49.42704	70
17-May-10 14:14:54	179.7068	136.5522	76.67246	168.20	18.82	95.16656	186.4	49.55991	70
17-May-10 14:44:54	179.801	136.4671	76.78232	168.26	18.89	95.73965	186.6	49.67197	70
17-May-10 15:14:54	179.8952	136.2131	76.89218	168.31	19.07	95.87311	186.5	49.78827	70
17-May-10 15:44:54	179.9894	136.3115	77.36768	168.25	18.98	95.63574	186.2	49.69151	70
17-May-10 16:14:54	180.0836	136.331	78.22108	168.07	18.88	96.04129	186.3	49.63786	70
17-May-10 16:44:54	180.1778	136.1408	77.89733	168.26	19.09	95.14907	186.3	49.52483	70
17-May-10 17:14:54	180.272	136.1958	77.64224	168.43	19.14	95.15813	186.1	49.3568	70
17-May-10 17:44:54	180.3662	136.0306	78.31902	168.30	19.17	94.65702	186.2	49.32857	70
17-May-10 18:14:54	180.3844	136.0629	78.50831	168.26	19.14	96.75541	186.0	48.91939	70
17-May-10 18:44:54	180.2806	135.8192	78.08483	168.30	19.30	95.89914	186.1	49.56104	70
17-May-10 19:14:54	180.1767	136.1791	77.61601	168.35	19.11	94.387	185.8	49.74761	70
17-May-10 19:44:54	180.0729	136.0864	76.92706	168.46	19.22	95.59064	186.2	49.80711	70
17-May-10 20:14:54	179.969	136.1861	76.23812	168.58	19.22	94.65692	186.1	49.69645	70
17-May-10 20:44:54	179.8651	136.2858	75.54918	168.70	19.22	96.37213	186.2	49.71483	70
17-May-10 21:14:54	179.7613	136.3855	74.86024	168.82	19.21	95.08189	186.3	49.69987	70
17-May-10 21:44:54	179.6574	136.4852	74.1713	168.94	19.21	95.9594	186.4	49.69025	70
17-May-10 22:14:54	179.5535	136.5849	73.48235	169.06	19.21	95.88428	186.5	49.45272	70
17-May-10 22:44:54	179.4497	136.6846	72.79341	169.18	19.21	94.92174	186.6	49.84166	70
17-May-10 23:14:54	179.3458	136.7843	72.46478	169.19	19.15	95.07503	186.7	49.84293	70
17-May-10 23:44:54	179.4577	136.8026	75.13619	168.45	18.79	96.04785	186.8	49.5059	70
18-May-10 00:14:54	180.0014	136.9589	77.55718	168.20	18.57	94.31216	186.8	49.33767	70
18-May-10 00:44:54	179.869	137.1061	74.85038	168.93	18.84	95.72852	187.0	49.0557	70
18-May-10 01:14:54	179.7366	137.1268	73.61198	169.19	18.95	96.04325	187.1	49.42021	70
18-May-10 01:44:54	179.6042	137.1104	72.758	169.34	19.03	96.34856	187.1	49.83162	70
18-May-10 02:14:54	179.446	137.2991	74.14874	168.75	18.64	95.57008	187.1	49.40594	70
18-May-10 02:44:54	179.2732	137.3076	71.57088	169.41	18.95	95.62054	187.3	49.17887	70
18-May-10 03:14:54	179.1474	137.4649	70.57511	169.60	18.95	95.86939	187.3	49.25064	70
18-May-10 03:44:54	179.0595	137.6451	69.63628	169.82	18.95	95.1937	187.5	49.28322	70
18-May-10 04:14:54	178.8391	137.9529	69.30579	169.72	18.72	96.01468	187.6	49.26587	70
18-May-10 04:44:54	178.5777	137.9426	68.00787	169.89	18.80	95.49616	188.0	49.49612	70
18-May-10 05:14:54	178.3282	138.108	66.7885	170.04	18.78	95.80374	187.9	49.27074	70
18-May-10 05:44:54	178.2811	138.1778	67.944	169.63	18.54	95.00928	188.1	49.51305	70
18-May-10 06:14:54	177.9066	138.2834	65.78399	169.96	18.64	95.41782	188.2	49.36225	70
18-May-10 06:44:54	177.7244	138.7115	62.68541	170.80	18.79	95.66736	188.3	49.29629	70
18-May-10 07:14:54	177.6108	138.6483	62.56842	170.73	18.79	95.62946	188.7	49.36093	70
18-May-10 07:44:54	177.4976	138.7201	62.4516	170.66	18.71	95.73771	188.6	49.08185	70



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Conclusions

- PI System is an excellent tool for capturing process data.
- Current Value and Timed Data functions permit versatile collection of information.
- Excel with the PI DataLink Add-In is a powerful tool for evaluating not only compressors, but any other process data.

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