PSC UPDATE

DOE-GMRC-PRCI Compression Infrastructure Project

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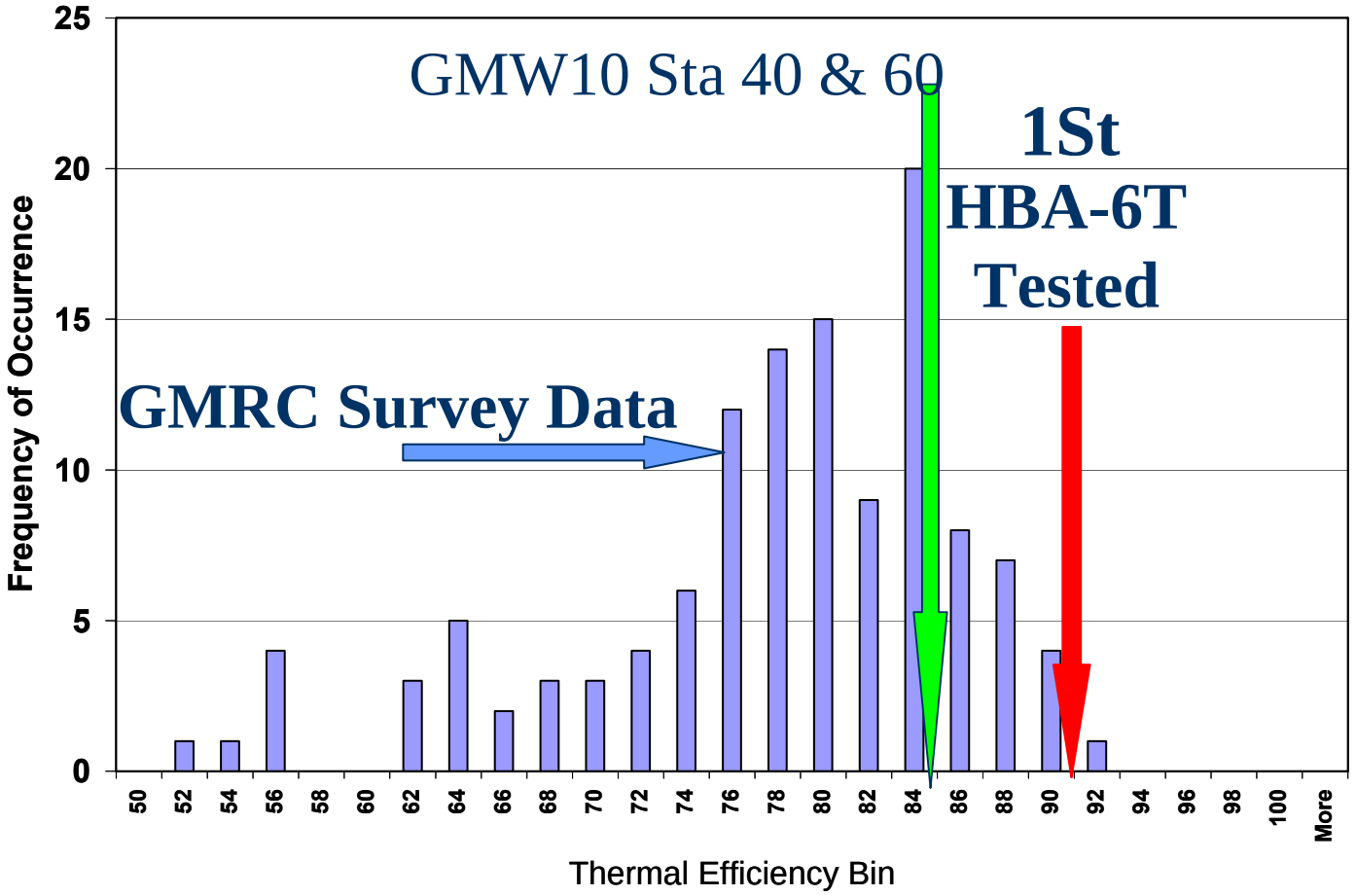
Project Objective

To develop and substantiate methods for operating integral engine/compressors in gas pipeline service which reduce *fuel consumption*, increase *capacity*, and enhance mechanical *integrity*.

Phase 3 Plans and Objectives



Goals for Phase III

- **Address Observed Range of Compressor Efficiency (52% to 92%)**
  - Raise bottom half of Distribution to equal top half, we get 10% More Industry Capacity for no Change in Driver or Permit.
- To Achieve These Goals, Industry will Require:
  - Clear understanding of factors influencing distribution of efficiency
    - Role of pulsation on performance
    - Role of manifold design on performance (installation efficiency)
    - Role of unit operation on efficiency (speed, ratio, SA, DA)
    - Potential benefit of manifold redesign
    - Bring current state-of-the-art in design to units which were either not designed with analog, or whose conditions have changed such that original design is no longer valid.
    - Expand flexibility by adding SA operation to existing units with improved manifold design

Phase III Approach

- Identify site(s) with poor compressor performance (loss of overall system efficiency).
- Complete initial screening of candidate sites identifying root cause of poor performance or limited operability (valve, orifice, pulsation, manifold pressure drop..), select test site.
- Complete detailed performance study including: comp. cylinder performance, valve losses. Include 1 or 2 compressor flow options + ΔT (allowing installation losses to be identified). Include engine fuel flow & RLM. (Eliminate power cylinder pressure, manifold pressures, crank strain.
- Redesign manifold to improve compressor performance with HP, capacity, operational window (SA perhaps).

Phase III Approach (cont.)

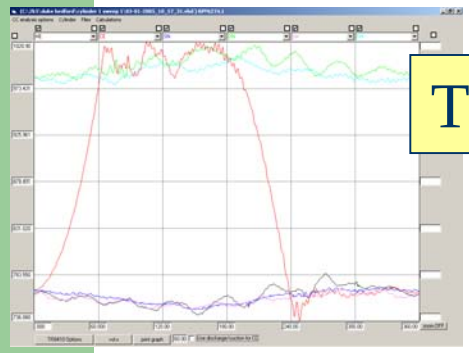
- Invite Host to Install Changes (have new bottle built and installed)
- Return for "After" Test
- Document Benefits with Prototyped Future "Horsepower Recovery" Service
  - Reduced Fuel for Given Useful Compression Work
  - Increased Capacity
  - Suggested Follow-On Project to Repeat GMRC Survey to Quantify Potential Industry-Wide Benefits

Preliminary Site Evaluations (Duke Energy Station)

- Multiple Clark HBA6 units
- Station modified with pair of electric drive centrifugal compressors
- Station ratio increased
- HBA's refitted with end deactivators to limit torque at higher ratios
- Since these changes, vibration and performance issues have occurred.

Unit 4: Clark HBA6

Cylinder 1 data (SA operation)



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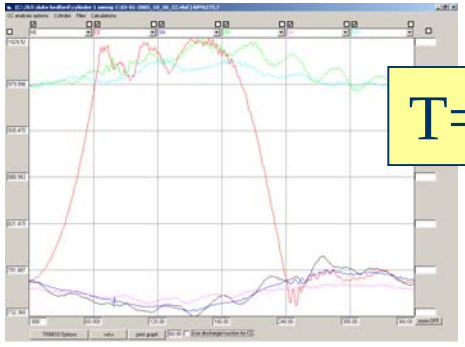

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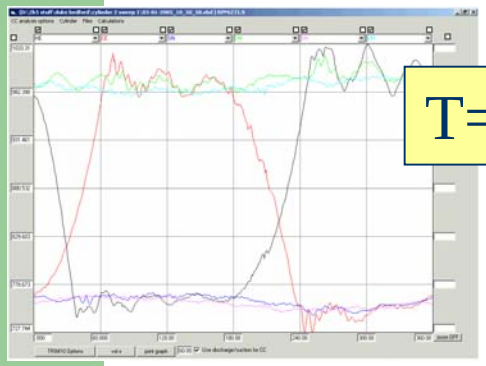
32 sample average

Cylinder 2 data (SA operation)



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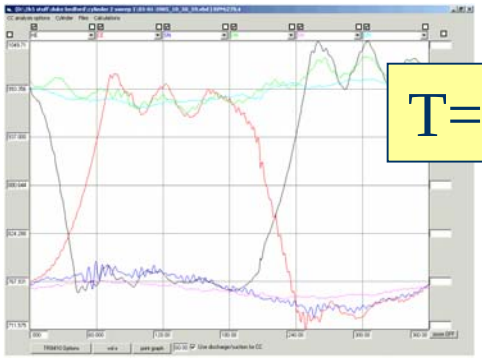

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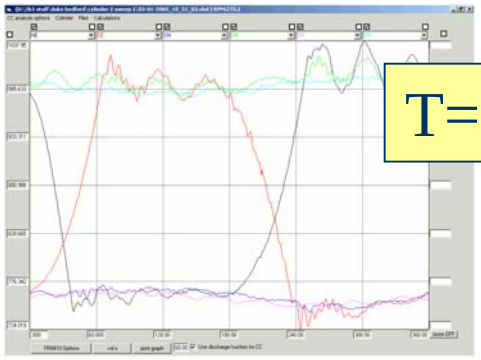

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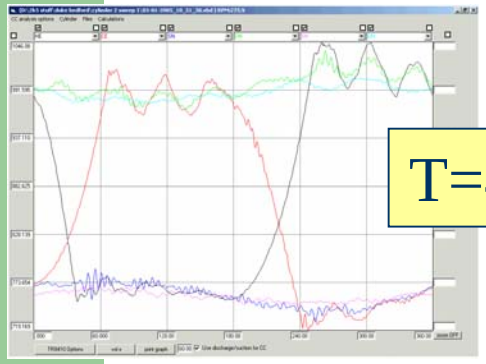

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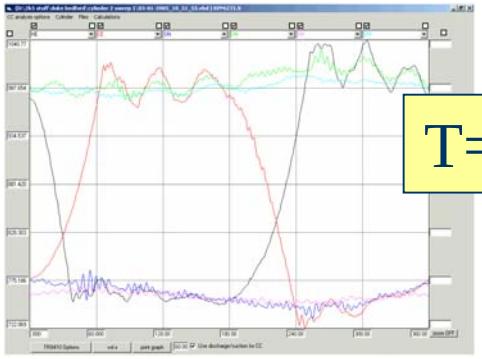

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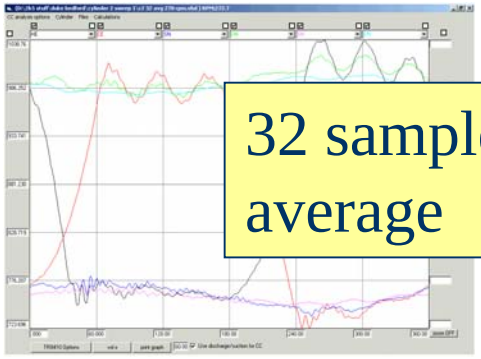


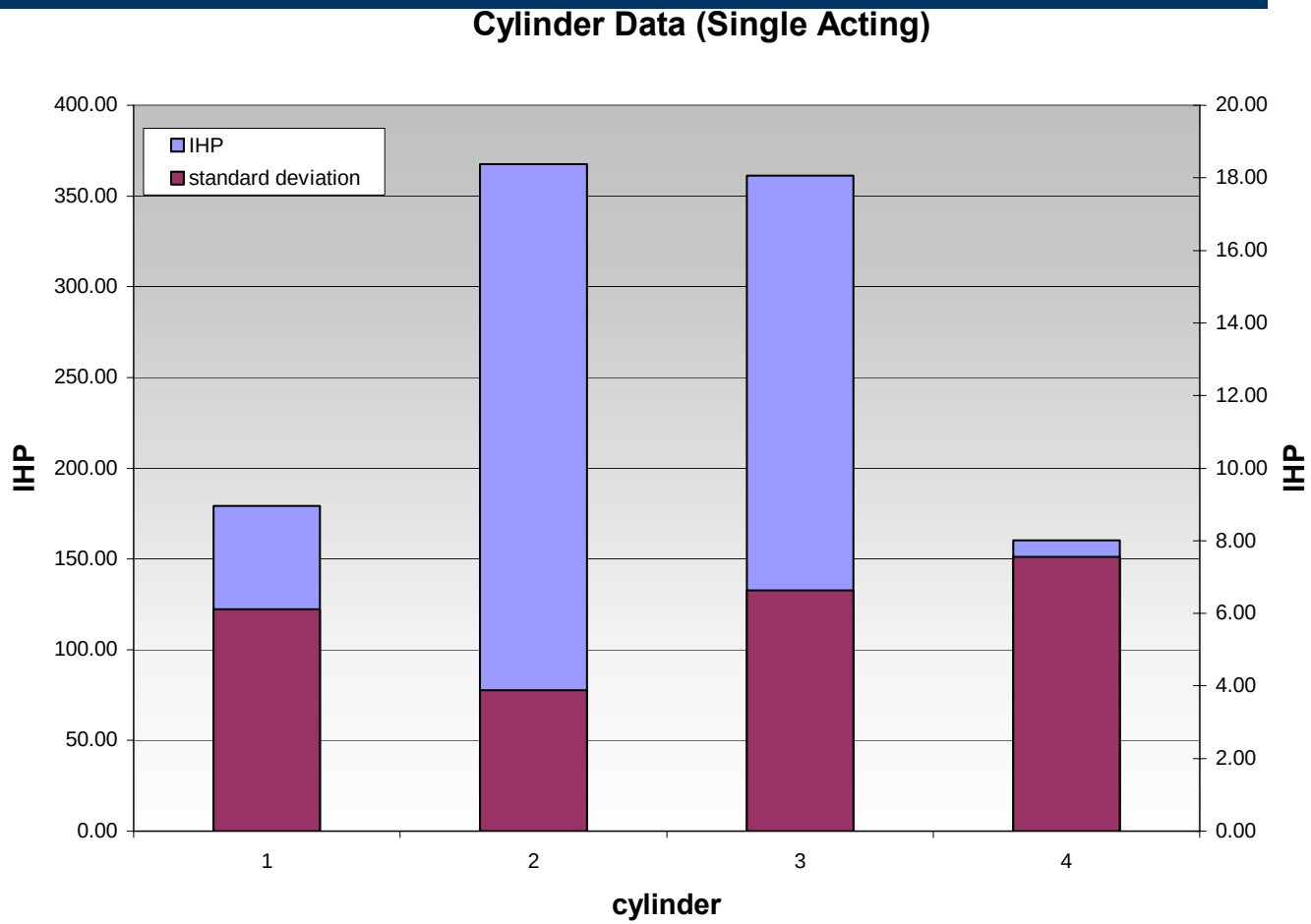
32 sample average

Cylinder 1 summary (SA testing)

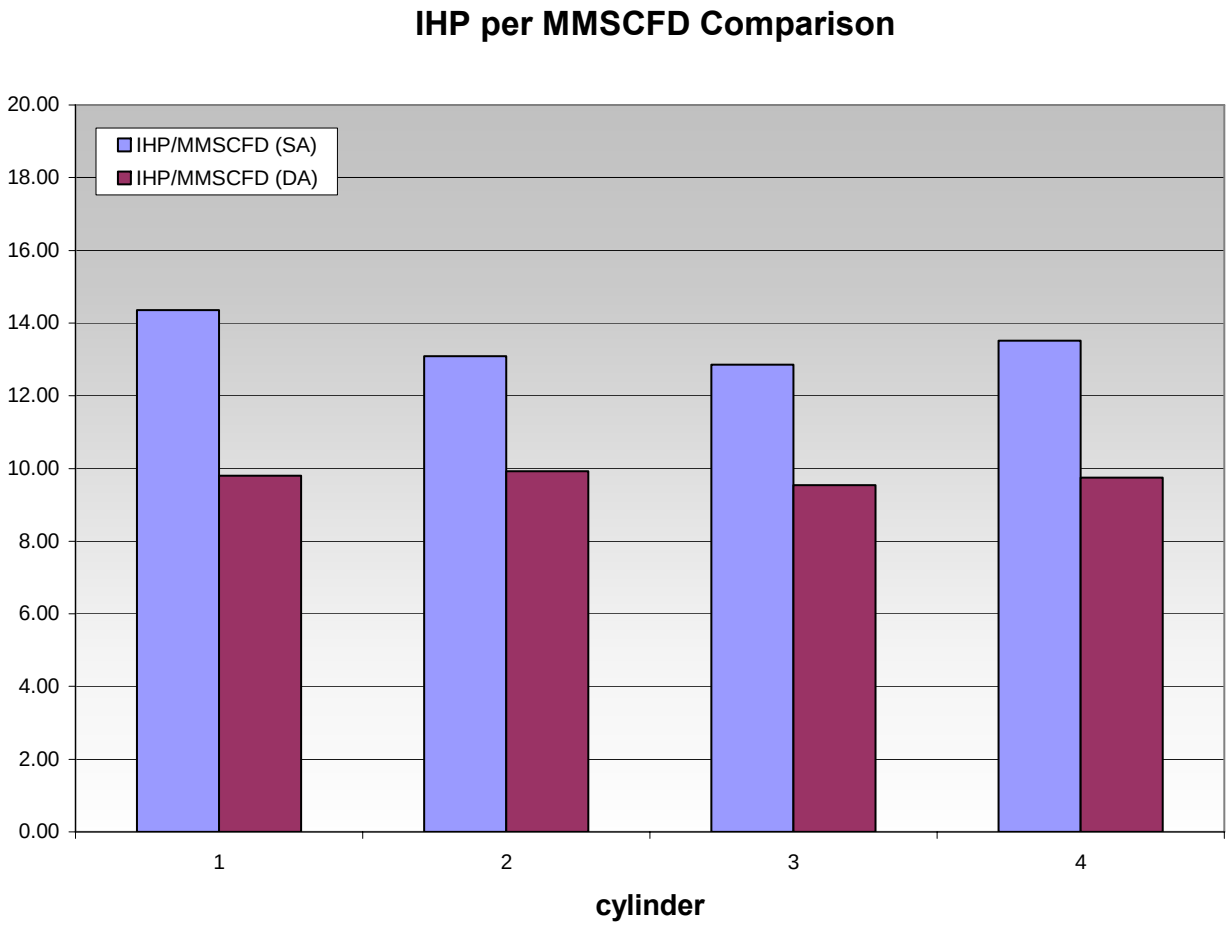
Cylinder 1 Data (Single Acting Operation (SA))

file	RPM	IHP	valve DIP%	sn pk-pk %	dn pk-pk %	sh P	dh P	sh pk-pk %	dh pk-pk %	ihp/mmscfd
03-01-2005_10_57_31.vbd	274.08	174.99	4.12	3.38	3.83	758.55	989.44	3.10	3.02	13.83
03-01-2005_10_57_33.vbd	274.00	185.06	3.27	6.06	5.41	757.84	989.54	3.19	3.12	14.81
03-01-2005_10_57_35.vbd	274.74	176.64	1.77	4.21	3.97	758.49	989.42	2.60	2.21	14.14
03-01-2005_10_57_36.vbd	275.69	170.62	1.89	4.90	5.28	757.89	989.26	2.93	2.79	14.03
03-01-2005_10_57_38.vbd	271.34	182.69	3.37	5.39	4.76	757.92	989.83	2.97	2.90	14.73
03-01-2005_10_57_40.vbd	274.91	185.94	2.00	5.43	5.55	757.88	989.51	3.28	3.29	14.86
03-01-2005_10_57_42.vbd	275.06	174.48	3.69	3.56	3.57	758.21	989.41	2.89	2.49	13.83
03-01-2005_10_57_43.vbd	279.06	177.39	6.33	5.67	5.20	757.96	989.42	3.32	3.65	13.98
03-01-2005_10_57_45.vbd	273.80	190.86	0.49	6.46	6.26	758.08	989.55	3.01	2.75	15.54
03-01-2005_10_57_47.vbd	271.44	174.42	6.44	4.61	4.65	758.18	988.98	3.27	3.89	13.85
03-01-2005_10_57_49.vbd	278.19	181.72	1.69	7.68	6.43	757.74	989.44	3.38	3.59	14.73
03-01-2005_10_57_50.vbd	272.37	173.45	1.88	2.09	3.72	758.65	989.57	3.03	1.80	13.87
03-01-2005_10_57_52.vbd	278.61	172.78	9.07	5.22	4.88	758.22	989.59	2.94	3.34	13.69
03-01-2005_10_57_54.vbd	277.33	186.25	1.91	7.35	6.43	758.03	989.57	3.33	3.32	15.06
03-01-2005_10_57_56.vbd	272.22	176.67	1.56	2.81	4.16	758.56	989.19	2.17	2.66	14.19
03-01-2005_10_57_57.vbd	277.31	175.59	8.49	4.67	4.43	758.11	989.32	3.06	3.59	13.74
03-01-2005_10_57_59.vbd	275.80	186.01	1.85	7.10	5.93	758.33	989.22	3.26	3.18	15.02
03-01-2005_10_58_01.vbd	273.08	177.91	2.07	4.16	4.72	759.09	989.45	3.17	3.07	14.22
03-01-2005_10_58_03.vbd	277.43	172.57	4.64	3.71	4.33	758.84	989.38	2.79	2.73	13.69
03-01-2005_10_58_04.vbd	275.95	178.80	2.97	5.34	5.06	758.55	989.34	2.95	2.51	14.12
03-01-2005_10_58_06.vbd	275.30	184.93	1.34	6.21	6.22	757.89	989.60	3.04	2.99	15.02
03-01-2005_10_58_08.vbd	272.27	171.43	2.47	2.01	3.73	758.43	989.30	2.67	2.09	13.86
03-01-2005_10_58_10.vbd	278.96	170.37	8.03	5.95	5.29	757.92	989.31	3.26	3.18	13.58
03-01-2005_10_58_11.vbd	275.73	191.02	1.59	7.42	6.19	757.85	989.52	3.19	3.03	15.50
03-01-2005_10_58_13.vbd	273.19	170.75	4.23	2.56	2.96	758.72	989.22	2.81	2.27	13.64
03-01-2005_10_58_15.vbd	273.92	184.77	3.20	6.69	5.38	758.18	989.64	3.23	3.05	14.82
03-01-2005_10_58_17.vbd	274.18	181.99	1.80	4.83	4.34	757.59	989.46	3.36	2.49	14.60
03-01-2005_10_58_18.vbd	276.01	179.55	2.28	4.03	4.90	757.98	989.52	2.58	2.59	14.19
03-01-2005_10_58_20.vbd	268.84	181.90	2.83	4.67	4.39	757.78	989.50	2.66	2.87	14.66
03-01-2005_10_58_22.vbd	275.75	185.41	3.85	6.31	5.68	757.90	988.92	2.98	3.11	14.73
average values	274.88	179.23	3.37	5.02	4.92	758.18	989.41	3.01	2.92	14.35
standard deviation	2.45	6.11	2.23	1.57	0.93	0.37	0.19	0.28	0.48	0.57
c1 32 avg 278 rpm.vbd	273.50	173.72	2.64	4.55	4.48	758.33	989.59	2.98	2.23	14.17

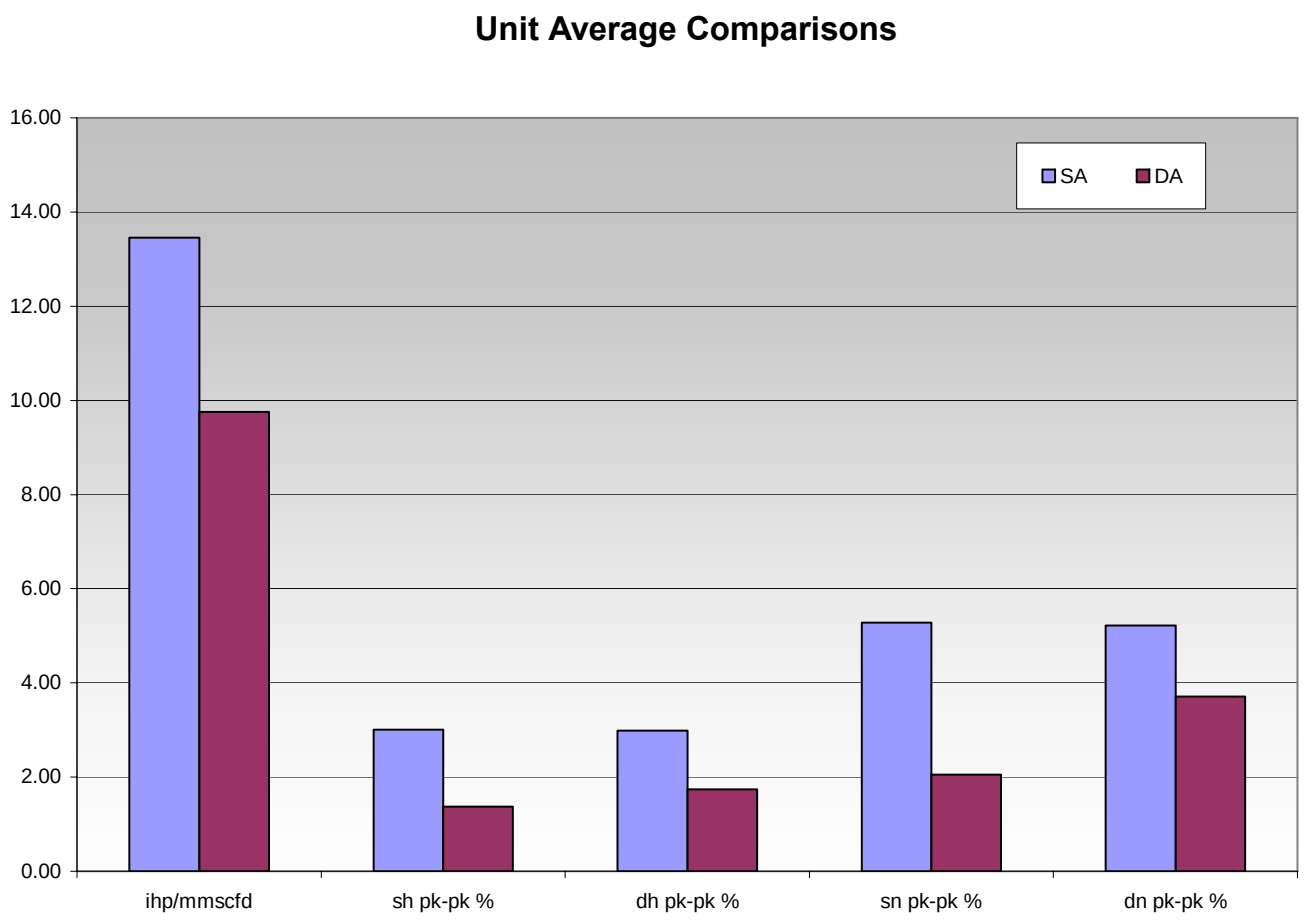
IHP (SA operation)



IHP per MMSCFD Comparison (SA and DA)



Performance Comparison



Summary Bedford Station

- Bottles not designed and able to filter 1st order pulsations when SA.
- All units run at or near same conditions which sets up strong beating in common headers.
- This beating occurs over period of several minutes.
- Pulsation levels in laterals and headers much greater than predicted for single unit operation.
- Overall thermal efficiency DA=87% (valves 6-7%, installation 5%, cylinder losses 1-2%).
- Overall thermal efficiency SA=84%.
- Ratio compensated IHP/MMSCFD drop in SA operation 7% .

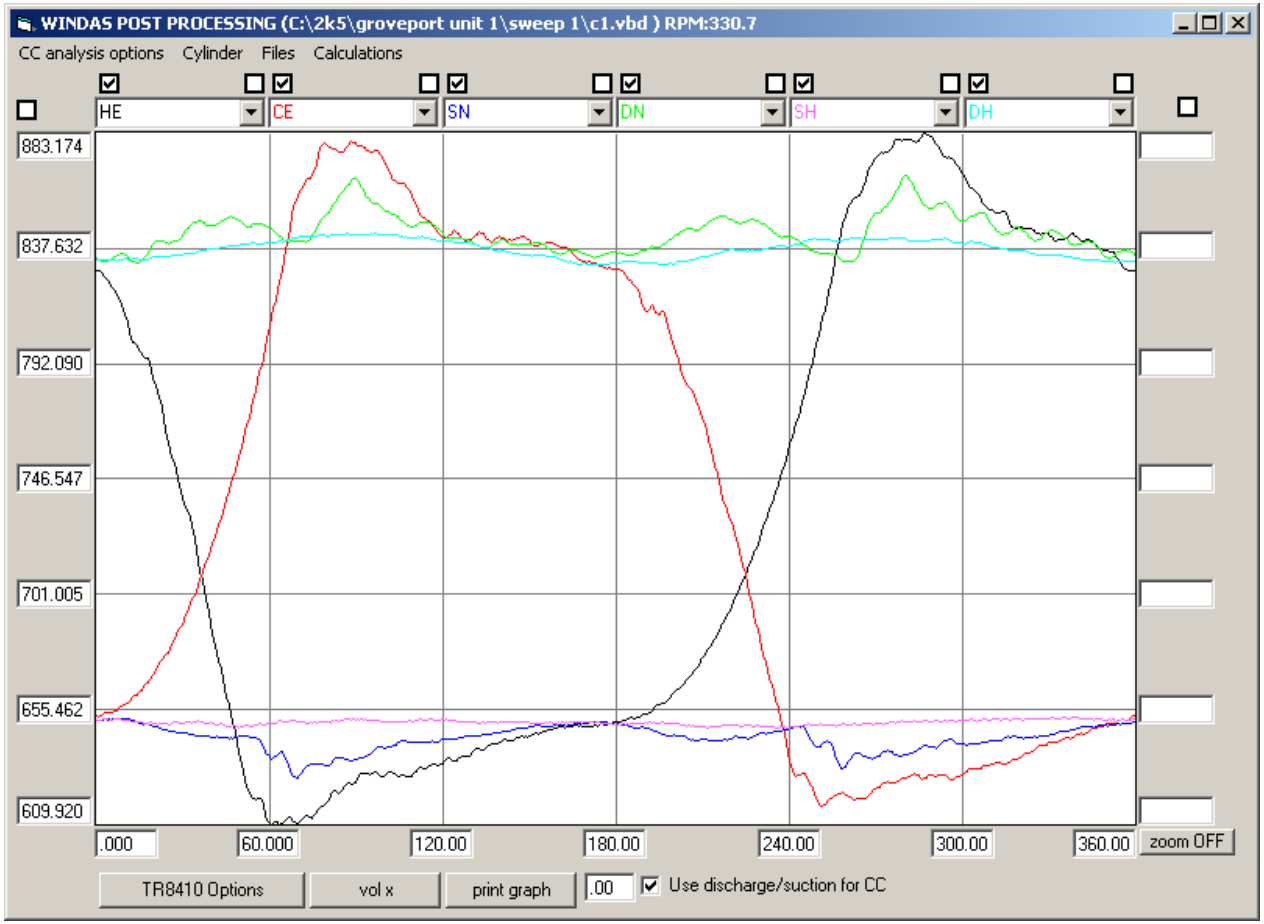
Preliminary Site Evaluations (Dominion Groveport Station)

- 3 DR TCVC 10's
- Noted poor performance and high vibration since installation Station operates in either transmission or storage, runs 24/7 (if possible)

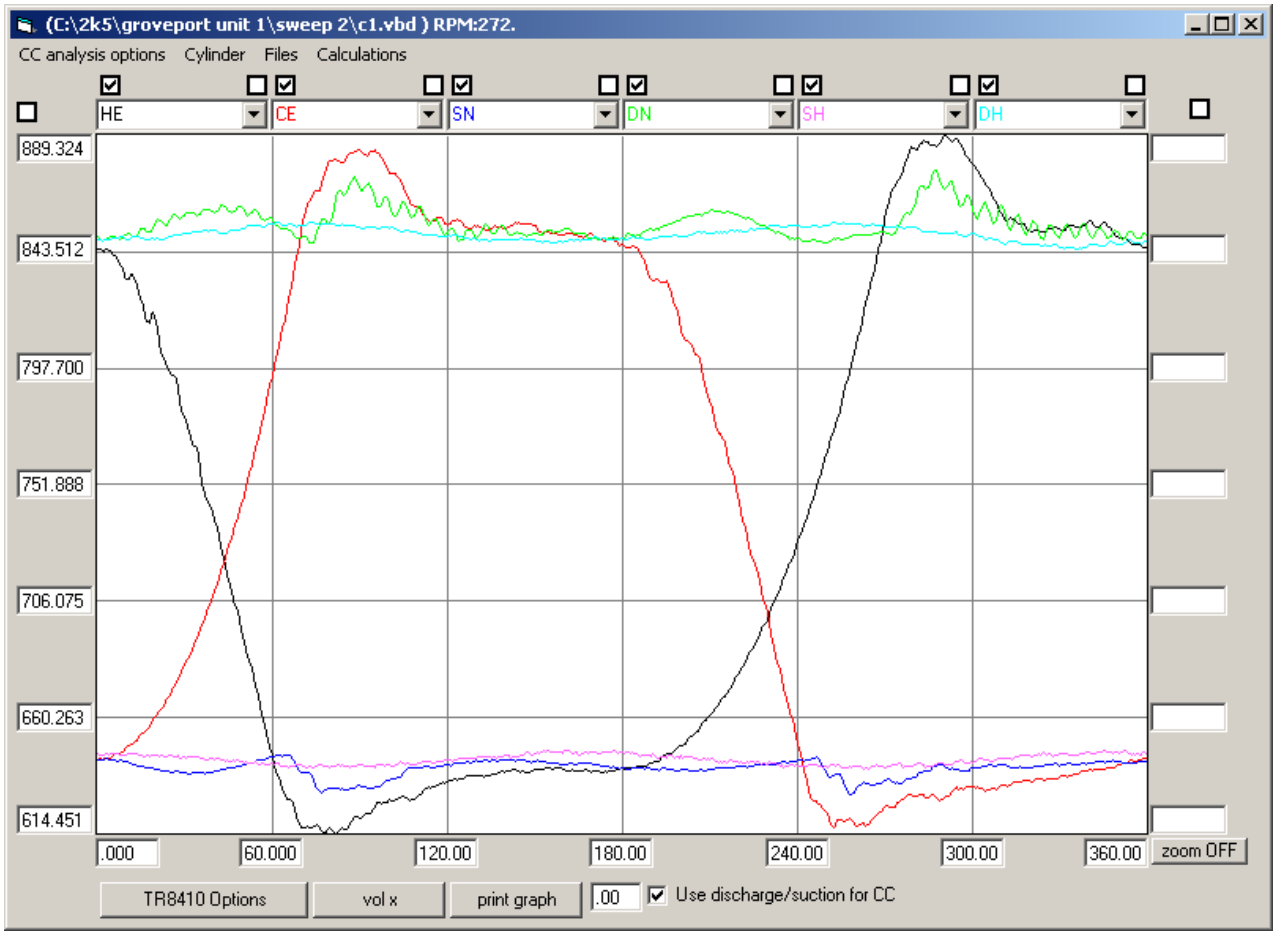
Unit 1 Groveport Station

Bracing On Lateral Lines

Cylinder 1 - 330 rpm



Cylinder 1 - 270 rpm



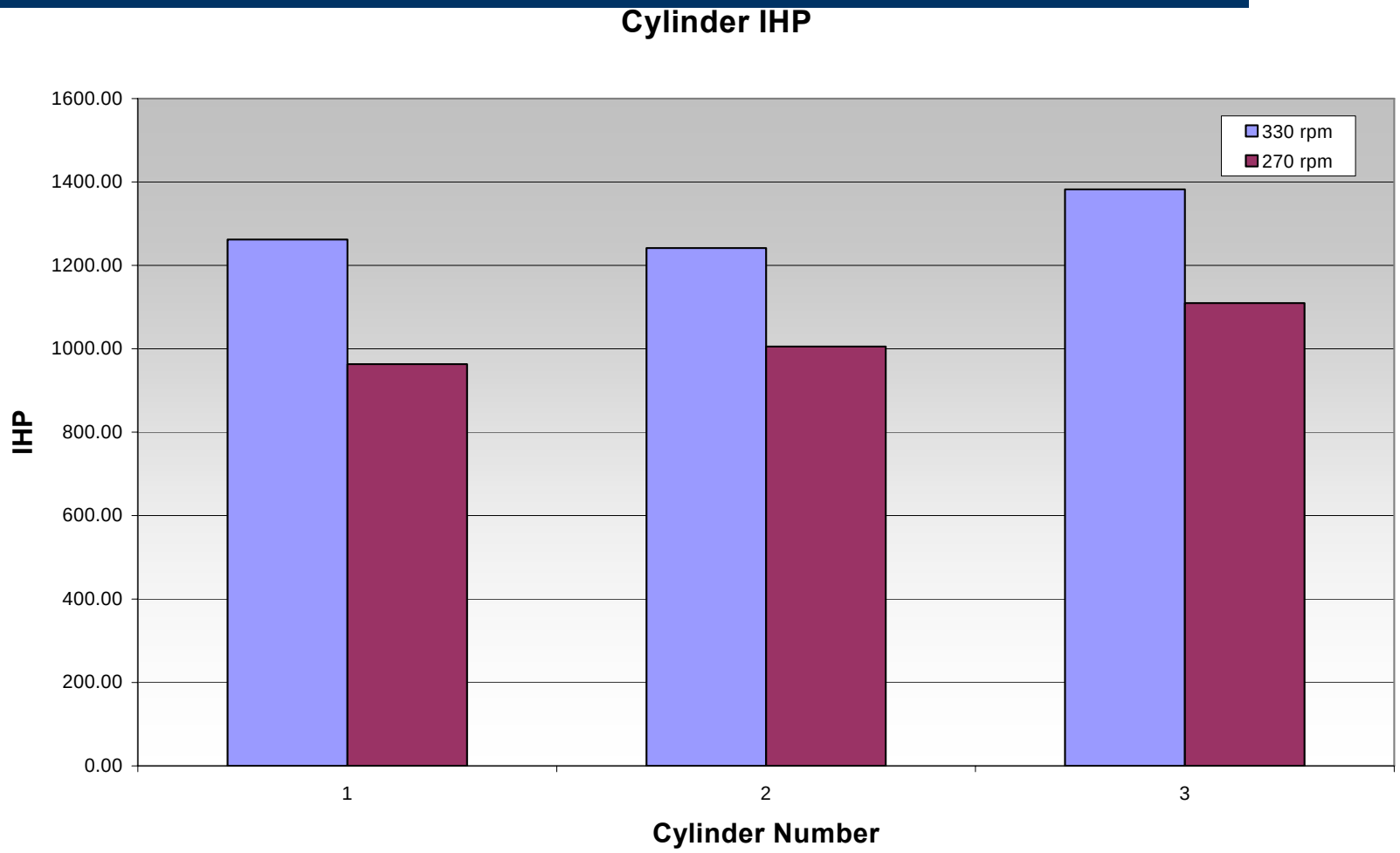
Cylinder Performance Summary

cylinder	RPM	IHP	MMSCFD	IHP/MMSCDF	total DIP%	total Valve DIP	SL Pressure	DL Pressure	sn pk-pk %	dn pk-pk %	SL pk-pk %	DL pk-pk %
1	330.68	1262.20	90.41	13.96	22.54	10.39	650.4	837.4	3.63	4.25	0.66	1.48
2	330.80	1241.51	90.91	13.66	19.64	10.93	650.2	838.5	3.23	4.58	0.64	1.50
3	331.25	1382.44	94.50	14.63	25.74	9.52	648.6	841.9	4.59	5.12	0.52	1.57
		3886.15	**275.82**		**22.64**	**10.28**			**3.82**	**4.65**	**0.61**	**1.52**

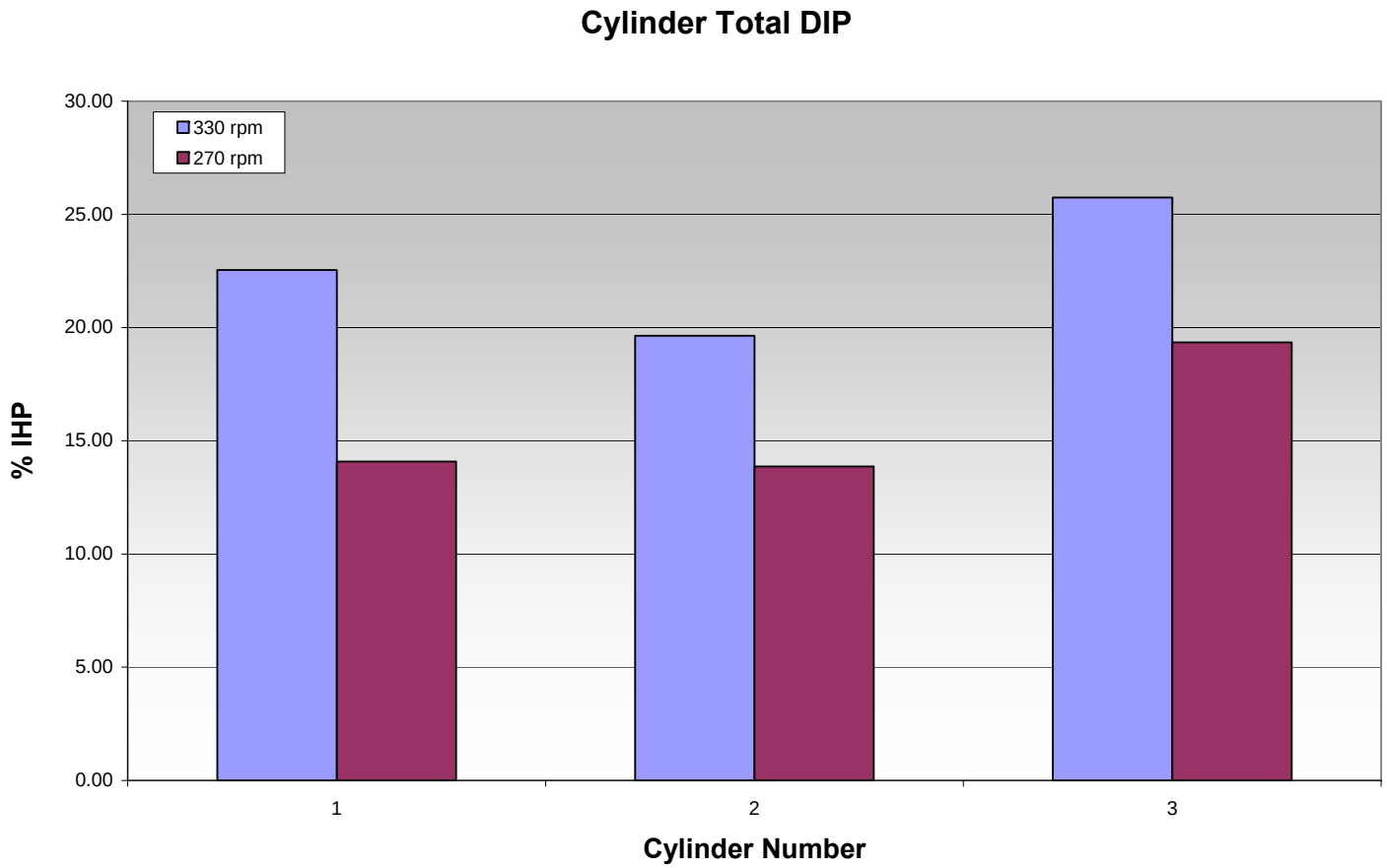
cylinder	RPM	IHP	MMSCFD	IHP/MMSCDF	total DIP%	total Valve DIP	SL Pressure	DL Pressure	sn pk-pk %	dn pk-pk %	SL pk-pk %	DL pk-pk %
1	271.95	963.30	67.83	14.20	14.09	8.05	643.7	850.5	2.55	3.67	1.38	1.28
2	271.18	1005.34	71.68	14.02	13.87	8.43	643.6	850.2	2.45	4.18	1.10	1.26
3	271.31	1109.44	75.36	14.72	19.34	7.24	642.9	850.4	3.44	4.47	1.12	1.22
		3078.09	**214.88**		**15.77**	**7.91**			**2.81**	**4.11**	**1.20**	**1.25**

ratio of flow	**1.2836038**
ratio of valve DIP	**1.3001786**
ratio of total DIP	**1.4360034**
Ratio of (total-valve)DIP	**1.5725987**

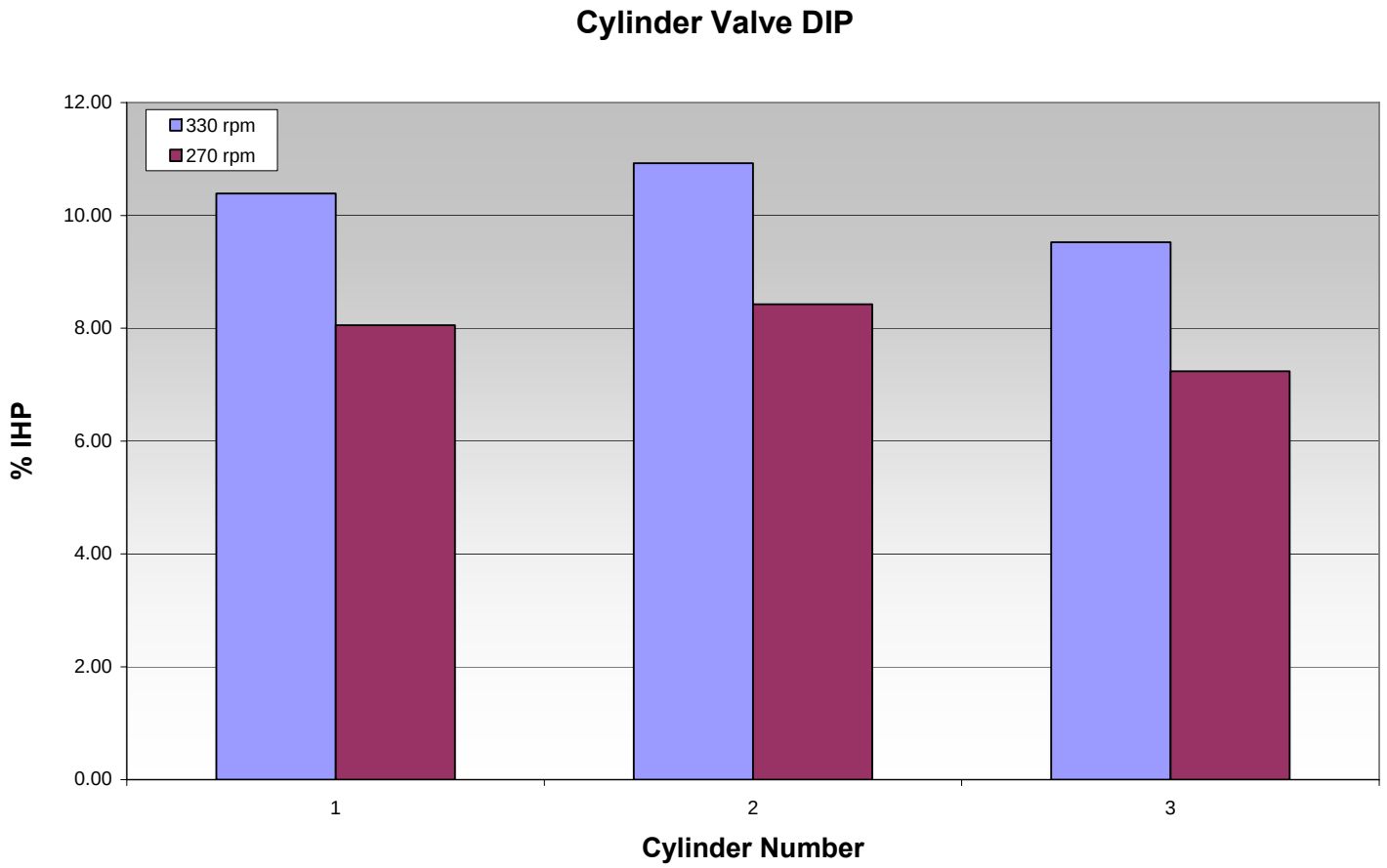
Cylinder IHP



Cylinder DIP



Cylinder Valve DIP



Overall Efficiency Calculations

Constant Entropy Discharge Conditions

330 RPM

Temperature	PSIA	entropy	enthalpy
51	665.2	2.154	219.859
90.5	851.7	2.161	237.829
83.5	851.7	2.154	233.474

Efficiency *75.77%*

Suction Conditions

270 RPM

Temperature	PSIA	entropy	enthalpy
51	657.2	2.156	220.152
92	864.7	2.161	238.363
87	864.7	2.156	235.247

Efficiency *82.89%*

Discharge Conditions

EFF=Constant Entropy Enthalpy Rise/Actual Enthalpy Rise

Distribution of Losses Groveport Station

- 330 rpm
  - Overall Efficiency 75%
  - Valve Losses 10%
  - Installation losses 13-15%
  - Losses appear to be pressure drop driven (rather than pulsation driven)
- 270 rpm
  - Overall Efficiency 82%
  - Valve Losses 8%
  - Installation losses 8-10%

Future Plans

- Finish 3rd site preliminary evaluation
- Select Candidate site
- Analyze current design and compare with possible future design options, predict benefit
- Work with site to have design constructed and installed
- Before and after site evaluation

Project Status Overview

- Project Completion Date September 2005
- ~$473,000 spent in $600,000 Program
- “Phase I” Complete
- “Phase II” Complete
- Phase III, Two preliminary sites tested