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Case Study 3
ONGC Heera
(Management of Gas Compression Facilities)

Enhancing Capacity by Field Testing

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Scope of Work

- Phase 1: Design data collection, software modelling
- Phase 2: Offshore testing, examination of maintenance records
- Phase 3: Turbine & PGC analyses
- Phase 4: Root-cause analyses & identification of improvement options
- Phase 5: Investigation of improvement options

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Project Objectives

- Develop a road map for management of Heera compression facilities
- Identify causes of recurrent reliability & availability issues
- Compare machinery performance & reliability levels against those achieved with emerging best practices
- Identify opportunities for capacity improvement

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Machinery Performance

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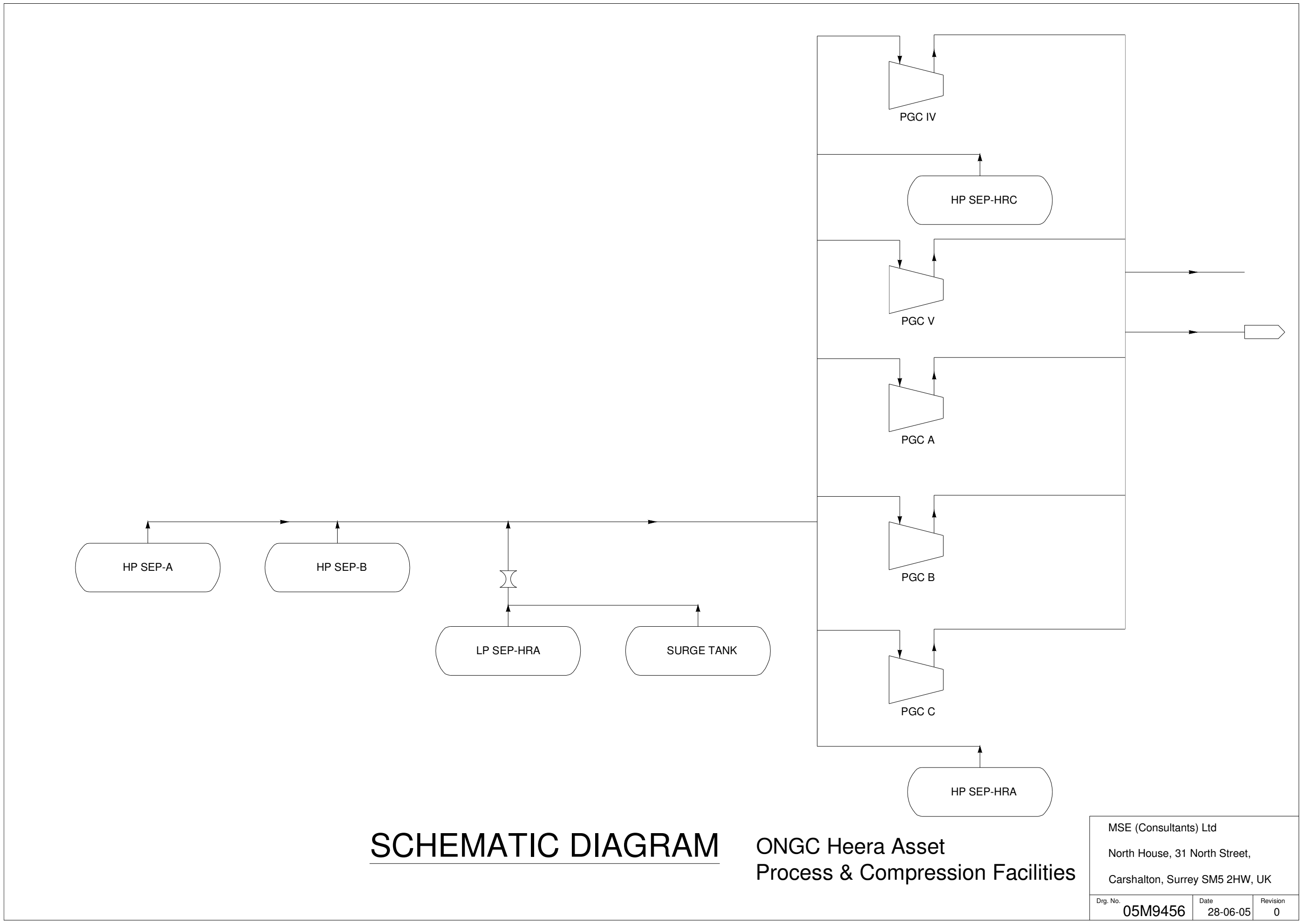
Heera Compression Management
Production Enhancement Opportunities

Immediate	Near Future	Future
Option 1a	Option 1b (or 1c)	Option 2 or 3
Recover performance of existing machinery and resolve process issues	Rewheel PGC's Upgrade MAN GHH Turbines	Replace existing 3 HRG trains with 2 trains of larger capacity

Introduce performance
Monitoring and assessment

Heera Separator & PGC Train Configuration



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Heera Facilities Overview – Current Gas Rates

Heera Typical Separator Operation		
Separator	Flow kSm^3/hr	Flow MSm^3/day
HP-A	64.17	1.54
HP-B	56.67	1.36
HP-HRC	34.75	0.83
HP-HRA	31.92	0.77
LP-HRA	0.67	0.02
Surge Tank	0.33	0.01
Total	188.5	4.52

Heera Typical 4 Train Operation		
Compression Train	Flow kSm^3/hr	Flow MSm^3/day
B	43	1.03
C	45	1.08
IV	55	1.32
V	58.5	1.40
Total	201.5	4.84
Ejector Process	4.72	0.11
Ejector "Power"	17.7	0.42
Net Flow	188.5	4.52
Export Gas	20.8	0.50
Net Lift Gas	167.7	4.03

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Design Flows of Existing Trains – 5 Trains

Existing Rated Design Flows (At Aerodynamic Design Point)								
Option	Rated Design Flow Per HRC Train (MSm^3/day)	Rated Design Flow Per HRG Train (MSm^3/day)	Number of HRC Trains	Number of HRG Trains	Total Number of Trains	Total HRC Rated Design Flow (MSm^3/day)	Total HRG Rated Design Flow (MSm^3/day)	Total Heera Rated Design Flow (MSm^3/day)
Existing (Rated)	1.33	1.2	2	3	5	2.66	3.60	6.26

Note: The Rated flow specified for the HRC trains is the approximate aerodynamic rated flow (at peak efficiency), not the flow referred to as "Rated - Case 2" on the Kawasaki datasheet (1.2 MSm^3/day). The flow of 1.33 MSm^3/day used above is more indicative of the volume flow capacity of the Kawasaki compressor.

Notes

- Above flows are design rated flows not maximum flows
- Design flows are conservatively selected, engines are rated at high ambient with additional driver margin
- PGC’s selected for a lower mol weight & higher pressure ratio
- Availability is currently an issue for 5 train operation

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Maximum Rates Achievable Currently (4 Train)

Maximum Flows Heera **4 Train** Operation At Max EGT for 30 °C Ambient For Machinery & System Conditions April 2005		
Compression Train	Flow kSm^3/hr	Flow MSm^3/day
B	43	1.03
C	45	1.08
IV	58	1.39
V	64	1.54
Total	210	5.04

<u>Maximum Flows Include Following Factors:</u>
MAN GHH Turbine degradations
KOD Cascade in HRG trains
Kawasaki PGC performance degradations
Train IV 18% power discrepancy
Train V 11% power discrepancy

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Maximum Rates Achievable Currently (5 Train)

Maximum Flows Heera **5 Train** Operation At Max EGT for 30 ^{o}C Ambient For Machinery & System Conditions April 2005		
Compression Train	Flow kSm^3/hr	Flow MSm^3/day
A	40	0.96
B	43	1.03
C	45	1.08
IV	58	1.39
V	64	1.54
Total	250	6.00

<u>Maximum Flows Include Following Factors:</u>
MAN GHH Turbine degradations
KOD Cascade in HRG trains
Kawasaki PGC performance degradations
Train IV 18% power discrepancy
Train V 11% power discrepancy

Factors Currently Limiting Capacity

- MAN GHH turbine performance
- KOD liquid drain system – recycling of gas
- Solar/Kawasaki apparent power imbalance
- Differences between current duty and original design intents
- What potential gains could be achieved?

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Flow Increases Achievable With Existing Equipment

Maximum Flows
Heera **5 Train** Operation
At Max EGT for 30 °C Ambient
MAN GHH Turbines Returned To As-Designed Condition
<u>MAN GHH Max EGT Limited to 687 °C</u>
Solar-Kawasaki Power Discrepancy Resolved
PGC Performance As April 2005

Compression Train	Flow kSm^3/hr	Flow MSm^3/day
A	59.4	1.43
B	59.4	1.43
C	59.4	1.43
IV	68.7	1.65
V	71.1	1.71
Total	318	7.63

<u>Maximum Assume the Following</u>

MAN GHH turbine EGT limited to 687 °C
No KOD cascade
PGC performance as measured April 2005

Note: PGC operating points close to choke where performances are more difficult to predict.

Compare with the 250 kSm^3/hr (6 MSm^3/day) that could presently be achieved with 5 trains at maximum EGT.

With 4 trains, 259 kSm^3/hr (6.2 MSm^3/day) could be achieved

Note: Above flows achieved without changes to PGC performances.

Offshore Testing

- Conducted in April
- All five trains tested (PGC’s and turbines)
- PGC flows varied by adopting 5 out of 4 train operation and speed control
- Good spread of PGC flows and turbine loads achieved
- Gas samples collected at various strategic points
- Additional design data collected
- Machinery trip log books interrogated
- Detailed analyses of test data completed at MSE offices

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PGC Performance Analyses
MAN GHH
Trains A, B & C

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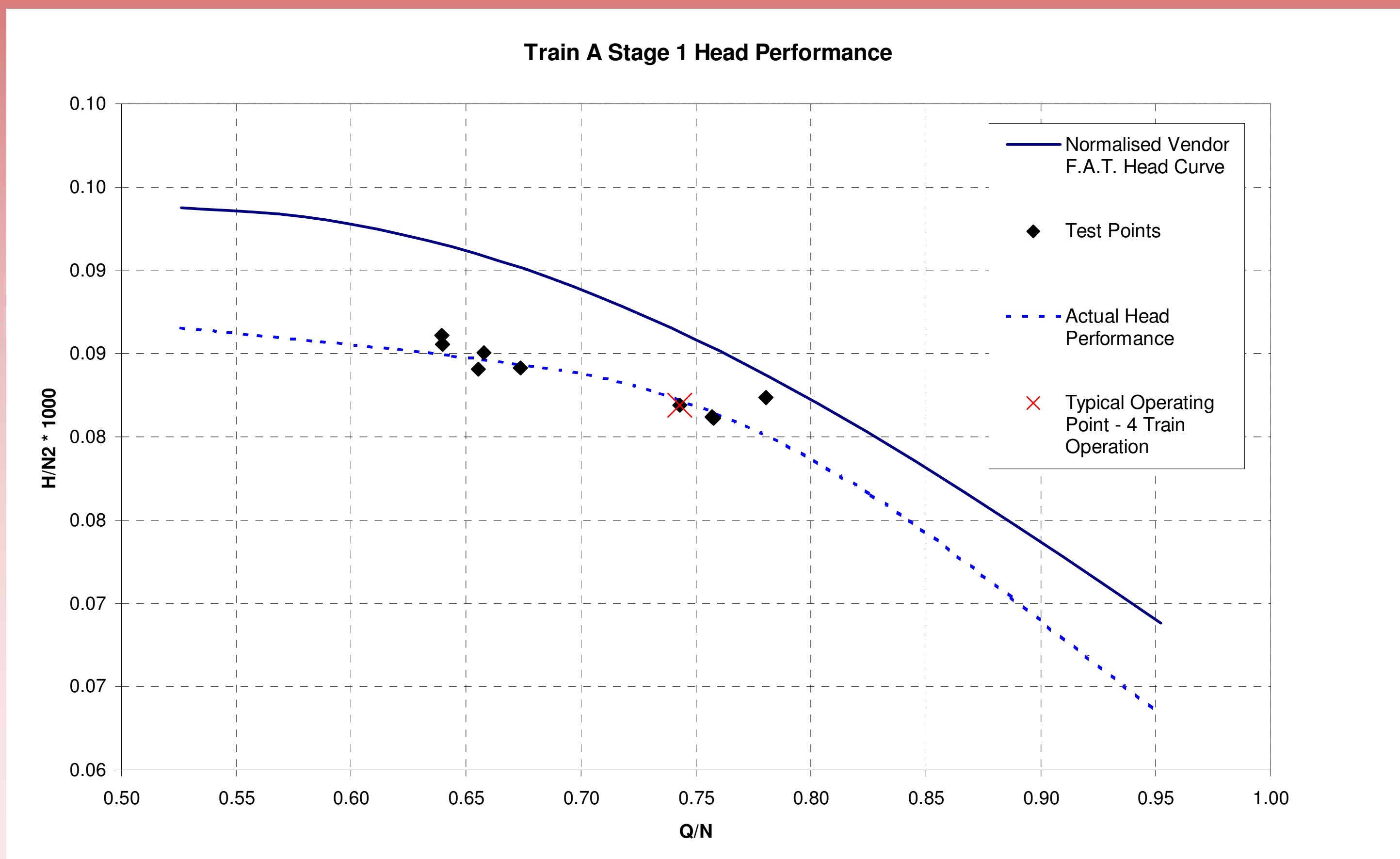
Range of Test Flows Achieved

MAN GHH trains typically run near max EGT, other flows achieved through 5 out of 4 operation



MAN GHH PGC Vendor-Stated Performances

- Compressors produced at time of merger, predicted curves produced by Elliot, Factory Acceptance (FAT) curves produced by MAN GHH.
- Important to appreciate which of vendor stated performances is realistic
- It would be uneconomical to spend money overhauling machines with the aim of achieving overly ambitious performance goals
- Head & efficiency losses have been referenced to both vendor FAT & vendor-predicted curves

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Realistic Compressor Performance Expectations

			Stage 1	Stage 2	Stage 3
F.A.T. Performance	Head	m	10205	13313	20922
	Head Coefficient	---	0.513	0.496	0.595
	Peak Efficiency	%	85	79	81
Vendor Predicted Performance	Head	m	9598	12947	19160
	Efficiency*	%	85.2	74.1	72.7
	Head Loss From F.A.T	%	6.0	2.8	8.4
	Efficiency Loss From F.A.T	%	0.4	6.1	10.6
CENTRIF Performance	Head Coefficient	---	0.482	0.483	0.545
	Efficiency	%	78.9	72.2	67.4
	Efficiency Loss From F.A.T	%	7.77	8.53	17.08

Note: Losses calculated using performance curves from F.A.T as a datum, **not** vendor predicted performance curves from API datasheet.

* From discharge temperature.

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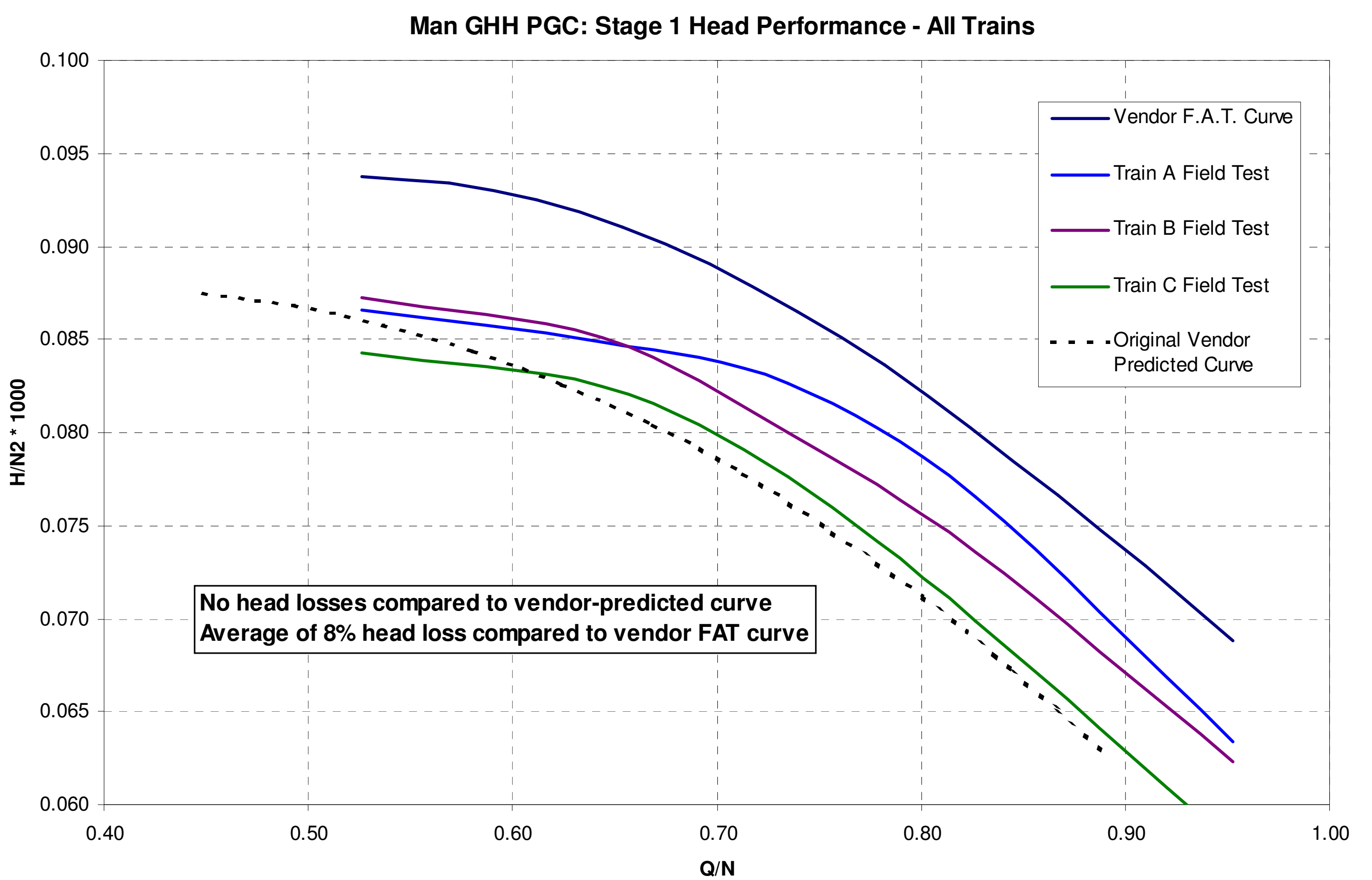
Stage 1 Head Performance



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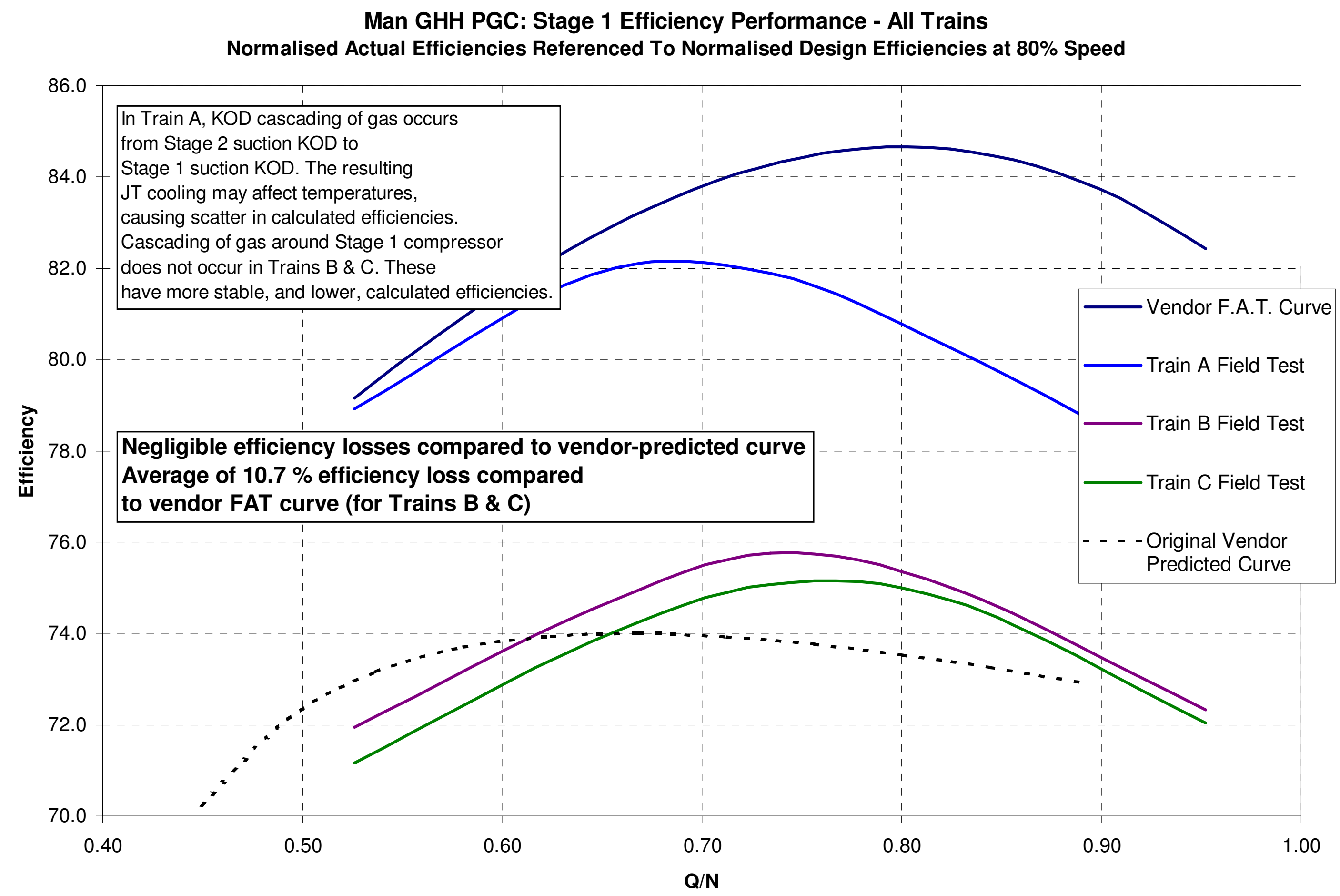
Stage 1 Efficiency Performance



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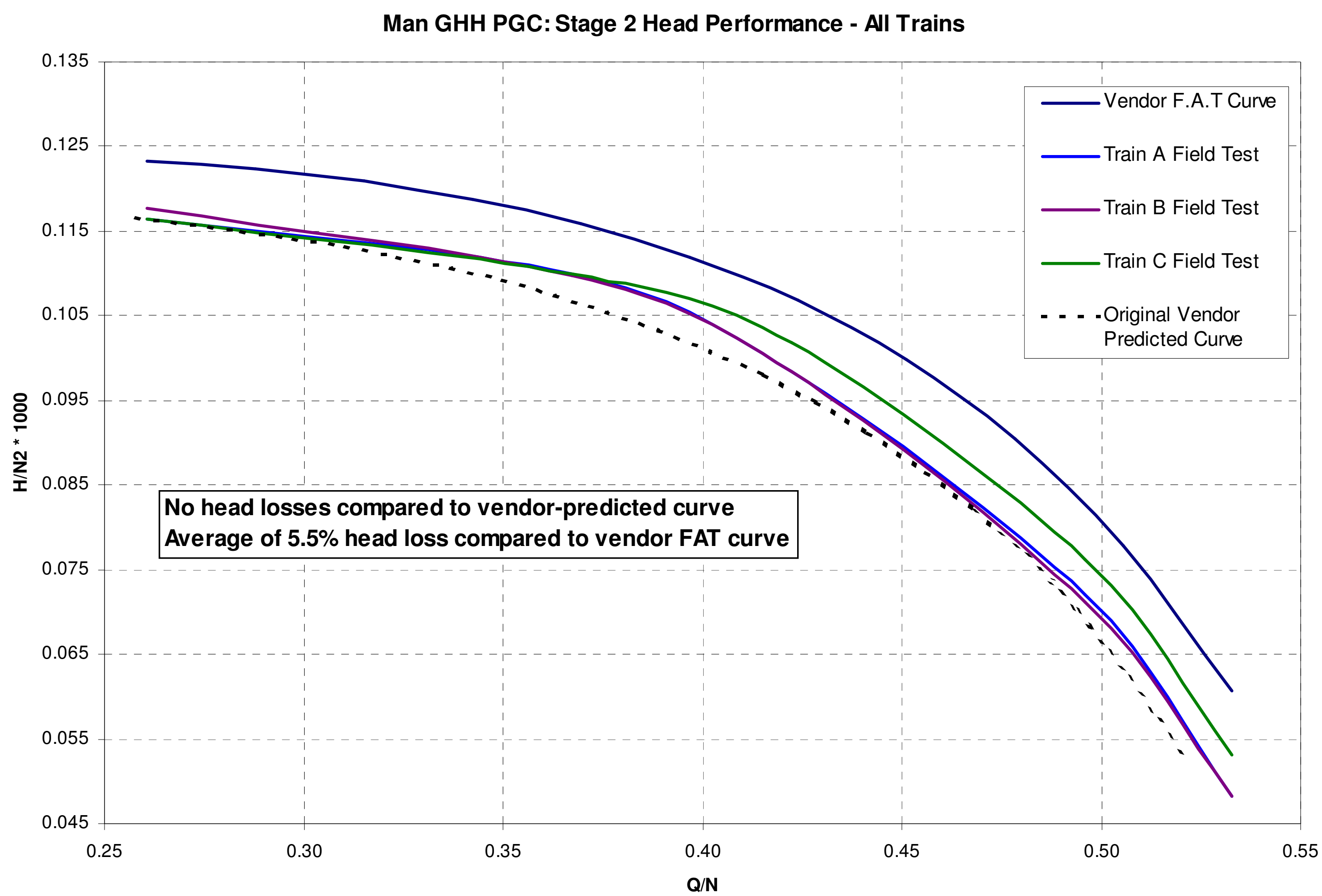
Stage 2 Head Performance



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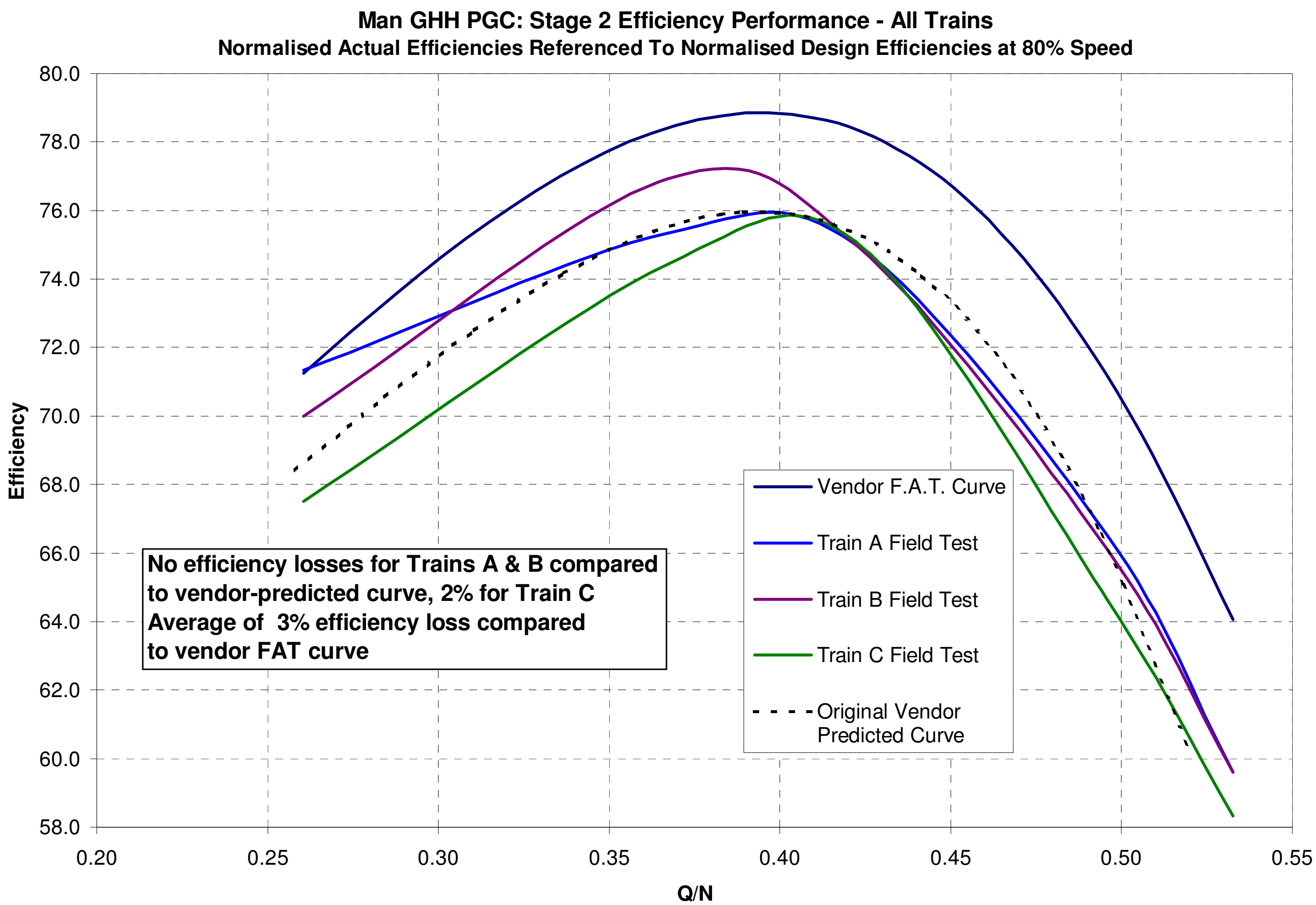
Stage 2 Efficiency Performance



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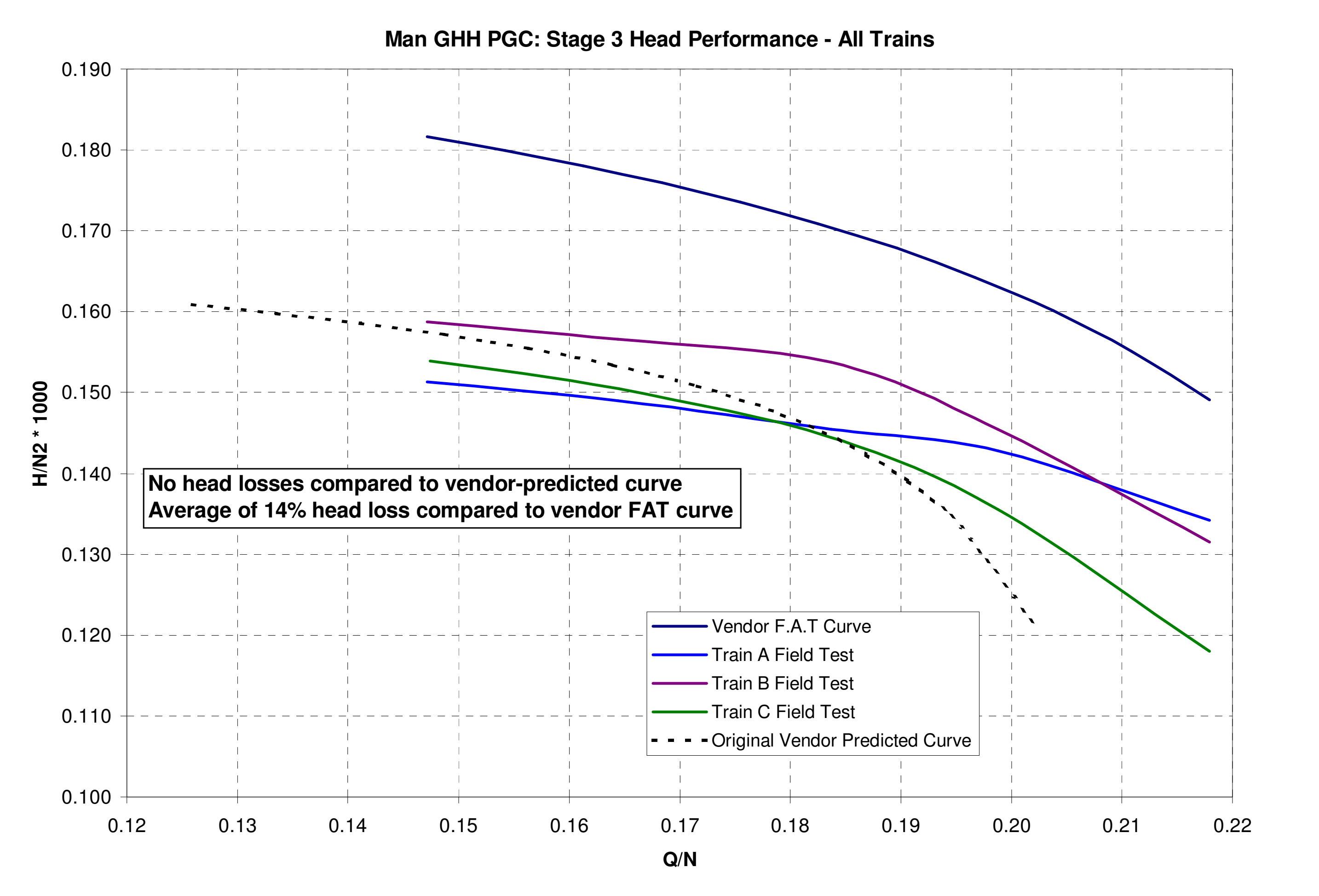
Stage 3 Head Performance



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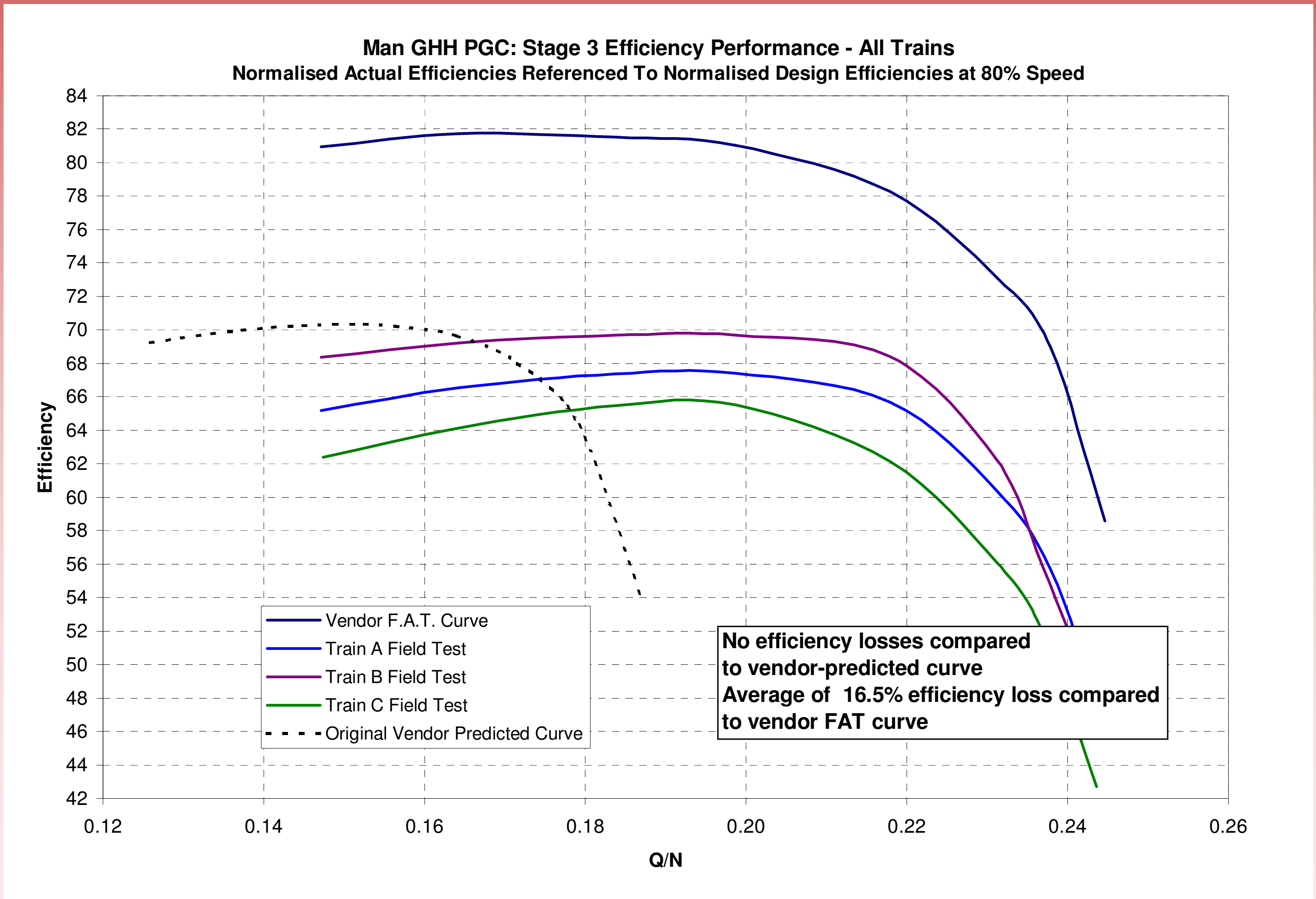
Stage 3 Efficiency Performance



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MAN GHH PGC Performance Summary

- When more realistic performance expectations (vendor-predicted, not FAT) are used as a datum, performances in all Stages are good
- Major overhauls of the bundles would not deliver significant increases in maximum process flows
- Improving production rates should be pursued through other means (turbines and KOD cascade)

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Additional Stage Flows In MAN GHH Trains

- Test measurements indicated flow discrepancies
- Flows were calculated from meter pressure drops to eliminate flow meter calibration issues
- After correction, additional flows in various stages were indicated
- Additional flows identified and confirmed through analysis of entire train (PGC & turbine) in GASMAN™
- Power balancing (turbine vs. PGC powers) provides a powerful indicator of the health of a compression train

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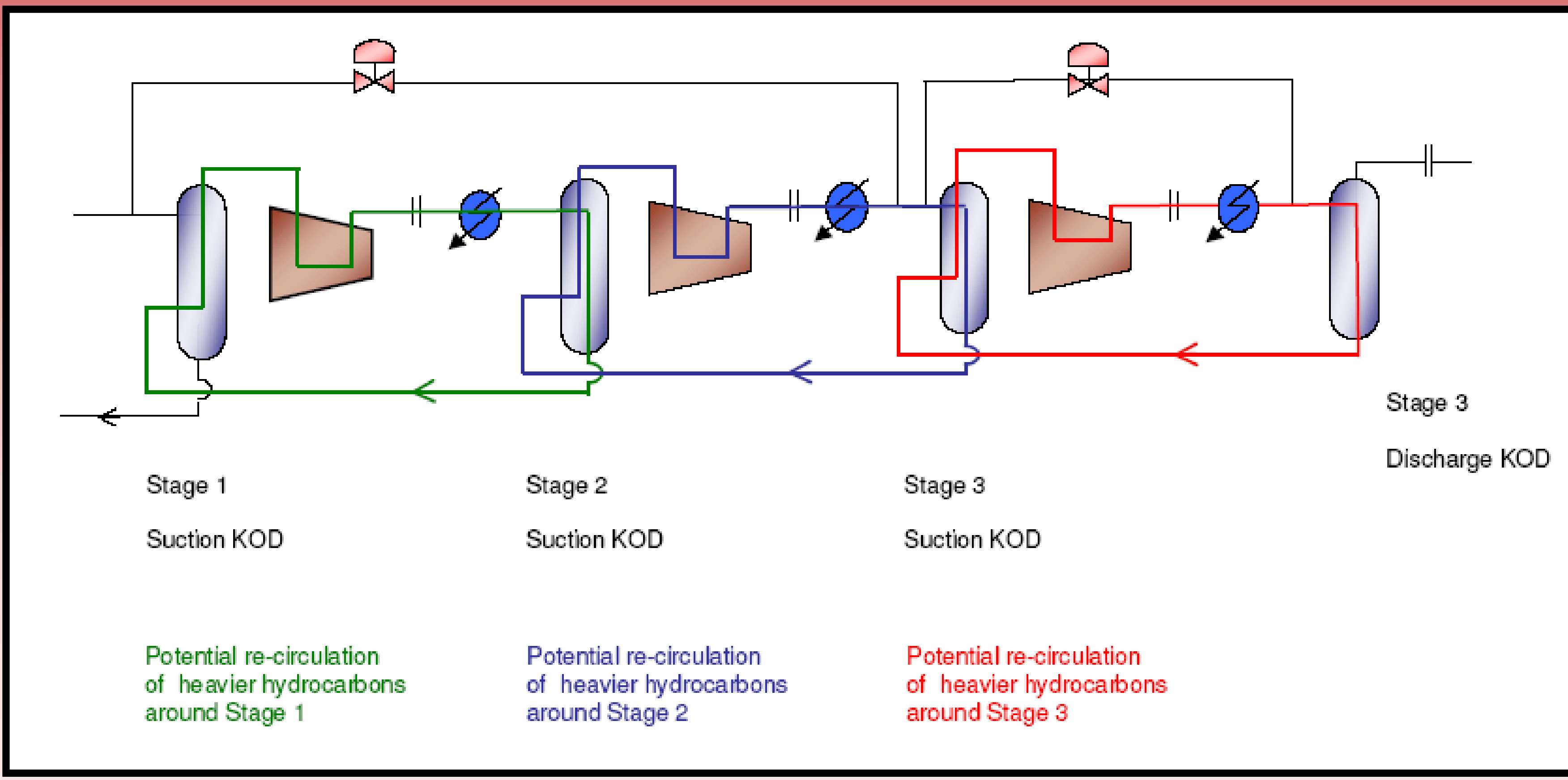
Additional PGC Stage Flows

Flows In **Addition** To Forward Flows		Stage 1	Stage 2	Stage 3
Train A	kSm^3/hr	4	0	15
Train B	kSm^3/hr	0	4	16
Train C	kSm^3/hr	0	0	4

Potential Leakage Paths via KOD Cascades



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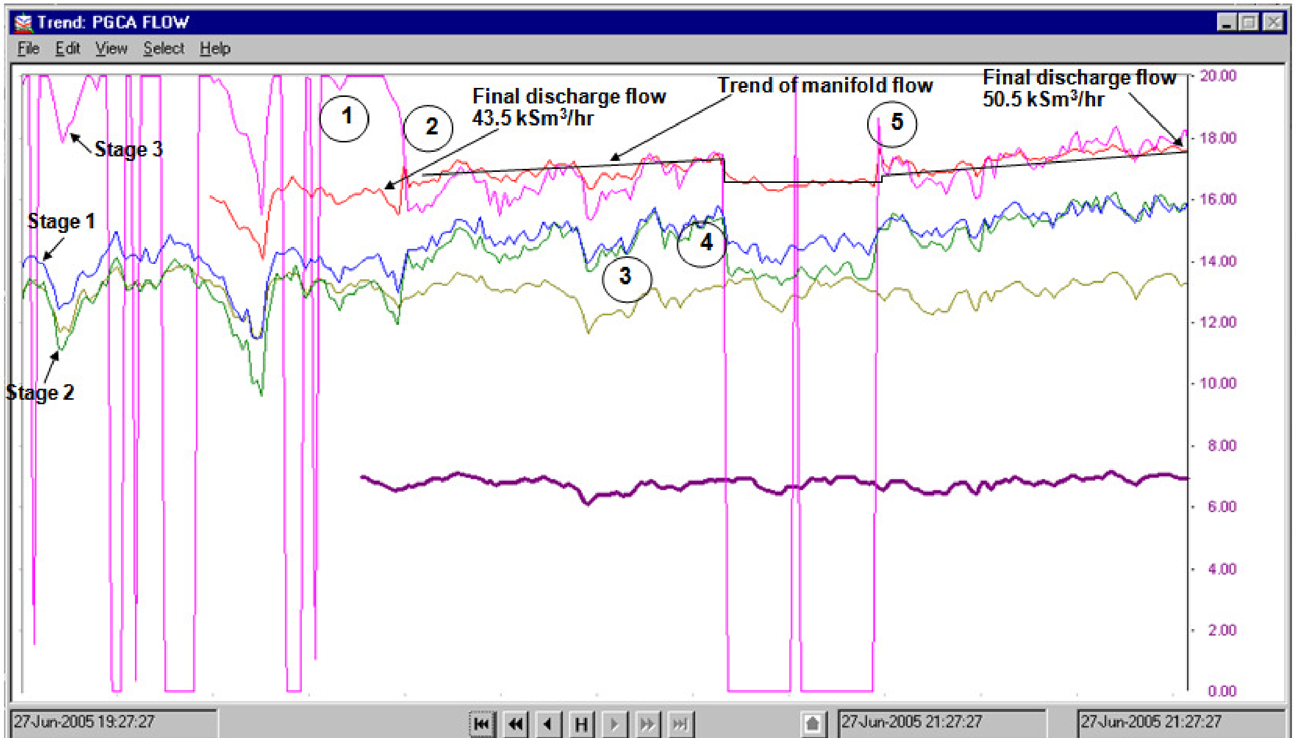
Cascad Test – Flow Traces Train A



Value	Point Tag	Attribute	Description	Scale	Sample Rate	Duration
52940.68	FI2155	PV	C2150 DISCH	0.00 to 66566.00 SM3/HR	30 Seconds	4 Hours
51039.80	FI2180	PV	DISCH TO E22	0.00 to 64897.00 SM3/HR	30 Seconds	4 Hours
51736.99	FI2240	PV	C2240 DISCH	0.00 to 57761.00 SM3/HR	30 Seconds	4 Hours
51041.23	FIC2261	PV	GAS COMP-1	0.00 to 58022.00 SM3/HR	30 Seconds	4 Hours
6.92	PIC2130	PV	GAS CMP.SUCT	0.00 to 20.00 KG/CM2	30 Seconds	4 Hours
6.65	PI2148	PV	C2150 SUCTIO	0.00 to 10.00 KG/CM2	30 Seconds	4 Hours

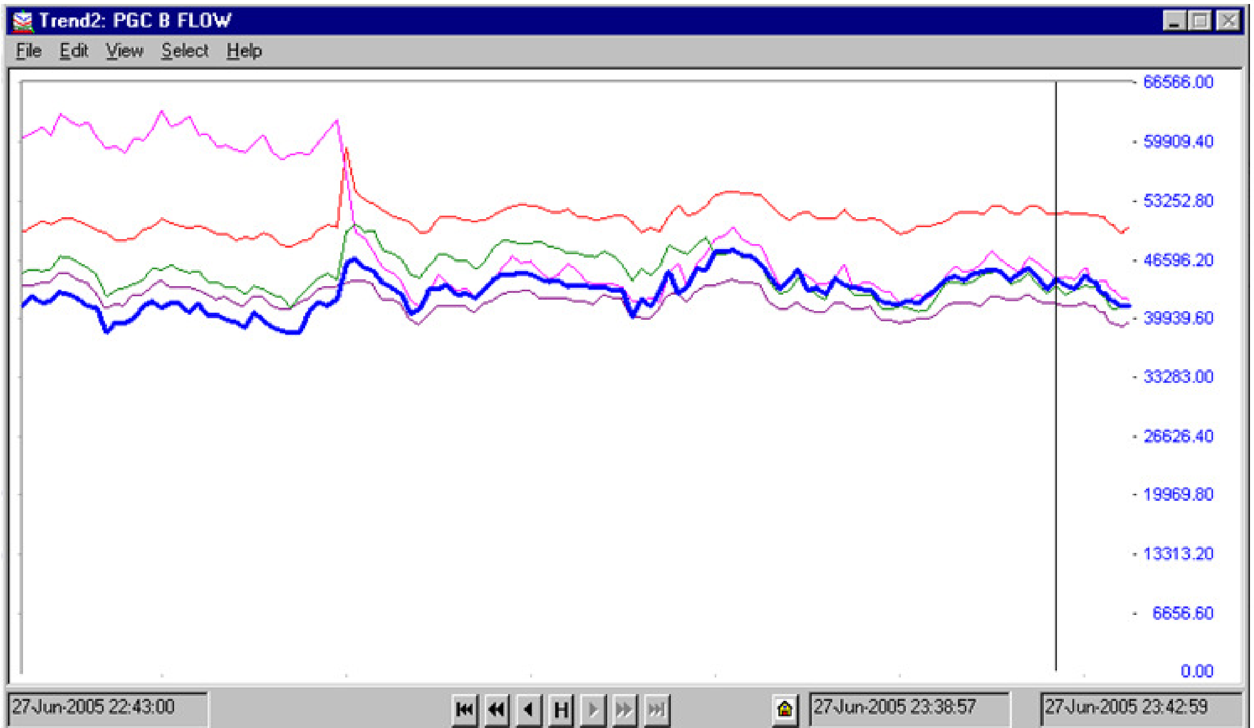
Time (1) Stage 3 flow over range, clipped, or zero. Stage 3 flow 53.9 kSm³/hr. Final discharge (manifold) flow 43.5 kSm³/hr

Time (2) Stage 3 KOD recycle isolated. Stage 3 flow drops dramatically. Final discharge flow rises. Flows in Stages 2 & 2 rise in line with increased manifold flow

Time (3) Stage 1 KOD recycle isolated. Stage 1 flow falls in line with stage 2.

Time (4) KOD cascade lines opened again. Stage 3 flow returns to over-range valves. Stage 1 flow rises above stage 2 again.

Time (5) Isolation of KOD cascade lines repeated. Final discharge flow rises to 50.5 kSm³/hr



Value	Point Tag	Attribute	Description	Scale	Sample Rate	Duration
44197.65	FI3155	PV	C3150 DISCH	0.00 to 66566.00 SM3/HR	30 Seconds	4 Hours
42396.76	FI3180	PV	DISCH TO E32	0.00 to 64897.00 SM3/HR	30 Seconds	4 Hours
38709.78	FI3240	PV	C3240 DISCH	0.00 to 57761.00 SM3/HR	30 Seconds	4 Hours
45147.80	FIC3261	PV	GAS COMP-1	0.00 to 58022.00 SM3/HR	30 Seconds	4 Hours
6.28	PI3148	PV	C3150 SUCTIO	0.00 to 10.00 KG/CM2	30 Seconds	4 Hours

Figure 14.3: Train B Flow Traces Recorded During MSE Testing of Reductions In Turbine Power That Can Be Achieved At The Same Manifold Flow By Elimination of Recycling of Process Gas Via KOD Liquid Drain Cascade Lines

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Value	Point Tag	Attribute	Description	Scale	Sample Rate	Duration
44197.65	FI3155	PV	C3150 DISCH	0.00 to 66566.00 SM3/HR	30 Seconds	4 Hours
42396.76	FI3180	PV	DISCH TO E32	0.00 to 64897.00 SM3/HR	30 Seconds	4 Hours
38709.78	FI3240	PV	C3240 DISCH	0.00 to 57761.00 SM3/HR	30 Seconds	4 Hours
45147.80	FIC3261	PV	GAS COMP-1	0.00 to 58022.00 SM3/HR	30 Seconds	4 Hours
6.28	PI3148	PV	C3150 SUCTIO	0.00 to 10.00 KG/CM2	30 Seconds	4 Hours

Ready | 1 Hr | CAP | NUM

Time (1) Stage 3 flow very high at 53.9 kSm³/hr. Stage 2 flow higher than stage 1. Turbine EGT 666°C

Time (2) Stage 3 cascade recycle isolated. Stage 3 flow drops dramatically. EGT falls to 646°C while final discharge flow remains constant.

Time (3) Stage 2 cascade recycle isolated. Stage 2 flow falls in line with stage 1. Turbine EGT 642°C

Figure 14.4: Train B Flow Traces Recorded During MSE Testing of Reductions In Turbine Power That Can Be Achieved At The Same Manifold Flow By Elimination of Recycling of Process Gas Via KOD Liquid Drain Cascade Lines - Events Log Added

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Offshore Test Performed 27-6-05

- Possible to eliminate cascade recycle via manual block valve at entry to next KOD in cascade.
- Measurements taken on Trains A and B with cascade system open
- Cascade isolation valves shut stage by stage and traces of stage flows recorded.
- Train A turbine power maintained at constant level (via EGT control)
- Forward flows recorded.

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Cascade Test – Train A Flows At Same Power

EGT Approx. 695 °C		With Cascade	Without Cascade
Stage 1	kSm^3/hr	43.5	51.5
Stage 2	kSm^3/hr	37.5	50.7
Stage 3	kSm^3/hr	53.2	50.5
Final Discharge	kSm^3/hr	44.5	50.9

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MAN GHH Trains - Conclusions

- Turbines are suffering from significant performance deterioration (up to 30%) – such losses are significantly limiting production capacity
- When compared to realistic compressor performance expectations, head and efficiencies produced are good in all stages in Trains A, B & C – compressor performances are not significantly affecting production capacity
- Recycling of gas via KOD liquid drain cascade system is significant and is consuming valuable turbine power that should be available for producing forward flow – recycling of gas via KOD drains is significantly limiting production

MAN GHH Trains – Action Plan To Increase Production Capacity Immediate Actions

Turbines

- Replace/repair bleed valves
- Investigate IGV schedules and actuation mechanisms
- Wash GG compressors
- Attend to instrumentation issues (e.g. CDT measurements)
- KOD Liquid Cascade System
- Investigate; liquid level control settings, suitability of positioning of level gauges, sizing of LLC control valves
- Ensure that presence of liquids is always maintained in KOD's to avoid "short-circuiting" gas path from one stage to another

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Solar/Kawasaki Trains - Conclusions

<u>Turbines</u>

- Turbines showing good performance
- <u>PGC's</u>
- Stage 3 (in both trains) showing significant performance losses & may benefit from new balance-piston seals. However, design of Stage 3 makes it vulnerable to in-service performance losses.
- <u>Apparent Power Imbalance</u>
- There are large differences between calculated turbine & PGC powers
- Controlling turbines to such calculated powers severely limits capacity of Trains IV & V

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Solar/Kawasaki Trains – Action Plan To Increase Production Capacity Immediate Actions

- Investigate reasons for differences between calculated turbine & calculated PGC powers
- Consider replacing balance-piston seals during next scheduled PGC overhaul

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Production Enhancement Opportunities

Option 1a

Resolve existing operating issues and overhaul MAN turbines

Option 1b

As Option 1a, but in addition, upgrade MAN turbines to 1304-11AP specification (11.2 MW ISO) and rewheel MAN PGC bodies. This option could also be achieved by replacing existing HRG units with three of the same specification as Train V.

Option 2

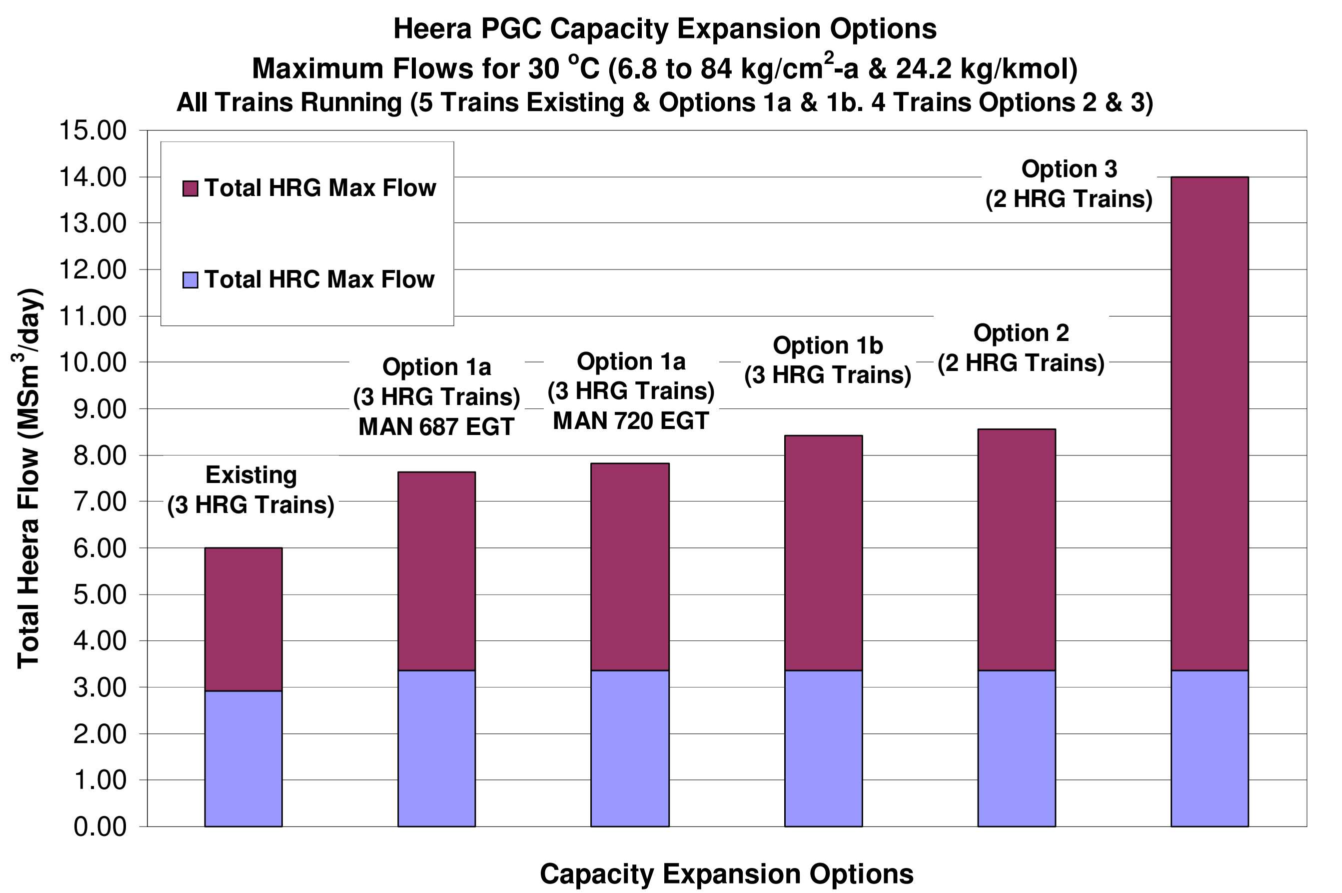
Replace three HRG trains with two trains, each with 15 MW ISO turbines

Option 3

Replace three HRG trains with two trains, each with 30 MW ISO turbines

In all options considered, the HRC trains remain unchanged

Production Enhancement Opportunities



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Option 1a
Overcome Factors Currently Limiting Capacity

- Restore MAN GHH turbine performance
- Eliminate recycling of gas via KOD liquid drain system
- Resolve apparent Solar/Kawasaki power imbalance
- PGC performances unchanged since current values are realistic of long-term in-service levels
- What potential gains could be achieved?

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Option 1a
Flow Increases Achievable With Existing Equipment

Maximum Flows
Heera **5 Train** Operation
At Max EGT for 30 °C Ambient
MAN GHH Turbines Returned To As-Designed Condition
MAN GHH Max EGT Limited to 687 °C
Solar-Kawasaki Power Discrepancy Resolved
PGC Performance As April 2005

Compression Train	Flow kSm^3/hr	Flow MSm^3/day
A	59.4	1.43
B	59.4	1.43
C	59.4	1.43
IV	68.7	1.65
V	71.1	1.71
Total	318	7.63

Maximum Assume the Following

MAN GHH turbine EGT limited to 687 °C
No KOD cascade
PGC performance as measured April 2005

Note: PGC operating points close to choke where performances are more difficult to predict.

Compare with the 250 kSm^3/hr (6 MSm^3/day) that could presently be achieved with 5 trains at maximum EGT. With 4 trains, 259 kSm^3/hr (6.2MSm^3/day) could be achieved Note: Above flows achieved without changes to PGC performances.