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CONTROL SYSTEM RESTRICTED PERFORMANCE FOR AVON COMPRESSOR UNITS

CSRP performance testing at Huntingdon and Chelmsford compressor stations

National Grid

[redacted]

Date: 18/08/2022

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Project name:	Control system restricted performance for Avon compressor units	[redacted]
Report title:	CSRP performance testing at Huntingdon and Chelmsford compressor stations	
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Customer contact:	[redacted]	
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Organisation unit:	[redacted]	
Report No.:	[redacted]	

Objective:

Undertake a detailed performance test on one compressor unit at Huntingdon and one compressor unit at Chelmsford compressor station to determine the effect of limiting the exhaust cone temperature on engine emissions and engine performance.

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1 EXECUTIVE SUMMARY

When operating at full power, National Grid's legacy Avon 1533 rotating machinery packages, have the potential to operate close to or exceed the NO_x emissions limits of 150mg/Nm^3 at 0 °C and 1 Atmosphere as defined in the Medium Combustion Plant Directive (MCPD).

The MCPD restrictions are enforced from 1st January 2030, therefore breaching units would need to be decommissioned. Operation beyond 1st January 2030 deadline is only possible for two scenarios, firstly derogation due to limited life or limited use. The second option is to make the units compliant with MCPD Emission Limit Values (ELV), this can be through DLE upgrades or derating.

National Grid has undertaken assessment of the existing emissions data for the Avon Units at Cambridge, Diss, Chelmsford and Huntingdon compressor stations. This was performed to evaluate the effect of compressor unit control systems restrictions to enable compliance with NO_x emissions limits. A viability assessment was also undertaken to assess the theoretical impact on the compressor operational envelope. National Grid needs to broaden its understanding of the technical solutions available for strategic planning. The Control System Restricted Programme project will provide a physical trial to analyse the possibility of a wider roll-out.

Therefore, NG and [redacted] will undertake an assessment on two compressor units, one at Huntingdon and one at Chelmsford compressor station, to examine the impacts of restricting high power running through control system modifications. The objective is to limit Avon NO_x emissions in order to comply with the MCPD. Assessment will be made on the Avon rotating machinery packages to determine the impact of such control system modifications on the unit performance and reliability.

The project scope is to implement proof of concept physical control system modifications/derating on the compressor trains and then undertake a thorough performance test of the compressor envelope. This will be compared with an initial baseline performance test to identify any loss of capability. Live emissions and unit performance data will be captured during the testing to determine the overall operational impacts and confirm the updates can ensure emissions compliance.

This report presents the results and conclusions from the testing and data analysis from testing at Huntingdon and Chelmsford compressor stations.

1.1 Conclusions

For Huntingdon compressor unit B

1) From historical data Huntingdon Unit B has the potential to operate close to or potentially exceed the 150 mg/m^3 NOx emissions levels as specified in the MCPD. During the testing a maximum emissions value of 128 mg/m^3 only was achieved due to ambient conditions and unfamiliarity with the ECT set points in the governor controller.

2) The historical emissions test data shows some inconsistencies, namely the 2012 and 2013 data sets were done on full recycle testing, which were the only data sets when the compressor breached the MCPD limits. A close agreement is seen between the emissions tests undertaken after 2017, and these also align well with the PEMS monitoring.

3) The NOx comparisons against ECT show a good relationship which should allow for a restriction in ECT to be seen as a suitable option to control NOx emissions to below the MCPD limits.

4) Maximum ECT during testing was much lower than expected due to unfamiliarity with the governor controller and consequently lead to some sensitivity over the predicted temperature at which the MCPD limits may be breached. The lowest ECT temperature at which it is predicted (from the testing) that the 150 mg/m^3 MCPD limit will be breached is 585 °C or a 10 °C drop. This is close to the peak ECT levels seen at 586 °C and a predicted NOx value of 149 mg/m^3.

For Chelmsford compressor unit A

5) From historical data, Chelmsford Unit A has not yet be seen to operate close to or potentially exceed the 150 mg/m^3 NOx emissions levels as specified in the MCPD. During the testing a maximum emissions value of 128 mg/m^3 was achieved due to ambient conditions and a restriction in station flow of 40 mscm/d.

6) A new engine was installed at Chelmsford in 2016 and the subsequent emissions test were all undertaken under loaded conditions, similar to the last few years at Huntingdon and therefore deemed to be representative.

7) A close agreement is seen between the emissions tests undertaken after 2017, and these also align well with the PEMS monitoring.

8) The NOx comparisons against ECT show a good relationship which should allow for a restriction in ECT to be seen as a suitable option to control NOx emissions to below the MCPD limits.

9) Maximum ECT during testing was much lower than expected due to limitations on station flow, but these restrictions would also prevent Chelmsford from exceeding the NOx limits.

1.2 Recommendations

1) Further CSRP testing is recommended at Huntingdon compressor station aimed to achieve higher exhaust temperatures, which should equate to higher NOx emissions levels. Testing should be undertaken at higher ambient temperatures (typically above 20 °C). In addition, the ECT limits in the governor controller can be modified to allow for much higher ECT values. If this test is successful, then Huntingdon could be recommended as a suitable site for CSRP.

2) Chelmsford compressor station may be capable of breaching the MCPD limits, if the station scrubbers were removed, or a by-pass fitted allowing the site to operate at higher flows. CSRP could then be used to limit the NOx values.

3) A check should be undertaken on the historic emissions test data from before 2015.

4) The testing campaigns at Huntingdon and Chelmsford have identified that whilst the units and governor controller are the same, unique differences in station operation, governor configuration, engine and compressor operation exist. This indicates each CSRP implementation will require tailoring to the unique set up of each individual unit. As a result, [redacted] would recommend individual assessments including, performance and CSRP testing, historic data analysis and thorough governor controller testing for any unit considered for CSRP.

5) If CSRP is implemented on a unit, consideration should be made around utilising the annual emissions data to provide verification that any ECT limit applied still ensures the NOx levels remain below the MCPD limit. This will be particularly relevant if engine changes occur.

2 INTRODUCTION

2.1 The Situation

When operating at full power, National Grid's legacy Avon 1533 rotating machinery packages, have the potential to operate close to or exceed the NO_x emissions limits of 150mg/Nm^3, defined in the Medium Combustion Plant Directive (MCPD).

The MCPD restrictions are enforced from 1st January 2030, therefore breaching units would need to be decommissioned. Operation beyond 1st January 2030 deadline is only possible for two scenarios, firstly derogation due to limited life or limited use. The second option is to make the units compliant with MCPD Emission Limit Values (ELV), this can be through DLE upgrades or derating.

National Grid has undertaken assessment of the existing emissions data for the Avon Units at Cambridge, Diss, Chelmsford and Huntingdon compressor stations. This was performed to evaluate the effect of compressor unit control systems restrictions to enable compliance with NO_x emissions limits. A viability assessment was also undertaken to assess the theoretical impact on the compressor operational envelope. National Grid needs to broaden its understanding of the technical solutions available for strategic planning. The Control System Restricted Programme (CSRP) project will provide a physical trial to analyse the possibility of a wider roll-out.

2.2 The Solution

NG and [redacted] will undertake the CSRP project on two compressor units one at Huntingdon and one at Chelmsford compressor station, to examine the impacts of restricting high power running through control system modifications. The objective is to limit Avon NO_x emissions in order to comply with the MCPD. Assessment will be made on the Avon rotating machinery packages to determine the impact of such control system modifications on the unit performance and reliability.

The project scope is to implement proof of concept physical control system modifications/derating on the compressor trains and then undertake a thorough performance test of the compressor envelope. This will be compared with an initial baseline performance test to identify any loss of capability. Live emissions and unit performance data will be captured during the testing to determine the overall operational impacts and confirm the updates can ensure emissions compliance.

[redacted]

3 SCOPE OF WORK

The scope of works will follow the CSRP scope document issued in September 2021. [redacted] have separated the scope into 7 stages described below.

3.1 Phase 1 - Project Management & Proof of concept

- Carry out all the necessary preparations to undertake proof of concept CSRP physical testing.
- Liaise with PESL to agree data that will be provided to enable them to undertake their 'best available technology' (BAT) assessments.
- Liaise with National Grid for support to control system access and any necessary temporary modifications.
- Liaise with the emissions monitoring and site teams to agree monitoring methodologies, parameters and periods.
- Identify/reaffirm (making reference to, and based on, similar works undertaken at Cambridge, Chelmsford, Diss and Huntingdon) what parameter(s) need to be adjusted within the control system to derate an Avon rotating machinery package.

3.2 Phase 1 - Planning Phase

- Develop a project plan and data requirements for both the technical note and reports in conjunction with PESL.
- Develop a baseline performance test matrix.
- Develop a CSRP performance test matrix.
- Produce test method statement.
- Site work planning meetings.
- Assess historic data to determine appropriate procedure and ensure adjustment parameter(s) are appropriate.

3.3 Phase 1 - Baseline performance testing Unit B (Pre-CSRP) – at Huntingdon compressor station

- Pre and onsite preparation – including installation / calibration checks of instrumentation at site and data integrity confirmation.
- Performance testing on Unit B to validate the compressor envelopes and peak NO_x emissions.
- Expert guidance on site operation pre, post and during performance testing – includes performance valve movement.
- Performance data and PEMS emissions data capture through the Alert system.
- CEMS emissions data captured via temporary onsite monitoring systems.

3.4 Phase 1 - CSRP performance testing – Unit B at Huntingdon compressor station

- Performance testing on Unit B to validate the compressor envelopes at 3 duty points. Performance test points will be limited to the compressor operating areas at which the ECT limits start to restrict the unit operation.
- Expert guidance on site operation pre, post and during performance testing – includes performance valve movement.

- Performance data and PEMS emissions data capture through the Alert system. Data will be integrated with the emissions laboratory measurements.

3.5 Phase 1 - Baseline performance testing Unit A (Pre-CSRP) – at Chelmsford compressor station

- Pre and onsite preparation – including installation / calibration checks of instrumentation at site and data integrity confirmation.
- Performance testing on Unit A to validate the compressor envelopes and peak NO_x emissions.
- Expert guidance on site operation pre, post and during performance testing – includes performance valve movement.
- Performance data and PEMS emissions data capture through the Alert system.
- CEMS emissions data captured via temporary onsite monitoring systems.

3.6 Phase 1 - CSRP performance testing – Unit A at Chelmsford compressor station

- Performance testing on Unit A to validate the compressor envelopes at 3 duty points – expected to be discrete settings 5, 10 & 20 degrees below the current ECT setpoint. Performance test points will be limited to the compressor operating areas at which the ECT limits start to restrict the unit operation.
- Expert guidance on site operation pre, post and during performance testing – includes performance valve movement.
- Performance data and PEMS emissions data capture through the Alert system. Data will be integrated with the emissions laboratory measurements.

3.7 Phase 1 - Reporting

- Supply technical essential information required by PESL for RIIO submission as soon as available.
- Supply a draft report, for discussion with NG, of the testing, findings, conclusions, and recommendations.
- Submit a final report of the testing, findings, conclusions, and recommendations.
- Provision of data and reports to NG and PESL at a handover meeting.

Reports will include,

- Determine how much shaft power is lost by adjusting the parameter(s) identified during testing.
- Determine how much of the compressor operating envelope is lost (i.e. define original and revised operating envelope).
- Determine the relationship between parameter adjustment and loss of power.
- Identification of how that loss of power and operating envelope translates to flow/head comparisons between CSRP and no CSRP.
- Assess the impact of this loss of envelope on compressor capability.

3.8 Phase 2

- Compare findings of physical trial with results using an appropriate model, software or methodology (using the same test parameter adjustments), in order to test the viability of a systems model to avoid future on-site trials – Huntingdon units only.

- Provide a cost estimate of implementing CSRP on a typical Avon rotating machinery package. This should include a full inventory of the control systems and costs to modify or upgrade them.
- Develop a roll-out plan of information required to determine if this approach could be applied to other Avon units.
- Provision of performance data to PESL and NG at a handover meeting.

[redacted]

4 HISTORIC DATA ASSESSMENT

As part of the CSRP process, historic data from both compressor sites was also looked at to see what the potential impact may be on operating conditions and what proportion of the compressor envelopes may be lost as a result of CSRP.

4.1 Huntingdon – Unit B

Figure 1 shows the historic running on Unit B at Huntingdon compressor station between September 2020 and November 2021. Please note that the flow on the X-axis is presented as a non-dimensional flow. The performance of a compressor is commonly described by non-dimensional (ND) flow and speed, the original equipment manufacturers (OEMs) provide performance curves using ND relationships. By substitution of variables, the ND values are calculated removing the physical quantity units, this allows simpler compressor performance assessment. The ALERT compressor maps are configured using these ND relationships.

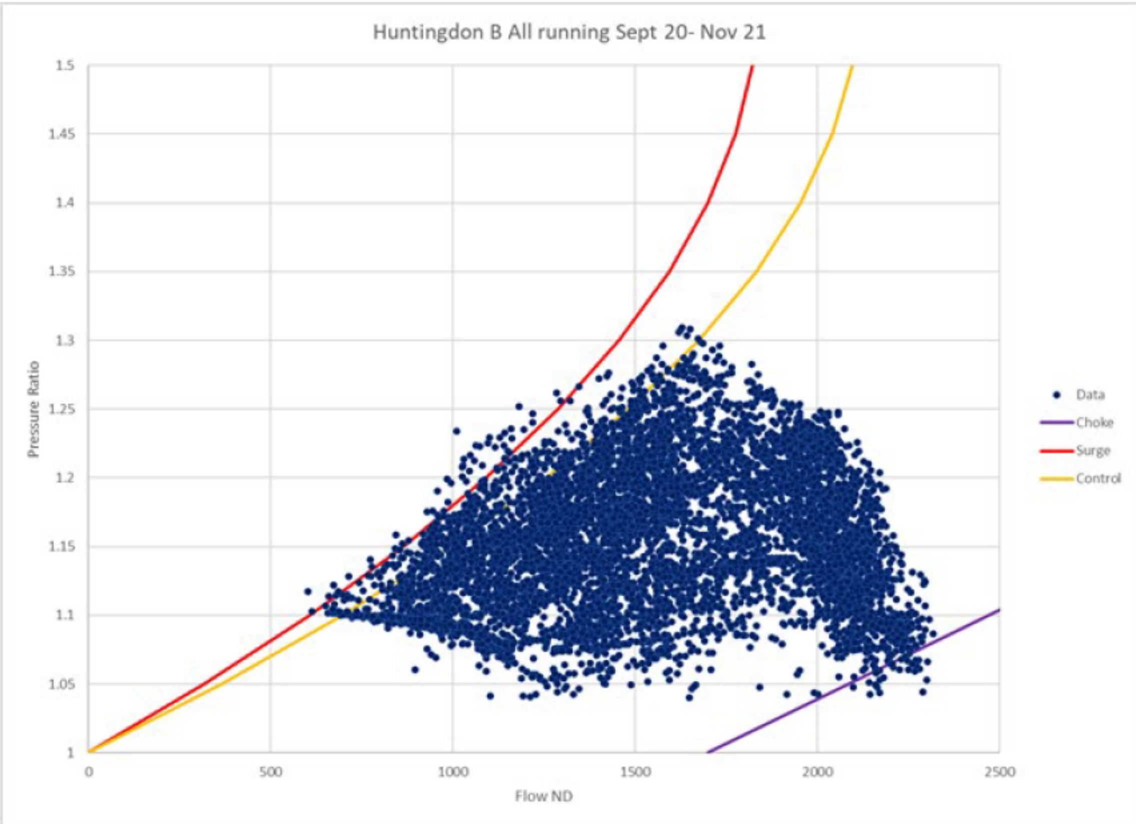

Figure 1 – Historic operating points for Unit B at Huntingdon compressor station

This figure shows that Unit B operated over a wide part of its compressor envelope and should provide a good representative set of data for comparing the effects of CSRP on compressor duty and operation. To see the likely effect that a reduction in exhaust cone temperature (ECT) would have on the compressor operating points, the operating points for Unit B were colour coded into 4 ECT bands as shown in Figure 2. As expected, Figure 2 shows that the highest ECT temperature occur at the maximum power of the compressor in the top part of the compressor envelope. It is also clear that there is an overlay of data in this area and that the ECT does vary at similar operating points. It is assumed that this is due to the variations in ambient conditions. Each point on the plot represents 10 minutes of averaged operational data. Figure 3 shows a similar compressor operating point plot, but this time coloured coded for variations in NOx. As NOx is linked to the ambient conditions this shows a greater separation between the different bands with a reasonable amount of operation of the compressor at NOx values above 140 mg/m^3 (Red markers).

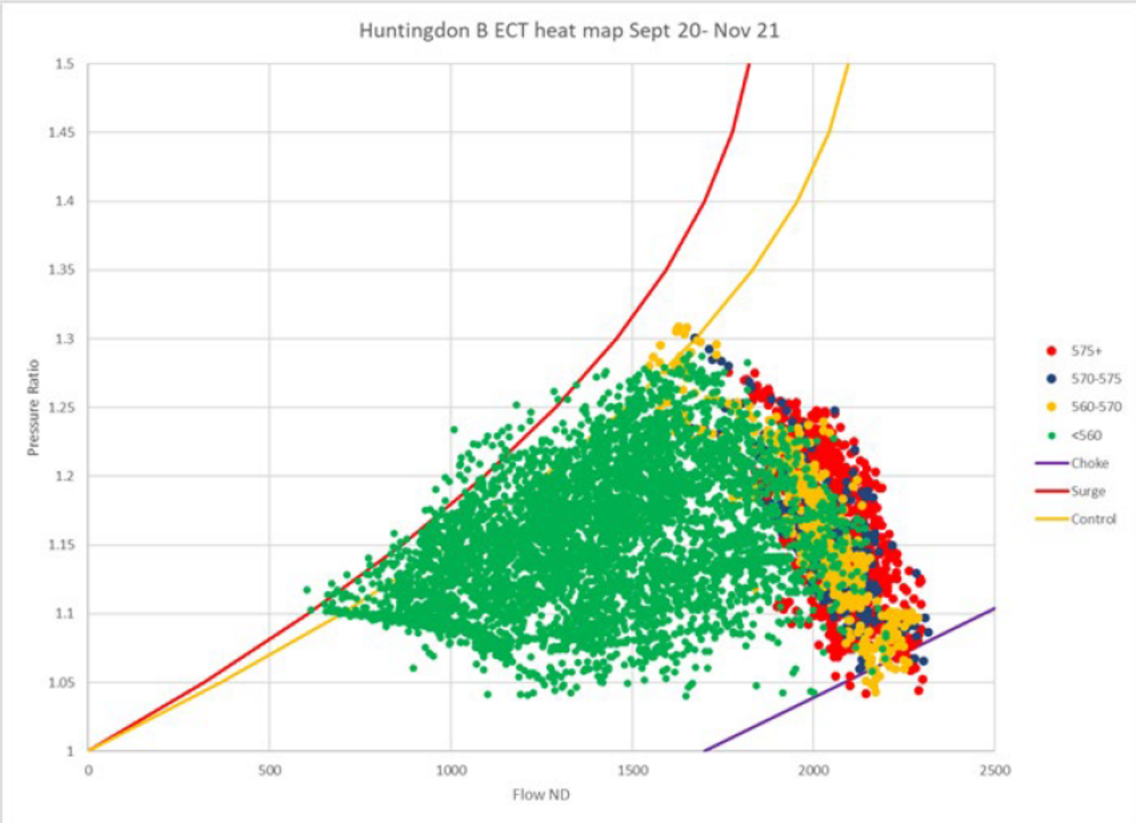

Figure 2 – Historic ECT temperatures for Unit B at Huntingdon compressor station

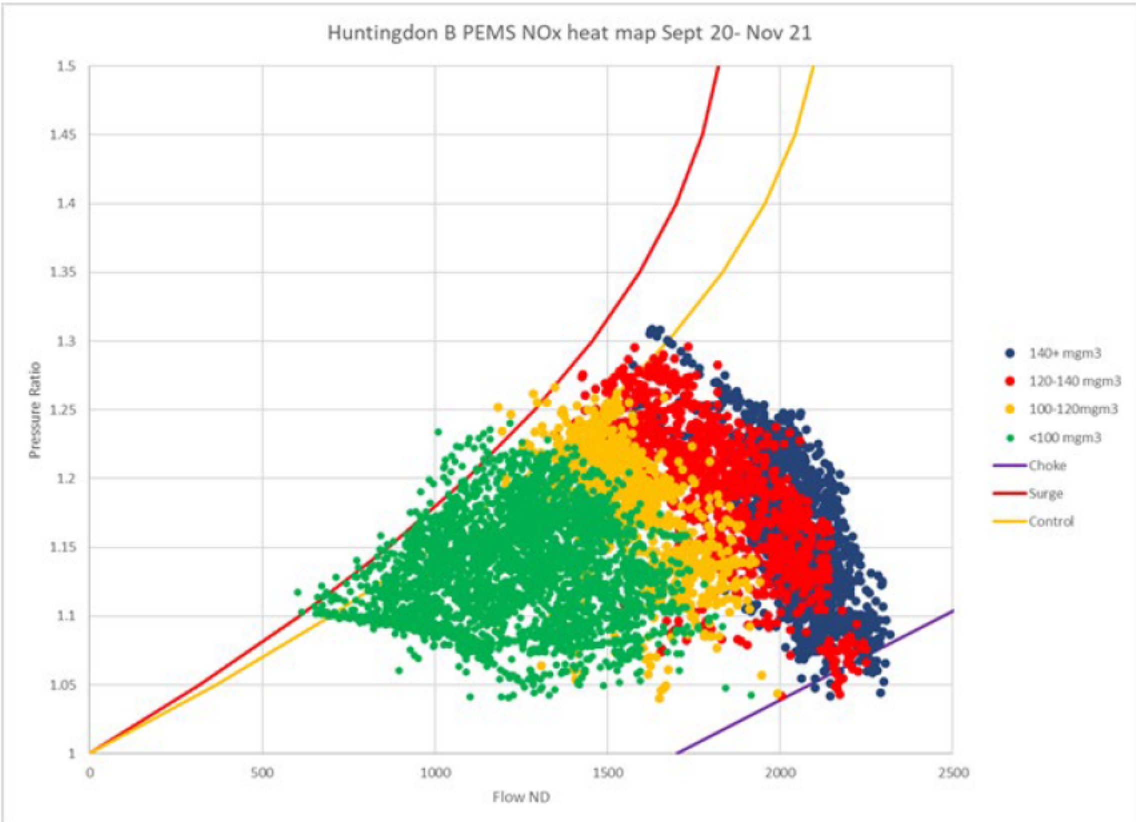

Figure 3 – Historic NOx emissions for Unit B at Huntingdon compressor station

[redacted]

Looking at Figure 3, it can be seen that the compressor was operating with emissions at above 140 mg/m^3 for a reasonable proportion of the compressor running time. It should be noted that none of the emissions exceeded the 150 mg/m^3 NOx emissions limit as specified in the MCPD.

This variation has led to an investigation into the historic emissions data for Huntingdon – Unit B. Historically there have been incidences at Huntingdon when the compressor was operating above the 150 mg/m^3 limit, but these were all before 2015. Figure 4 shows the variation between ECT and NOx from the past 6 emissions tests undertaken. This shows that only the 2013 data appears to have breached the 150 mg/m^3 NOx MCPD limits, even when no CSRP reduction has been applied.

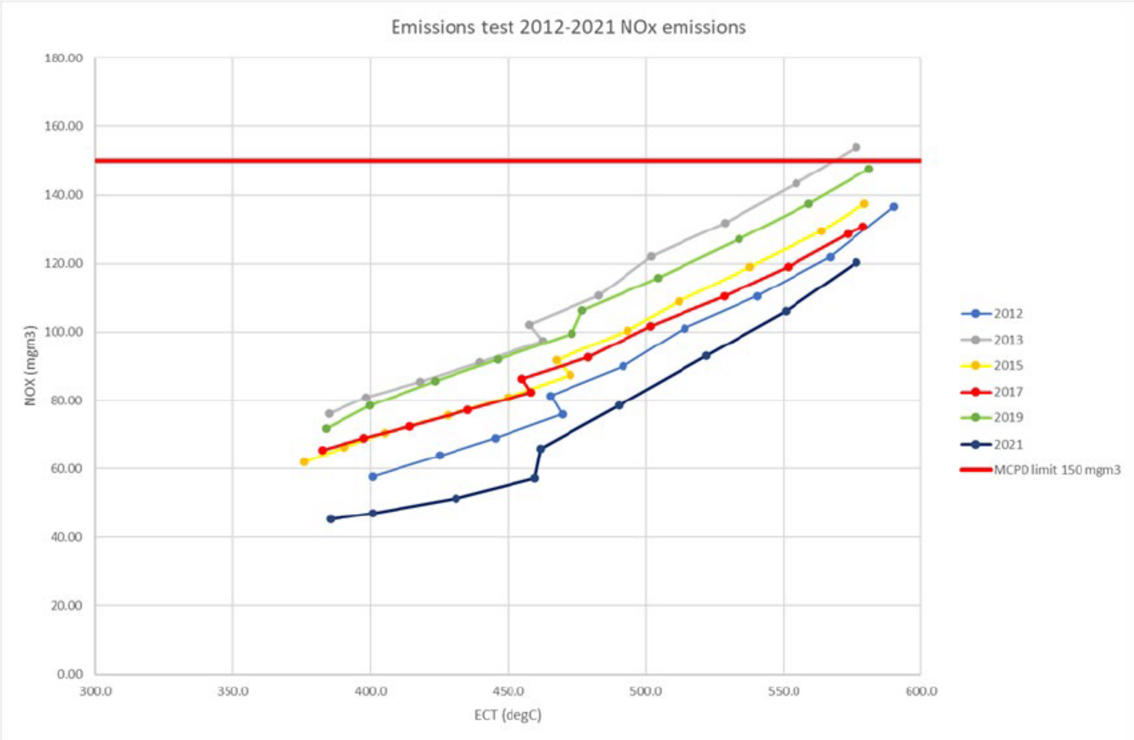

Figure 4 – Historic emissions test data plot showing variation in ECT and NOx

Looking at Figure 5, it can be seen that there appears to be a difference in in how the emissions testing was undertaken. The 2012 / 2013 data clearly shows the compressor being tested on what is likely to have been full recycle with little capability for generating a head. The engine is clearly running very inefficiently in this area of the envelope and peak emissions during testing were 154 mg/m^3. The later testing from 2017 onwards is shown to be operating in the middle of the compressor envelope and shows a peak emissions figure of 147 mg/m^3. The variations in emissions between the different tests from 2017 and 2021 are likely to be linked to the ambient conditions at which the emissions testing was undertaken. Table 1 shows a comparison between ECT / Peak NOx and ambient conditions for the historic emissions tests assessed at Huntingdon.

[redacted]

Table 1 – Huntingdon historic emissions testing conditions

Emissions test year	ECT (°C)	Ambient (°C)	NOx (mg/m^3)
2012	590.0	12.7	136
2013	576.4	9	154
2015	579.5	14	137
2017	578.9	10	131
2019	581.0	16	148
2021	576.5	5	120
Performance test	577.0	11	128

Figure 6 shows the historic emissions test peak NOx vs ECT plot. This shows a reasonably good relationship between NOx and ECT if the data points from the full recycle testing in 2012/2013 are removed from the dataset.

It is recommended that an analysis of the historical data is undertaken for any Avon driven compressor unit which may be affected by the MCPD to see if the historic data is too conservative.

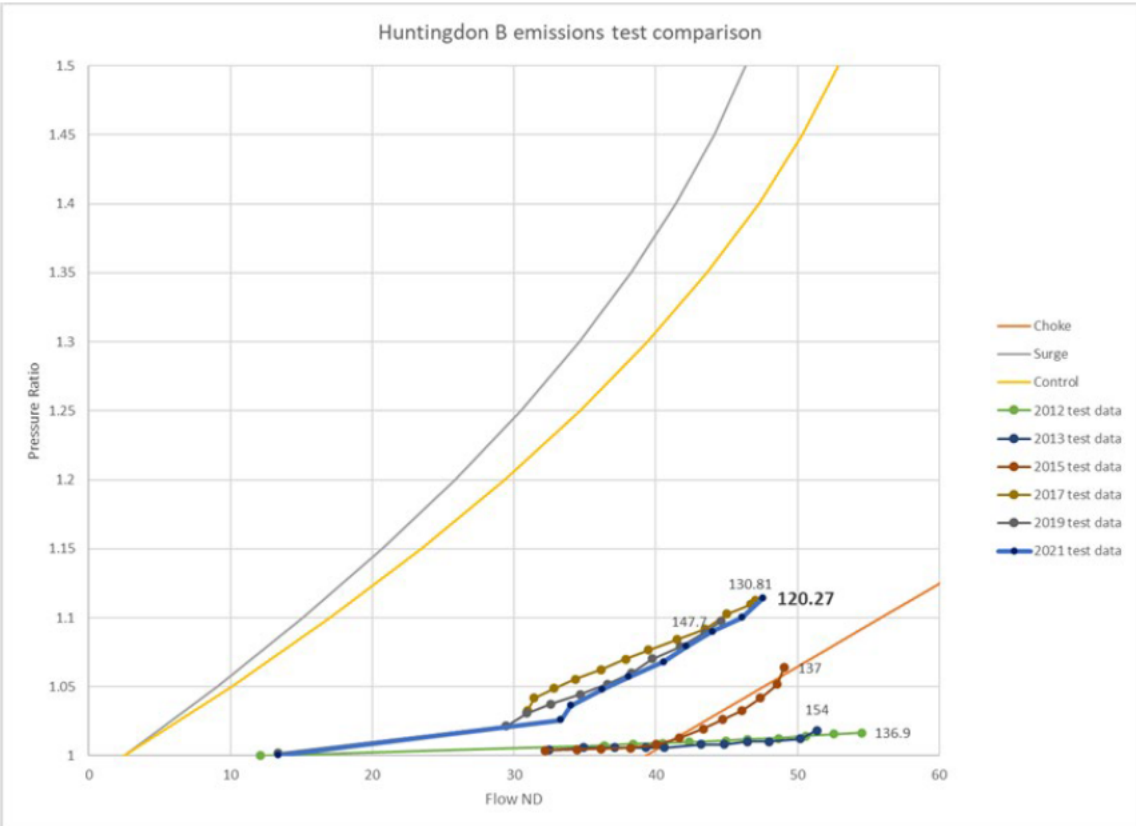

Figure 5 – Historic emissions test operating points

[redacted]

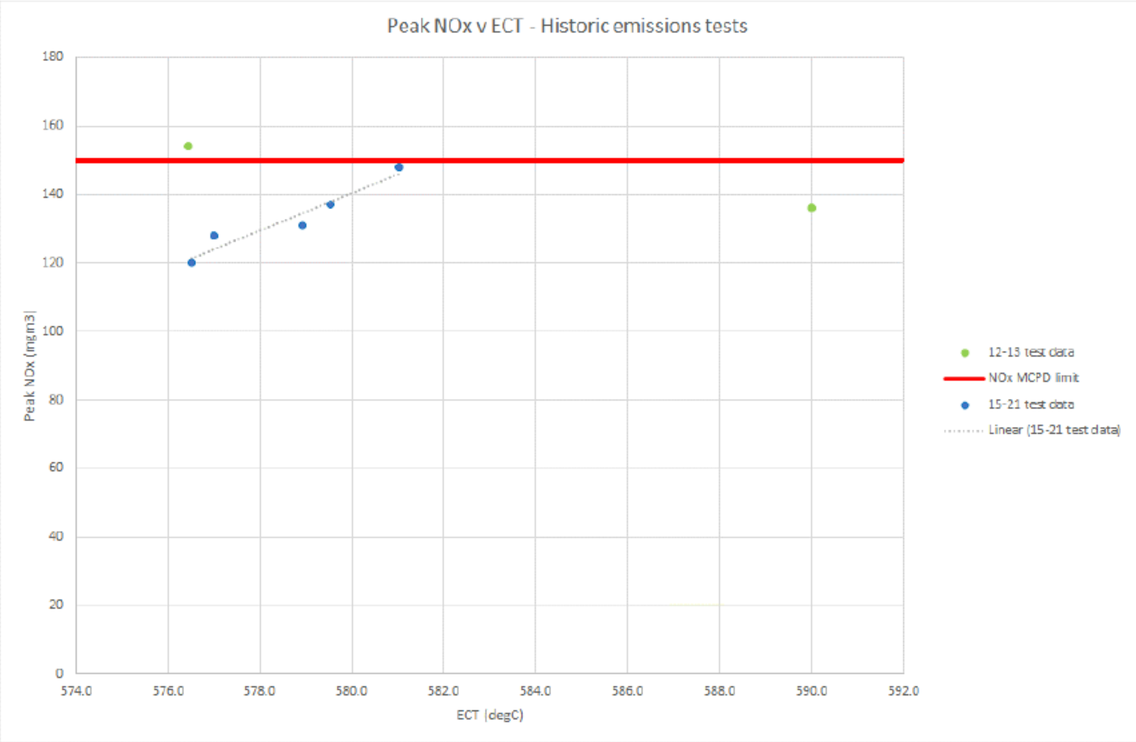

Figure 6 – Historic emissions test peak NOx vs ECT plots

[redacted]

4.2 Chelmsford – Unit A

Figure 7 shows the historic running on Unit A at Chelmsford compressor station between February 2018 and January 2022.

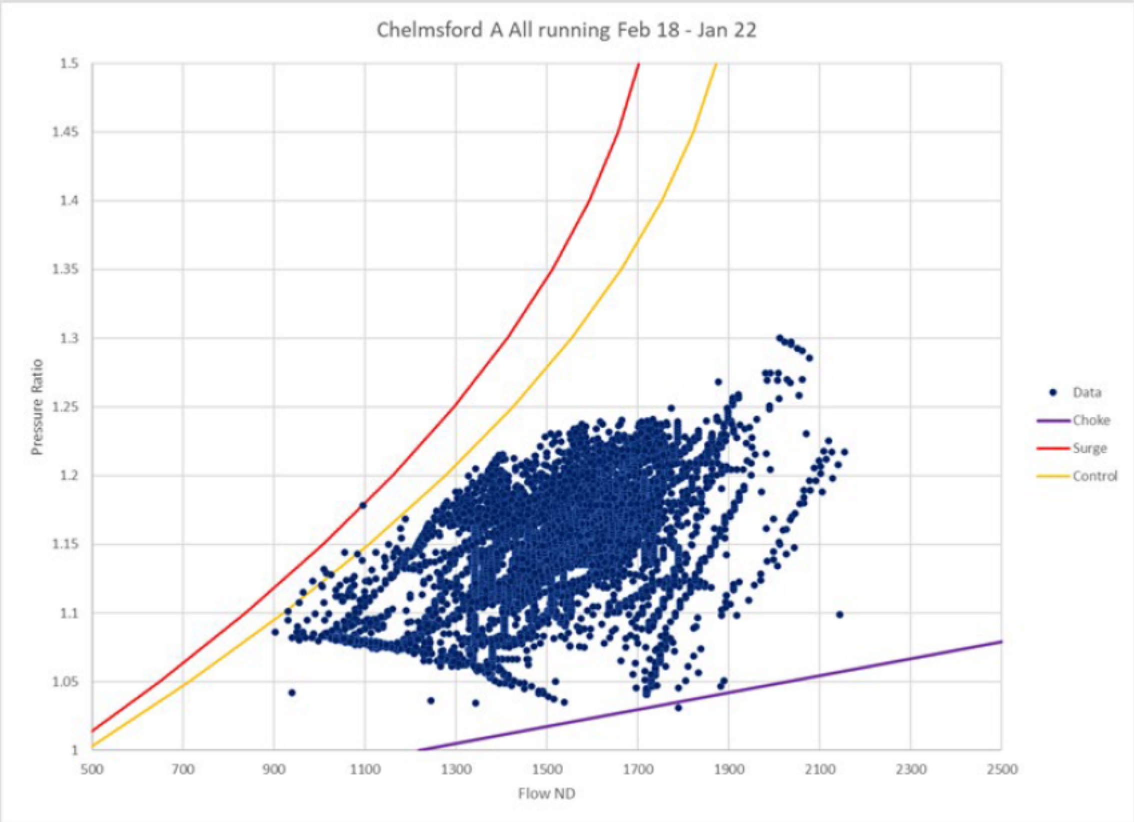

Figure 7 – Historic operating points for Unit A at Chelmsford compressor station

This figure shows that Unit A operated over a reasonable part of its compressor envelope but only sees limited operation. The timeframe for the historic data capture was extended from nominally 1 year (as used for Huntingdon compressor station) to nearly 4 years to get a representative amount of compressor operation. To see the likely effect that a reduction in exhaust cone temperature (ECT) would have on the compressor operating points, the operating points for Unit A were colour coded into 4 ECT bands as shown in Figure 8. As expected, Figure 8 shows that the highest ECT temperature occur at the maximum power of the compressor in the top part of the compressor envelope. It is also clear that there has been very little operation at the higher end. Figure 9 shows a similar compressor operating point plot, but this time coloured coded for variations in NOx. Peak NOx values are all low and never breached the 140 mg/m^3 band.

[redacted]

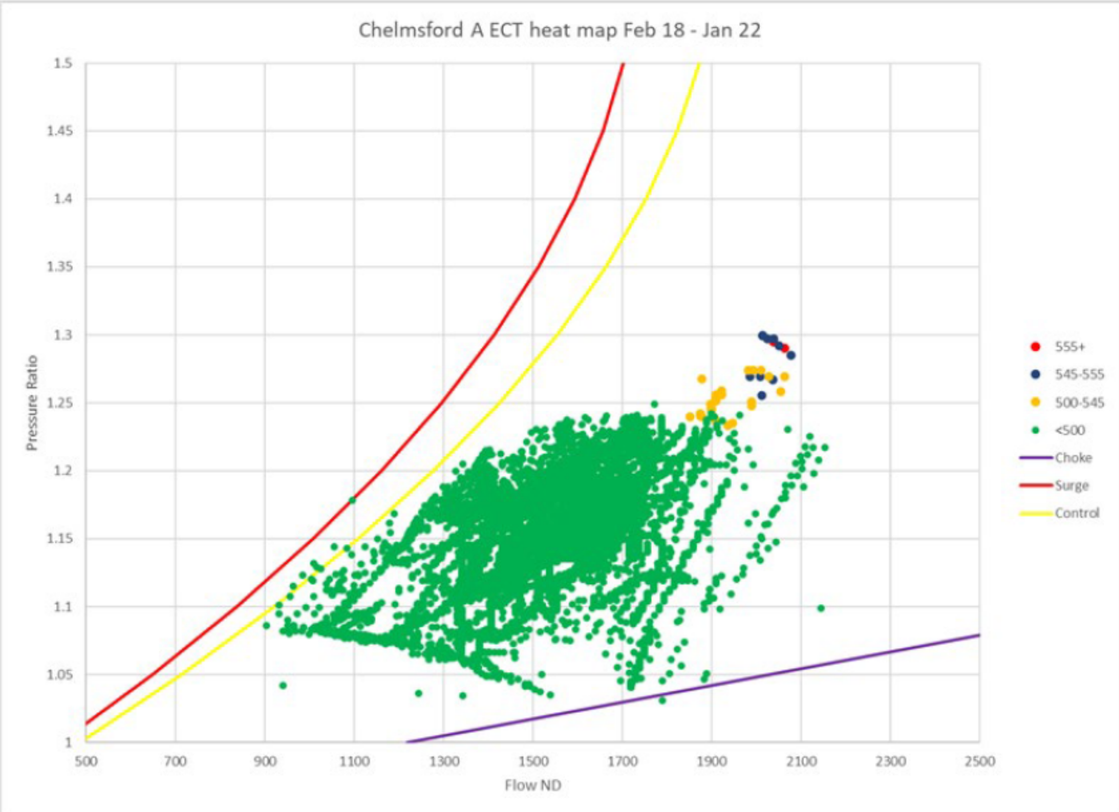

Figure 8 – Historic ECT temperatures for Unit A at Chelmsford compressor station

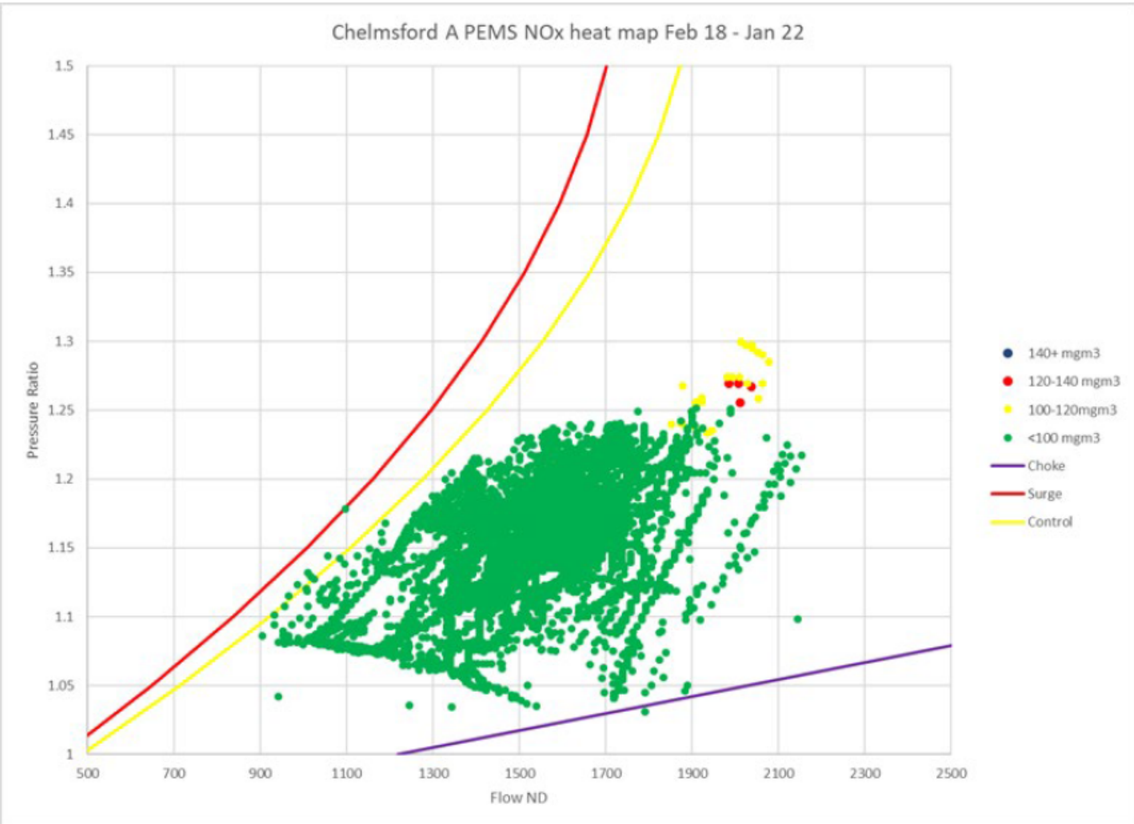

Figure 9 – Historic NOx emissions for Unit A at Chelmsford compressor station

[redacted]

Looking at Figure 9, it can be seen that the compressor was operating with emissions at above 140 mg/m^3 for only a few instances (each data point represents 1 minute averaged operational data). None of the emissions exceeded the 150 mg/m^3 NOx emissions limit as specified in the MCPD.

Unit A at Chelmsford compressor station had an engine swap in September 2016 so only emissions testing data from 2017 onwards can provide a valid comparison. Figure 10 shows the variation between ECT and NOx from the past 3 performance tests undertaken (post engine change). These tests look to all be in alignment based on the current emissions testing procedure with a peak NOx value of 131 mg/m^3.

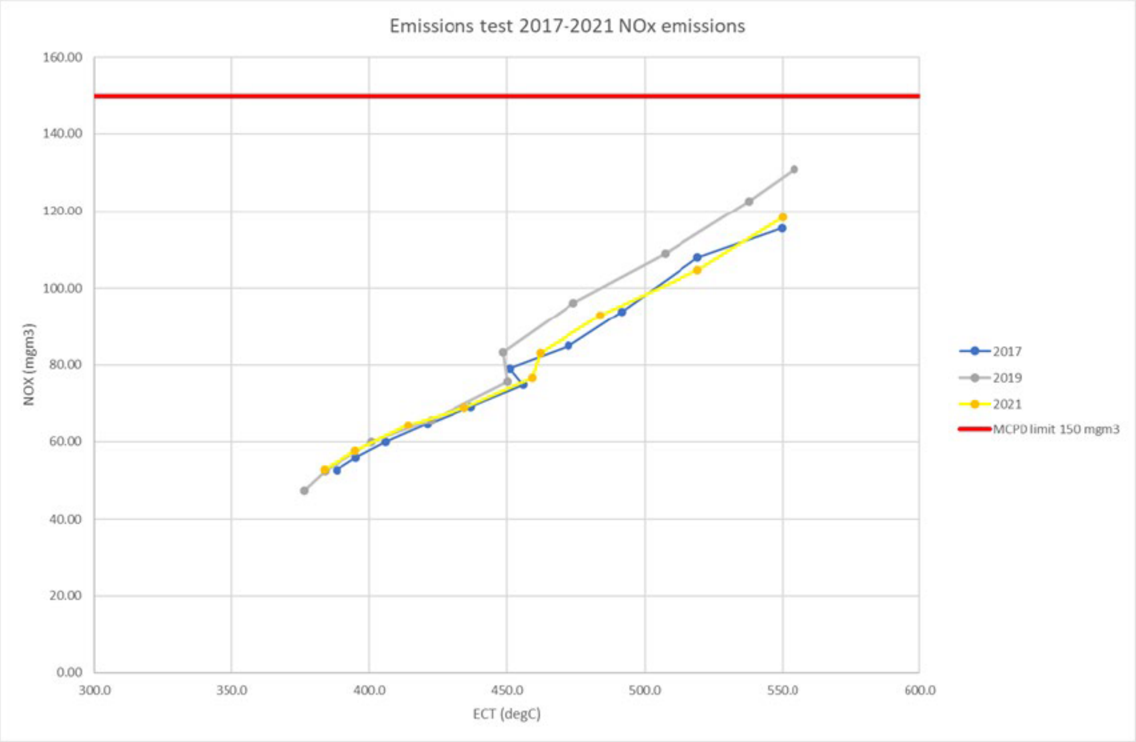

Figure 10 – Historic emissions test data plot showing variation in ECT and NOx

Figure 11 shows the historic emissions test peak NOx vs ECT plot. This shows a reasonably good relationship between NOx and ECT.

[redacted]

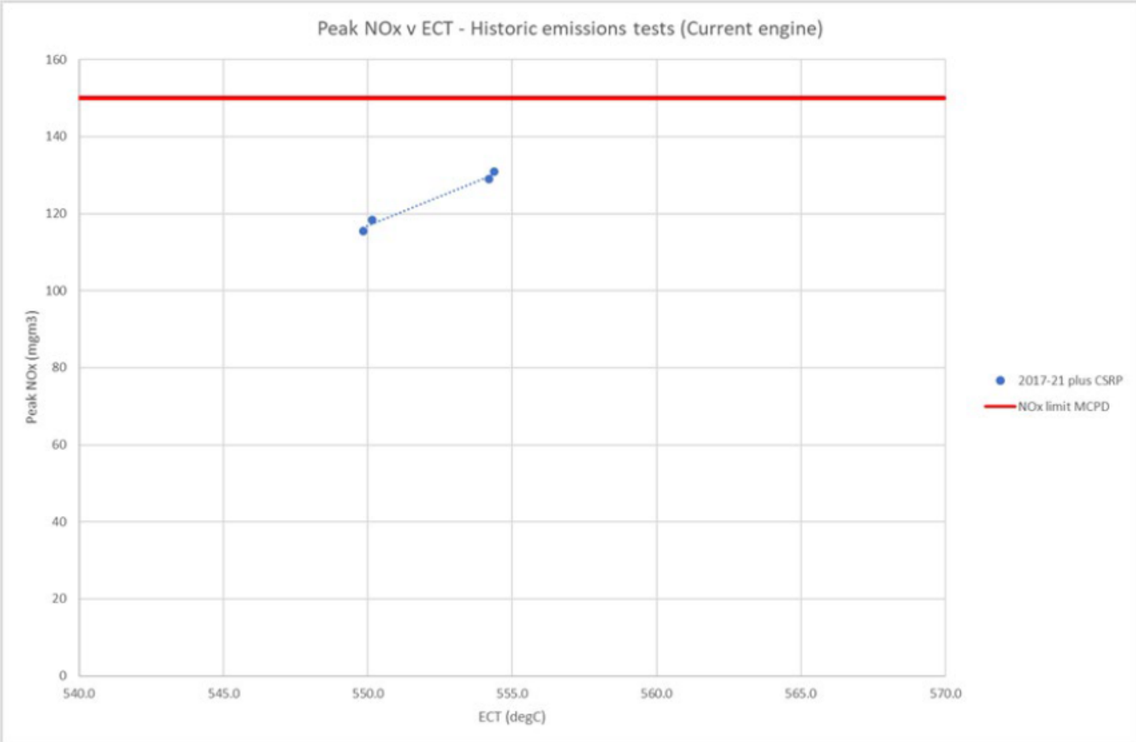

Figure 11 – Historic emissions test peak NOx vs ECT plots

[redacted]

5 TEST METHOD STATEMENT

An example test method statement has been included in Appendix A for Chelmsford compressor station. The method statement for Huntingdon is very similar except for valve numbers which are different on each site.

The test method is split into several phases as follows:

1) Site preparations – this involves the installation of additional sensors (surface mounted temperature probes), calibration checks, reviewing the process for undertaking testing using the performance valve and process for altering the ECT limit in the governor controller.

2) Performance testing – Full unit performance test over 4 speed lines covering the current configurations on site – Establishes a full baseline prior to CSRP testing

3) CSRP testing – Reduction in maximum ECT temperature set-point in the governor controller. Three different set-points to be assessed nominally -10, -20 and -30 °C. After the temperature reduction has been implemented, undertake a further set of performance test points showing the restriction in compressor operation as a result from a reduction in ECT.

4) Each performance test point is taken after readings have been stabilised and temperature variations for the compressor are less than 0.05 °C/min. A full set of averaged data points has been collected from the ALERT system and combined with the emissions data collected by the National Grid emissions team on site at the same time.

[redacted]

6 BASELINE PERFORMANCE TESTING AT HUNTINGDON COMPRESSOR STATION

6.1 Unit selection

Initially, the project was meant to test both units at Huntingdon compressor station, but due to the timings of signing the contracts and winter operation, GNCC could only give up one unit for testing in November 2021, and no units in January 2022.

Unit B was selected as the one unit to be tested for several reasons as follows:

- More reliable ALERT data
- Less hours since wash
- Recent emissions test

6.2 Test points

Appendix B – Table B1 shows the tabulated results from all the performance test points for Huntingdon Unit B. These have also been shown graphically in Figure 12.

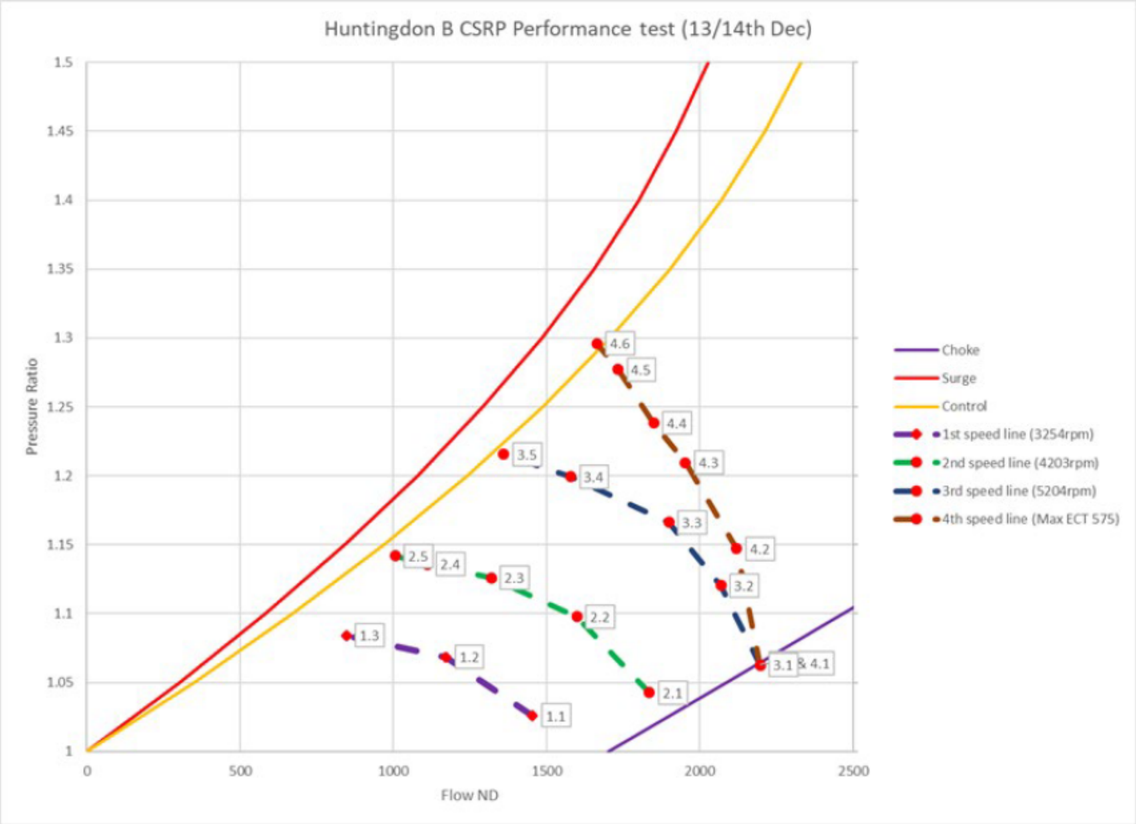

Figure 12 – Huntingdon compressor Unit B performance test points

It should be noted that the maximum speed line was limited by the ECT in the governor controller at around 575 °C, so the 4th speed line could actually be used as an additional CSRP line.

[redacted]

7 CSRP PERFORMANCE TESTING AT HUNTINGDON COMPRESSOR STATION

7.1 ECT

The exhaust cone temperature (ECT) is an averaged value taken from up to 8 temperature sensors located in the gas generator exhaust. The averaged value is used in the governor controller as a controlling parameter alongside engine / compressor speed, gas temperature and pressure, vibration, amongst other parameters to control the engine speed and power to within safe limits.

Changing the ECT limits was a little more difficult than originally thought. The maximum ECT temperature in the governor controller is actually derived from a chart rather than a single value, so that it makes an allowance for ambient air temperature. The higher the ambient temperature the higher the ECT limit is set as shown in Figure 13.

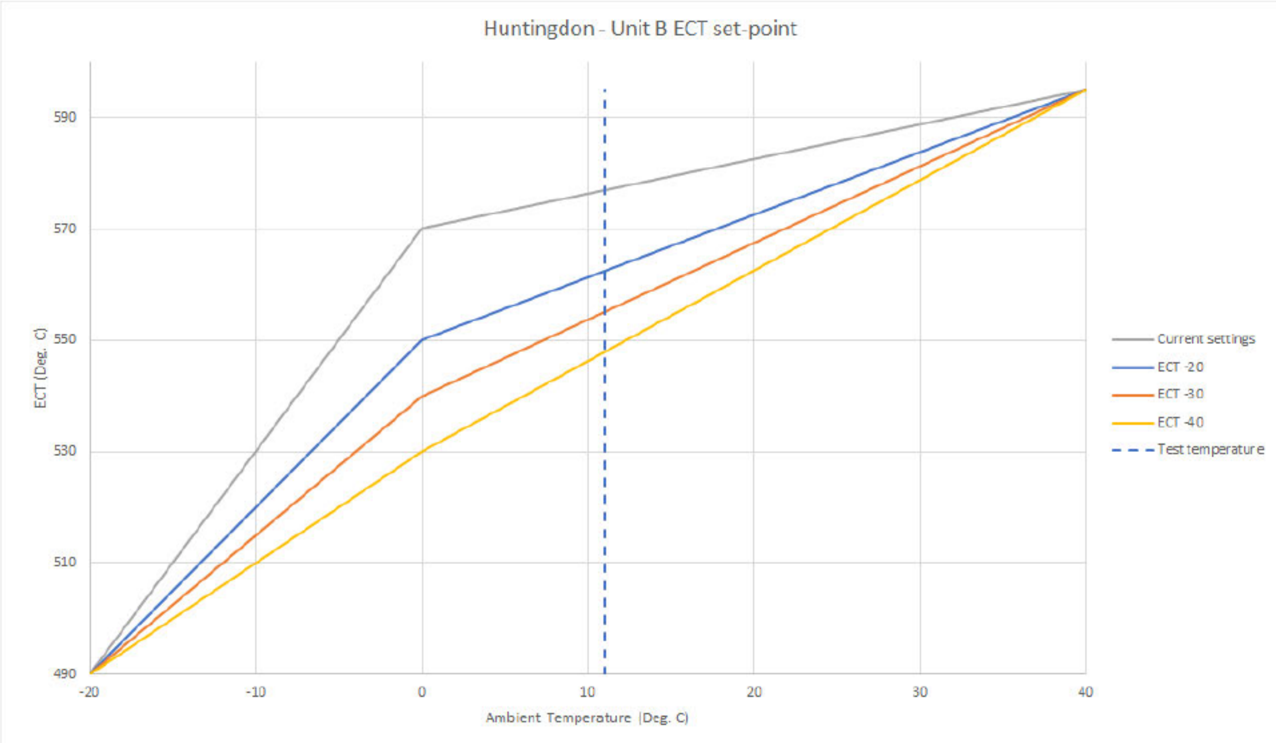

Figure 13 – ECT variation with ambient temperature for Huntingdon Unit B

Because of this profile, it was unclear how to best define a temperature reduction and it was decided to change the 0 °C data points for each test only as shown in Table 2. I.e., only the 0 °C set-point was changed by either 20, 30 or 40 °C. which changed the actual set-point at the conditions of testing by 14 °C, 20 °C and 29 °C respectively. These lines have also been shown in Figure 13.

In theory the maximum ECT allowed in the governor controller would be 595 °C based on an ambient temperature of 40 °C.

[redacted]

Table 2 – ECT set-points for Huntingdon – Unit B

ECT Label	-20 °C set-point	0 °C set-point	40 °C set-point	Actual ECT limit during testing at around 11 °C ambient
Normal	490 °C	570 °C	595 °C	575 °C
ECT - 20	490 °C	550 °C	595 °C	561 °C
ECT -30	490 °C	540 °C	595 °C	555 °C
ECT -40	490 °C	530 °C	595 °C	546 °C

7.2 Manual temperature measurements

No adequate position could be found which was suitable for accurate manual temperature readings, therefore site instrumentation was used as an alternative, which is likely to affect the compressor efficiency calculations Engine calculations will not be affected.

7.3 Results

Appendix B – Table B.2 shows the full results from the CSRP testing undertaken at Huntingdon and Figure 14 shows the maximum power limits (restricted by ECT) for Unit B on the compressor operating envelope during CSRP testing. Figure 15 shows a similar graph except that the restrictions have been replaced by NOx emission reductions. This chart shows that the NOx emissions reduction at the ECT -30 set-point was around 10 mg/m^3 from 128 mg/m^3 down to 118 mg/m^3.

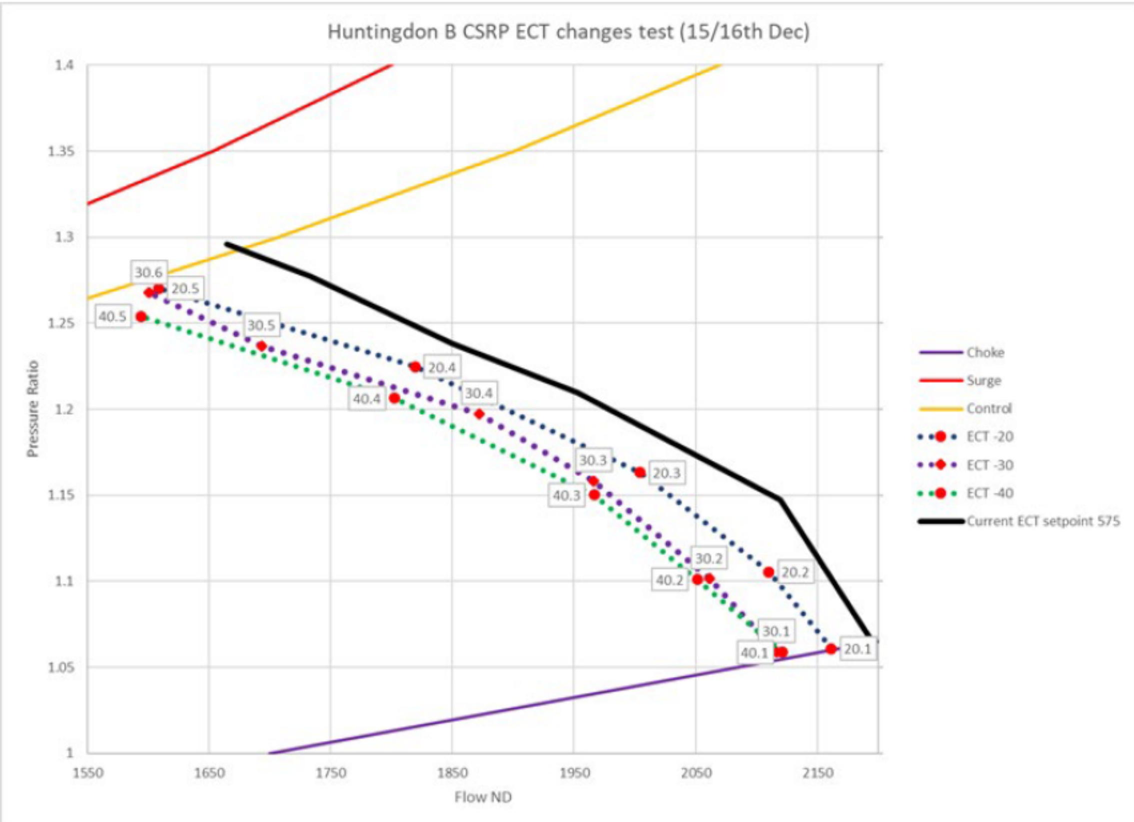

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Figure 14 – Huntingdon – Unit B CSRP set-point limitations

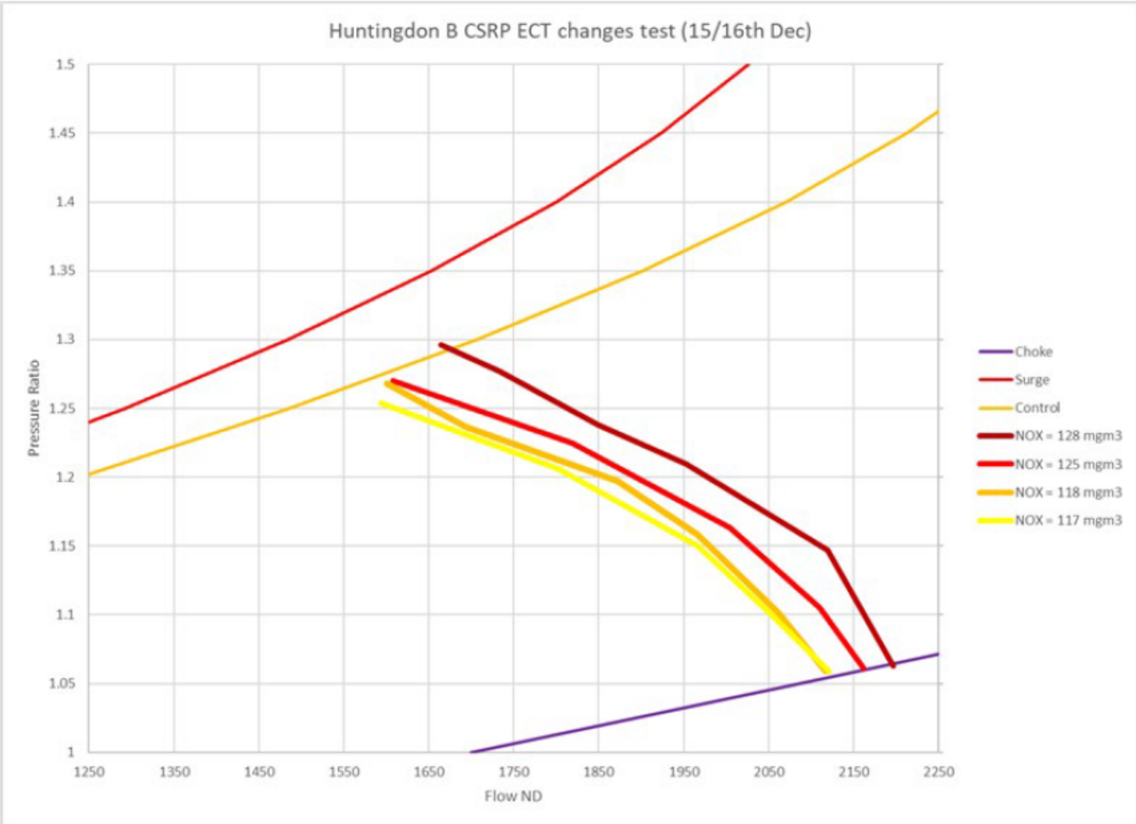


Figure 15 – Huntingdon – Unit B CSRP NOx restrictions

7.4 Discussion

The CSRP results for Huntingdon – Unit B would indicate that CSRP is likely to be able to provide a reduction of NOx emissions. Figure 16 and Figure 17 show the relationship between NOx and ECT and NTI (net thermal input) respectively. Both the performance test data and the emissions test data show a good agreement with the data points lying on a slight curve as shown in the respective figures.

The difficulty has been that none of the data points collected during the testing or recent emissions tests breached the MCPD limit of 150 mg/m^3 NOx which would appear to mean that CSRP would not be required at Huntingdon. The differences could be put down to the ambient conditions at which the testing took place. At higher ambient temperatures the NOx emissions will be higher as the ECT values will increase (and still be below the maximum allowable set-point of 595 °C).

Figure 16 also shows some trend lines to see how the NOx varies with ECT. Slightly different lines are drawn depending on whether the performance test data or the CSRP test data is used, with the ECT required to breach the NOx MCPD limits varying between 585 °C and 611 °C. A combination of using all the data gives a predicted ECT at 150 mg/m^3 NOx at 604 °C which is above the maximum temperature set in the governor controller.

Due to this sensitivity, it is recommended that further testing is undertaken when the ambient conditions are more suitable (summer time) and the restrictions on the ECT can be removed to see the maximum potential values for the unit.

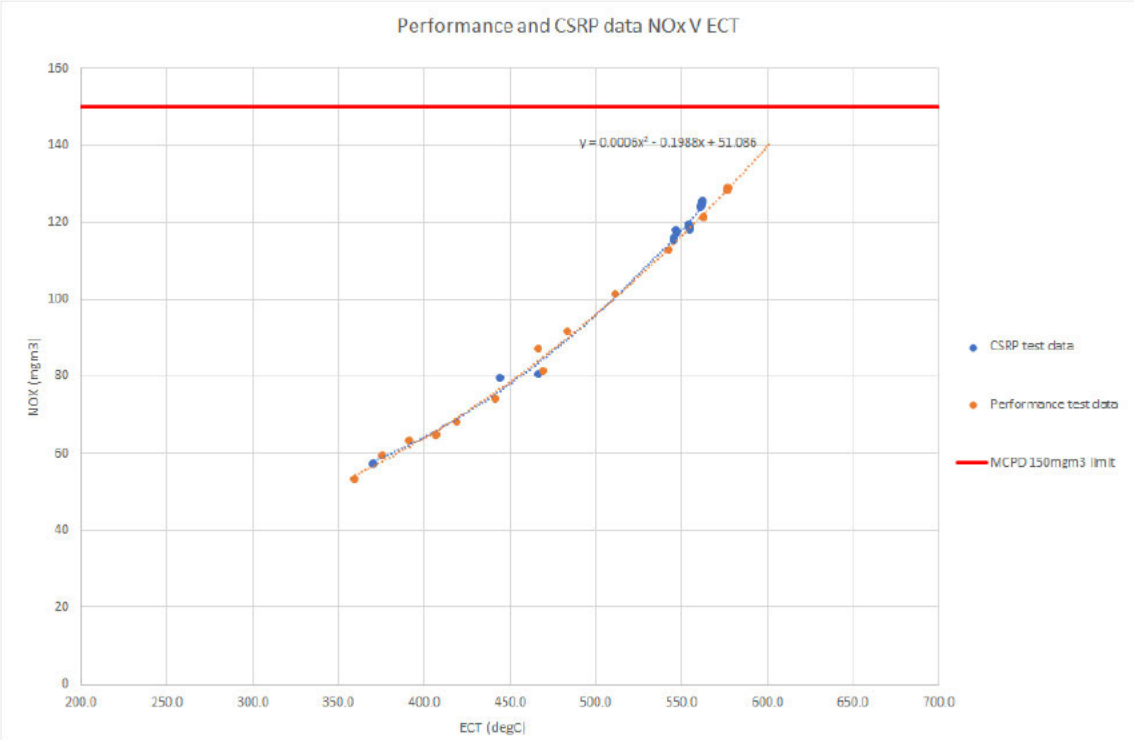


Figure 16 – Huntingdon – Unit B relationship between NOx and ECT

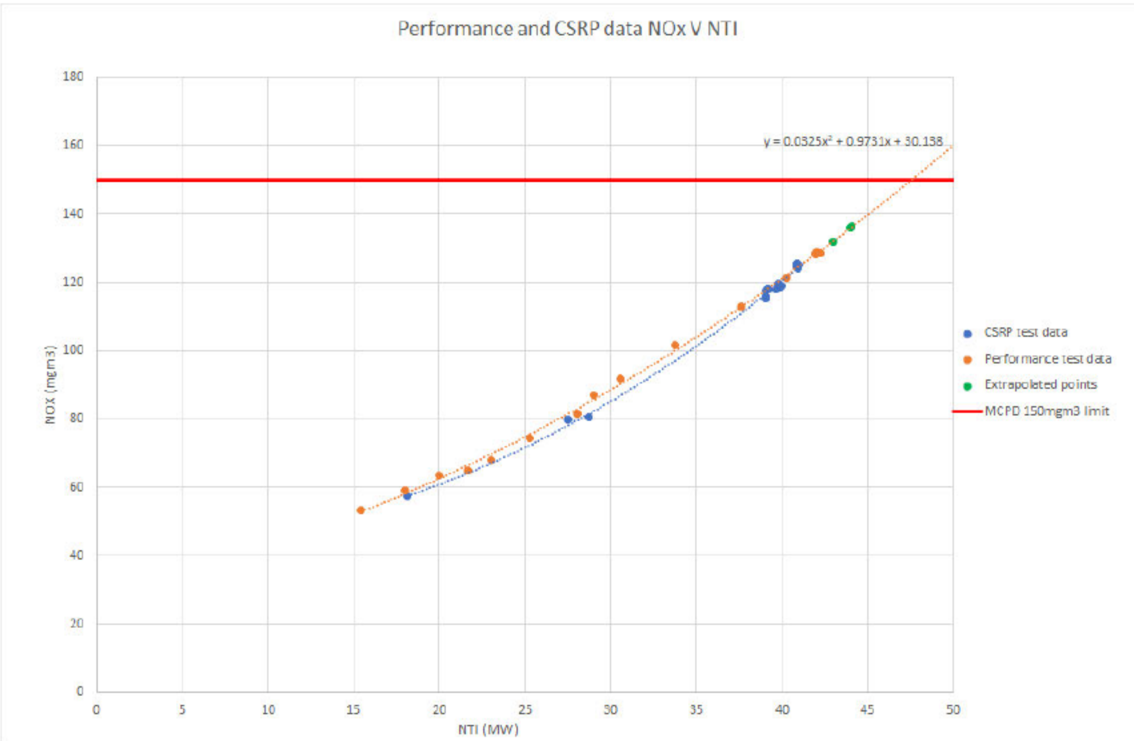


Figure 17 – Huntingdon – Unit B relationship between NOx and NTI

7.5 Data assessment

In addition to the performance data points, 3 additional data test points were interpolated to help with the BAT analysis being undertaken by PESL. Figure 18 shows the original performance test points with a new set of interpolated data points (5.1 to 5.3). The historical operation of the compressor over the last year has also been included and shows that the newly interpolated data points encompass almost the entire operating envelope.

The method used to interpolate the additional data points involved analysis of the historic compressor operation of the unit using the ALERT data. The specific points where selected by choosing data points at the extremities of the compressor operational range – not achievable during the test visit. This was to explore the peak NOx emissions in these regions of the compressor map. Once each operational point was selected, the timestamp was used to capture the corresponding operational parameters to map alongside the existing points captured during the test visit.

The ambient conditions for the interpolated points ranged from 7-13 °C. It appears limited high load running with high ambient temperatures occurred between September 2020 and November 2021. This would be a limitation of the historic dataset used. The peak NOx reading interpolated was 136 mg/m^3, which remained below the MCPD limit. Higher NOx emissions would be expected during high load running in warmer ambient temperatures (+20 °C).

These data points have also been included in Appendix B – Table B.1.

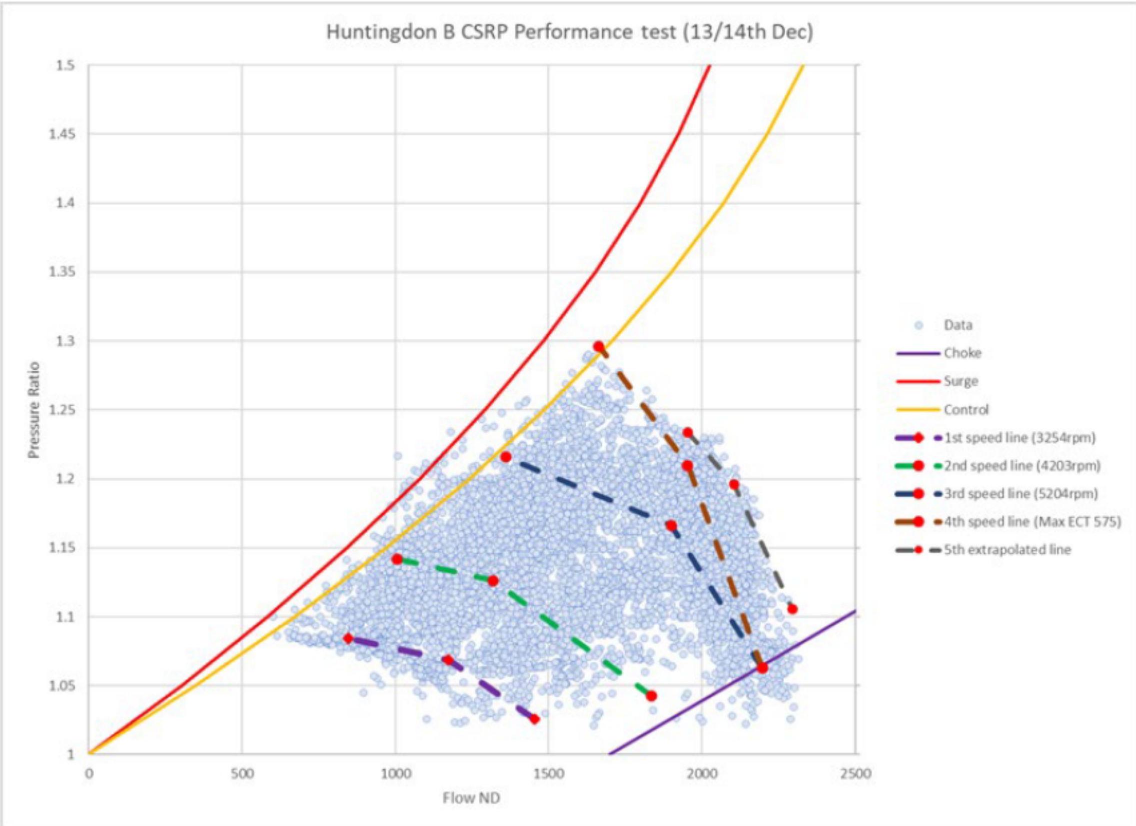


Figure 18 – Huntingdon – Unit B performance points and extra interpolated data points

[redacted]

8 BASELINE PERFORMANCE TESTING AT CHELMSFORD COMPRESSOR STATION

8.1 Unit selection

Initially, the project was meant to test both units at Huntingdon compressor station, but due to the timings of signing the contracts and winter operation, GNCC could only give up one unit for testing in November 2021 and no units in January 2022. Therefore, Unit A at Chelmsford was selected as an alternative unit. This decision was based on the following parameters:

- The governor controller at Chelmsford is identical to Huntingdon, allowing for the easy implementation of CSRP
- Chelmsford is less in demand on the grid and as a result could accommodate the testing in agreement with GNCC
- Unit A at Chelmsford has seen significantly more operation than Unit B (although still limited)

8.2 Test points

Appendix B – Table B3 shows the tabulated results from all the performance test points for Chelmsford Unit A. These have also been shown graphically in Figure 19. The maximum power line was limited by ECT at around 552 °C

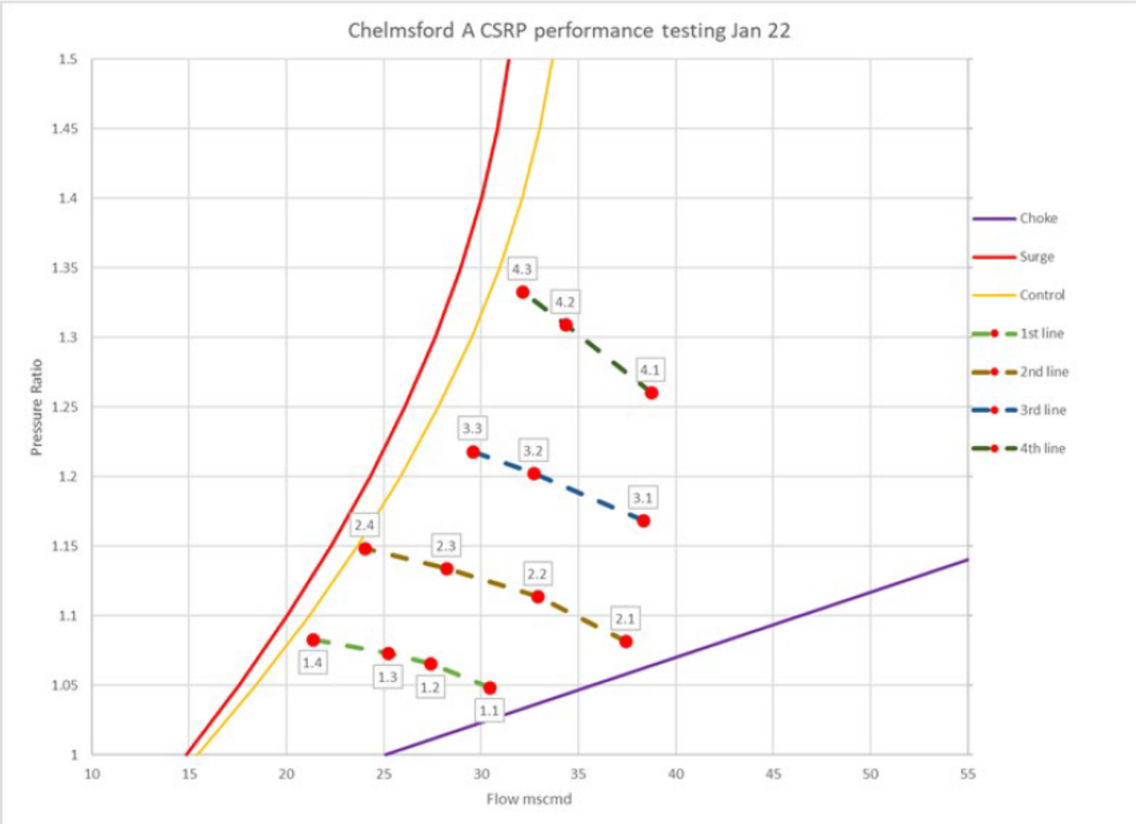


Figure 19 – Chelmsford compressor Unit A performance test points

One problem encountered at Chelmsford which had not been expected was a restriction in the station maximum flow to 40 mscm/d. This flow limit is due to the name plate capacity for the two station scrubbers working in parallel and cannot be changed easily. By comparison, Huntingdon reached a maximum flow of 52.6 mscm/d during testing and could have reached more if ECT limits had been raised. Consequently, the performance testing at Chelmsford could only operate at the left side of the compressor envelope limiting the number of data points.

[redacted]

9 CSRP PERFORMANCE TESTING AT CHELMSFORD COMPRESSOR STATION

9.1 ECT

The configuration of ECT at Chelmsford was very similar to Huntingdon except that the values were different.

The higher the ambient temperature the higher the ECT limit is set as shown in Figure 13.

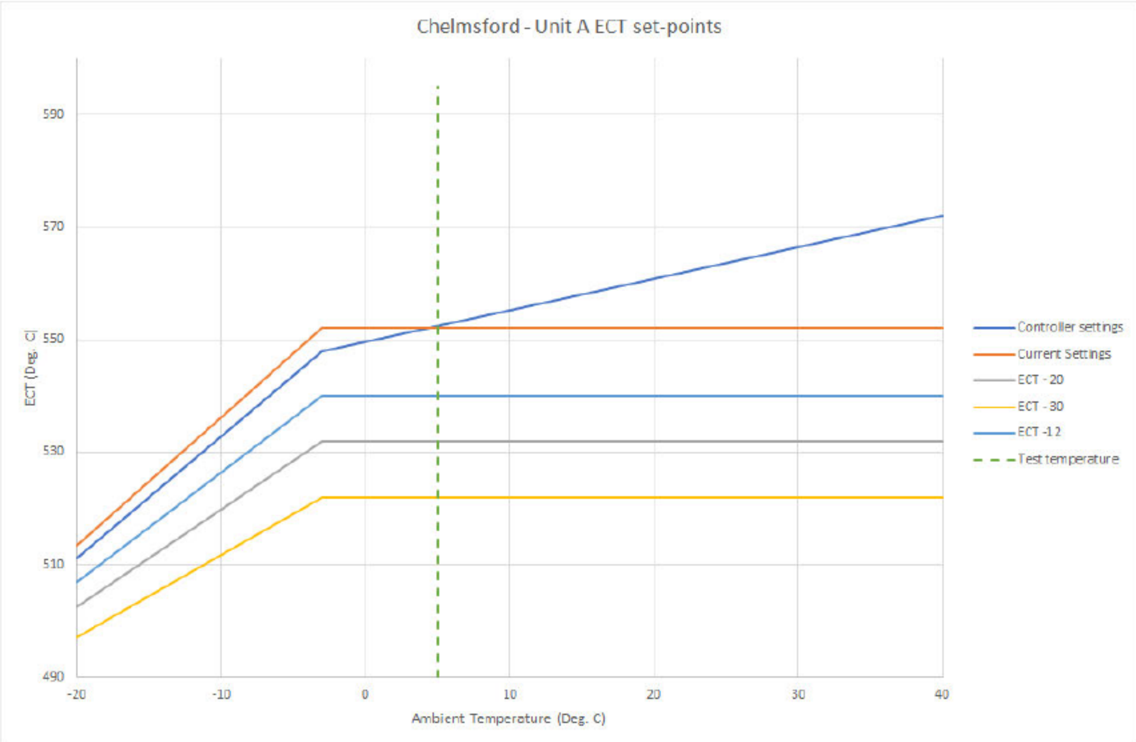


Figure 20 – ECT variation with ambient temperature for Chelmsford Unit A

The temperature profile was altered from the original set-points in the governor controller to generate a flat line, initially at the first test conditions (around 5 °C) and then dropped by 20 °C, 30 °C and finally 12 °C. Table 3 shows the set-points used at Chelmsford. This slightly different technique was adopted for Chelmsford to make the relevant changes simpler to follow and remove any variations due to slight changes in ambient conditions.

[redacted]

Table 3 – ECT set-points for Chelmsford – Unit A

ECT Label	-40 °C set-point	-3 °C set-point	40 °C set-point	Actual ECT limit during testing at around 5 °C ambient
Performance test	468 °C	552 °C	552 °C	552 °C
ECT - 20	468 °C	532 °C	532 °C	532 °C
ECT -30	468 °C	522 °C	522 °C	522 °C
ECT -40	468 °C	540 °C	540 °C	540 °C

9.2 Results

Appendix B – Table B.4 shows the full results from the CSRP testing undertaken at Chelmsford and Figure 21 highlights the maximum power limits (restricted by ECT) for Unit A on the compressor operating envelope during CSRP testing. Figure 22 shows a similar graph except that the restrictions have been replaced by NOx emission reductions. This chart shows that the NOx emissions reduction at the ECT -20 set-point was around 9 mg/m^3 from 128 mg/m^3 down to 119 mg/m^3.

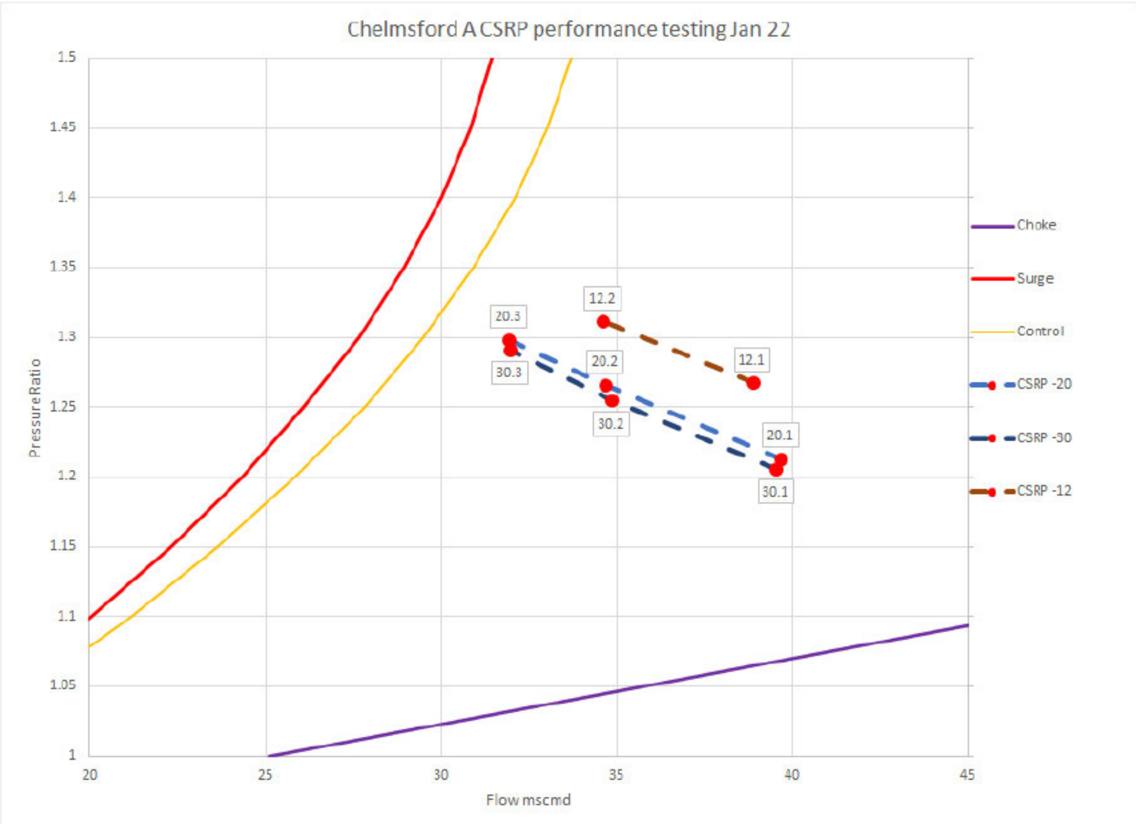


Figure 21 – Chelmsford – Unit A CSRP set-point limitations

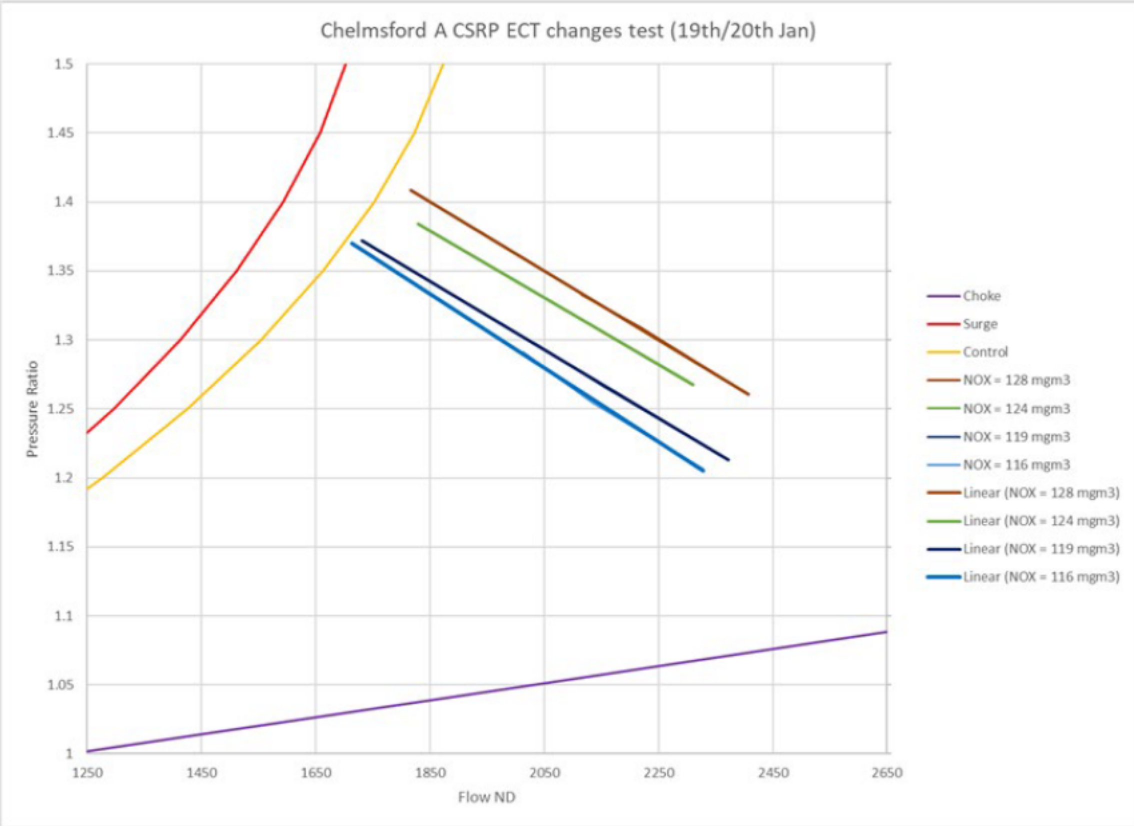


Figure 22 – Chelmsford – Unit A CSRP NOx restrictions

9.3 Discussion

The CSRP results for Chelmsford – Unit A would indicate that CSRP is likely to be able to provide a reduction of NOx emissions. Figure 23 and Figure 24 show the relationship between NOx and ECT and NTI (net thermal input) respectively. Both the performance test data and the emissions test data show a good agreement with the data points lying on a slight curve as shown in the respective figures.

Figure 23 also show some trend lines to see how the NOx varies with ECT. Slightly different lines are drawn depending on whether the performance test data or the CSRP test data is used with the ECT required to breach the NOx MCPD limits, but they are all trending to cross the 150 mg/m^3 MCPD limit above the maximum value for ECT set in the governor controller at the moment of 572 °C.

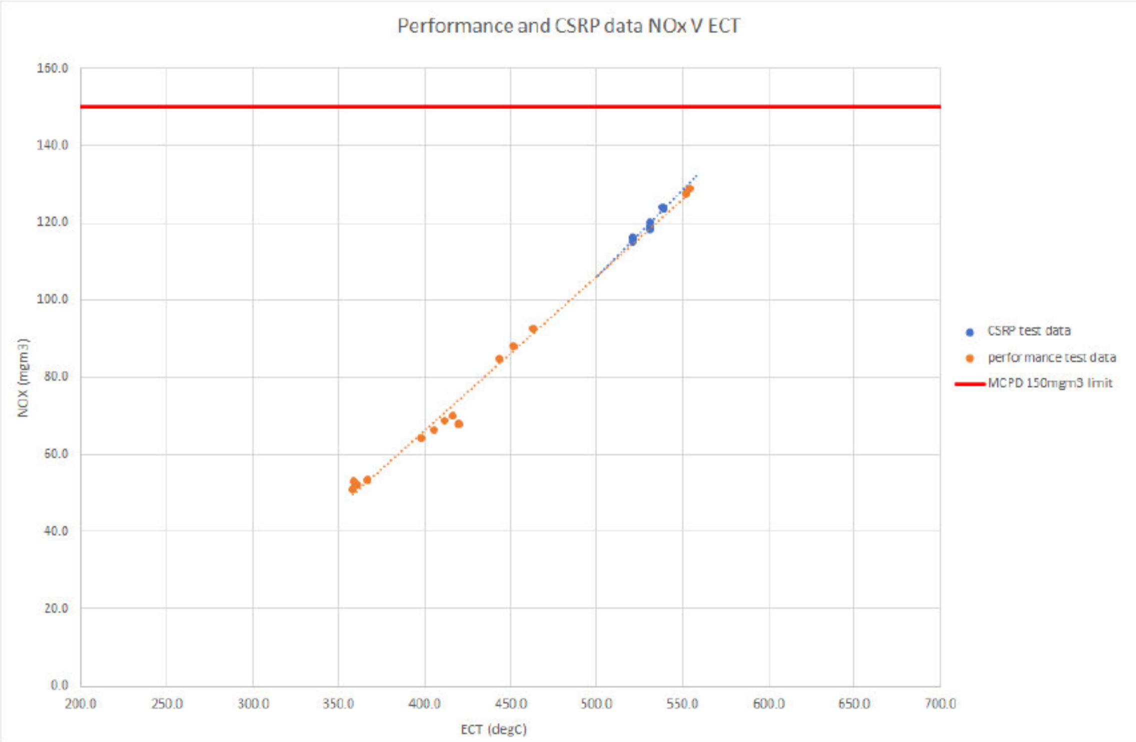


Figure 23 – Chelmsford – Unit A relationship between NOx and ECT

Figure 24 – Chelmsford – Unit A relationship between NOx and NTI

10 IMPLICATIONS OF RESULTS

10.1 Huntingdon – Unit B

If CSRP was to be deployed at Huntingdon, then there is the possibility that parts of the compressor operating envelope where Huntingdon do currently operate will not be achievable. Figure 25 shows the total run hours of data for Unit B at Huntingdon from September 2020- November 2021, together with the run hours which would not be achievable if CSRP was adopted at a given ECT temperature below 595 °C. For example, if the NOx emissions had to be reduced by 10 mg/m^3, an ECT restriction of around 20 °C would be needed (575 °C) which would present just under a 10% loss of available operating capacity based on run hours and National Grid would need to decide if that restriction would be acceptable for network operation. A review of the data collected over the last year showed a maximum NOx emission of 149 mg/m^3 (for a 10-minute period) at an ECT of 586 °C. Restricting the unit to this level would not lead to a loss of compressor operability based on the compressor operation observed between September 2020 and November 2021.

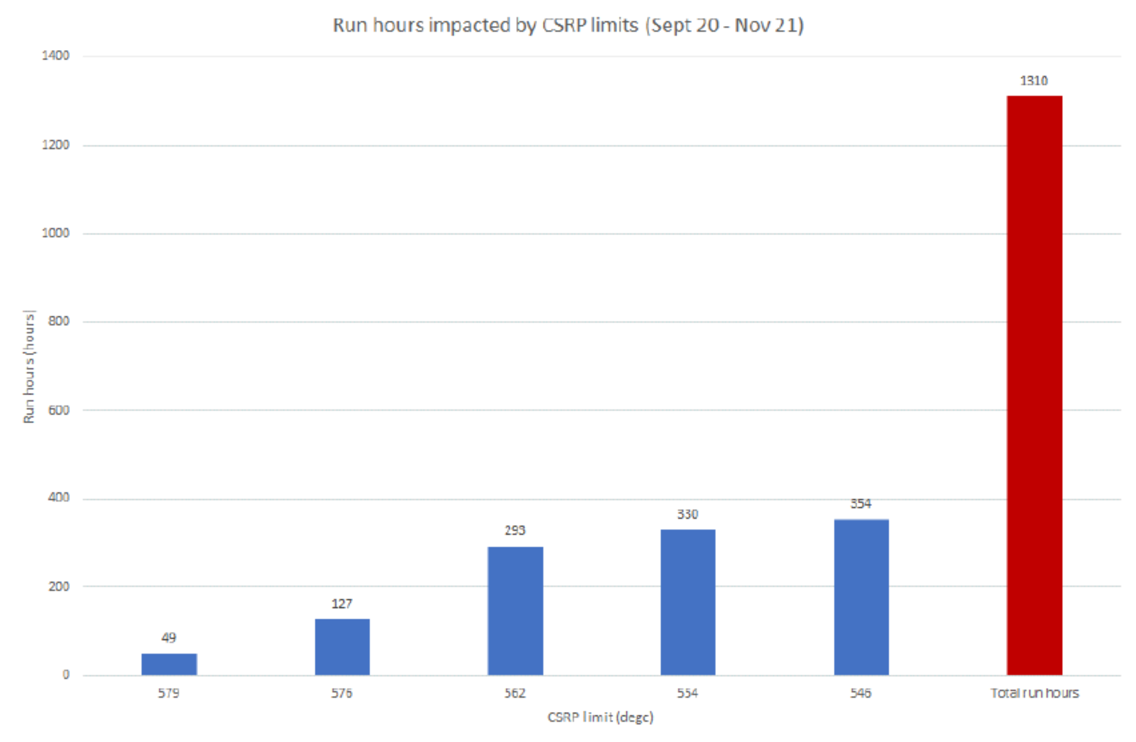


Figure 25 – Limitations in run hours for various ECT restrictions for Huntingdon Unit B

10.2 Chelmsford – Unit A

If CSRP was to be deployed at Chelmsford, then there is the possibility that parts of the compressor operating envelope where Chelmsford do currently operate will not be achievable. Figure 26 shows the total run hours of data for Unit A at Chelmsford over the last 3 years, together with the run hours which would not be achievable if CSRP was adopted at a given ECT temperature below 572 °C. For example, if the NOx emissions had to be reduced by 10 mg/m^3, an ECT restriction of around 20 °C would be needed (552 °C) which would present just under a 0.1% loss of available operating capacity based on run hours.

Ultimately, CSRP should not be required at Chelmsford if the station operating restrictions remain in place, but confirmation would be required as to whether the environmental regulator would allow an Avon unit to be classed as complaint with MCPD limits beyond 2030 without having any modifications to its current control system. Alternatively, a nominal CSRP setpoint may be necessary to ensure the unit is incapable of ever exceeding the NOx limits.

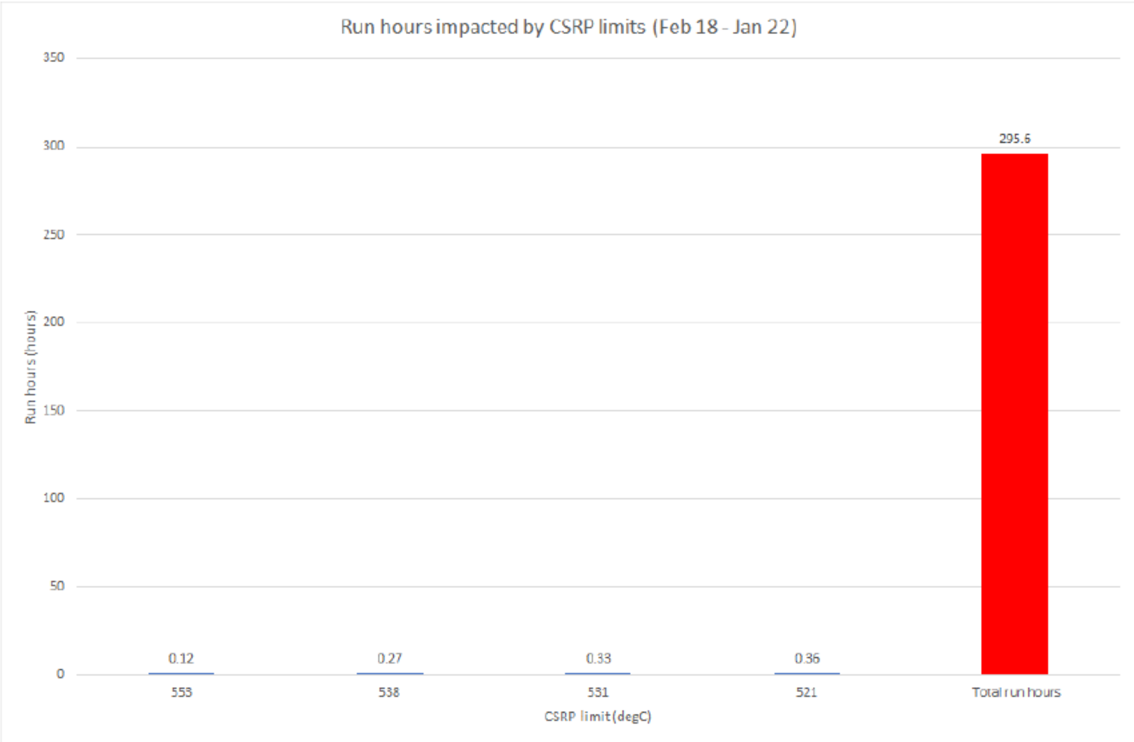


Figure 26 – Limitations in run hours for various ECT restrictions for Chelmsford Unit A

10.3 General comments

The testing campaigns at Huntingdon and Chelmsford have identified that whilst the units and governor controller are the same, unique differences in station operation, governor configuration, engine and compressor operation exist which can affect the emissions from a compressor. This indicates that the implementation of CSRP on a given site/compressor unit will require tailoring to the unique set up of each individual unit. As a result, [redacted] would recommend individual compressor unit assessments including, performance and CSRP testing, historic data analysis and thorough governor controller testing for any unit considered for CSRP.

If CSRP is implemented on a unit, consideration should be made around utilising the annual emissions data to provide verification that any ECT limit applied still ensures the NOx levels remain below the MCPD limit.

This will be particularly relevant if engine changes occur when a slightly more detailed CSRP emissions test would be recommended.

[redacted]

11 COMPARISON OF EMISSIONS MONITORING SYSTEMS

Currently all gas driven units on the National Grid compressor fleet use an emissions monitoring system called PEMS (predictive emissions monitoring). This system predicts the emissions based on fuel flow, ambient and operating conditions. It is derived using an algorithm from annual emissions tests. The ALERT PEMS has provided reportable continuous emissions monitoring for NO_x, CO and EU ETS CO_2 across the NG fleet for over 20 years. PEMS is permitted by the regulator (EA, SEPA) provided the results are within 20% of the actual results over the full operating range.

The performance testing undertaken at Huntingdon and Chelmsford provided a useful exercise to compare the PEMS, with the mobile NG CEMS (continuous emissions monitoring) laboratory, as it is not often that there is 3-4 days of testing on a unit with parallel emissions monitoring.

Table 4 and Table 5 present the results from Huntingdon and Chelmsford respectively and these are also shown graphically in Figure 27 and Figure 28.

The quality assurance criteria for emissions monitoring systems detailed in the industrial emissions directive (IED) states an acceptable limit of 10% for CO and 20% for NO_x. The CSRP test data from Huntingdon and Chelmsford demonstrates the ALERT PEMS has the adequate accuracy levels to satisfy the regulators and demonstrate equivalence to CEMS. For reference the same quality assurance limits are applicable to CEMS.

[redacted]

Table 4 – CEMS vs PEMS comparison data for Huntingdon Unit B

Timestamp	Test reference	Lab CO (mgm3)	CO Alert (mgm3)	Difference (%)	Lab NOx (mgm3)	NOx Alert (mgm3)	Difference (%)
13/12/2021 11:32	1.1	788.9	729.5	7.5	63.5	45.8	27.9
13/12/2021 12:04	1.2	930.9	819.2	12.0	59.3	43.4	26.9
13/12/2021 12:43	1.3	1209.9	927.9	23.3	53.3	40.8	23.5
13/12/2021 13:53	2.1	452.3	443.3	2.0	87.1	67.4	22.6
13/12/2021 15:07	2.2	555.9	518.2	6.8	74.3	53.7	27.7
13/12/2021 16:14	2.3	696.8	649.5	6.8	64.8	48.3	25.5
14/12/2021 09:23	3.1	252.0	251.0	0.4	128.4	119.3	7.1
14/12/2021 10:35	3.2	300.7	310.0	-3.1	112.9	103.4	8.5
14/12/2021 11:33	3.3	406.9	413.5	-1.6	91.7	75.5	17.7
14/12/2021 12:27	4.1	252.0	251.0	0.4	128.4	119.3	7.1
14/12/2021 12:54	4.2	242.2	250.3	-3.4	128.9	119.5	7.3
14/12/2021 14:10	4.3	245.9	251.9	-2.4	128.8	119.0	7.6
15/12/2021 15:04	30.1	282.0	289.3	-2.6	118.1	109.0	7.7
15/12/2021 15:22	30.2	278.6	289.3	-3.8	118.5	109.0	8.1
15/12/2021 15:48	30.3	275.9	289.5	-4.9	118.5	108.9	8.1
15/12/2021 16:08	30.4	274.8	290.2	-5.6	118.8	108.7	8.5
15/12/2021 16:30	30.5	272.1	289.1	-6.3	119.1	109.0	8.5
16/12/2021 10:38	30.6	263.1	290.9	-10.6	119.7	108.5	9.3
16/12/2021 11:08	40.1	280.4	303.1	-8.1	118.0	105.2	10.8
16/12/2021 11:33	40.2	277.0	301.9	-9.0	117.9	105.5	10.5
16/12/2021 11:55	40.3	275.7	302.3	-9.7	117.5	105.4	10.3
16/12/2021 12:17	40.4	278.3	305.5	-9.8	116.0	104.6	9.9
16/12/2021 12:44	40.5	276.6	305.6	-10.5	115.2	104.6	9.2
16/12/2021 13:17	20.1	257.8	278.4	-8.0	124.2	111.9	9.9
16/12/2021 13:50	20.2	252.7	276.5	-9.4	125.2	112.4	10.2
16/12/2021 14:14	20.3	250.4	276.4	-10.4	125.3	112.4	10.3
16/12/2021 14:52	20.4	248.7	276.6	-11.2	125.5	112.4	10.5
16/12/2021 15:25	20.5	248.7	277.5	-11.6	124.4	112.1	9.9
Overall discrepancy				**-3.0**			**12.9**
Acceptable regulatory discrepancy				10.0			20.0

Table 5 – CEMS vs PEMS comparison data for Chelmsford Unit A

Timestamp	Test reference	Lab CO (mgm3)	CO Alert (mgm3)	Difference (%)	Lab NOx (mgm3)	NOx Alert (mgm3)	Difference (%)
18/01/2022 10:35	1.1	1263.0	1296.1	-2.6	40.6	53.1	-30.8
18/01/2022 10:54	1.2	1223.5	1274.1	-4.1	41.7	52.2	-25.1
18/01/2022 11:24	1.3	1235.7	1308.2	-5.9	41.4	51.8	-25.1
18/01/2022 11:51	1.4	1257.8	1385.5	-10.2	40.8	51.0	-25.0
18/01/2022 12:39	2.1	581.5	581.5	0.0	66.3	70.0	-5.6
18/01/2022 13:32	2.2	614.3	606.3	1.3	64.5	68.6	-6.5
18/01/2022 13:59	2.3	668.0	650.1	2.7	61.7	66.3	-7.4
18/01/2022 14:33	2.4	737.2	706.7	4.1	58.6	64.3	-9.9
18/01/2022 15:23	3.1	378.0	359.9	4.8	87.1	92.8	-6.5
18/01/2022 15:54	3.2	398.4	394.6	1.0	82.1	88.2	-7.4
18/01/2022 16:22	3.3	423.9	421.6	0.5	78.6	84.9	-8.0
19/01/2022 12:30	4.1	192.0	188.5	1.8	125.8	127.7	-1.5
19/01/2022 13:12	4.2	191.5	189.1	1.3	125.9	127.5	-1.3
19/01/2022 13:39	4.3	188.7	185.1	1.9	126.7	128.9	-1.8
19/01/2022 14:05	20.1	224.0	216.9	3.2	116.7	118.4	-1.5
19/01/2022 14:29	20.2	224.2	218.3	2.6	116.7	118.9	-1.9
19/01/2022 14:48	20.3	224.4	216.2	3.7	116.6	120.0	-2.9
19/01/2022 15:13	30.1	239.7	230.0	4.1	112.3	116.4	-3.6
19/01/2022 15:39	30.2	239.6	231.7	3.3	112.4	115.8	-3.1
19/01/2022 16:18	30.3	239.7	233.8	2.5	112.3	115.1	-2.4
20/01/2022 11:43	12.1	212.7	200.6	5.7	119.9	123.8	-3.3
20/01/2022 12:00	12.2	212.2	197.6	6.9	120.1	124.2	-3.5
Overall discrepancy				**1.3**			**-8.4**
Acceptable regulatory discrepancy				10.0			20.0

[redacted]

Figure 27 – CEMS vs PEMS comparisons for Huntingdon – Unit B

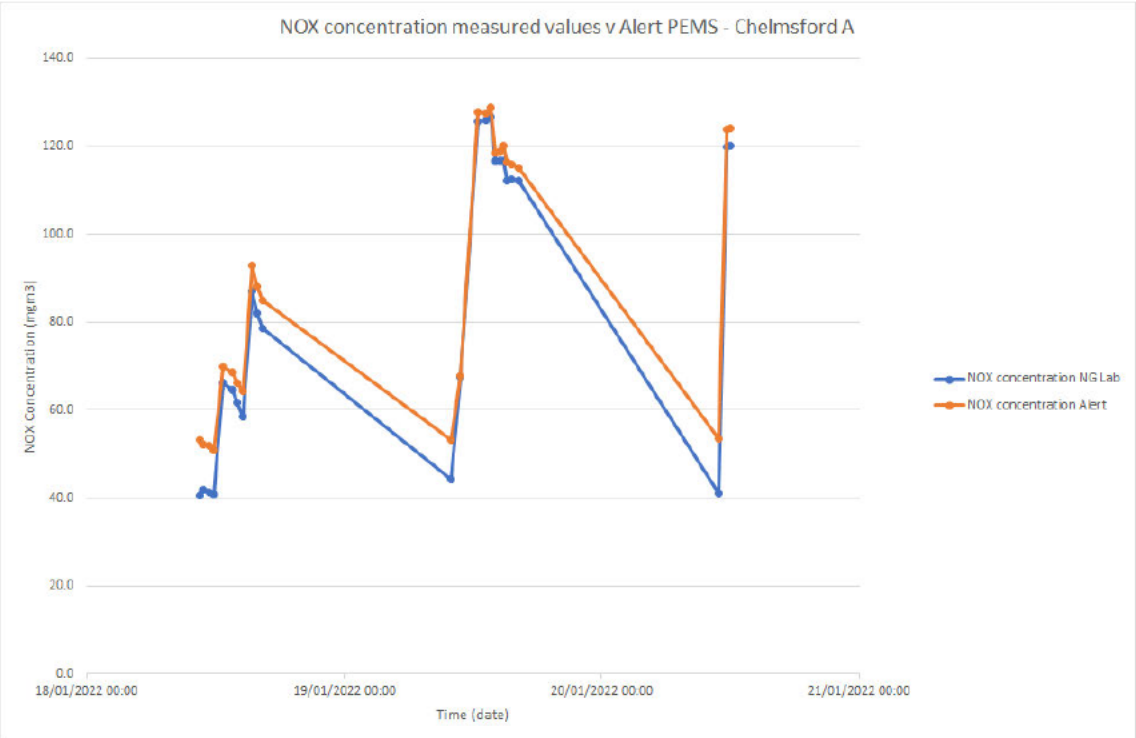


Figure 28 – CEMS vs PEMS comparisons for Chelmsford Unit A

[redacted]

12 CONCLUSIONS

CSRP testing has been successfully undertaken on two National Grid compressor units (Huntingdon – Unit B and Chelmsford – Unit A) between December 2021 and January 2022. The following conclusions can be drawn from the testing:

For Huntingdon compressor unit B

1) From historical data Huntingdon Unit B has the potential to operate close to or potentially exceed the 150 mg/m^3 NOx emissions levels as specified in the MCPD (at 0 °C and 1 Atmosphere). During the testing a maximum emissions value of 128 mg/m^3 only was achieved due to ambient conditions and unfamiliarity with the ECT set points in the governor controller.

2) The historical emissions test data shows some inconsistencies, namely the 2012 and 2013 data sets were done on full recycle testing, which were the only data sets when the compressor breached the MCPD limits. A close agreement is seen between the emissions tests undertaken after 2017, and these also align well with the PEMS monitoring.

3) The NOx comparisons against ECT show a good relationship which should allow for a restriction in ECT to be seen as a suitable option to control NOx emissions to below the MCPD limits.

4) Maximum ECT during testing was much lower than expected due to unfamiliarity with the governor controller and consequently lead to some sensitivity over the predicted temperature at which the MCPD limits may be breached. The lowest ECT temperature at which it is predicted (from the testing) that the 150 mg/m^3 MCPD limit will be breached is 585 °C or a 10 °C drop. This is close to the peak ECT levels seen at 586 °C and a predicted NOx value of 149 mg/m^3.

For Chelmsford compressor unit A

5) From historical data, Chelmsford Unit A has not been seen to operate close to or potentially exceed the 150 mg/m^3 NOx emissions levels as specified in the MCPD. During the testing a maximum emissions value of 128 mg/m^3 was achieved due to ambient conditions and a restriction in station flow of 40 mscm/d.

6) A new engine was installed at Chelmsford in 2016 and the subsequent emissions test were all undertaken under loaded conditions, similar to the last few years at Huntingdon and therefore deemed to be representative.

7) A close agreement is seen between the emissions tests undertaken after 2017, and these also align well with the PEMS monitoring.

8) The NOx comparisons against ECT show a good relationship which should allow for a restriction in ECT to be seen as a suitable option to control NOx emissions to below the MCPD limits.

9) Maximum ECT during testing was much lower than expected due to limitations on station flow, but these restrictions would also prevent Chelmsford from exceeding the NOx limits.

13 RECOMMENDATIONS

The following actions are recommended:

1) Further CSRP testing is recommended at Huntingdon compressor station aimed to achieve higher exhaust temperatures, which should equate to higher NOx emissions levels. Testing should be undertaken at higher ambient temperatures (typically above 20 °C). In addition, the ECT limits in the governor controller can be modified to allow for much higher ECT values. If this test is successful, then Huntingdon could be recommended as a suitable site for CSRP.

2) Chelmsford compressor station may be capable of breaching the MCPD limits, if the station scrubbers were removed, or a by-pass fitted allowing the site to operate at higher flows. CSRP could then be used to limit the NOx values.

3) A check should be undertaken on the historic emissions test data from before 2015.

4) The testing campaigns at Huntingdon and Chelmsford have identified that whilst the units and governor controller are the same, unique differences in station operation, governor configuration, engine and compressor operation exist. This indicates each CSRP implementation will require tailoring to the unique set up of each individual unit. As a result, [redacted] would recommend individual assessments including, performance and CSRP testing, historic data analysis and thorough governor controller testing for any unit considered for CSRP.

5) If CSRP is implemented on a unit, consideration should be made around utilising the annual emissions data to provide verification that any ECT limit applied still ensures the NOx levels remain below the MCPD limit. This will be particularly relevant if engine changes occur.

[redacted]

14 REFERENCES

/1/ Medium Combustion Directive (MCPD) - (EU) 2015/2193

/2/ Industrial Emissions Directive (IED) - 2010/75/EU

APPENDIX A
Test method statement example

NATIONAL GRID

CHELMSFORD COMPRESSOR STATION

CSRP PERFORMANCE TESTING - UNIT A/B

METHOD STATEMENT

DOCUMENT NUMBER MS-10324497-CHELMSFORD

Date: 11th January 2022

[redacted]

[redacted]

[redacted]

REVISION HISTORY:

Rev	Prepared By	Checked By	Approved By	Reviewed By	Date
0	[redacted]				11/01/2022
1					
2					
3					

[redacted]

1 INTRODUCTION

This document identifies responsibilities and work methods relating to [redacted] conducting CSRP performance tests on the National Grid's Chelmsford compressor station on the National Gas Transmission System, focusing on compressor unit designated Unit A or Unit B. The test procedure is also included.

This method statement applies to the following compressor test work on the gas turbine driven compressor unit A or B at Chelmsford to validate the manufacturers' compressor performance envelopes and determine effects of CSRP restrictions on compressor performance:

a) Recording of performance test data along compressor speed lines relative to head and flow

b) Determine baseline performance of the compressor over nominally 60%, 80%, 90% and 100% speed lines

c) Record emissions data at each performance test point

d) Record the reduction in compressor power and emissions due to CSRP – 3 test cases

2 SCOPE

The following will apply:

a) Measurements and test methods will be in general accordance with ASME PTC10 (Performance Test Code on Compressors and Exhausters – 1997 – reaffirmed in 2014).

b) Site instrument measurements required for performance tests may be calibration checked by [redacted] before tests commence using portable reference standards.

c) Additional instrumentation will be fitted by [redacted] for the performance tests.

d) Test data will be recorded automatically using ALERT and manually using portable instruments on site.

e) Permits and gas tests will be required for the use of portable equipment and a camera. [redacted] will provide certified personal gas detectors for their own use).

The compressor station will need to be configured to enable the site performance valve to be used to control the flow and head at the compressor.

3 RESPONSIBILITIES

3.1 National Grid Responsibilities

National Grid will be responsible for the following:

a) All aspects of safety on the compressor site and ensuring that all procedures, safety measures and permits are in place before tests can commence.

b) Advising of any special arrangements or documentation needed before tests can take place. For example:

   a. G/35 for any temporary modifications that will be required during the tests.

   b. Software engineer or other engineering specialist required to re-programme station logic to enable the required tests to be carried out.

c) Liaison with GNCC to establish clear lines of communication between National Grid Operations and [redacted]

d) Having sufficient staff available for permits and operation of the compressor site and performance valve.

e) Ensuring all indication, control, and protection instrumentation are in good working order and calibrated.

f) Ensuring that the compressor machinery is in good working order prior to the commencement of tests.

g) All valve operations required for the tests.

h) Operating with the station gas flow passing through the performance valve located on the suction pipework may reduce the unit suction temperature and pressure below what are considered normal operating conditions. It should therefore be ensured that low suction temperature or low suction pressure trips will not operate during the tests.

i) Ensuring that any flow or pressure control actions will not limit or interfere with test requirements.

j) Provision of gas compositions for each test day and advising of any major changes anticipated in gas composition over the test period. Gas composition will be logged from the ALERT system and will be the average of the previous days composition.

3.2 [redacted] Responsibilities

[redacted] will be responsible for the following:

a) Additional instrumentation to validate site instrument measurements:

   a. Three surface temperature sensors and insulation will be installed on both the suction and discharge pipework inside the compressor cab. **Note Site personnel have been requested to remove a section of box lagging from the Unit to be tested on both the suction and discharge pipework.**

An example of how the temperature sensors will be installed on the compressor pipework is shown in Figure 3 and Figure 4.

Figure 3 – Surface Temperature sensor installation on pipe

Figure 4 – Temporary insulation of temperature sensors

Temperature sensors can be installed on top of thin paint or epoxy coatings without affecting temperature measurement. If the coating is thicker than about 0.5mm (e.g. Plasguard), a small area will need to be removed and repaired after the

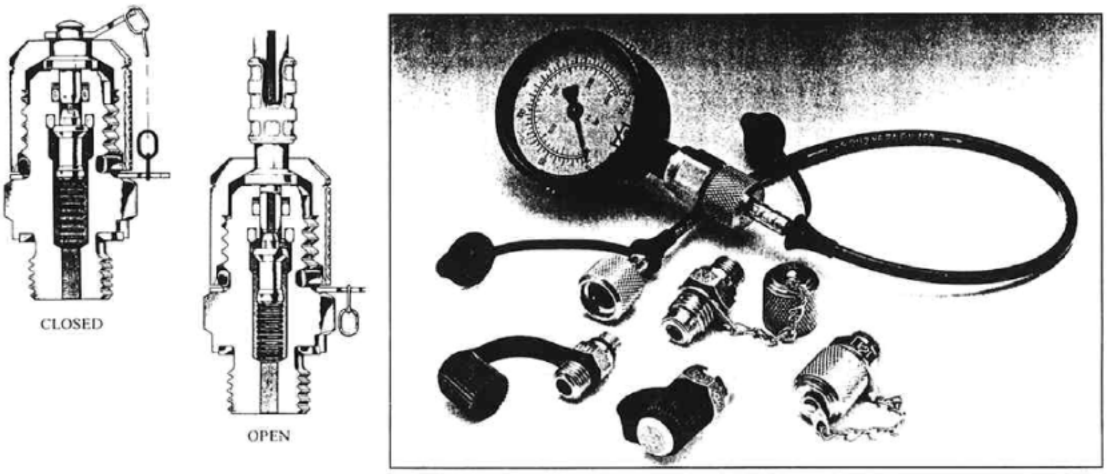
[redacted]

tests (by National Grid). Note: Temperature sensors will be arranged so that they can pass out through the seals of the rear compressor door during testing. No entry to the compressor cab will be required during testing.

b) Temporary reference pressure transmitters may be connected to the process pipework via site transmitter vent valve ports, using Hydrotechnik high pressure hoses rated at 630 bar as shown in Figure 8. Note: These will only be used to provide an additional calibration check of the site instrumentation. These measurements will not be needed when the units are operational.

HYDROTECHNIK Unit 4, 55A Yeldham Road Hammersmith London W6
Tel 081 741 9934 *Fax 081 741 9935*

MINICHECK™ GAS PRESSURE TEST POINTS



The MINICHECK™ Test Point system is a low cost, robust, quick release self sealing access point for taking pressure readings, without the loss of pressure or gas. Minicheck is designed for both high and low pressure applications. The units are available in either, Stainless Steel or Brass. Pressure ratings are up to 250 Bar for the Brass unit and 630 Bar for the Stainless Steel design. The system may be used for either permanent or frequent connection and disconnection of gauges or transducers.

Applications are numerous: eg. governors, pressure reduction stations, transmission lines etc. - in fact, wherever a frequent or permanent pressure reading is required. The test point is opened by either a high pressure micro bore flexi hose or by a direct gauge/transducer adaptor. The MINICHECK system is widely used in Europe and more recently by British Gas for both high and low pressure applications. The product has DVGW Certification.

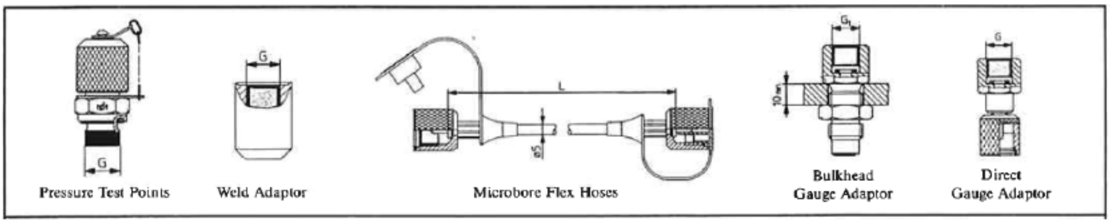


Figure 5 – Hydrotechnik pressure connections and hose

An example of how a pressure measurement will be carried out is shown in Figure 7.

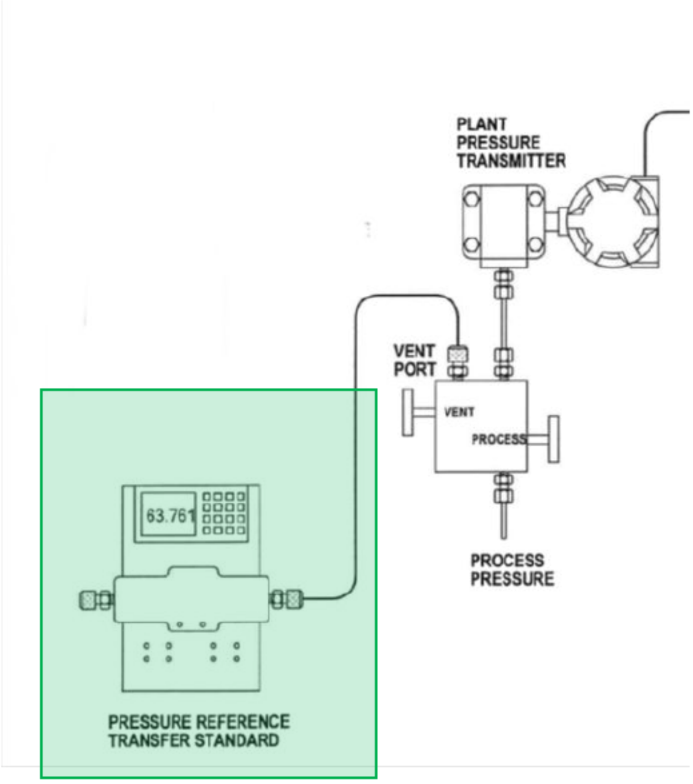


Figure 7 – Pressure measurement arrangement

c) The locations where these additional measurements are required are indicated in Figure 8.

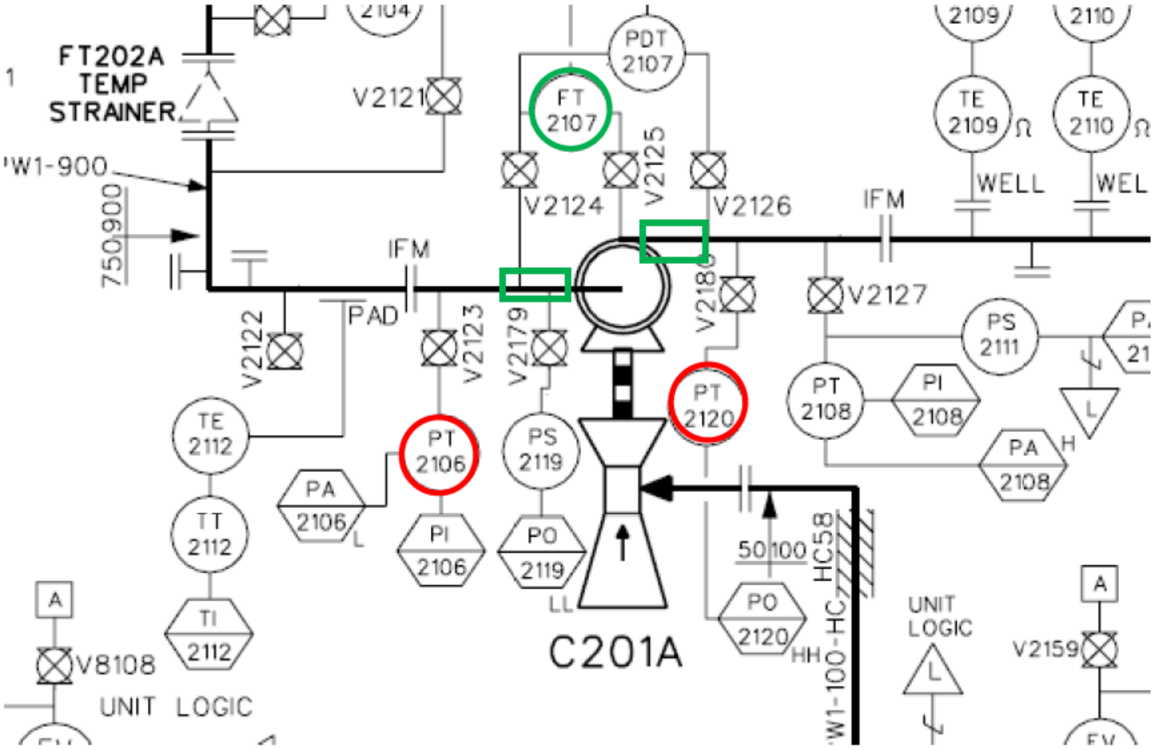


Figure 8 - Unit A instrument connections

d) An infrared camera (FLIR supplied by [redacted] will be used to try and determine if the unit surge control valves are fully closed with no leakage during the performance tests. If the valves are leaking, the upstream pipework temperature will be closer to compressor discharge temperature. Note: the camera is Non-IS and will need the use of a Personal Atmosphere Monitor (PAM). As the recycle line valve is located in the compressor pits, it is requested that 1 or 2 of the concrete slabs above the valve are removed and barriered off ahead of the start of testing by National Grid. Once the FLIR images have been recorded, these slabs can be put back in place.

e) Up to three test engineers will be present during the compressor test periods. The main test engineer will coordinate test requirements from the control building and liaise with site staff. The other test engineers will provide support for Alert / manual readings.

f) [redacted] will set up a test log file and record test data in ALERT. Tests will be carried out to ensure the ALERT system is fully operational prior to commencement of the performance tests.

4 TEST PROCEDURE

4.1 Full Performance Test

The following will apply for the performance tests:

a) One [redacted] test engineer will be based in the control building and will co-ordinate operations from that location via radio. The test engineer will be observing the compressor parameters. This engineer will be referred to as the Performance Test Engineer and will be in complete control of the performance test.

b) Test data will be recorded in the ALERT test log.

c) Prior to testing, a check should be undertaken on the current operating conditions in the Feeder pipework.

d) The suction pressure will drop by between 13 and 14 bar during the testing, so ideally a Feeder pressure of at least 60-65 barg is desired. This would give the most representative operating conditions for testing.

e) Ideally there would also be some gas flow past the site (Approximately 20 mscm/d to allow for a suitable amount of gas cooling (Unit maximum flow is around 40 mscm/d). For performance test points it is essential that there is thermal stability. This will occur more quickly if there is a reasonable flow past the site and also prevent the discharge temperatures from rising to trip levels.

f) The station will need to be configured to operate through the station performance valve. This will necessitate the following valve position changes:

   a. Open the performance valve (V1012) and performance loop isolation valve (V1011)

   b. Close Suction inlet valve (V723002)

   c. GNCC to open station by-pass valve(s) on the AGI – numbers to be confirmed by GNCC. Note – If no suitable valve is available on the AGI then Site could open the site by-pass valve (V723001).

g) The ECT governor controller parameters should be adjusted to provide the maximum allowable ECT across the temperature range (by adjusting the 0 Deg. C ECT valve up to the same value as the +40 Deg. C value)

h) GNCC should be informed that testing is about to commence

i) Start Unit A/B and bring up to minimum speed. The unit should be set in local manual speed control. Once at minimum speed, allow it to settle and warm up. This will become the first performance test point.

j) During the warm-up period, manual checks of site instruments will be carried out and all signals required for performance tests checked on [redacted] instrumentation in the control building, and on ALERT.

k) Illustrations of test flow scenarios are shown in Figure 9. When the compressor unit flow is less than the NTS flow past the station (Figure 9 - top), the flows are split and recombined. When the compressor flow exceeds the NTS flow (Figure 9 - bottom), a portion of the flow re-circulates to maintain the NTS flow balance. The consequence of the Figure 9 bottom situation is that warm discharge gas is re-circulated to the compressor inlet. This causes the suction and discharge temperature to gradually rise, making it difficult to obtain stable test data. The bigger the difference between the operating flow of the compressor and the flow passing the station, the longer it can take for the gas temperature to reach an equilibrium.

[redacted]

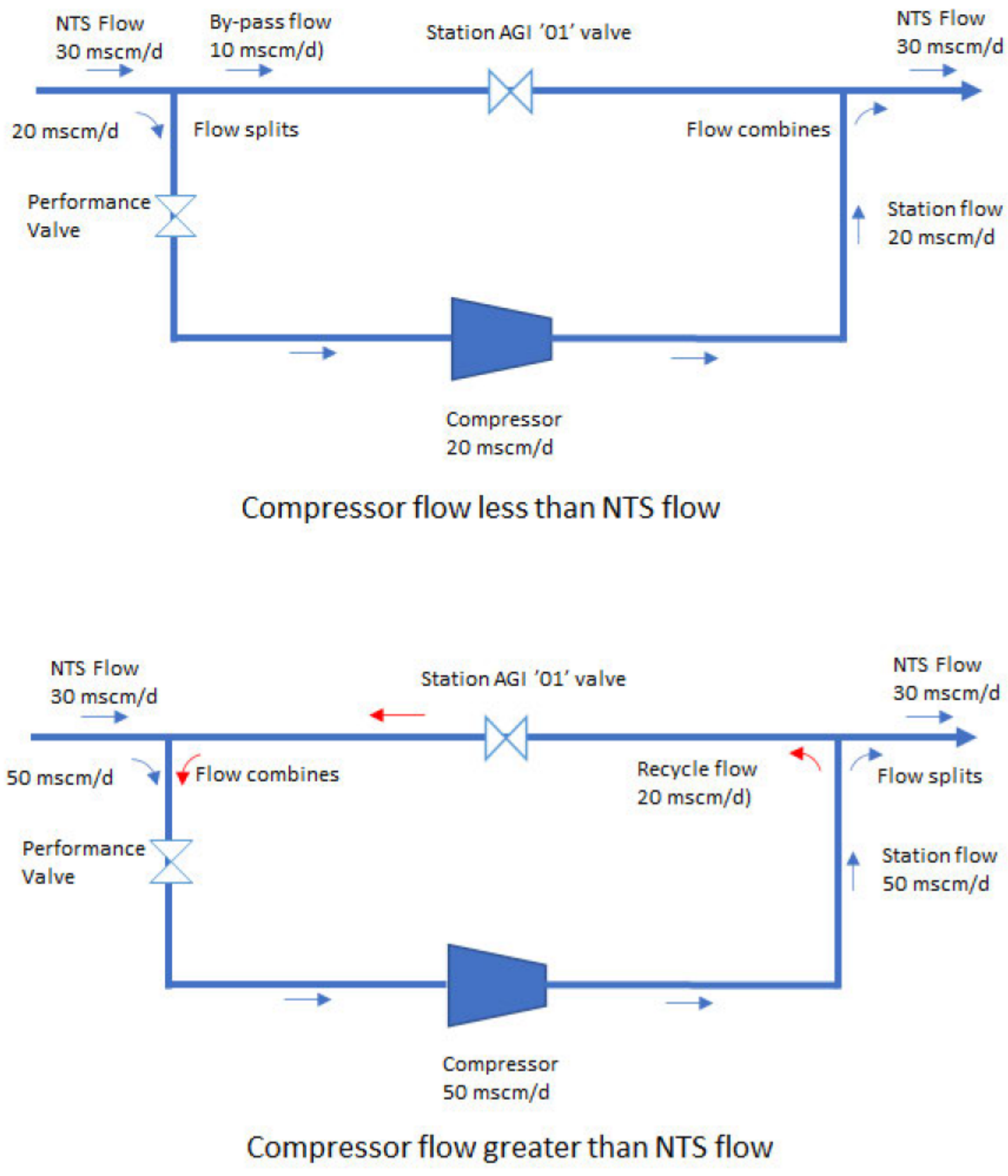


Figure 9 – Compressor flow vs NTS flow

l) An idealised compressor map is shown in Figure 10. The following information has been added by [redacted] to illustrate how tests will be conducted and approximately where onset of surge, and maximum power lines may occur:

a. Maximum power line – this will limit the maximum flow that will be achieved for a given head.

b. Test points – (shown as red circles) these are idealised points; in practice, it may not be possible to achieve full coverage of the compressor map due to operational constraints or limits.

c. An outline of test points currently proposed

m) At each test point, the conditions will be held stable until the suction and discharge temperatures have stabilised (normally less than 0.1 °C change in 2 minutes).

n) At this point a ‘Snapshot’ of the SCADA data in ALERT will be collected.

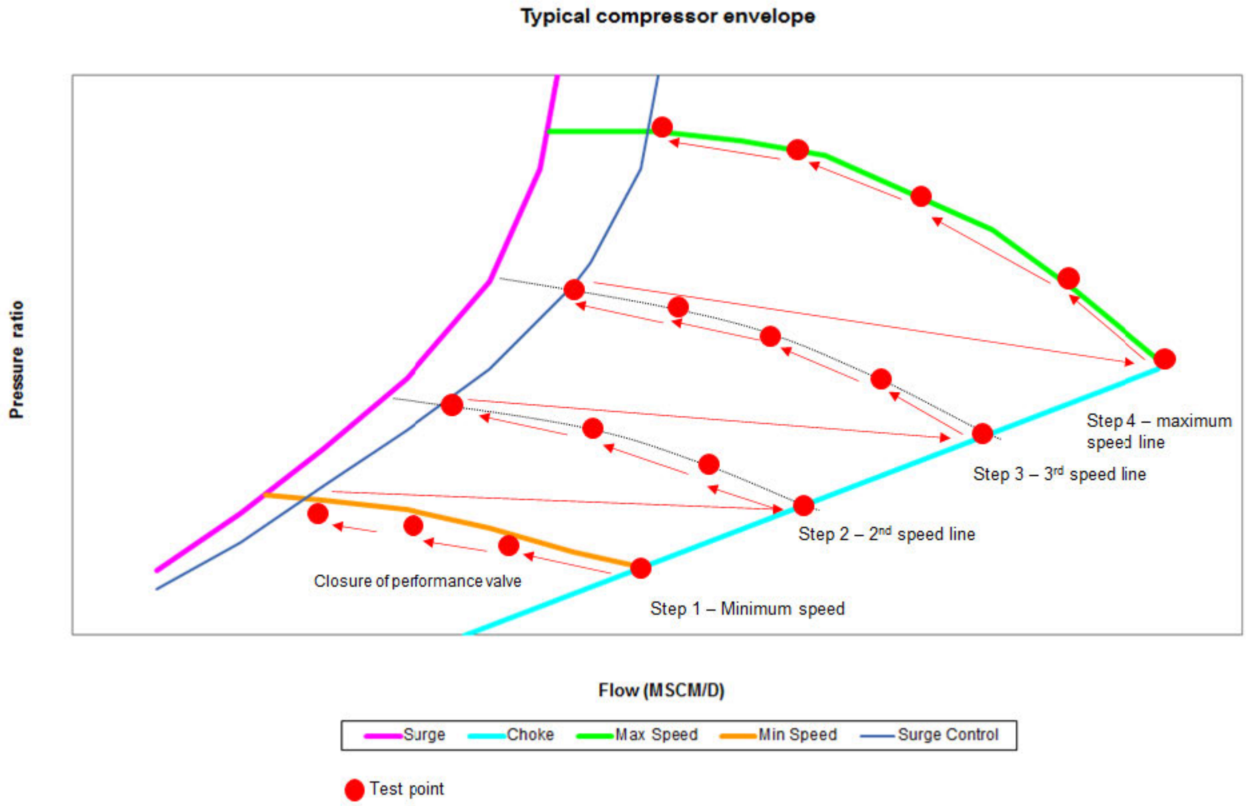


Figure 10 – Idealised compressor envelope

a) After the data has been collected the performance valve can be slowly moved to shift the operating point closer to surge till the next test point is reached when again the compressor needs to stabilise. Note: For performance tests, the machine will be operated with the surge control system working normally.

b) 4 to 5 data points will be recorded between the choke area and surge control line for each compressor speed. This includes where the operating point begins to open the surge control valve to define where the surge control line is located; see Figure 10. Note: This step will also act to verify the correct set-up of the surge control line following surge testing.

c) Ideally, enough points will be recorded to give good coverage of the compressor map. However, it may not be possible to achieve all of these points due to operational or GNCC flow configuration limits.

4.2 CSRP Performance verification (Test 1)

Following on from the performance test, testing will immediately move on to undertake CSRP testing. This testing will involve the re-programming of the ECT maximum limit in the governor controller to reduce the temperature from maximum setpoint used for performance testing to ECT -20 Deg. C and undertake additional performance test points as per the following steps.

o) Site configuration and roles / responsibilities will be exactly the same as for the performance testing with the exception of the following:

p) CSRP Performance test points will only be collected according to Figure 11 below. In addition, to allow for cross referencing to the initial performance test – 3 'test' reference points will also be recorded as indicated in Figure 11.

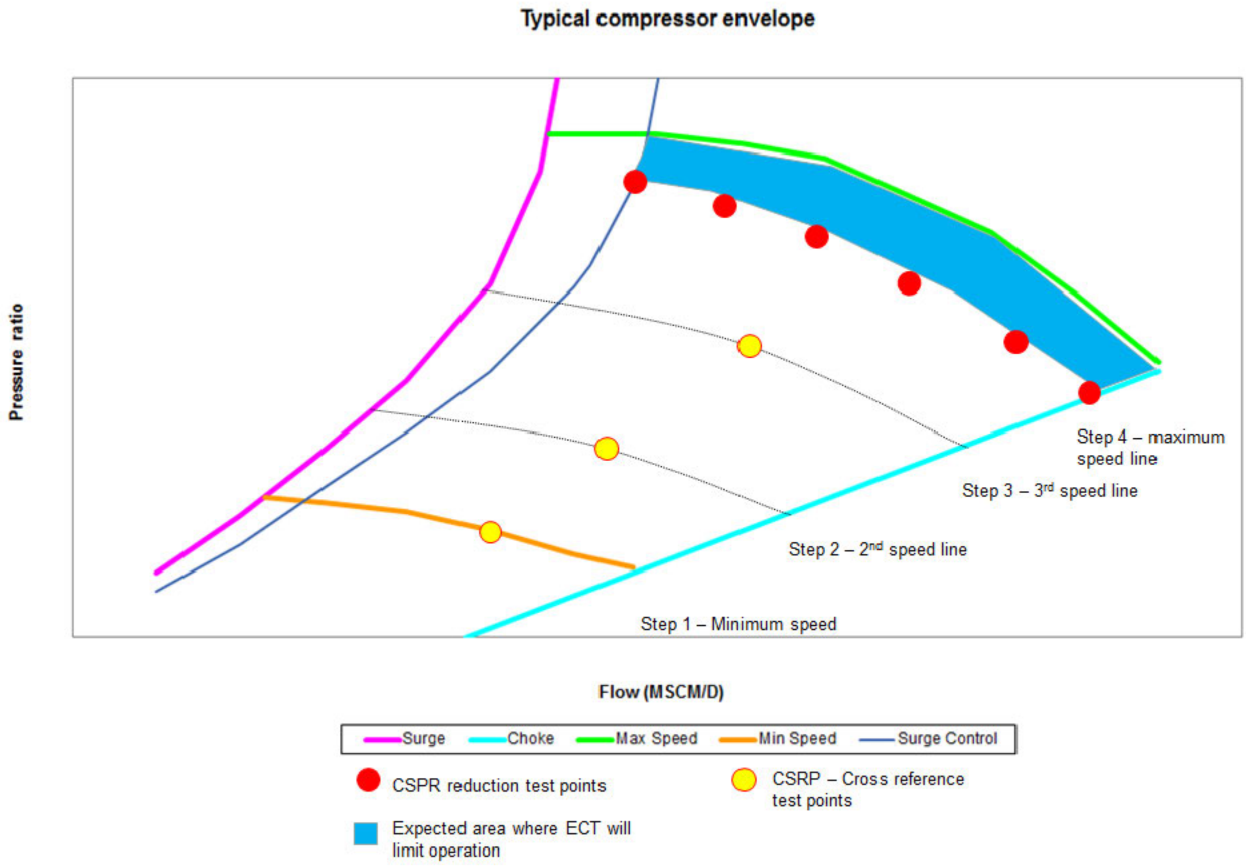


Figure 11 – CSRP restricted compressor envelope

q) At each CSRP test point, the conditions will be held stable until the suction and discharge temperatures have stabilised (normally less than 0.1 °C change in 2 minutes).

r) At this point a 'Snapshot' of the SCADA data in ALERT will be collected.

s) The number of data points collected will depend on the extent of the restriction to the compressor envelope but will be sufficient to accurately map the affected area.

4.3 CSRP Performance verification (Test 2/3)

Following on from the first CSRP performance test, a review will be made of the effect a 20 °C reduction has had on the compressor envelope and emissions. Further testing will then focus on the sensitivity of the ECT reduction. This testing will involve the further re-programming of the ECT maximum limit in the governor controller to ECT max – 30 °C and ECT max – 10 °C. These settings will be confirmed following the initial CSRP test with National Grid.

5 METHOD STATEMENT FOR EACH TEST DAY

The following steps should be undertaken each day during the test programme:

1. Site to confirm with GNCC that testing can go ahead that day.
2. Emissions team undertake their daily calibration checks and set the emissions monitoring system logging.
3. Site to switch the station to local control and configure the station suction / performance valve loops for operation during through the performance loop. Note: - Performance valve should be fully open.
4. Confirm with GNCC that the AGI has been set-up correctly to allow for performance testing
5. Making any control logic changes if required for the start of the testing (I.e., ECT maximum temperature reduction)
6. Place a start on the unit being tested
7. Allow to stabilise at minimum speed
8. With the unit set in manual speed control, adjust the speed to the required speed and gently close the performance valve till the required test point has been reached
9. Allow the system to stabilise and ensure temperature readings are steady (less than 0.1 °C change in 2 minutes)
10. Once temperatures are stable, record a ‘snap-shot’ data set in ALERT and record the manual temperature readings from the installed temperature probes
11. Confirm that the emissions logging is still monitoring
12. Move the compressor operating point to the next test point
13. Once testing has been completed at the end of each day ensure that the following have been completed:
    a. Unit shutdown
    b. ECT alterations for testing reset to pre-test values
    c. Suction and performance valve configurations reset for normal station operation
    d. GNCC informed that testing for the day has been completed and AGI valve configuration changes can be reset
    e. Unit handed back to GNCC in remote control

[redacted]

Test closure sign-off

	[redacted] – Competent Person	Site Operations
ECT values have been reset to the original values		
Performance valves have been reset to their normal positions		

END OF METHOD STATEMENT

Last update: Version 0 – 11th January 2022

[redacted]

[redacted]

APPENDIX B

Performance and CSRP test data

Table B.1 Huntingdon compressor station – Performance test points

Date (2021)	Performance test reference	PT Speed	fuel flow (scm/h)	CO2 rate (g/s)	CO (mgm3)	NOx (mgm3)	Oxygen (%)	power NTI (MW)	Exhaust Temp (°C)	Suction pressure (bar)	Discharge pressure (bar)	Process flow (Mscm/d)	Suction Temp (°C)
13/12	1.1	3254	2045	1134.0	788.9	63.5	18.6	20.0	391.0	63.8	65.4	38.7	18.9
	1.2	3254	1843	1021.9	930.9	59.3	18.7	18.02	375.8	61.2	65.5	30.9	18.0
	1.3	3254	1579	875.6	1209.9	53.3	18.8	15.43	359.5	60.3	65.4	23.4	17.3
	2.1	4205	2964	1643.5	452.3	87.1	17.9	28.97	466.3	62.6	65.3	44.9	20.1
	2.2	4205	2870	1591.4	479.1	81.6	18.1	28.06	469.3	59.3	65.2	38.8	18.8
	2.3	4205	2581	1431.2	555.9	74.3	18.3	25.26	441.1	57.7	65.1	31.5	17.9
	2.4	4205	2348	1302.0	640.0	68.1	18.4	23.01	418.8	55.8	63.5	26.2	16.9
	2.5	4205	2221	1231.6	696.8	64.8	18.5	21.66	406.7	55.6	63.6	24.0	16.2
14/12	3.1	5143	4329	2400.4	252.0	128.4	16.9	42.25	576.7	61.6	65.6	52.6	21.9
	3.2	5200	4116	2282.3	271.1	121.5	17.0	40.24	562.6	58.4	65.5	46.9	21.0
	3.3	5200	3850	2134.8	300.7	112.9	17.2	37.64	542.8	56.0	65.5	41.2	19.7
	3.4	5200	3455	1915.8	352.2	101.5	17.4	33.78	511.3	54.4	65.4	34.7	18.8
	3.5	5200	3123	1731.7	406.9	91.7	17.6	30.53	483.4	53.6	65.4	29.5	18.0
	4.1	5143	4329	2400.4	252.0	128.4	16.9	42.25	576.7	61.6	65.6	52.6	21.9
	4.6	5408	4291	2379.4	245.9	128.8	16.9	42	576.2	55.8	64.2	45.8	19.3
	4.2	5600	4299	2383.8	244.8	128.7	16.9	42.03	576.5	54.1	65.6	40.8	19.7
	4.3	5765	4298	2383.3	242.2	128.9	16.9	42.01	577.1	52.8	65.6	37.8	19.4
	4.4	5965	4293	2380.5	241.3	128.5	16.9	41.97	576.2	50.5	64.8	34.8	16.4
	4.5	6100	4295	2381.6	240.1	128.2	16.9	41.98	576.1	49.5	64.4	33.0	15.7
Interpolated	5.1	5759	4471	2479.2	275.5	136.0	16.7	44.01	579.2	51.8	57.3	47.7	15.5
	5.2	5615	4469	2478.1	276.2	136.3	16.7	44.08	580.3	50.5	60.4	42.1	15.4
	5.3	5456	4411	2445.9	267.5	131.8	16.8	42.96	578.7	52.4	64.7	40.3	14.9

[redacted]

Table B.2 Huntingdon CSRP test data

Date (2021)	CSRP test reference	CSRP Stage	fuel flow (scm/h)	CO2 rate (g/s)	CO (mgm3)	NOx (mgm3)	Oxygen (%)	power NTI (MW)	Exhaust Temp (°C)	Suction pressure (bar)	Discharge pressure (bar)	Process flow (Mscm/d)	Suction Temp (°C)
	30.1	ECT-30	4039	2239.6	282	118.1	17.1	39.67	554.7	62.0	65.7	51.1	20.8
	30.2	ECT-30	4053	2247.4	278.6	118.5	17.09	39.77	554.7	59.3	65.4	47.6	20.2
15/12	30.3	ECT-30	4057	2249.6	275.9	118.5	17.08	39.89	554.6	56.0	65.0	42.9	19.2
	30.4	ECT-30	4059	2250.7	274.8	118.8	17.08	39.92	554.2	54.1	64.9	39.1	18.6
	30.5	ECT-30	4068	2255.7	272.1	119.1	17.08	40	554.8	52.0	64.6	34.8	18.4
	30.6	ECT-30	4052	2246.8	263.1	119.7	17.08	39.8	553.8	51.4	65.4	32.9	17.8
	40.1	ECT-40	3980	2206.9	280.4	118	17.15	39.18	546.8	61.9	65.6	51.1	21.3
	40.2	ECT-40	3983	2208.6	277	117.9	17.14	39.21	547.5	59.4	65.5	47.4	20.7
	40.3	ECT-40	3967	2199.7	275.7	117.5	17.12	39.04	547.2	56.8	65.5	43.3	20.0
	40.4	ECT-40	3963	2197.5	278.3	116	17.13	39.02	545.4	54.1	65.5	38.2	19.0
16/12	40.5	ECT-40	3966	2199.2	276.6	115.2	17.13	39.03	545.4	52.0	65.4	33.0	18.4
	20.1	ECT-20	4158	2305.6	257.8	124.2	17.03	40.93	561.0	61.7	65.6	51.7	21.8
	20.2	ECT-20	4167	2310.6	252.7	125.2	17.01	41.02	562.0	58.3	64.5	47.4	23.5
	20.3	ECT-20	4149	2300.6	250.4	125.3	17.01	40.91	562.1	55.2	64.4	42.6	21.4
	20.4	ECT-20	4156	2304.5	248.7	125.5	17.01	40.85	562.0	52.4	64.4	37.2	21.0
	20.5	ECT-20	4151	2301.7	248.7	124.4	17.01	40.86	561.5	51.2	65.3	33.0	18.2

[redacted]

Table B.3 Chelmsford Performance test points

Date (2022)	Performance test reference	PT Speed	fuel flow (scm/h)	CO2 rate (g/s)	CO (mgm3)	NOx (mgm3)	Oxygen (%)	power NTI (MW)	Exhaust Temp (°C)	Suction pressure (bar)	Discharge pressure (bar)	Process flow (Mscm/d)	Suction Temp (°C)
18/01	1.1	2525	1813	1005.2	1296.1	53.1	18.63	17.83	358.2	56.9	59.7	30.4	10.0
	1.2	2525	1784	989.0	1274.1	52.2	18.63	17.54	360.5	55.9	59.6	27.4	9.6
	1.3	2525	1751	971.0	1308.2	51.8	18.63	17.22	359.5	55.3	59.4	25.2	9.1
	1.4	2525	1689	936.7	1385.5	51.0	18.66	16.61	358.1	54.5	59.1	21.4	8.3
	2.1	3305	2666	1478.3	581.5	70.0	18.14	26.22	416.0	54.7	59.2	37.4	14.5
	2.2	3305	2599	1441.3	606.3	68.6	18.17	25.56	411.8	52.9	59.1	32.9	13.9
	2.3	3305	2494	1383.1	650.1	66.3	18.24	24.53	405.3	51.7	58.8	28.2	12.2
	2.4	3305	2369	1313.8	706.7	64.3	18.32	23.30	398.1	50.6	58.3	24.0	10.2
	3.1	4100	3484	1931.9	359.9	92.8	17.71	34.26	463.3	49.4	58.0	38.3	18.8
	3.2	4100	3311	1835.9	394.6	88.2	17.79	32.56	451.5	47.6	57.5	32.7	16.1
	3.3	4100	3197	1772.5	421.6	84.9	17.85	31.44	443.3	46.8	57.2	29.6	14.6
19/01	4.1	4885	4638	2571.8	188.5	127.7	16.94	45.61	552.1	45.9	58.1	41.9	23.6
	4.2	5024	4650	2578.4	189.1	127.5	16.95	45.73	552.3	44.1	58.1	37.1	23.3
	4.3	5098	4639	2572.6	185.1	128.9	16.94	45.63	554.2	43.3	58.0	34.8	22.4

Table B.4 Chelmsford CSRP test points

Date (2022)	CSRP test reference	CSRP Stage	fuel flow (scm/h)	CO2 rate (g/s)	CO (mgm3)	NOx (mgm3)	Oxygen (%)	power NTI (MW)	Exhaust Temp (°C)	Suction pressure (bar)	Discharge pressure (bar)	Process flow (Mscm/d)	Suction Temp (°C)
19/01	20.1	CSRP -20	4273	2369	216.9	118.4	17.12	42.02	530.9	47.9	58.3	39.7	25.3
	20.2	CSRP -20	4264	2364	218.3	118.9	17.13	41.93	531.0	45.8	58.2	34.7	23.3
	20.3	CSRP -20	4287	2377	216.2	120.0	17.13	42.16	530.9	44.7	58.3	31.9	22.3
	30.1	CSRP -30	4146	2299	230.0	116.4	17.21	40.77	520.9	48.4	58.6	39.5	25.0
	30.2	CSRP -30	4143	2297	231.7	115.8	17.22	40.74	520.9	46.3	58.4	34.9	23.0
	30.3	CSRP -30	4164	2309	233.8	115.1	17.22	40.95	520.8	44.5	57.8	32.0	18.7
20/01	12.1	CSRP-12	4672	2591	200.6	123.8	17.05	46.00	538.7	48.1	61.3	38.9	25.1
	12.2	CSRP-12	4687	2599	197.6	124.2	17.04	46.15	538.6	46.5	61.3	34.6	25.3

[redacted]

[redacted]