Central – Wan Chai Bypass

and Island Eastern Corridor Link

APS Commissioning Test Plan

(under Condition 2.7 of EP-482/2013/A)

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APS COMMISSIONING TEST PLAN

(CONDITION 2.7 OF OPERATION ENVIRONMENTAL PERMIT, EP-482/2013/A)

1. Introduction

1.1 The approved EIA Report, AEIAR-125/2008 and AEIAR-041/2001 (hereafter referred as "the EIA report") studying for the engineering feasibility of Wan Chai Development Phase II (WDII) and Central-Wan Chai Bypass (CWB) was completed and approved in Year 2008 and 2001 respectively. Subsequently in Year 2010, the Government has decided to incorporate an air purification system (APS) in the CWB project, which will bring enhancement to the air quality of tunnel exhaust before discharging them into the atmosphere.

1.2 The Environmental Permit, EP-482/2013/A (hereafter referred as "the OEP"), for the operation phase of the CWB tunnel was issued on 22 December 2016. As stipulated in Condition 2.6(d) of the OEP, "an air purification system (APS), including an electrostatic precipitator system (EPS), with removal efficiency of at least 80% of dust to reduce the level of respirable suspended particulates (RSP), and a NO_2 removal system with removal efficiency of at least 80% for NO_2, shall be adopted to improve the air quality before discharging to the atmosphere via the WVB, CVB and EVB and its vent shaft."

1.3 As stipulated in Condition 2.7 of the OEP, "The Permit Holder shall, no later than three months before the commencement of operation of the Project, submit to the Director for approval four hard copies and one electronic copy of a APS Commissioning Test Plan, which shall be certified by the ET Leader and verified by the IEC as conforming to the Application of this Environmental Permit including all attachments submitted by the Permit Holder (Application No. AEP-482/2013), to provide the testing schedule and methodology for the commissioning test of the APS described under Condition 2.6(d) above."

2. APS System Description

2.1 The Air Purification System (APS) is a system dedicated to remove dust particles PM_{10} and NO_2 in the exhaust airstream of vehicle tunnels. The APS consists of the dust filtering part by means of an electrostatic precipitator (ESP) and the NO_2 removing part (De-NO_2 system). The APS are adopted at West Ventilation Building (WVB), Central Ventilation Building (CVB) and East Ventilation Building (EVB) and its vent shaft.

2.2 In the ESP, the dust is captured from the airstream where an electric field is created using charged metal plates in the form of anodes and cathodes by means of a high voltage DC power generator. When the collector plates are covered with dust, they will be washed down with a water spray. The ESP filter shall be dried by pressurized air and become ready for use.

2.3 Activated carbon gas adsorption shall remove NO_2. The use of thick carbon array and the activated carbon shall maintain its adsorption performance during a long serviceability for a period of two to three years. Replacement of the activated carbon shall then take place.

3. Testing Schedule and Methodology

3.1 The testing of APS at three different ventilation buildings will be separated into 2 stages.

3.2 The first stage testing will include the factory performance test of electrostatic precipitator and factory adsorption test of De-NO_2 filter which tests will be carried out before manufacturing and delivery to Hong Kong, Site Acceptance Test (SAT) of two crucial

equipment, i.e. High Voltage Transformer (HVT) & ESP System (ESP Ioniser and Collector) and routine test of the activated carbon.

3.3 For the factory performance test of ESP, the tests were conducted under the requirements stated in Particular Specification for HyD's Contract No. HY/2011/08 – Central – Wan Chai Bypass – Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning PS37.23(2)(i), (ii) and (iii). The details of the Factory Performance Test for ESP and the Particular Specification are attached in Appendix 5 and Appendix 7 for reference. The tests were carried out inside the laboratory at conditions similar to the tunnel environment and measured the PM_{10} concentration before and after the ESP modules. The two test ESP modules were mounted in a galvanized steel frame with rectangular cross-section and sheeted to form a duct. Adapters connected the ESP module duct for testing to the test rig ducting. The test rig consisted of a circular air channel, a variable speed ventilation fan, a dosing unit for injection of test duct and measuring equipment for determination of particle separation rates and air velocity. The channel was insulated to ensure appropriate temperature conditions. The testing parameters and testing values are listed in the below table. A sample of the test report for performance test of ESP is attached in Appendix 1 for reference. The test was inspected and accepted by relevant parties including Contractor, Resident Site Staff, and witnessed by EMSD and HyD to ensure the ESP would meet the performance requirements.

Test Parameter	**Test Value**
Velocity	1) 2m/s 2) 4m/s 3) 6m/s
PM_{10} inlet concentration	1) 0.2mg/m^3 2) 0.5mg/m^3 3) 1mg/m^3
Air temperature / Relative humidity	1) 30˚C/80% 2) 35˚C/65% 3) 40˚C/50% 4) 27.5˚C/90% 5) 22.3˚C/98.5%
Ioniser / Collector voltage	1) 16/7kV 2) 15/5kV 3) 15.5/6.5kV 4) 14/4.5kV

3.4 For the factory adsorption test of De-NO_2 filter, the tests were conducted under the requirements stated in Particular Specification for HyD's Contract No. HY/2011/08 – Central – Wan Chai Bypass – Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning PS37.23(3)(i) and (ii). The details of the Factory Performance Test for De-NO_2 filter and the Particular Specification are attached in Appendix 6 and Appendix 7 for reference. The tests were carried out inside the laboratory at an environment similar to the APS plenum in terms of temperature, humidity and the design airflow velocity. The adsorption tests were conducted in Camfil's Molecular Media Test Rig (MMTR). The rig consisted of cylindrical columns in which carbon medium beds are formed. One column was kept empty for measuring the upstream concentration during the tests. One analyser was used to measure the challenge substance concentrations both upstream and downstream of the sample. This was done by sequentially changing the sampling point between the columns. The challenge gas was mixed with temperature and humidified controlled air. The testing parameters and testing values are listed in the below table. A sample of the adsorption test report for De-NO_2 filter is attached in Appendix 2 for reference. The tests were inspected and accepted by relevant parties including Contractor, Resident Site Staff, and witnessed by EMSD and HyD to ensure the De-NO_2 filter would meet the performance requirements.

Test Parameter	Test Value
Flow	1) 45l/min
NO_2 inlet concentration	1) 200ppb 2) 1ppm
Air temperature / Relative humidity	1) 30˚C/80% 2) 35˚C/65% 3) 40˚C/50% 4) 27.5˚C/90%

3.5 For the Site Acceptance Test of High Voltage Transformer and ESP System, the start-up of the HVT and ESP System will be checked on site at different ventilation buildings and inspected by relevant parties including Contractor, Resident Site Staff, and witnessed by EMSD and HyD to ensure the installed components of APS are properly functioned according to Particular Specification for HyD's Contract No. HY/2011/08 – Central – Wan Chai Bypass – Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning PS 37.24(2)(i), (ii) and 37.24(3)(i). The Particular Specification is attached in Appendix 7 for reference. A sample of the checklists for start-up of HVT and ESP Systems are attached in Appendix 4 for reference.

3.6 Routine testing of activated carbon for De-NO_2 filter will be conducted according to Particular Specification for HyD's Contract No. HY/2011/08 – Central – Wan Chai Bypass – Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning PS 37.22(3)(ii) when the activated carbon is departing factory to ensure the activated carbon is in appropriate condition. The Particular Specification is attached in Appendix 7 for reference. The routine test will be conducted by the laboratory of the activated carbon factory. A sample of the routine testing report for activated carbon is attached in Appendix 3 for reference.

3.7 The second stage testing will include the Efficiency Tests of the APS for all three ventilation buildings. The Efficiency Test will be conducted 30 days after the CWB tunnel is commissioned according to Particular Specification for HyD's Contract No. HY/2011/08 – Central – Wan Chai Bypass – Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning PS37.24(4)(i) and (ii). The Particular Specification is attached in Appendix 7 for reference. The tests will verify the performance efficiency (80% removal rate of NO_2 and PM_{10}) of the APS. The Efficiency Test will be conducted by the Contractor, supervised and accepted by Resident Site Staff and witnessed by EMSD and HyD.

3.8 A summary table of 2 stages testing including schedule, acceptance criteria and testing methods is listed below.

1st stage Testing					
Test	**Testing Date**	**Duration**	**Frequency of Testing**	**Testing Method/Requirement**	**Acceptance Criteria**
Factory Performance Test of ESP	26/10/15 – 2/11/15	7 days	Total of 9 tests for the combinations of conditions listed in3.3	Refer to Appendix 5	Refer to item 3.9
Factory Adsorption Test for De-NO_2 filter	13/3/17 – 17/3/17	4 days	Total of 16 tests for the combinations of conditions listed in3.4	Refer to Appendix 6	Refer to item 3.9

Site Acceptance Test for HVT and ESP System	To conduct by July 2018 (tentative)	1 week for each ventilation building	Once for each HVT and ESP System installed at each ventilation building	Check and ensure the HVT and the ESP system including ionizer and collector are functioning	Refer to Appendix 4
Routine Test of Activated Carbon	-	-	1 sample for every 25,000kg of activated carbon departed factory	Testing of weight, density, size (pellet diameter), moisture content of activated carbon	Refer to Appendix 3 (Columns under Spec. min and Spec. min)

2nd stage Testing					
Test	**Testing Date**	**Duration**	**Frequency of Testing**	**Testing Method/Requirement**	**Acceptance Criteria**
Efficiency Test	30 days after the CWB tunnel is opened	To be confirmed	Once for each ventilation building	The Contractor shall engage an accredited independent laboratory to verify the installation and calibration of the installed air monitoring devices. Based on the installation and calibration of the installed air monitoring devices and site constraint, the accredited independent laboratory shall propose additional air quality measurement in the air stream before and after passing through the ESP and De-NO_2 filters for the Efficiency Test in each ventilation building	Refer to item 3.9

3.9 The factory performance test of ESP, factory adsorption test for De-NO_2 filter and the Efficiency Test have the following acceptance criteria. With the ESP system and De-NO_2 filter limitation, the removal efficiency of PM_{10} and NO_2 may not be able to achieve an 80% removal rate at lower level of concentration of PM_{10} and NO_2. The abovementioned tests were or will be inspected and accepted by relevant parties including Contractor, Resident Site Staff, and witnessed by EMSD and HyD. The acceptance criteria of the removal efficiency of PM_{10} and NO_2 is stated under Particular Specification for HyD's Contract No.

HY/2011/08 – Central – Wan Chai Bypass – Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning PS 37.2(1)(i) and (ii). The Particular Specification is attached in Appendix 7 for reference.

When inlet concentration of NO_2 is equal to or greater than 0.25ppm, not less than 80% of NO_2 shall be removed.
When inlet concentration of NO_2 is lower than 0.25ppm, the outlet concentration of NO_2 shall not be greater than 0.05ppm.
When inlet concentration of PM_{10} is equal to or greater than 0.5mg/m3, not less than 80% of PM_{10} shall be removed
When inlet concentration of PM_{10} is lower than 0.5mg/m3, the outlet concentration of PM_{10} shall not be greater than 0.1mg/m^3

In case the monitored air pollutant levels under Air Quality Monitoring Plan (AQMP) submitted in accordance with condition 2.9 of EP-482/2013/A exceed the approved criteria, the Permit Holder shall complete the investigation to identify the source/reason of exceedance and submit the investigation report, with recommended remedial actions to the DEP, within 2 weeks of detection of the exceedance. The Permit Holder shall fully and properly implement the recommended remedial actions according to the deposited investigation report.

4. Submission Schedule

4.1 The first stage APS Commissioning Test Report, including the factory performance test of electrostatic precipitator, factory adsorption test of De-NO2 filter, Site Acceptance Test of High Voltage Transformer (HVT), ESP System (ESP Ioniser and Collector) and routine test of the activated carbon will be submitted to the Director of Environmental Protection at least one month before the commencement of operation of the Project in accordance with condition 2.8 of EP-482/2013/A.

4.2 Efficiency Tests for the APS will be carried out after the CWB tunnel is opened for 30 days. To allow two months for verifying the test results, the second stage APS Commissioning Test Report will be submitted to the Director of Environmental Protection around three months after the CWB tunnel is opened.

DESIGN STANDARDS/CRITERIA

General 37.2 **(1)** The APS shall be designed to the following system performance requirements :-

(i) For particle, when inlet concentration equal to or greater than 0.5mg/m^3, not less than 80% of PM_{10} shall be removed after the air is treated by the APS. For inlet concentration lower than 0.5mg/m^3, the outlet concentration shall not be greater than 0.1mg/m^3.

(ii) For NO_2, when inlet concentration equal to or greater than 0.25ppm, not less than 80% of NO_2 shall be removed after the air is treated by the APS. For inlet concentration less than 0.25ppm, the outlet concentration shall not be greater than 0.05ppm.

(4) Airflow Capacity and Evenness

(i) The Contractor shall design, supply, install, test and commission all necessary partitions inside the plenums to ensure the APS equipment is performing to its requirements as per Clause 37. 2 (1).

(ii) The Contractor shall design, supply, install, test and commission airflow guide vanes to achieve the evenness of airflow at intake positions of ESP filters and De-NO_2 filters. Test shall be developed and carried out by the Contractor to verify the evenness of airflow at intake position of ESP filters and De-NO_2 filters.

(iii) The Contractor shall provide remedial measures at his own costs to restore the performance of the APS when unsatisfactory results are obtained from the Site Acceptance Tests and subsequent operation records within the Maintenance Period for the APS.

Air Quality Control 37.7 (1) The gases generated from the APS operation shall comply with EPD's requirement and/or practice.

(2) The Contractor shall submit the constituents of the gases that will be generated and retained in the airstream after passing through the ESP filter and De-NO_2 filter within 90 days after the Date of Commencement of the Contract. After the Factory Acceptance Test, the Contractor shall submit documentary proof of the constituents of the gases that will be generated and retained in the airstream after passing through the ESP filter and De-NO_2 filter as part of the test results for the Engineer's approval.

(3) (i) Before the CWB tunnel commission, the Contractor shall engage an accredited independent laboratory with experience in measuring air quality approved by the Engineer to verify the installation and calibration of the installed air monitoring devices. Based on the installation and calibration of the installed air monitoring devices and the site constraint, the accredited independent laboratory shall propose additional air quality measurement in the air stream before and after passing through the ESP filter and De-NO_2 filter for the Efficiency Test in each ventilation building. The testing procedures shall be submitted to the Engineer for approval 90 days before the Efficiency Tests. After the CWB tunnel is commissioned for 30 days, the Contractor shall carry out Efficiency Test for the APS to verify the performance efficiency of the APS in the tunnel. The accredited independent laboratory shall verify the installation and calibration of the installed air monitoring devices again and witnesses the air quality measurements, certifying their results and efficiency in accordance with Clauses 37.2(1)(i) and (ii) over a seven days period. The accredited independent laboratory shall also conduct additional air quality measurement based on the approved procedure. The result of the additional air quality measurement shall be used as one of the reference in the test report. The Contractor shall coordinate and liaise with TD and the tunnel operator for the arrangement of the Efficiency Test.

(ii) Within 7 days after the Efficiency Test, the test results of the ESP filter and De-NO_2 filter, constituents of the gases shall be submitted to the Engineer for approval. If the test results cannot meet the design criteria as stipulated in Clauses 37.2(1)(i) and (ii), the Contractor shall submit the investigation report and rectification proposal to the Engineer for approval and shall be obliged to carry out all the necessary rectification works at his own costs (e.g. modification of the Tunnel Ventilation System) to improve the performance of the APS. Upon completion of the rectification, the Contractor and the accredited independent laboratory shall conduct the Efficiency Test again in accordance with the approved testing procedures until the test results in compliance with the design criteria as

stipulated in Clauses 37.2(1)(i) and (ii).

TESTING AND COMMISSIONING

Inspection and Testing 37.22

(3) Production quality checks and inspection

Production quality checks and inspections shall be performed as per the manufacturer quality procedures. Production quality checks and inspections shall include but not be limited to the

following items :-

(i) Visual Testing

(a) The products shall be without noticeable defects.

(b) The dimension, tolerances and details shall conform to fabrication drawings.

(ii) Routine Test

(a) The following routine tests shall be carried out for the activated carbon at a rate of 1 sample per 25,000kg of materials, to ensure consistency :-

Test Requirements	Relevant Standard
Carbon Tetrachloride Adsorption CTC	ASTM D3467
Moisture	ASTM D2867
Hardness	ASTM D3802
Bulk density	ASTM D2854
Ignition temperature	ASTM D3466
Ash content	ASTM D2866
Surface area	BET nitrogen adsorption (See note below)
Particle size	Sieve analysis, with reported value for each sub-size.

(Note: BET adsorption is a theory on the physical adsorption of gas molecules on a solid surface. If alternative technology (for example, activated carbon gas absorption) is proposed by the Contractor, the Contractor shall propose the associated routine test to the Engineer for approval.)

The deviation of the test results shall be within the limits of the relevant standards. The Contractor shall submit the test reports to the Engineer for approval within 21 days after the test and before the bulk order of the materials.

The Contractor shall arrange an independent laboratory and/or university to verify the details of the material content of NO_2 removal unit (activated carbon) and compare the result with the specification provided by the Contractor in association with the APS supplier to the Engineer for information.

- Continuity and insulation tests for all filters.
- Energised test for 10% of the filters.

(c) Test record for shall be submitted for the Engineer's approval.

Factory Acceptance Test

37.23 (1) General

(i) Performance and electrical property tests shall be conducted for the ESP filter. One specimen shall be produced for the tests.

(ii) Not used.

(iii) The Contractor shall develop and submit the test plan and the test procedure to the Engineer for approval.

(iv) The Contractor shall provide a minimum of 20 working days notice to the Engineer of the intention to conduct the tests.

(2) ESP Filters

(i) The size of the ESP filter shall not be less than 0.9m(W)x0.6m(H).

(ii) Electrical Testing

(a) Full electrical tests with HV DC supply of the ESP filter specimen meeting the manufacturer's design and EMSD's CoP requirement.

(b)

(iii) Performance Tests

(a) Tests shall be carried out at conditions similar to the tunnel environment and the design airflow velocity.

(b) Types and particle size distributions of the test duct shall include PM_{10}, $PM_{2.5}$, $PM_{1.0}$.

(c) The test shall measure the particle concentration before and after the ESP filters.

(3) Activated Carbon

(i) Size of Activated Carbon for Testing

(a) For confirmation of NO_2 adsorption efficiency, the specimen size of activated carbon for a laboratory scale test under controlled and isolated environment shall be proposed by the Contractor.

(b) The size of the activated carbon filter for confirmation of pressure drop shall not be less than 0.9m(W)x0.6m(H).

(ii) Performance Tests

(a) The activated carbon shall be subject to a NO_2

adsorption test. The test shall be carried out in a totally concealed environment in meeting the local Health Safety and Environmental requirements. The test shall be performed in 3 stages: 1) NO_2 alone, 2) NO_2 and ozone (approx. 0.5ppm) and 3) NO_2 and toluene (approx. 10ppm) to simulate realistic gas concentrations in the tunnel exhaust environment. The media shall meet the system performance requirements in all cases. Adsorption efficiency shall be calculated based on the NO_2 level before and after the activated carbon.

(b) The NO_2 detection system used to monitor the performance during the tests shall have a lower level of detection value of =/< 1.0 parts per billion.

(c) The test shall be conducted in an environment similar to the APS plenum in terms of temperature, humidity and the design airflow velocity.

(d) The concentration of the test gas shall be similar to the tunnel conditions but in no case be more than 1ppm NO_2.

(e) Pressure drop test for De-NO_2 filter shall be conducted based on the proposed filter arrangement. The test shall be conducted in an environment similar to the APS plenum in terms of temperature, humidity and the design airflow velocity.

(iii) Not used

Site Acceptance Tests 37.24 (1) General

(i) The site acceptance testing for APS shall cover installation inspection and electrical testing. It shall cover the tests on wash down plant, water recycling plant, regeneration plant, pneumatic system, sensors, verification of waste, etc. The Contractor shall develop and submit the test plan, test procedure, format of the test report to the Engineer for approval before the test can be carried out.

(ii) The Contractor shall provide a minimum of five working days notice to the Engineer of the intention to conduct the tests.

(iii) Except the Efficiency Test as mentioned in Clause 37.24(4), all site acceptance testes shall be completed by the Contractor and approved by the Engineer before the tunnel is open.

(2) Installation inspection

(i) On completion of equipment installation at site, and prior to testing/commissioning, an inspection is to be performed by the Contractor in the presence of the Engineer.

(ii) The inspection shall confirm or otherwise in writing to the Engineer that the equipment is :-

(a) Satisfactorily installed to the specification and project requirements

(b) Ready for full site testing and commissioning

(3) Electrical testing

(i) Electrical testing shall include, but not be limited to, measurement and record of voltage, current and capacity and also the EMSD's CoP requirement

(4) Efficiency Test

(i) Efficiency Test for the APS shall be conducted after the CWB tunnel is commissioned for 30 days as per Clause 37.7(3) to demonstrate the efficiency of the APS can achieve the design criteria as stipulated in Clauses 37.2(1)(i) and (ii).

(ii) The Contractor shall meet the requirements for Efficiency Test as stated in Clause 37.2(4) and Clause 37.7(3).

1. INTRODUCTION

This test report summarises the measurements recorded and the results obtained during the tests conducted in accordance with the $DeNO_2$ Filter Factory Acceptance Test (FAT) Procedure H2613/CSF/APS/00713-R6 and associated Inspection Test Plans (ITP), Inspection and Test Reports (ITR), Environmental Assessment and Safety Plans of FILTRONtec and Camfil's Technical Center, Trosa, Sweden from 13 to 17 March 2017.
The tests are conducted on samples of activated carbon Addsorb VA10, 4mm, which is the activated carbon selected for the $DeNO_2$ filter for the Central-Wan Chai Bypass – Air purification System in accordance with the PS37.23 requirements.

Adsorption test: $DeNO_2$ Filter FAT is done in accordance with PS37.23 (3) (i) (a) and (ii) (a) to (d) and to H2613-ITP-FT-FDN: Inspection and Test Plan for Factory Acceptance Test of $DeNO_2$ Filter, covering but not limited to:

i. Size of activated carbon
   a. For confirmation of NO_2 adsorption efficiency, the specimen size of activated carbon for a laboratory scale test under controlled and isolated environment shall be proposed by the Contractor.
   b. The activated carbon shall be subject to a NO_2 adsorption test. The test shall be performed in 3 stages: 1) NO_2 alone, 2) NO_2 and ozone (approx. 0.5ppm) and 3) NO_2 and toluene (approx. 10ppm) to simulate realistic gas concentrations in the tunnel exhaust environment.
   c. The NO_2 detection system used to monitor the performance during the tests shall have a lower level of detection value of =/< 1.0 parts per billion.
   d. The test shall be conducted in an environment similar to the APS plenum in terms of temperature, humidity and the design airflow velocity.
   e. The concentration of the test gas shall be similar to the tunnel conditions but in no case be more than 1ppm NO_2.

Due to natural fluctuations of the set value during the test, accuracy of the equipment and the measuring devices, and the usual practice of having +/- tolerances, some tests were done at concentrations above 1ppm NO_2 (please refer to Appendix D for explanation). All conditions were agreed with and accepted by the witnesses.

The activated carbon bed proposed for adsorption test has the following dimensions: 70mm (bed depth) x 50mm (diameter). One sample of activated carbon is used for each set of test conditions.

The adsorption tests are conducted in Camfil's Molecular Media Test Rig (MMTR). The MMTR consists of cylindrical columns in which carbon media beds are formed. One column is kept empty for measuring the upstream concentration during the tests. One analyser is used to measure the challenge substance concentrations both upstream and downstream of the sample. This is done by sequentially changing the sampling point between the columns. The challenge gas is mixed with temperature and humidifity controlled air. Details of the adsorption test rig are attached in Section 2.1

And;

Pressure drop test: A test filter sample which includes perforated sheet in accordance with H2613/MSF/APS/00408 to contain the activated carbon at a bed depth of 400mm is subjected to pressure drop test in accordance with the FAT described in PS37.23 (3)(i)(b) and (ii)(e):

a) The size of the activated carbon filter for confirmation of pressure drop shall not be less than 0.9m(W)x0.6m(H).Types and particle size distributions of the test duct shall include PM_{10}, $PM_{2.5}$, $PM_{1.0}$.
b) Pressure drop test for De-NO_2 filter shall be conducted based on the proposed filter arrangement. The test shall be conducted in an environment similar to the APS plenum in terms of temperature, humidity and the design airflow velocity.

Following international industry standards for laboratory filter testing, the filter for pressure drop testing is reduced to a sample size of 600mm (W) x 600mm (H).

The pressure drop tests are conducted in Camfil's Molecular Filter Test Rig (MFTR), EN779 ISO 1. Details of the pressure drop test rig are attached in Section 2.2.

The following series of tests are undertaken all in accordance with the ESP Factory Acceptance Test Procedures H2613/CSF/APS/00713-R6:

90% humidity condition for adsorption test:
According to $DeNO_2$ Filter Factory Acceptance Test (FAT) Procedure H2613/CSF/APS/00713-R6 one set of tests is to be conducted at 27.5°C & 90% RH. Test conditions above 80% RH cannot be set in the test facility as condensation would occur in the low diameter parts and in the sampling tubes. Thus, the carbon media to be tested has to be pre-conditioned in a desiccator cabinet under controlled humidity conditions to ensure that the activated carbon is subjected to at least 90% RH. This method is feasible as the carbon adapts to the high humidity condition when pre-conditioned for a sufficiently long time. On the other hand, the desorption process is very slow when exposed to an air stream of 80% RH allowing the carbon to remain in the pre-conditioning state for the whole duration of the test.

The pre-conditioning humidity inside the desiccator cabinet is chosen to be 99%. Thus, the test condition is to be renamed in this report to 27.5°C and 99%RH.

The demonstration of the validity of this method was done during FAT. Therefore, one additional activated carbon sample is pre-conditioned under 99%RH (see Fig.1 below). The sample is taken out of the desiccator cabinet at the same time as the sample to be used for the adsorption test at 27.5°C and 99%RH. Some carbon is taken to determinate the moisture content inside the sample (see Fig. 2). The remaining carbon is placed inside the climate chamber where the air for the adsorption test is taken from (see Fig. 3). The controlled test conditions inside the climate chamber were 27.5±6°C & 80±5% RH over the whole duration of the test. After completion of the adsorption tests at 27.5°C/99%RH another sample of the reference carbon was used for moisture content determination (see Fig. 4). As shown in Figures 2 and 4 the moisture content of the carbon before and after the tests remained unchanged. Validation of pre-conditioning procedure is recorded in pages 17 & 18 of Appendix A.

Figure 1

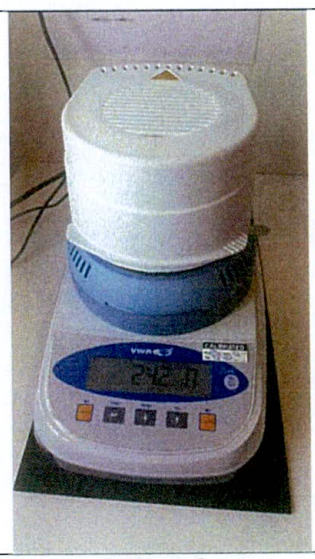


Figure 2

Figure 3

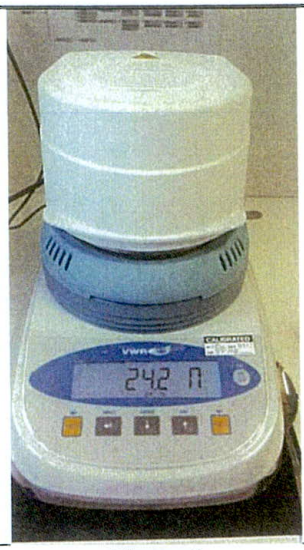


Figure 4

Note: The relative humidity recorded during the testing and included in Appendix A.4 refers to the value that was measured for the air stream. The relative humidity inside the carbon is related to the pre-conditioning status and is equal to 99% RH.

1.1. Adsorption Test of DeNO$_2$ Filter

Adsorption test of the activated carbon is conducted to determine the NO_2 adsorption rates under a set of pre-determined parameters to simulate conditions similar to the tunnel environment (PS37.23 (3) (ii) (a), (b), (c) and (d)).

1. Temperature 27.5°C, Relative Humidity 99%[1]

Air flow rate [l/min]	Contact time [s]	NO_2 inlet concentration [ppm]	Ozone inlet concentration [ppb]	Toluene inlet concentration [ppm]
45	0.18	0.2	0	0
45	0.18	1	0	0
45	0.18	1	500	0
45	0.18	1	0	10

Note[1]:Refer to Section 1- Introduction

2. Temperature 30°C, Relative Humidity 80%

Air flow rate [l/min]	Contact time [s]	NO_2 inlet concentration [ppm]	Ozone inlet concentration [ppb]	Toluene inlet concentration [ppm]
45	0.18	0.2	0	0
45	0.18	1	0	0
45	0.18	1	500	0
45	0.18	1	0	10

3. Temperature 35 °C, Relative Humidity 65%

Air flow rate [l/min]	Contact time [s]	NO_2 inlet concentration [ppm]	Ozone inlet concentration [ppb]	Toluene inlet concentration [ppm]
45	0.18	0.2	0	0
45	0.18	1	0	0
45	0.18	1	500	0
45	0.18	1	0	10

4. Temperature 40°C, Relative Humidity 50%

Air flow rate [l/min]	Contact time [s]	NO_2 inlet concentration [ppm]	Ozone inlet concentration [ppb]	Toluene inlet concentration [ppm]
45	0.18	0.2	0	0
45	0.18	1	0	0
45	0.18	1	500	0
45	0.18	1	0	10

The following values are recorded:

- NO_2 / Ozone / Toluene inlet concentration
- NO_2 outlet concentration
- Air flow rate
- Temperature, relative humidity

The test series is executed in Camfil´s Technical Center in association with FILTRONtec staff.

1.2. Pressure Drop test of $DeNO_2$ Filter

Pressure drop test is conducted to determine the pressure drop across the $DeNO_2$ Filter under a set of predetermined parameters to simulate conditions similar to the tunnel environment (PS37.23 (3) (ii) (e)).

Test temperature [°C]	Air flow rate [m^3/h]	Air velocity [m/s]
23	683	0.53
23	648	0.50
23	583	0.45
23	518	0.40

The test for the air flow rate of 683m³/h was added during the testing on request of the witnesses to make sure that the air velocity through the carbon bed was always equal to or above 0.5m/s. This was required as the air flow rate tolerances inherent to the system of +/- 35m³/h also have allowed an air flow rate of less than 648m³/h and therefore a velocity of less than 0.5m/s.

Pressure loss tests are done at approximately 23°C/50%RH in accordance with standards for filter testing (EN779:2012 and/or ISO16890). Pressure loss is independent of temperature and humidity variation in the range of temperatures and humidities considered to occur in natural environment, i.e. between -10°C and +50°C as well as 20% to 100% RH.

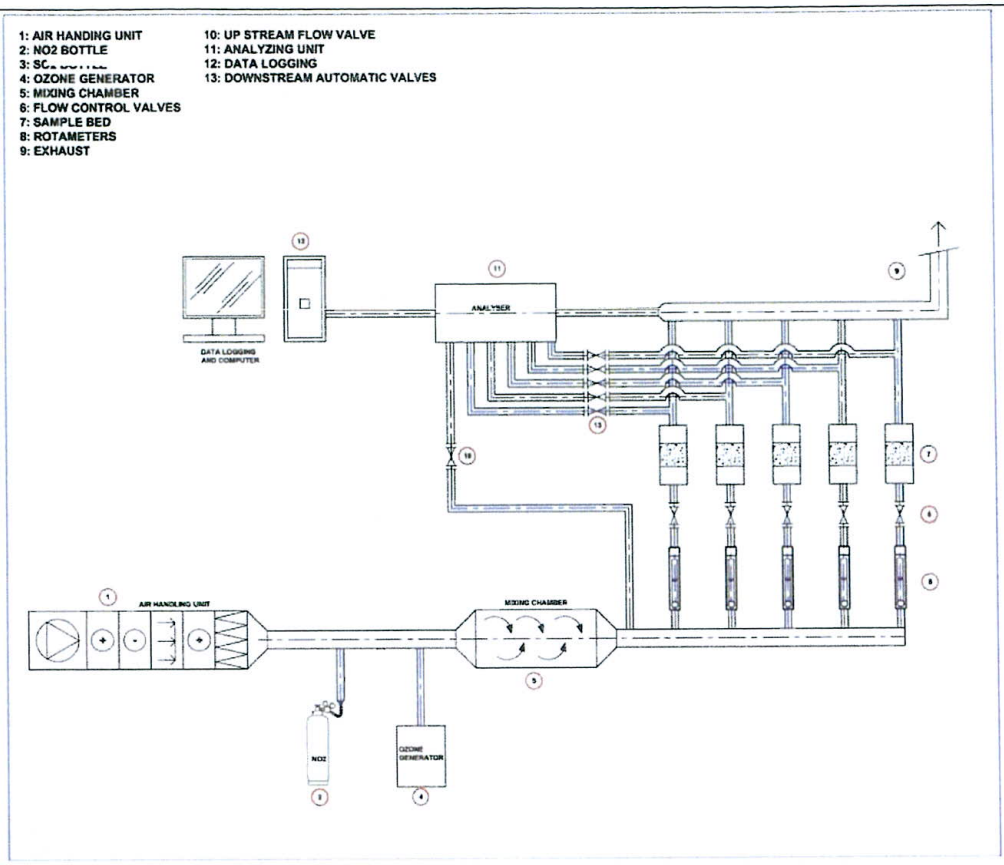
The following values are recorded:

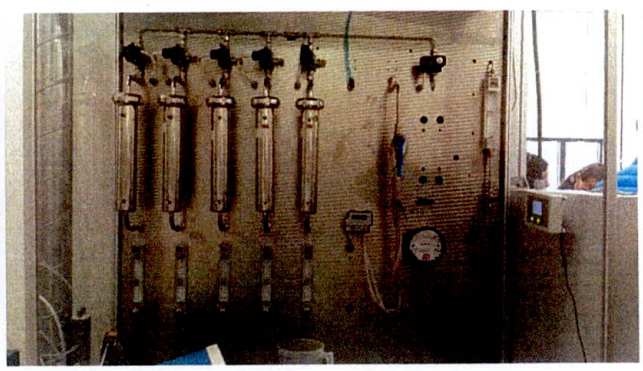
- Air flow rate
- Pressure drop across the filter
- Temperature, relative humidity

2. TEST APPARATUS

2.1 Test Rig for Adsorption Test (MMTR)

FILTRONtec engaged Camfil Svenska AB for the purposes of using their Molecular Media Test Rig available in the Technical Center based in Trosa, Sweden. The layout of the MMTR is shown in the figure below:





Molecular Media test Rig at Camfil Svenska AB in Trosa, SE

MMTR Test apparatus components:

Side Channel Fan: Ventur SC-F-10-220T FC (VENTUR tekniska AB, Sweden)

NO_2 Analyser: 17C Analyser (Thermo Environmental Instruments Inc., USA)

Ozone Analyser: 205 Ozone Monitor (2B Tech Inc., USA)

FID Analyser: Bernath Atomic 3006 (Palgo AB, Sweden)

Installed Temperature and RH Device: Hygroflex5 HF5 (Rotronic AG, Switzerland)

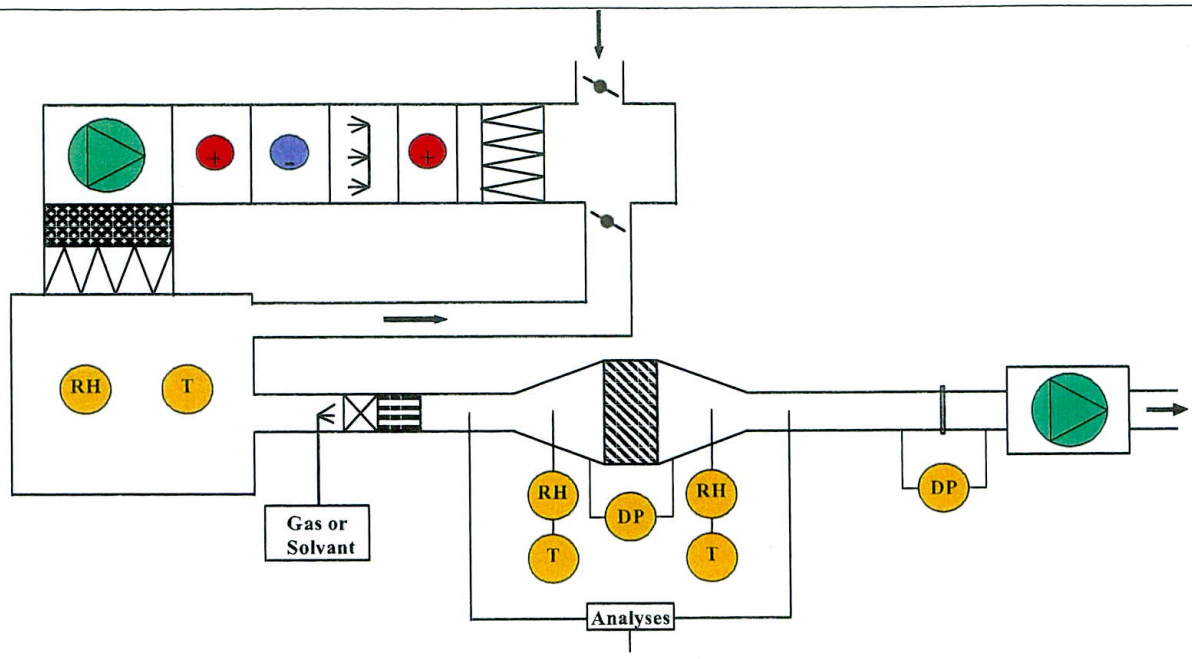
Reference Temperature and RH Sensor: 3000MD Hygroclip (Swema AB, Sweden)

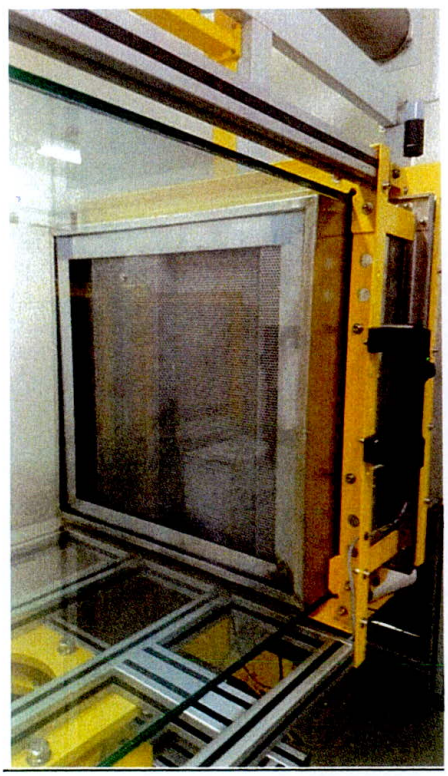
Installed Flowmeter: Rotameter GTF3AHSBÄR10 – 0-100ml/min (CT Platon SAS, France)

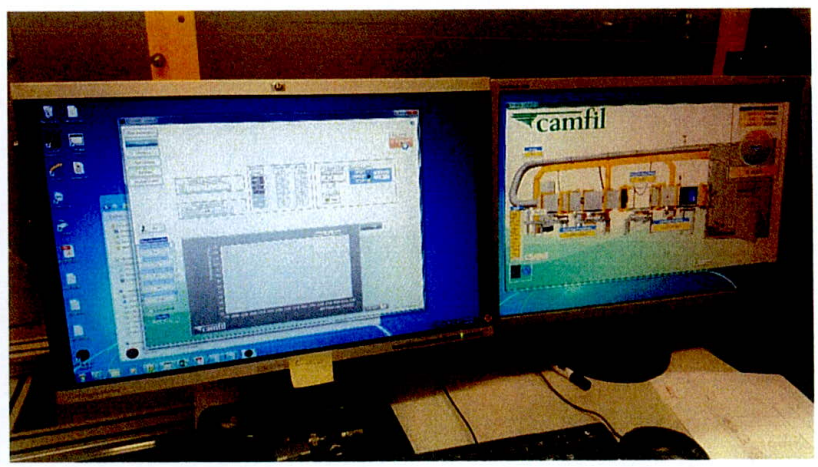
Reference Flowmeter: GSM-B5TA-BN00/GSM-B3TA-BN00 (Vögtlin Instruments AG, Switzerland)

2.2 Test Rig for Pressure Drop Test (MFTR)

The Pressure Drop test is conducted in Molecular Filter Test Rig also available in Camfil´s Technical Center. The layout of the MMTR is shown in the figure below:







Molecular Filter test Rig at Camfil Svenska AB in Trosa, SE

MFTR Test apparatus components:

Installed Temperature and RH Device: KGC3/5 (Galltec+Mella GmbH, Germany)

Reference Temperature and RH Sensor: 3000MD Hygroclip (Swema AB, Sweden)

Installed Thermal mass flowmeter: Sensyflow FMT400-VTS (ABB Automation Products GmbH, Germany)

Reference Flowmeter: GSM-B5TA-BN00/GSM-B3TA-BN00 (Vögtlin Instruments AG, Switzerland)

Differential Pressure Transmitter: Setra 267110CLD2EG2HD (Setra Systems Inc., USA)

Reference Differential Pressure Meter: 3000MD (Swema AB, Sweden)

3. TOLERANCES:

The individual variables of the test are adjusted to the certified calibration test values. The following deviations are considered as acceptable for the test conditions

Adsorption Test
Temperature: ±5%
Relative humidity: ±6%
NO_2 Inlet Concentration: 200ppb / 1ppm ±15%
Ozone Inlet Concentration: 500ppb ±15%
Toluene Inlet Concentration: 10ppm ±15%

Pressure Drop Test
Temperature: ±3%
Relative humidity: N/A (RH does not affect pressure loss)
Airflow rate: +/- 35m^3/h

Calibration certificates for measurement device for both adsorption and pressure drop test are summarised in Appendix C. Please also refer to Appendix D for explanation on the tolerances for environmental conditions and gas concentrations.

4. INSPECTION OF MMTR TEST FACILITY (13.03.2017)

Prior to the execution of the adsorption test, a thorough inspection of test facility was conducted. The following items were checked:

- Position of installed sensors correct,
- Calibration certificates of installed sensors available and valid.

5. ADSORPTION TEST EXECUTION from 13.03.2017 to 16.03.2017

An introduction presentation was conducted outlining the test procedures, housekeeping and safety measures to be observed over the four days.

The tests were executed on 13rd, 14th, 15th and 16th March to determine the influence of NO_2 inlet concentration, test conditions & ozone and toluene presence on the NO_2 adsorption efficiency. Several tests at different NO_2 inlet concentration and temperature & relative humidity conditions were conducted. Tests were also conducted in presence of ozone and toluene.

Please refer to Appendix A for complete test record.

5.1 TEST PARAMETERS 13.03.2017

Test 1:

Start time:	11:10	End time:	11:25
Duration of sampling:		2 minutes each for inlet and outlet	
Air condition:	Temperature:	30°C	Rel. Humidity: 80%
Airflow rate:	45l/min		
Contact time:	0.18s		
NO_2 inlet concentration:		200ppb	

Test 2:

Start time:	14:45	End time:	15:01
Duration of sampling:		2 minutes each for inlet and outlet	
Air condition:	Temperature:	30°C	Rel. Humidity: 80%

1. INTRODUCTION

This test report summarises the measurements recorded and the results obtained of tests conducted in accordance with the Electro Static Precipitator (ESP) Factory Acceptance Procedure H2613/CSF/APS/00456-R6 and associated Inspection Test Plans (ITP), Inspection and Test Reports (ITR), Environmental Assessment and Safety Plans of FILTRONtec and Ilgen Laboratory, Leipzig, Germany from 26 to 30 October 2015.
The tests are conducted on two new ESP specimens selected randomly from the product destined for the ESP filter for the Central-Wan Chai Bypass – Air purification System in accordance with the PS37.23 requirements.

Visual inspection and electrical test: ESP Module FAT in accordance with PS37.23 (2) (i) and (ii) and to H2613-ITP-FT-FEP: Inspection and Test Plan for Factory Acceptance Test of ESP Filter, covering but not limited to:

i. The size of the ESP filter shall not be less than 0.9m(W) x 0.6m(H).
ii. Electrical Testing
    a. Full electrical test with HV DC supply of the ESP filter specimen meeting the manufacturer's design and EMSD's CoP requirement.

One ESP Module specimen, model ESP-1000-123 No. 077, is subjected to a visual and dimensional inspection and tested according to the factory check with a continuity, insulation and full electrical test.

And;

Performance Test: Two specimen ESP Module, model ESP-1000-123 No. 076 and 077, are subjected to the performance test in accordance with the FAT described in PS37.23 (2) (iii):

a) Tests shall be carried out at conditions similar to the tunnel environment and design airflow velocity.
b) Types and particle size distributions of the test duct shall include PM_{10}, $PM_{2.5}$, $PM_{1.0}$.
c) The test shall measure the particle concentration before and after the ESP filters.

The ESP Modules are mounted in a galvanised steel frame with rectangular cross-section and sheeted to form a duct. Adapters connect the ESP Module duct for testing to the test rig ducting. The test rig consists of a circular air channel, a variable speed ventilation fan, a dosing unit for injection of test dust and measuring equipment for determination of particle separation rates and air velocity. The channel is insulated to ensure appropriate temperature conditions. Please refer to FT-HCWB-9001[D] drawing attached for the test facility layout and dimensions. Please refer to Appendix A for the test rig details.

The following series of tests are undertaken all in accordance with the ESP Factory Acceptance Test Procedures H2613/CSF/APS/00456-R6:

1. ESP Module Visual inspection

Visual inspection is to confirm that the manufactured ESP modules conform to FILTRONtec´s assembly drawing FT-HCWB-123-10000 and to verify the absence of noticeable defects. The visual inspection is in accordance with Inspection and Test Records (ITR) covering the following details:

- Check assembly of components, according to FT-123-10000
- Measure ESP module dimensions (0.6mH x 1mW x 0.594mD)
- Check bolt, nuts and rivets
- Check number of plates and spacing
- Check for smoothness (no burrs or uneven stamping) of stamped stainless steel profiles.
- Check that insulators are free from defects

2. Continuity and Insulation test

Continuity test is to confirm that the three electrical circuits (earth, collector live parts, ioniser live parts) are sound and without any short circuit. Continuity test is done using a multimeter.
Insulation resistance is determined using a Megger Insulation Tester. This insulation test is repeated after the electrical test (see below 3. for electrical test description).

3. Electrical test

Electrical test is to confirm the ESP specimen meets FILTRONtec´s design voltages and EMSD´s CoP requirements (refer PS37.23 (2)(ii) (a)), through application of high voltage DC supply to the ioniser and the collector plates up to the required rating. The detected values are recorded against the required operating values using a multimeter with HV probe.

4. Performance Type Test of ESP Module

Performance type test of the ESP Module specimen is conducted to determine the particle separation rates under a set of predetermined parameters to simulate conditions similar to the tunnel environment (PS37.23 (2) (iii) (a).

1. Temperature 27.5°C, Relative Humidity 90%

Air velocity [m/s]	Dust (PM_{10}) inlet concentration [mg/m³]	Ioniser Voltage [kV]	Collector Voltage [kV]
2	1	16	7
2	1	14	4.5
4	0.2	16	7
4	0.5	16	7
4	1	16	7
4	0.2	15	5
4	0.5	15	5
4	1	15	5
6	0.2	16	7
6	0.5	16	7
6	1	16	7
6	1	15.5	6.5

2. Temperature 30°C, Relative Humidity 80%

Air velocity [m/s]	Dust (PM_{10}) inlet concentration [mg/m³]	Ioniser Voltage [kV]	Collector Voltage [kV]
4	0.2	16	7
4	0.5	16	7
4	1	16	7
4	0.2	15	5
4	0.5	15	5
4	1	15	5
6	0.2	16	7
6	0.5	16	7
6	1	16	7

3. Temperature 35 °C, Relative Humidity 65%

Air velocity [m/s]	Dust (PM_{10}) inlet concentration [mg/m³]	Ioniser Voltage [kV]	Collector Voltage [kV]
4	0.2	16	7
4	0.5	16	7
4	1	16	7
4	0.2	15	5
4	0.5	15	5
4	1	15	5
6	0.2	16	7
6	0.5	16	7
6	1	16	7

4. Temperature 40°C, Relative Humidity 50%

Air velocity [m/s]	Dust (PM_{10}) inlet concentration [mg/m³]	Ioniser Voltage [kV]	Collector Voltage [kV]
4	0.2	16	7
4	0.5	16	7
4	1	16	7
4	0.2	15	5
4	0.5	15	5
4	1	15	5
6	0.2	16	7
6	0.5	16	7
6	1	16	7

5. A long-term test is also conducted in order to demonstrate ESP efficiency still fulfils the PS requirements after a continuos operating period of 23 hours. Test conditions are shown below:

Temperature [°C]	27.5
Relative Humidity [%]	90
Air velocity [m/s]	4
Dust (PM_{10}) inlet concentration [mg/m³]	1
Ioniser Voltage [kV]	16
Collector Voltage [kV]	7

6. In addition to the test included in ESP FAT 2 Procedures, tests are conducted to determine the influence of changing collector and ioniser voltages on ESP efficiency at high humidity conditions. These tests are done at 27.5°C and 90% RH.

Air velocity [m/s]	Dust (PM_{10}) inlet concentration [mg/m³]	Ioniser Voltage [kV]	Collector Voltage [kV]
6	0.5	14	4.5
6	0.5	15	5
6	0.5	15.5	6.5

7. Once ESP FAT2 is concluded one additional test is conducted to verify the efficiency of ESP Filter at high relative humidity conditions, i.e. close to 100% RH.

Air velocity [m/s]	4
Dust (PM_{10}) inlet concentration [mg/m³]	1
Ioniser Voltage [kV]	16
Collector Voltage [kV]	7

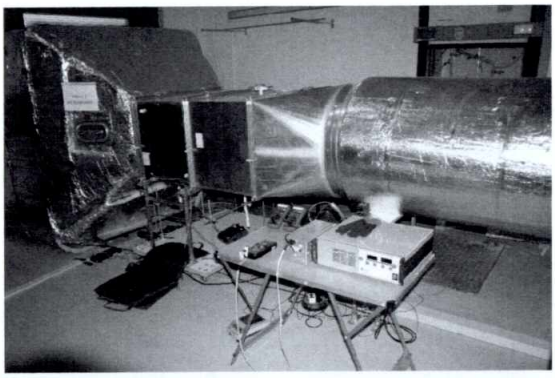
The following values are recorded:

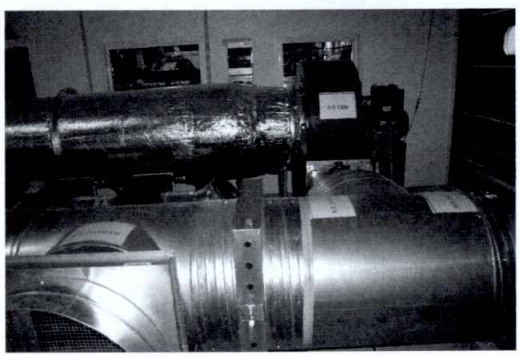
- Particle separation rate for PM_{10}, $PM_{2.5}$ and PM_1
- Electrical parameters of the HV units (voltages)
- Air velocity (air flow rate)
- Temperature, relative humidity
- Pressure loss across the ESP module

The test series are executed in Ilgen Laboratory in association with FILTRONtec staff. The test dust used is standardised by ASHRAE 52.2 and DIN EN 779.

2. TEST APPARATUS

FILTRONtec engaged Ilgen Laboratory for the purposes of using their research and testing laboratory based near Leipzig, Germany to setup a test rig as shown in the figures below.





FILTRONtec ESP Testing Apparatus

Test apparatus components:

High Voltage Units:

REMO HSE:	GMR-D-400N20N 10-20m-P	for Collector	(REMO HSE GmbH, Germany).
	MMR-SP-400N20-20mP	for Ioniser	(REMO HSE GmbH, Germany).

Duct size: Ø 800/630mm

Airflow Range: 2 – 6 m/s

Mistral MR 80/2 Directly Coupled fan (Mistral Srl, Italy)

Dust Generator: PALAS RBG 1000 (PALAS GmbH, Germany)

Dust: ISO 121003-1 A1 (PTI, USA)

Particle Measurement Device: Dust Trak APS 3321 Particle counter (TSI Inc., USA)

Installed Temperature and RH Device: Hygrasgard KFTF 20 I (S+S Regeltechnik GmbH, Germany)

Reference Temperature and RH Sensor: Testo 645 (Testo Industrial Services GmbH, Germany)

Pressure Device: Testo 521 (Testo Industrial Services GmbH, Germany)

High Voltage Probe: TT-HVP 40 AC (TestTec Elektronik GmbH, Germany)

3. TOLERANCES:

The individual variables of the test are adjusted to the certified calibration test values. The following deviations are considered as acceptable for the test conditions and consistent with PS37 requirements for Air Monitoring Equipment:

Temperature: ±1°C

Relative humidity: ±3%

Air velocity: ±5%

Inlet Concentration: 0,2 ± 0,050 mg/m^3

0,5 ± 0,075 mg/m^3

1,0 ± 0,100 mg/m^3

Calibration certificates for Particle measurement device are summarised in Appendix B.

4. INSPECTION OF TEST FACILITY (26.10.2015)

Prior to the execution of the performance test, a thorough inspection of test facility was conducted. The following items were checked:

- Position of installed sensors correct,
- Calibration certificates of installed sensors available and valid,
- Calibration curve verified for analogue output signal of HV transformer displayed at multimeter vs. voltage measured at ESP module,
- Readings at multimeters connected to high voltage probes verified against voltage measured at ESP module.

Test records for all ESP FAT test facility inspection steps are included in Appendix F.

5. ESP MODULE INSPECTION AND ELECTRICAL TEST (26.10.2015), Module no. 077

Please refer to Appendix G for complete test record of modules 076 and 077.

Test 1: Visual Inspection

All items, measurements in accordance with the ESP-1000-123 assembly drawing FT-123-10000.

Tolerances recorded for a sample of 3 collector plate spacings (9.0 ± 0.5mm), counting from left:

- 11^{th}: 9.0mm
- 28^{th}: 8.8 mm
- 39^{th}: 9.15mm

Tolerance recorded between first and last ioniser plate to earthed frame (26.6 ± 0.5mm), counting from left:

- 1^{st}: Top-26.1 mm Middle-26.6mm Bottom-26.2mm
- 16^{th}: Top-26.35 mm Middle-26.35mm Bottom-26.2mm

Test 2: Continuity and Insulation Test

➢ Continuity Test

Resistance recorded between ioniser live parts (Resistance < 1Ω), counting from left:

- 2^{nd}-3^{rd}: 0.39 Ω
- 15^{th}-16^{th}: 0.37Ω

Resistance recorded between collector live parts (Resistance < 1Ω), counting from left:

- 44^{th}-46^{th}: 0.32 Ω
- 1^{st}-46^{th}: 0.35 Ω

Resistance recorded between earthed parts (Resistance < 1Ω), counting from left:

- 45^{th}-47^{th}: 0.28 Ω
- 1^{st}-47^{th}: 0.39 Ω

Prior to the continuity test a reference measurement was conducted with the tester showing a value of 0.32 Ω.

➢ Insulation Test

Resistance value between ioniser and earth (before electrical test): 7.09kV/163.3µA → 43.4MΩ
Resistance value between ioniser and earth (after electrical test): 7.08kV/133.4µA → 53.07MΩ
Resistance value between collector and earth (before electrical test): 4.03kV/131.8µA → 126.7MΩ
Resistance value between collector and earth (after electrical test): 4.09kV/30.2µA → 135.43MΩ

Test 3: Electrical Test

Ioniser (maximum 17.6kV): 16kV

Collector (maximum 7.7kV): 7.1kV

Remarks Recorded: No spark over/flash overs were observed during the electrical test.

Conclusion

The ESP Module specimen has been manufactured within the dimensional tolerances of the FT-123-10000 drawing. The electrical circuits within the module are sound and are well insulated by the ceramic insulators.

The voltages applied to ioniser and collector circuits during electrical test are according to the design voltages.

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-CEP-05

Title/description			
Start up HVT			
Revision	**Date**	**Site**	**Building**
004			

Approved	Yes	No	Signature
QM Representative			
Project Manager			
Project Director			

General information to be read BEFORE switching on HV system

Synchronisation Prometos gamma control unit User Information

1. General

Synchronisation is to be understood as the allocation of the trigger pulses to the correct thyristors of the thyristor controller in the main circuit. If this allocation is incorrect, the high voltage system cannot function since the regulating arm of the control loop does not work.

A new system has passed the factory tests and is, therefore, synchronised. Nevertheless, for the sake of general understanding, the relationships will be explained below. It can, in fact, often happen in new systems that the distribution of the trigger pulses may go wrong as the result of later modifications or the changing of spare parts, for example. It is also necessary that the three phase input system shapes a clockwise turning field.

2. Trigger pulse Amplifier

If we limit ourselves to single phase systems that are controlled by an anti-parallel pair of thyristors, there are always two twin conductor trigger pulse channels. One conductor of a channel (red) is connected to the cathode of the appropriate thyristor (reference voltage), the other is connected to the gate. The appropriate terminals on the trigger pulse amplifier are marked with G1 (gate 1, white), K1 (cathode 1, red) and G2 (gate 2, white), K2 (cathode 2, red). The gate and cathode connections are also clearly marked on the thyristor module.
With a three phase current system, there is a further detail to consider: The three phases can rotate in left or in right direction. To operate the three phase current high voltage system correctly, the three phases have to rotate in right direction.

Under no circumstances should gate and cathode connections be confused.

If the connections to the gates and cathodes are correct, there still remain two possibilities for the allocation of the trigger pulse channels.

The correct one applies the trigger pulse to the thyristor that has a positive voltage on its anode and will therefore conduct when triggered.

The synchronisation is not, however, only influenced by this allocation.

3. Principle

The main circuit, mainly the three phases L1, L2 and L3, are mostly hard-wired within the control cabinet. The arrangement of the B6 thyristor bridge, -V1-1V1, 2V1 and 3V1 in the main circuit is also fixed.

In order to determine the timing of the trigger pulse correctly, the Prometos gamma control unit requires an image of the supply voltage. From this it finds the zero crossings and sets the timing.

The trigger pulse amplifier derives this signal from its own 3 x 18 V AC supply, delivered by the control transformer, whose waveform corresponds to the main supply voltage.

Any error in this chain leads to a loss of synchronisation and a failure of the system.

This could result, for example, from swapping the primary connections when changing the control transformer or reversing the 380 V AC (110 V AC) supply lines to the trigger pulse amplifier. Similar problems occur, when the three phase input voltage does not shape a clockwise turning field.
Although we are dealing with an alternating current system, the lines must not be crossed, as phasing is necessary for correct triggering of the thyristors.

Item No.	Inspection / Activity	Pass [Y/N]
1	**Pre Check**	
	HVT for ESP-Ioniser Serial Number: _____ – Check fuse for control voltage – Visual check of safety relief valve and pressure switch	
	HVT for ESP-Collector Serial Number: _____ – Check fuse for control voltage – Visual check of safety relief valve and pressure switch	
2	**Start up**	
2.1	**Control Panel** **MAKE SURE ALL** **CIRCUITBREAKERS, SWITCHES etc ARE OPEN** **MAKE SURE HV-cable is not connected to HV-aggregate and ESP** **MAKE SURE ACCESS TO ESP IS IMPOSSIBLE** **Lock up area and place signs in position "Danger High Voltage Testing – do**	

Item No.	Inspection / Activity	Pass [Y/N]
	not enter", "Authorized Personnel only" – Switch on Power feeding from Substation o **(to terminal L1-L2-L3 expected : 380V AC / 50Hz, right turning field)**	
2.2	**Ionizer** – Switch on main circuit breaker – Switch on HV Transformer Control Panel o Measure voltage on control transformer –T1 o **(expected secondary : 2 x 230V AC / 24 V DC)** – Switch on fuses and circuit breakers, check voltages 230 VAC rsp 19 VAC rsp 24 VDC – Switch on Prometos Controller, check the start up and synchronization signal – Check the Overtemperature, Overpressure and Oil Level signals from the T/R set and the emergency button of the cubicle door. – Switch on the high voltage in Service Mode o Check the emergency button of the cubicle door o Check if no voltage and no current indication o Turn on a small ignition angle (ca. 15 %); check if voltage increases and no significant current is flowing o Turn on a medium ignition angle (ca. 30 %); check if voltage increases and small current is flowing; double check current with clamp meter o Switch off Service Mode – Switch off the cubicle, disconnect main circuit breaker, ground the system. Connect the high voltage cable. – Switch on HV-unit in manual mode for start up ramp o Increase ignition angle to ca 20 %; check voltages and currents, double check with clamp meter, operate ESP for 20 min o Increase ignition angle to ca 40 %; check voltages and currents, double check with clamp meter, operate ESP for 30 min o Increase ignition angle to ca 50%; check voltages and currents, double check with clamp meter, operate ESP for 30 min – Decrease high voltage to zero and change from manual to automatic mode **(power will increase)** o Write down reached values (primary and secondary voltage and current values)	
2.3	**Collector** – Switch on main circuit breaker – Switch on HV Transformer Control Panel o Measure voltage on control transformer –T1 o **(expected secondary : 2 x 230V AC / 24 V DC)** – Switch on fuses and circuit breakers, check voltages 230 VAC rsp 19 VAC rsp 24	

Item No.	Inspection / Activity	Pass [Y/N]
	VDC – Switch on Prometos Controller, check the start up and synchronization signal – Check the Overtemperature, Overpressure and Oil Level signals from the T/R set and the emergency button of the cubicle door. – Switch on the high voltage in Service Mode o Check the emergency button of the cubicle door o Check if no voltage and no current indication o Turn on a small ignition angle (ca. 15 %); check if voltage increases and no significant current is flowing o Turn on a medium ignition angle (ca. 30 %); check if voltage increases and small current is flowing; double check current with clamp meter o Switch off Service Mode – Switch off the cubicle, disconnect main circuit breaker, ground the system. Connect the high voltage cable. – Switch on HV-unit in manual mode for start up ramp o Increase ignition angle to ca 20 %; check voltages and currents, double check with clamp meter, operate ESP for 20 min o Increase ignition angle to ca 40 %; check voltages and currents, double check with clamp meter, operate ESP for 30 min o Increase ignition angle to ca 50%; check voltages and currents, double check with clamp meter, operate ESP for 30 min – Decrease high voltage to zero and change from manual to automatic mode **(power will increase)** o Write down reached values (primary and secondary voltage and current values)	

Remark: After test shut down the power, open all circuit breakers and EARTH ESP.

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-CEP-05

Conclusion / Results and Comments:

Inspection / Test carried out by:

[Name FILTRONtec Inspector]	[Signature]	[Date]
[Name RICO Inspector]	[Signature]	[Date]
[Name Leighton JV Representative]	[Signature]	[Date]

Checked / Inspected by:

[Name Aecom Inspector]	[Signature]	[Date]
[Name EMSD Witness]	[Signature]	[Date]
[Name HyD Witness]	[Signature]	[Date]

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-CEP-06

Title/description			
Check ESP and Energise ESP systems (ESP-Ioniser & ESP-Collector)			
Revision	**Date**	**Site**	**Building**
003			

Approved	Yes	No	Signature
QM Representative			
Project Manager			
Project Director			

Item No.	Inspection / Activity	Pass [Y/N]
1	**Prepare ESP-Ioniser and ESP-Collector for start-up**	
	Make sure high voltage is still switched off and ESP is connected to earth before entering high voltage area. **Install Signs "Danger – High Voltage – Authorised Personnel only".** **Inside control Panel all circuit breakers are open and secured with lockers.**	
1.1	Earthing Module to Module is connected	
1.2	Earthing Rack connected with local earth grid and fixed	
1.3	High voltage connection from Module to Module is mounted and fixed	
1.4	High voltage connection from Row to Row is mounted and fixed (with V4A 316SS; 40x5mm)	
1.5	High voltage connection from busbar to HV cable is mounted and fixed	
1.6	2 grounding kits installed and earthed	
1.7	Ioniser HV-cable connection fixed to ESP-Ioniser. M8 Bolt, Nut and Spring Washers were used.	
1.8	Collector HV-cable connection fixed to ESP-Collector. M8 Bolt, Nut and Spring Washers were used.	
1.9	Check installation emergency stop button at APS plenum.	
2.0	Short Circuit Test between HV terminal and earth terminal.	

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-CEP-06

MAKE SURE ACCESS TO ESP IS IMPOSSIBLE DURING CONTROL PANEL IS ALIVE

Note: After test shut down the power, open all circuit breakers and EARTH ESP.

Conclusion / Results and Comments:

Inspection / Test carried out by:

[Name FILTRONtec Inspector]	[Signature]	[Date]
[Name RICO Inspector]	[Signature]	[Date]
[Name Leighton JV Representative]	[Signature]	[Date]

Checked / Inspected by:

[Name Aecom Inspector]	[Signature]	[Date]

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-CEP-06

[Name EMSD Witness]	[Signature]	[Date]
[Name HyD Witness]	[Signature]	[Date]

Certificate of Analysis

Lot No.:	87070055	**Date Issued:**	11-Jul-2017
Quantity:	14,500 kg	**Date Manufactured:**	9-Aug-2017
Grade:	AddSorb VA10, 4.0mm, 500 kg, BN, 2BP	**Date Printed:**	4-Apr-2018

Parameter	Method	Spec. min	Spec. max	Value	Unit
CTC (Base, as calc.)	ASTM D5742	60.0	70.0	**61.8**	%
K2CO3 Impregnation	Jacobi T4079	10.0	11.0	**10.2**	%
Moisture Content	ASTM D2867		15.0	**12.9**	%
Ash (Base)	ASTM D2866		12.0	**9.6**	%
Apparent Density (as rec'd)	as rec'd D2854	550	620	**620**	g/l
Hardness (Base)	ASTM D3802	95		**97**	%
Pellet Diameter	T4022	3.6	4.4	**4.1**	mm

This document is valid and generated automatically from our Enterprise Quality Management system

Jacobi Carbons is certified to ISO 9001:2008

Inspection & Test Record

FILTRONtec
EMISSION CONTROL SYSTEMS

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-FDN-02

Title/description	
Adsorption test for FAT of Activated Carbon filter	
Revision	**Date of revision**
01	16/02/2017

Approved by	**Yes**	**No**	**Signature**
QM Representative	—	—	—
Project Manager	—	—	—
Project Director	✓		E. Deux

Test conditions

Test equipment: Please refer to details of instruments and calibration certificates

Place of testing: Filter test laboratory, Trosa, Sweden

Schedule of testing: 13 March 2017 [Date] | 9:00 am [Start time] | 5:30 pm [End time] | Please refer to the attached test record [Duration of indiv. tests]

Test media / Test parameters: 50mm [Carbon bed diameter] | 70mm [Carbon bed depth] | 45l/min [Air flow rate] | 0.18s [Contact time] | Addsorb VA10, 4mm [Type of carbon]

Acceptance Criteria

According to PS37.2(1)(ii) and the information submitted during tender stage: For NO_2, when inlet concentration equal to or greater than 0.25ppm, not less than 85% of NO_2 shall be removed after the air is treated by the APS. For inlet concentration less than 0.25ppm, the outlet concentration shall not be greater than 0.05ppm.

ED CE

CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-FDN-02

No.	Test Conditions									Measured gas concentrations			Purging time before sampling	Time of test result taken
	Test Temperature [°C]		Test Relative Humidity [%]		NO_2 inlet conc. [ppm]	Ozone inlet conc. [ppm]		Toluene inlet conc. [ppm]		NO_2 inlet conc. [ppm]	NO_2 outlet conc. [ppm]	Separation rate [%]		
	PTC**	Rec.*	PTC**	Rec.*	PTC**	PTC**	Rec.*	PTC**	Rec.*					
1.1	30	30.8	80	77.7	0.2	–	–	–	–	0.211	–	92.9	Purging time before sampling: 11:10-11:11	11:11-11:13
1.2	30	30.8	80	77.7	0.2	–	–	–	–	–	0.015		Purging time before sampling: 11:13-11:23	11:23-11:25
2.1	30	30.8	80	78.1	1	–	–	–	–	1.126	–	96.8	Purging time before sampling: 14:45-14:50	14:50-14:52
2.2	30	30.8	80	78.1	1	–	–	–	–	–	0.036		Purging time before sampling: 14:52-14:59	14:59-15:01
3.1	30	30.0	80	79.0	1	0.5	0.533	–	–	0.998	–	98.0	Purging time before sampling: 15:51-15:53	15:54-15:56
3.2	30	30.0	80	79.0	1	–	–	–	–	–	0.020		Purging time before sampling: 15:56-16:04	16:04-16:06
4.1	30	30.7	80	78.5	1	–	–	10	11.08	1.131	–	96.1	Purging time before sampling: 16:18-16:21	16:21-16:23
4.2	30	30.7	80	78.5	1	–	–	–	–	–	0.044		Purging time before sampling: 16:23-16:26	16:26-16:28

*Rec: Recorded conditions

**Proposed testing conditions

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CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08

ITR No. FT-ITR-FDN-02

Remarks:

1) Based on the standard set up of the laboratory and the FAT Procedure H2613-CSF-APS-00713, the upstream gas concentration measurement is taken first followed by the downstream measurement.
2) Before each measurement a purging period is required to remove the residual gas in the feed pipe to the measuring device.
3) The upper and the lower limits for the temperature and relative humidity are as follows (taking into account the sensor tolerances):
    - Temperature (±5%): 28.5°C to 31.5°C
    - Relative Humidity (±6%): 75.2% to 84.8%
4) The upper and the lower limits for the concentration of NO_2, ozone and toluene are as follows (taking into account the sensor tolerances):
    - NO_2 concentration (±15%): 0.17 to 0.23ppm, 0.85ppm to 1.15ppm
    - Ozone concentration (±15%): 0.425ppm to 0.575ppm
    - Toluene concentration (±15%): 8.5ppm to 11.5ppm
5) The raw data measured during the tests are attached to this test form.
6) Please refer to laboratory report nos. MMTR17-010, MMTR17-011, MMTR17-025 and MMTR17-014, for the summary of test results.
7) The raw data of inlet concentration of ozone is attached to this test form.
8) The raw data of inlet concentration of toluene is attached to this test form.

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CLIENT: Highways Department
CONTRACTOR: Leighton Joint Venture
SITE: Central Wan Chai Bypass
CONTRACT: HY/2011/08
ITR No. FT-ITR-FDN-02

Inspection / Test carried out by:

Dr. Elke Deux	E. Deux ED	17/03/2017
[Name FILTRONtec Inspector]	[Signature]	[Date]
CHRIS ECOB	ChrEcob CE	17/03/2017
[Name Camfil Laboratory Inspector]	[Signature]	[Date]

Witnessed by:

Perry W.Y. YEUNG		17 MAR 17
[Name Leighton JV Representative]	[Signature]	[Date]
Y. C. CHEUNG		17 Mar 2017
[Name AECOM Representative]	[Signature]	[Date]
H. T. CHEUNG	J	17 Mar 2017
[Name EMSD Representative]	[Signature]	[Date]
PETER W C WONG		17/03/2017
[Name HyD Representative]	[Signature]	[Date]

ED CE J

LEIGHTON 禮頓

Test Report for Electrostatic Precipitator Performance Test

Project : HY/2011/08 - Central-Wan Chai Bypass - Tunnel Buildings, Systems and Fittings, and Works associated with Tunnel Commissioning

Testing Date: 28 October 2015

Equipment to be tested: ESP filter ESP 1000-123 (no. 076)

Testing Time: 08:30 to 17:00

Test Location : Filter test laboratory, Labor Ilgen, Krostitz, Germany

Data Log Ref: Please refer to remarks

Voltages: Ioniser: 14kV Collector:4.5kV

No.	Test Condition			Average Dust Concentration									Pressure Drop
				PM_{10}			$PM_{2.5}$			PM_1			
	Temperature	Relative Humidity	Velocity	Inlet	Outlet	Separation rate	Inlet	Outlet	Separation rate	Inlet	Outlet	Separation rate	
	[°C]	[%]	[m/s]	[mg/m^3]	[mg/m^3]	[%]	[mg/m^3]	[mg/m^3]	[%]	[mg/m^3]	[mg/m^3]	[%]	[Pa]
1	27.5	90	2	1.030	0.026	97.5	0.671	0.023	96.6	0.579	0.023	96.0	7
2													
3													
4													
5													
6													
7													
8													
9													

Remarks: All the measured data is attached to this test record sheet (2 Sheets in total).

Data log reference: No.1- 055/073

According to PS37.2(1)(i): For particle, when inlet concentration equal or greater than 0.5mg/m3, not less than 80% of PM10 shall be removed after air is treated by the APS.
For inlet concentration lower than 0.5mg/m3, the outlet concentration shall not be greater than 0.1mg/m3.

Test Conducted by:	Witnessed by:	Witnessed by:	Witnessed by:	Witnessed by:
Name : Elke Deux	Name : Kent Fan	Name : Eric Cheung	Name : Harvey Chu	Name : RAYMOND WAN
Company: FILTRONtec	Company: Leighton Joint Venture	Company: AECOM	Company: EMSD	Company: HyD
Signature : E. Deux	Signature :	Signature :	Signature :	Signature :
Date: 30/10/2015	Date: 30 Oct 2015	Date: 30 Oct 2015	Date: 30 Oct 2015	Date: 30.10.2015