Introduction of water/salt test procedure for ETN Air filtration Working Group

Gas Turbine / Compressor Air Inlet Filter Systems

Definition: Most air filters are affected by salt / water spray are located on Offshore platforms, FPSO or coastal sites (defined <10km) from the Sea.

3rd draft for comment.

Date: 6th July 2018

To be added:

See review note for draft 1-8

Contents

Foreword

The ventilation and combustion air system usually consists of a filter house structure, silencers, fans, and associated ductwork. The filter house is comprised of weather hoods, droplet vanes or similar, air filter elements, optional chiller or anti-icing coils, and plenum chamber assembly. Air from the plenum assembly is ducted to the turbine engine intake for combustion and sometimes to the turbine and generator compartments for cooling and ventilation.

Image to be added later

Image to be added later

High Efficiency Particulate Air filters ((H)EPA) filters static filters can be fitted behind pulse filters to optimize the air cleanliness for the compressor (or act as a secondary barrier filter especially in areas of high hydrocarbons particles).

Image to be added later

Introduction

The use of gas turbines in the oil & gas industry represents one of the most challenging applications for this engine technology. The major constraint of the oil & gas business is to run 24/7 at full load with minimum downtime. In oil & gas activity, it is of prime importance to run the installation as close as possible to 100% of the time with the highest level of efficiency (current production compared to nominal production).

An additional challenge for oil & gas applications lies in the absence of a back-up on site especially for mechanical-drive gas turbine configurations.

To complete the picture, the coastal and offshore environment probably represents the harshest conditions for gas turbines. Humidity, rainfall and wind dust are the most obvious visible conditions that operators face on site. Hidden in the combustion air, alkali such as potassium, sodium or magnesium, as well as sulfur, soot, volatile hydrocarbons, oily vapors, and particles all generate gas turbine issues including compressor fouling, air-cooling passage fouling, vane and blade erosion, and compressor corrosion. Combined with sulfur in fuels, these alkali in combustion air create hot corrosion. Finally, heavy rainfall may induce filter washings that release filtered particles into the compressor. All these phenomena impact the gas turbine availability on site. An operating company aiming for excellence has to strive to minimize lack of availability and performance deterioration in order to make the asset more energy efficient and profitable.

The role of a highly efficient air filtration system is to maintain the engine cleanliness by preventing the introduction of contaminants into the gas turbine air intake. Achieving a high level of engine cleanliness helps maintain engine integrity and efficiency and reduces the need for water washes which generate avoidable downtime. Consequently, this reduces OPEX by minimizing the requirement for onsite maintenance and overhaul.

Currently, high efficiency filter elements are characterized by a limited number of parameters, namely filter efficiency and MPPS (Most Penetrating Particle Size). These parameters, related to a single filter element, are measured in laboratory conditions close to favorable inland conditions with synthetic dust. Consequently, these conditions are far from the reality observed on site, offshore or near coast, where filter elements are usually part of a system. The test results do not therefore provide a basis for predicting either operational filter performance or service life.

The objective of ISO 29461 - Part 5 is to close the gap between the current filter element characterization conditions (e.g.: ISO 29641 – Part 1) and the site environment. As a first criterion, the standard considers the effect of humidity and alkali such as salt changing its structure with humidity. The tested air flow passing through the filter element is close to the air flow operated on site for the three different concepts: low, medium or high velocity filter elements.

Soot, volatile hydrocarbons, oily vapors and particles also have impact on filter characterization. Particles are covered in separate parts of ISO 29461, while soot, volatile hydrocarbons and oily vapors will have to be addressed in future revisions of ISO 29461 – Part 5. The work on the current revision has revealed that current test methods are not mature enough for inclusion of soot, volatile hydrocarbons and oily vapors.

The ageing of a filter element installed offshore and near coast is addressed to allow the prediction of operational filter performance and its associated service life. It is of paramount importance to understand how filter elements perform during different cycles representing typical site conditions such as heavy rainfall, low and high humidity, filter element unloaded and loaded. In addition, these test outcomes allow a true comparison of the three different concepts and the different brands.

Depending on the gas turbine applications, the service life of the filter element is also a criterion to take into consideration. A minimum service life of 3 years is required, especially for LNG applications. In this case the robustness, loading capacity and pressure drop characteristics of the filter elements become key parameters for design and testing.

Finally, how to test and measure the performance of a complete intake air filter system (series of different filter elements, vane separators, etc.) against the offshore and coastal harsh conditions is addressed through ISO 29461 - Part 5.

Terms and definitions

Review note for draft 1: To be added

1. Scope

The scope of this procedure includes methods for performance testing of individual filter elements (M5-EPA) and of the complete filtration system. This procedure is intended for filter elements and filter systems which operate at flow rated up to 8000 m3/h per filter element.

2. Description of test method

Air intake filters in marine and offshore installations are almost constantly exposed to high humidity, wet foggy conditions and sea water spray containing mainly NaCl salt.
Salt ingestion into the gas turbine can cause either or a combination of erosion, fouling and corrosion depending on amounts. Hot corrosion may also occur.

Within the GT industry differential pressure (dP) is the most common way to indicate end of life of air filter elements. Often salt breach and salt related damages can be experienced even without the air intake differential pressure showing any significantly high or increasing dP values. This depends both on system design and air filter selection.

When testing in lab conditions, most conditions i.e. salt and dust load must be accelerated to be practical. The acceleration compared to real life must be done without creating a new failure mechanism.

The following test method is designed to challenge the air intake test object (the test object could be a complete system, a single filter or a multi-stage filter system) with sub-micron salt to ensure that the fiber structure is challenged deep within the filter and not only on the surface. This allows simulation of salt loading, and the cycling of relative humidity allows simulation of aging because the salt particulates will transform from dry to liquid phase. In real life the filters are exposed to both sub-micron and larger salt particles and water droplets.

Main "failure" modes – weaknesses to detect using this test procedure/method:

a) **Bypass of salt and water through not properly sealed construction.**
Example: To little glue between frame parts causing leakage.

b) **Penetration of salt and water through the filter media.**

Example: Construction is sealed good, but the filter media has poor water repellency causing leaks through media.

c) **Penetration of dry salt through filter.**
Example: Low particle filtration efficiency, not suitable as final filter.

d) **High dP spikes** (i.e. passing 600 Pa or similar pre-set value) during in more than 3 subsequent cycles or whenever passing 1000 Pa.

Observations to be made during test

a) Media bulging
b) Filter breaking
c) Pleat deformations
d) Water penetration

Challenges

Small leakages are hard to detect by instrumentation. Regardless of the slope on the test duct floor, it takes a certain volume to flow to a low collection point. Can be solved by collecting the water using a sponge of known weight and weighing the sponge again after collecting the water in it.

3. Test apparatus

3.1. General

At this point in the draft we are not able to describe everything to the point were its possible to just order and build a test rig according to what is described in this document. The goal as time progresses is of course to do further testing and add levels of detail until that is the case. For now we have chosen to simple list the equipment that we've used so far in our trials.

3.2. Test duct

3.2.1. Test rig layout

The test rig (see Figure 3) consists of several duct sections (may be rectangular or square) with a typical 650mm x 650mm (25.6" x 25.6") nominal inner dimensions. If different, cross section dimensions to be stated in the report. The section where the test filter is installed is to be representative of the cross-sectional area and geometry for a single filter within the proposed offshore inlet system.

In case of circular cartridges, the test setup (mounting of the filters in the test duct) shall be as close to the real application as possible. This must however be analysed specifically for each construction, taking into consideration possible jetting effect that can affect the velocity and aerosol concentration in the test duct cross section.

The test rig is operated in a negative pressure airflow arrangement, which represents the typical air flow condition for a gas turbine. A positive pressure arrangement is not typically encountered in gas turbine air inlet systems.

3.2.2. Test air conditioning

A HEPA class H13 filter shall be placed in the loop to ensure high quality air is entering in the measurement area.

Depending on numerus external factors such as the ambient relative humidity of the test lab etc. additional equipment might need to installed in the test rig in order to adjust the conditions of the test air to within specification (see section 4.1.1)

3.2.3. Adjustment of the volume flow rate

Filters shall always be tested at by one of the three default airflows or by customer specific airflow. It shall be possible to adjust the volume flow rate by means of a suitable provision (e.g. by changing the speed of the fan, or with dampers) to a value ± 5 % of the nominal flow rate which shall then remain constant within ± 5 % throughout each test.

Default airflows:

Depending on the intended use of the filter, choose a corresponding airflow for the test to be run at. Airflows as follows:

a. **Nominal airflow**
   4250 m3/h
b. **Increased airflow**
   6000 m3/h
c. **High Velocity**
   8000 m3/h

Review note for draft 2: Current testing has been done at 4250m3/h, it is unknown what effects there would be when using higher than nominal airflow. To be tested.

3.2.4. Measurement of the volume flow rate

The volume flow rate shall be measured using a standardized or calibrated method (e.g. measurement of the differential pressure using standardized equipment such as orifice plates, venturi tubes etc.)

3.2.5. Measuring points for pressure drop

The measuring points for pressure drop shall be so arranged that the mean value of the static pressure in the flow upstream and downstream of the filter can be measured. The planes of the pressure measurements upstream and downstream shall be positioned in regions of an even flow with a uniform flow profile.

In rectangular or square test ducts, smooth holes with a diameter of 1 mm to 2 mm for the pressure measurements shall be bored in the middle three of the channel walls, the hole in the floor should be left out as there is a high risk of that hole clogging with water and/or salt. The holes should be bored normal to the direction of flow. The three holes shall be interconnected with a circular pipe/tube.

3.2.6. Aerosol mixing section

The aerosol input and the mixing section shall be so constructed that the aerosol concentration measured at individual points of the duct cross section, directly in front of the test filter, shall not deviate by more than 15 % from the mean value of at least 9 measuring points, over the channel cross section.

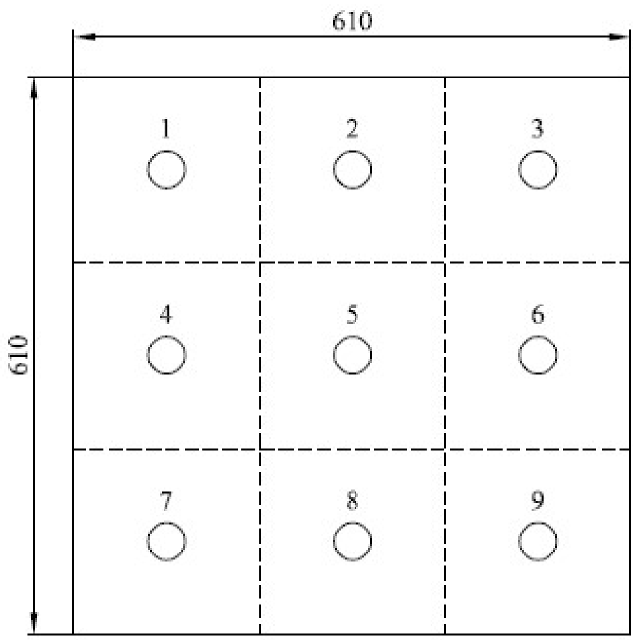


Figure 1. Test points for aerosol uniformity testing.

3.2.7. Test filter mounting assembly

Review note for draft 3: Too be included in final version.

3.3. Measurement equipment

Rig test typical instrumentation:

- Pressure transducers for measuring atm. pressure as well as pressure drop over filters, droplet separators etc. Also using an orifice for flow measurement.
- Humidity sensors.
- Thermocouple

Flame Photometer:

When a solution of metallic salt is sprayed as fine droplets into a flame. Due to the heat of the flame, the droplets dry leaving a fine residue of salt. This fine residue converts into neutral atoms.

Due to the thermal energy of the flame, the atoms get excited and after that return to ground state. In this process of return to ground state, excited atoms emit radiation of specific wavelength. This wavelength of radiation emitted is specific for every element.

This specificity of the wavelength of light emitted makes it a qualitative aspect. While the intensity of radiation depends on the concentration of element. This makes it a quantitative aspect.
Elements of Group IA and Group IIA (like Li, Na, K & Ca, Mg) are only analyzed.
The radiation emitted in the process is of a specific wavelength. Like for Sodium (Na) 589nm radiation, Potassium 767nm range radiation.

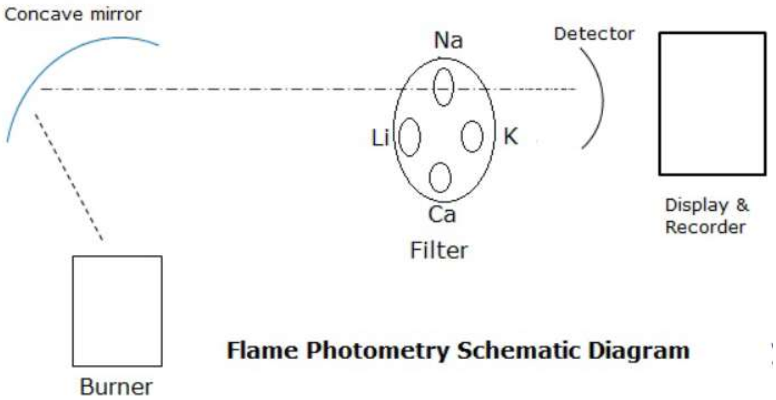


Figure 2. Flame Photometry Schematic Diagram

SMPS & CPC:
Please refer to EN1822-2:2011.

3.4. Aerosol generation

Review note for draft 4: Salt generator – see APPENDIX A "Mk. II Prototype salt generator"

3.4.1. Salt concentration

Review note for draft 5: To be defined

3.5. Water injection system

Review note for draft 6: Too be specified in more detail at a later stage. For now please refer to section 3.6 to see what equipment we used (Camfil and Gore).

3.6. Equipment used during trials

Review note for draft 7: See APPENDIX B "Equipment used during trials"

3.7. Water collection

The collection basins connected to the drains shall be built and configured in such a way that they can be closed off from the rig and removed while keeping the rig free from leaks (i.e by using ball valves). They should also have ventilation that is connected back to the test rig to ensure free flow of water into the basins.

4. Test method for single filter or multi-stage system

4.1. Test rig and equipment

4.1.1. Test conditions

Room air or outdoor air may be used as the test air source. The air temperature shall be in the range of 10 °C to 45 °C. The exhaust flow may be discharged outdoors, indoors or re-circulated.

4.1.2. Test rig

The test rig can be configured in multiple different ways depending on if the object being tested is a single filter element or a multi-stage solution (see Figure 3&4). Larger images can be found in APPENDIX C and D.

In case of circular cartridges, the test setup (mounting of the filters in the test duct) shall be as close to the real application as possible. This must however be analyzed specifically for each construction, taking into consideration possible jetting effect that can affect the velocity and aerosol concentration in the test duct cross section.

If part of the system, the high velocity vane separator shall be installed upstream of the droplet separator included in Figure 4.

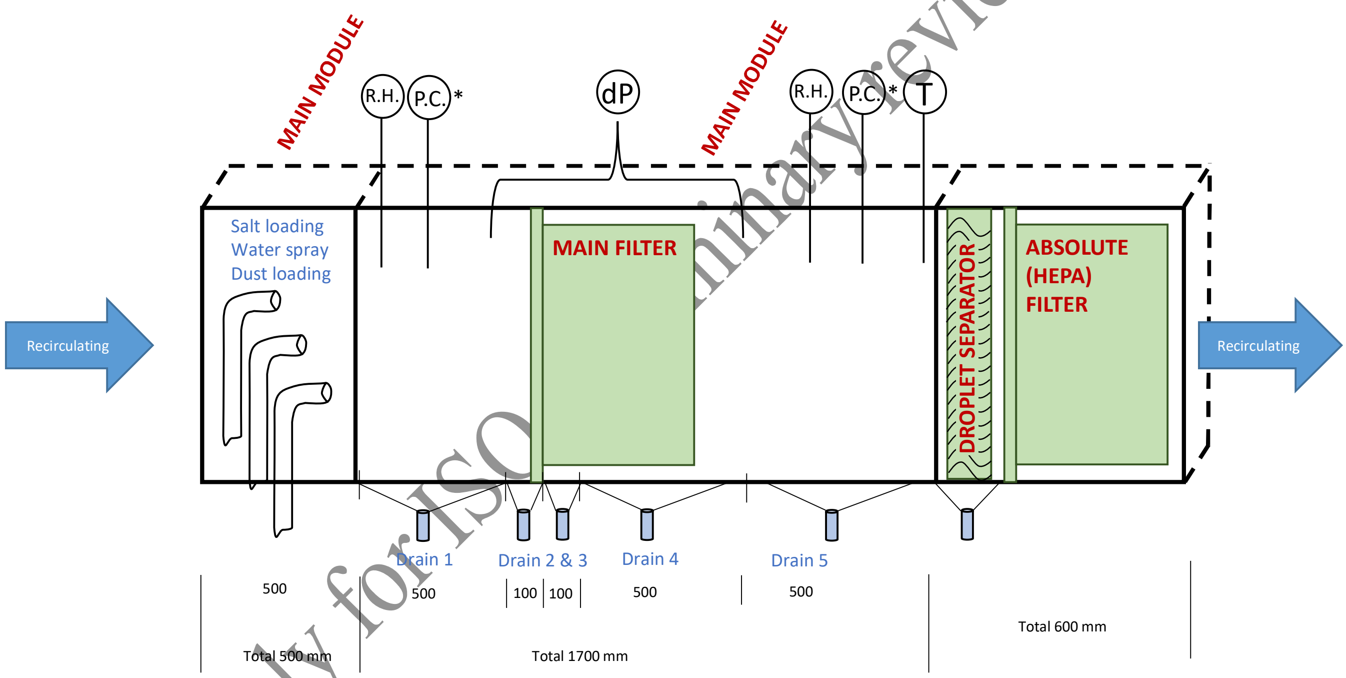


Figure 3. Test duct configure for testing of single filter element.

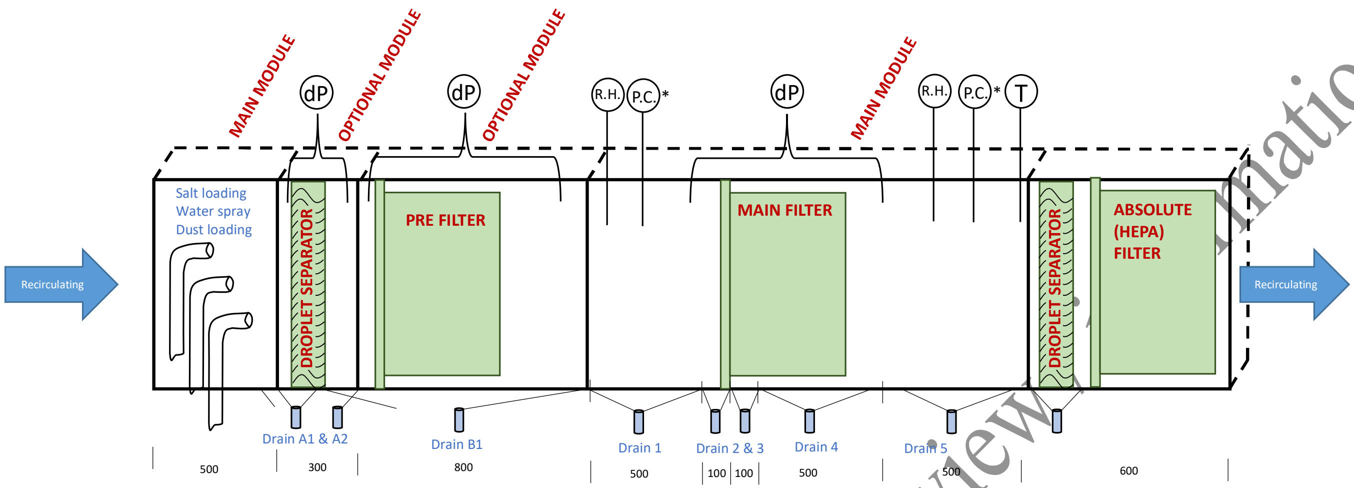


Figure 4. Example of test duct configuration for testing of complete system

Instrumentation:

Upstream:

- Sub-micron salt injection using salt generator (described in section 3.4)
- Water spray nozzles (described in section 3.5)
- dP sensing port (according to section 3.2.5)
- Low point drainage point with collecting basin
- Sodium flame photometer

Downstream:

- dP sensing port (according to section 3.2.5)
- temp and r.H. sensor.
- Low point drainage point with collecting basin.
- Sodium flame photometer

4.2.Test method

4.2.1. Idea

The size and weight of salt particles changes drastically during periods of high and low relative humidity. It is therefore important to transfer this into the lab test by cycling the RH from low to high while introducing the salt particles from the salt generator, the accelerated cycling will cause accelerated aging. The tested filter will be challenged by salt in all phases as it transforms with relative humidity levels. A fine water spray is used to determine the water repellency of the filter and visually allows detection of any leakages. The process is repeated until water bypasses the filter media or pressure drop reaches a certain limit.

4.2.2. Preparatory checks

After switching on the test apparatus the following parameters shall be checked:

a. Operational readiness of the measuring instruments:

Before each measurement the sodium flame photometer need to be turned on and warmed-up as specified by the instrument maker.

b. Zero count rate of the particle counter and/or sodium flame photometer:
The measurement of the zero count rate shall be carried out using flushing air which is free of particles.

c. Absolute pressure, temperature and relative humidity of the test air:
These parameters shall be checked to ensure that they comply with the specifications described in section 4.1.1.

4.2.3. Starting up the aerosol generator

Before turning on the heater, start by checking the level in the tank containing the saline solution to see that it is at the appropriate level as specified in APPENDIX A.

Have the salt generator been unused for one week or more, remove the water container and rinse it completely in order to remove any salt build-up that may have occurred due to evaporation of the saline solution. Make sure that the holes in the laskin nozzles are not clogged.

After adjusting the operating parameters of the dry salt generator and observing an appropriate warming-up period, the salt concentration shall be checked to ensure that it complies with the requirements specified in section 3.4.1. The salt concentration shall be determined as close to the filter mounting assembly as possible i.e. by sampling through the upstream sampling probe.

4.2.4. Installation of the test filter

The test filter shall be handled in such a way as to ensure that it is not damaged.

The test filter shall be installed in the mounting assembly with regard to air flow direction and gasketing side as it is foreseen for use.

The interface between the filter element and the duct shall use the filter's production gasket and compressed to the filter manufactures recommended setting by max 4 fixation points. The gasket shall not be sealed by any other means (i.e. tape).

4.2.5. Flushing the test filter

In order to reduce the self-emission of particles by the test filter and to equalize the temperatures of the test filter and the test air, the test filter shall be flushed with test air for 10 minutes at the nominal volume flow rate.

4.2.6. Measurements to be made

a. Measuring the pressure drop
The pressure drop across the test filter shall be measured in the unloaded state using the pure test air. The nominal volume flow rate shall be set up, as specified in section 3.2.3. The measurements shall be made when a stable operating state has been reached. The pressure drop across the test filter shall be continuously measured and recorded for the complete duration of the test.

b. Measure the dry salt removal efficiency
Using the sodium flame photometer a number of efficiency reading needs to be taken during the test. Using the upstream and downstream sampling probes.

c. **Measure the water removal efficiency**

Measure the water removal efficiency by collecting the water at each of the drains and note how much water each drain has collected in relation to the water injected into the test rig. In the event that the volume of the water found downstream of the filter is low enough that it will not run towards the drain, weigh a piece of paper or similar before and after drying out the duct with said paper.

4.3. Test cycle

a. Zero test rig (no 'test object')

1. With an empty test rig (no 'test object'), turn on the air flow.
2. Allow the air flow to stabilize (variation of +/- 100m3) at the desired test volumetric air flow (4,250 m3/hr, 6,000 m3/hr, 8,000 m3/hr or other).
3. Turn on the sodium flame photometer (SFP) and the salt generator (SG).
4. Measure the salt concentration with the SFP.
5. When the salt concentration (4.) has been verified turn off the SFP and the SG.
6. Turn on the water challenge, water volumetric flow 1.7g water /m3 of air.
7. Measure the water challenge dispersion plumes.
8. When the water challenge dispersion plumes (7.) have been verified, increase the water challenge, water volumetric flow 3.4g water /m3 of air.
9. Measure the water challenge dispersion plumes.
10. When the water challenge dispersion plumes (9.) have been verified, turn off the water challenge and air flow.

b. Cleaning of test rig

11. With the air flow turned off, thoroughly clean down the test rig, ensuring no salt, condensation/moisture or free standing water is on any of the test rig or installed equipment surfaces, including measuring probes etc. Also ensure that all drainage points are clean and free to drain.

c. Primary weighing of the 'test object'

12. Prior to installation into the test rig, the 'test object' is to be weighed in a new and dry condition (air temperature to be 25C +/-5C and 40% RH +0/-10%).

    Note: If the laboratory room conditions are significantly different to the 'weighing' conditions above, the 'test object' could be installed in the test rig with air flow turned on in order for the desired weighing conditions to be achieved. The ‘warming’ duration in the test rig being 1 hour minimum.

d. Installation of the ‘test object’

13. If not already done so to accommodate cleaning of the test rig as per 12 above, remove any test rig components i.e. removable panels, viewing windows etc that are required to be removed to accommodate the installation of the ‘test object’.

14. Install the ‘test object’ into the test rig. The installation configuration shall be as intended to be supplied or as actually installed in the offshore application i.e. orientation, retention, gasket sealing and compression.

15. Re-install any test rig components i.e. removable panels, viewing windows etc that were removed to accommodate the installation of the ‘test object’.

e. Primary water deluge challenge

16. Turn on the air flow.

17. Allow the air flow to stabilize (variation of +/- 100m3) at the desired test volumetric air flow (4,250m3/hr, 6,000m3/hr, 8,000 m3/hr or other), air temperature to be 25C +/-5C and 40% RH +0/-10%.

18. Turn on the water challenge with a water volumetric flow 3.4g water /m3 of air and run for a period of 1 hour.

19. Turn off the water droplet challenge.

20. Allow the ‘test object’ to dry at an air temperature to be 25C +/-5C and 40% RH +0/-10% for a period of 1 hour and return to the initial Dp.

f. Salt loading

21. Turn on the SFP and the SG for the remaining entirety of the test.

22. 1 hour salt loading of salt.

g. Salt and water deluge challenge

23. Increase the air RH to >95% with the temperature remaining at 25C +/-5C.
Note: the RH ramp up duration from 40% +0/-10% to >95% is to be 15 minutes, with a linear RH increase over this duration.

24. Turn on the water deluge challenge, water volumetric flow 1.7g water /m3 of air, and run for a period of 1 hours.

25. At the end of the 1 hour period turn off the water deluge challenge.

h. Relative humidity cycles

26. Decrease the air RH from >95% to 40% +0/-10% with the temperature remaining at 25C +/-5C.
Note: the RH ramp down duration from >95% to 40% +0/-10% is to be 30 minutes, with a linear RH decrease over this duration.

27. Run for a period of 1.5 hours at RH 40% +0/-10%.

28. Increase the air RH to >95% with the temperature remaining at 25C +/-5C.
Note: the RH ramp up duration from 40% +0/-10% to >95% is to be 15 minutes, with a linear RH increase over this duration.

29. Run for a period of 60 minutes at RH >95%.

30. Decrease the air RH from >95% to 40% +0/-10% with the temperature remaining at 25C +/-5C.
Note: the RH ramp down duration from >95% to 40% +0/-10% is to be 30 minutes, with a linear RH decrease over this duration.

31. Run for a period of 1.5 hours at RH 40% +0/-10%.

32. Repeat steps 24 to 30 until water is found to be downstream of the 'test object'.

33. On cessation of the test due to failure mode(s), decrease the air RH to 40% +0/-10% with the temperature remaining at 25C +/-5C for a period of 1 hour, permitting the 'test object' to dry.

i. Secondary weighing of the 'test object'

34. Remove any test rig components i.e. removable panels, viewing windows etc that are required to be removed to accommodate the extraction of the 'test object'.

35. Extract the 'test object' from the test rig.

36. The extracted 'test object' is to be weighed in a loaded condition (air temperature to be 25C +/-5C and 40% +0/-10%).

5. Report

Review note for draft 8: To be added at a late stage.

The report shall describe all deviations from the test setup specified in this standard.

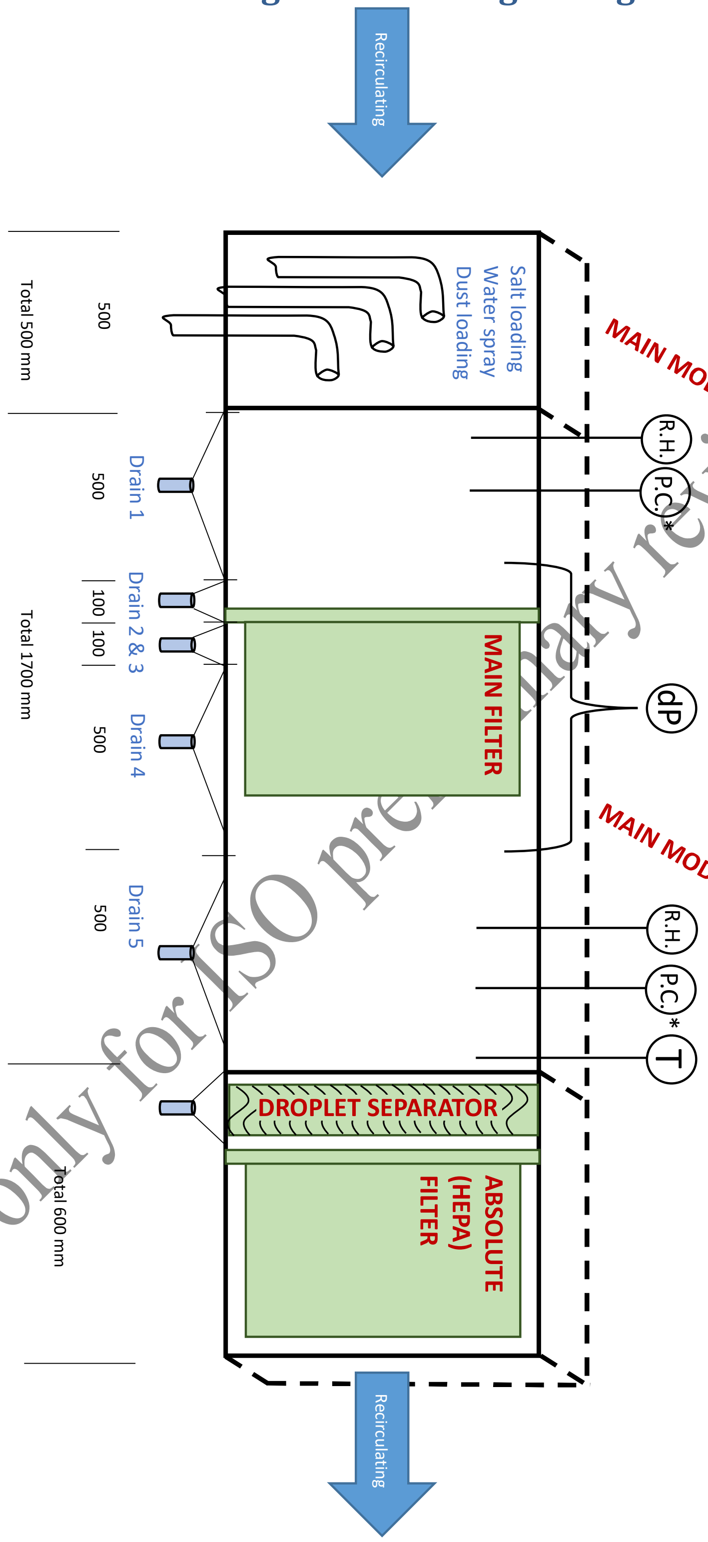
APPENDIX A – Mk. II Prototype salt generator

See separate document.

APPENDIX B - Equipment used during trials

See separate document.

APPENDIX C – Test duct configure for testing of single filter element.



APPENDIX D - Test duct configuration for testing of complete system