ISO 29461-5 Draft: Air intake filter systems for rotary machinery - Part 5: Test methods for static filter systems in marine and offshore environments

Evaluation Tests

European Turbine Network
Air Filtration Working Group
MAN Diesel & Turbo SE
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Provide Inputs to Current Draft Document

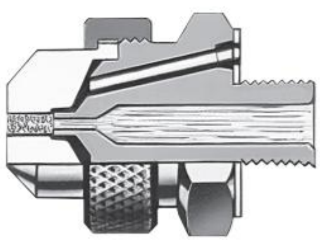
- 6.1 & 7.1 Test rig and equipment
- 6.2 & 7.2 Saline solution aerosol generation
- 6.3 & 7.3 Saline solution aerosol removal efficiency

Agenda

- Review salt mist generation method with atomizing nozzle
- Develop method to measure salt breach
- Evaluate three inlet air filters for salt protection

Salt Mist Generation

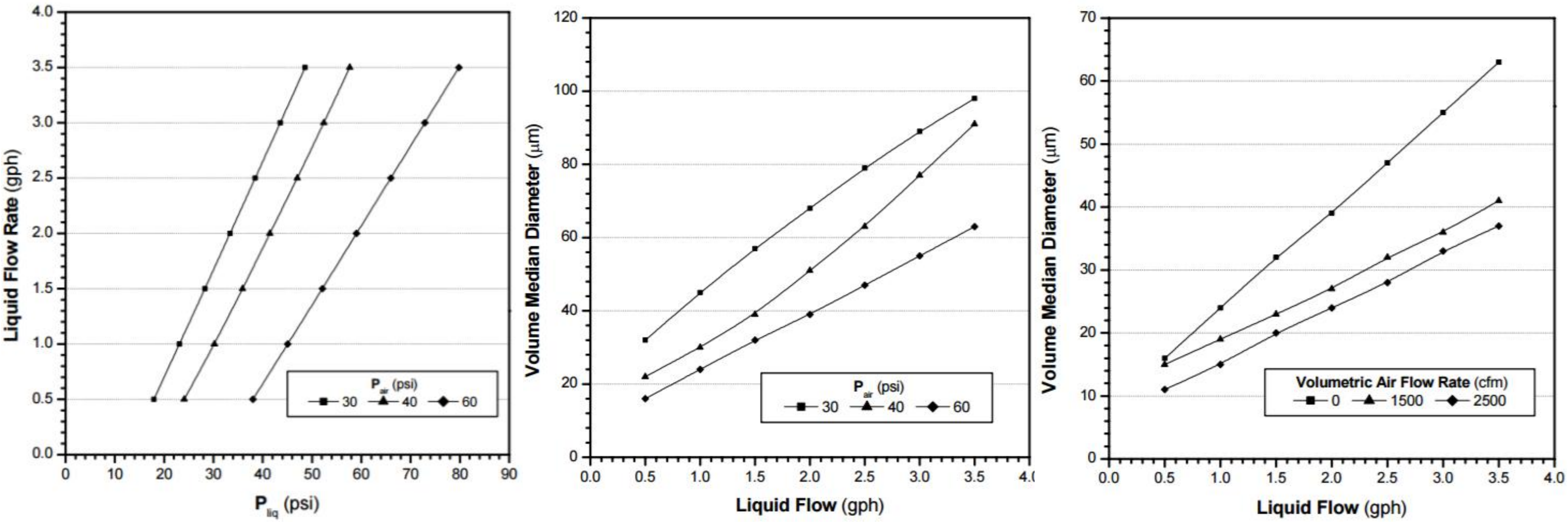
- Atomizing nozzle (Spraying Sys 1/4J+SU11)
- Salt solution: KCl 3.5 g /L in DI water



Internal mix with
pressure set-ups:
Round spray patterns

Salt Mist Generation

- Size distribution of droplets are influenced by liquid feed rate, air pressure, and air flow (Schick & Knasiak, 2003)



Schick, R. and Knasiak, K. (2003) Characterization of Two Fluid Spray Nozzles For NOx Control Applications. POWID 2003

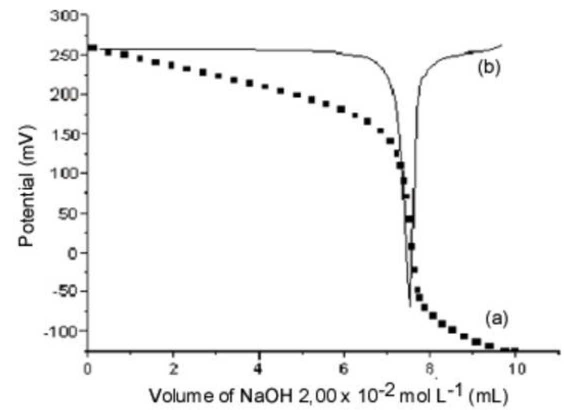
Salt Mist Generation

- VMD increases linearly with liquid feed rate
  - Increasing the number of nozzles help to decrease the droplet size
- VMD decreases with air pressure
  - Up to 60 psi (4 bar)
- Very important to clearly specify the operating conditions

Schick, R. and Knasiak, K. (2003) Characterization of Two Fluid Spray Nozzles For NOx Control Applications. POWID 2003

Titration Method

- Principle: chloride is treated with standard silver nitrate ($AgNO_3$); the electromagnetic potential with a reference cell is monitored; when the chloride ions completely precipitate, the potential rapidly changes; the volume of nitrate added determines the mole of chloride in the solution
- Metrohm 916 Ti-Touch Potentiometric Titrator
  - Measure to ppm levels
  - Can measure high salt concentration by dilution
- Sample preparation is manual – batch process



Fog Characteristics

Definitions

The international definition of fog is a visibility of less than 1 kilometer (3,300 ft); mist is a visibility of between 1 kilometer (0.62 mi) and 2 kilometers (1.2 mi) and haze from 2 kilometers (1.2 mi) to 5 kilometers (3.1 mi).

Fog and mist are generally assumed to be composed principally of water droplets, haze and smoke can be of smaller particle size.

http://www.lyyn.com/showroom/visibility/fog-and-haze/

Table 6.1 *International classification of visibility (Meteorological Office 1969)*

Visibility	*Description*
Less than 40 m	Dense fog
40–200 m	Thick fog
200–1000 m	Fog
1–2 km	Mist (if mainly due to water droplets) Haze (if mainly due to smoke or dust)
2–4 km	Poor visibility
4–10 km	Moderate visibility
10–40 km	Good visibility
over 40 km	Excellent visibility

Musk, Leslie (2003) Highway Meteorology edited by A.H. Perry, L.J. Symons, published by E. & FN. Spon, London, p. 93

LWC between 0.128 to 0.287 g/cm^3 corresponds to 100 m dense fog based on Elkdridge's model

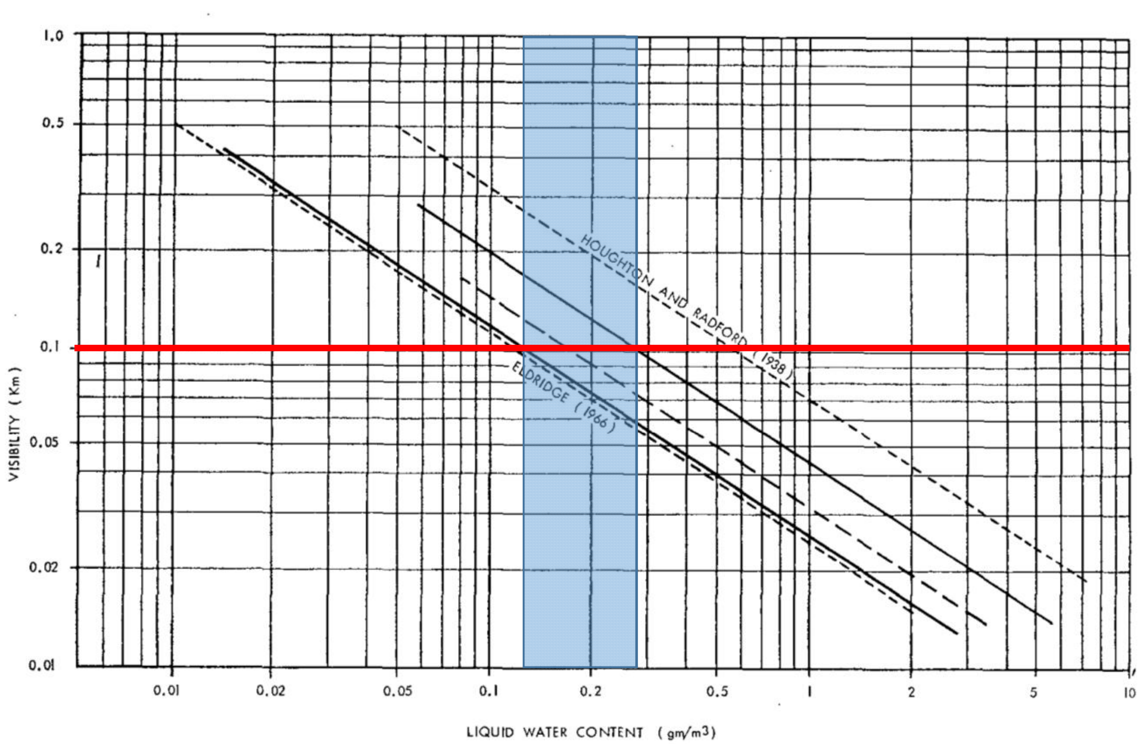


FIG. 3. Visibility as a function of liquid water content in a stable fog. The short dashed curves are the original published data, while the two solid curves represent modifications of the original data. The long dashed curve is the final translocation of the Houghton and Radford (1938) curve in accordance with the procedure presented in the text.

Eldridge, Ralph (1971) The relationship between visibility and liquid water content in fog. J. Atm. Sci. Vol. 28 P. 1183 is based on liquid water content (*LWC*) and droplet number concentration (N_d). The US current Rapid Update Cycle (RUC) model uses a *Vis-LWC* relationship for fog visibility (Smirnova et al. 2000; Stoelinga and Warner, 1999). Using information that *Vis* decreases with increasing N_d and *LWC*, a relationship between Vis_{obs} and $(LWC.N_d)^{-1}$ called the "*fog index*" is determined as

$$Vis_{obs} = \frac{1.002}{(LWC \cdot N_d)^{0.6473}} . \qquad (1)$$

This fit suggests that *Vis* is inversely related to both *LWC* and N_d. The maximum limiting *LWC* and N_d values used in the derivation of (1) are about 400 cm^{-3} and 0.5 g m^{-3}, respectively. The minimum limiting N_d and *LWC* values are 1 cm^{-3} and 0.005 g m^{-3}, respectively. In (1), N_d can be fixed as 100 cm^{-3} for marine environments and 200 cm^{-3} for continental fog conditions. These

	Marine Environment		Continental	
	Nd, #/cc	100	Nd, #/cc	200
Visibility, km	1/(LWC*Nd)	LWC, g/m3	1/(LWC*Nd)	LWC, g/m3
0.05	0.010	1.026	0.010	0.513
0.1	0.028	0.352	0.028	0.176
0.2	0.083	0.121	0.083	0.060
0.5	0.342	0.029	0.342	0.015
1	0.997	0.010	0.997	0.005

Model predicts LWC between 0.176 to 0.352 g/m^3

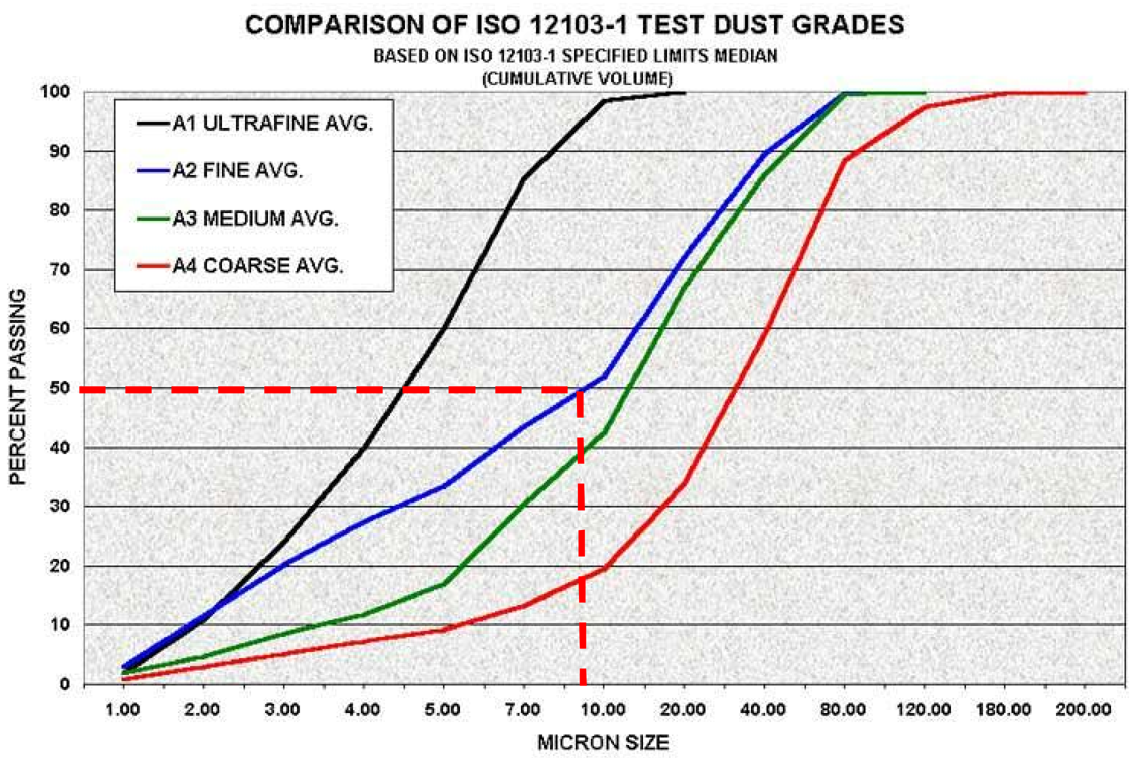
Ref.: Gultepe et al. (2009) Visibility forecasting for warm and cold fog conditions observed during fram field projects. Aviation, Range and Aerospace Meteorol. Spec. Symp. on Weather-Air Traffic Management Integration, 2009 AMS Annual Mtg., Phoenix, AZ, 12-15 January, P1.22

When set to max water feed rate with the test system (8.4 L/h) and airflow rate of 6,000 m3/h, the resulting LWC is equivalent to a dense fog with 40 m visibility in marine environment.

Water Feed, L/h	8.4
Mass Feed, kg/h	8.4
Air Flow Rate, m3/h	6000
LWC, g/m3	1.4
Visibility, km	0.041

Aging with Dry Dust

- ISO 12103-1 A2 Fine Test Dust

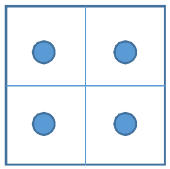


Components	Quantity
silica (fine dust)	69-77 %
aluminium oxide	8-14 %
calcium oxide (mineral)	2.5-5.5 %
potassium oxide (mineral)	2-5 %
sodium oxide (mineral)	1-4 %
Iron(III) oxide (hematite)	4-7 %
magnesium oxide	1-2 %
titanium dioxide	0-1 %

Is there trace amount of halides?

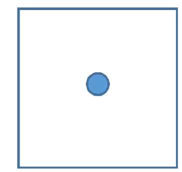
Salt Mist Generation Setup

- Four atomizing nozzles positioned at four corners of the test duct
- Liquid feed rate
  - Total: 8.4 L/h
  - Each nozzle: 2.1 L/h
- Estimated VMD: 10-20 μm
- LWC = 1.4 g/m3
- Injection Location: 3 meter from filter wall
- One peristaltic pump
- No neutralization of charge



Dust Generation Setup

- Topaz Solid Aerosol Generator 410H with ISO injector
- Dust injected at the center the test duct
- No neutralization of charge
- Concentration 0.57 mg/m^3



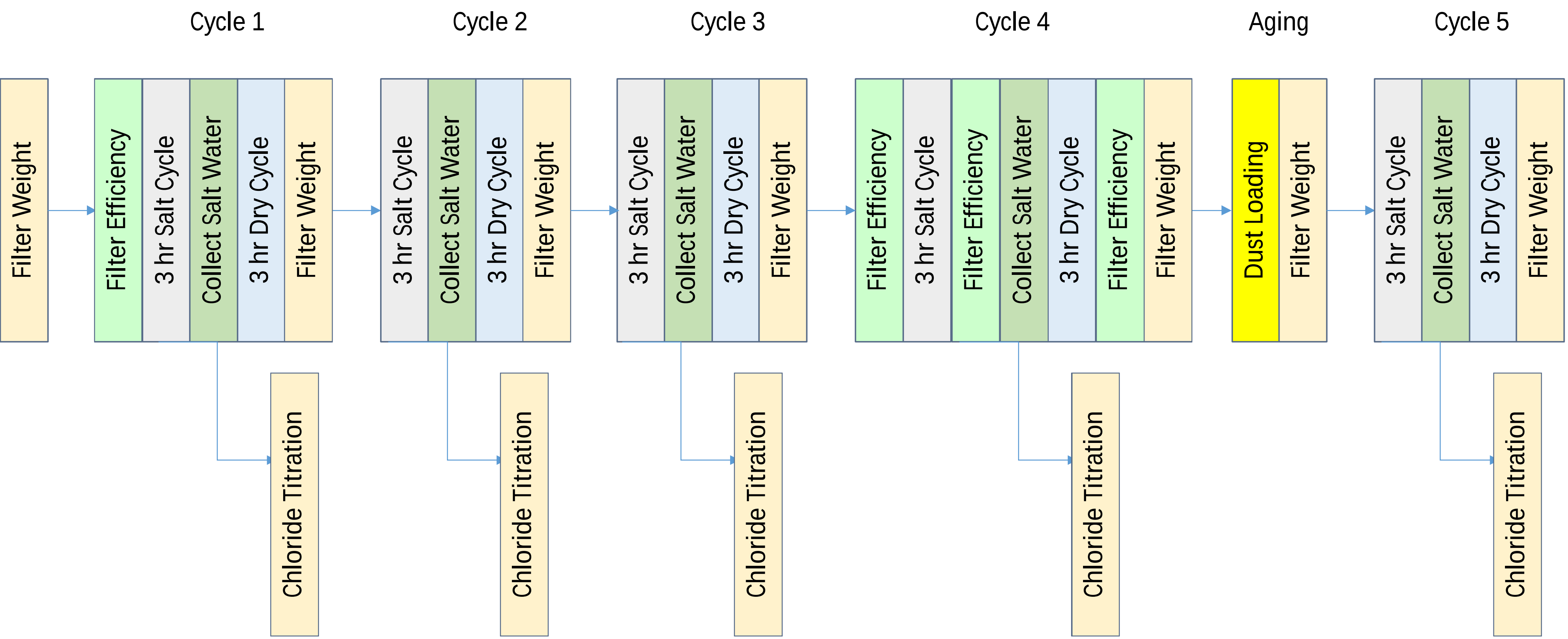
Test Samples

- Filter: V-panels
- # of Samples: 3 (A,B,C)
- Air flow rate: 6,000 m3/h
- Efficiency rating: E12

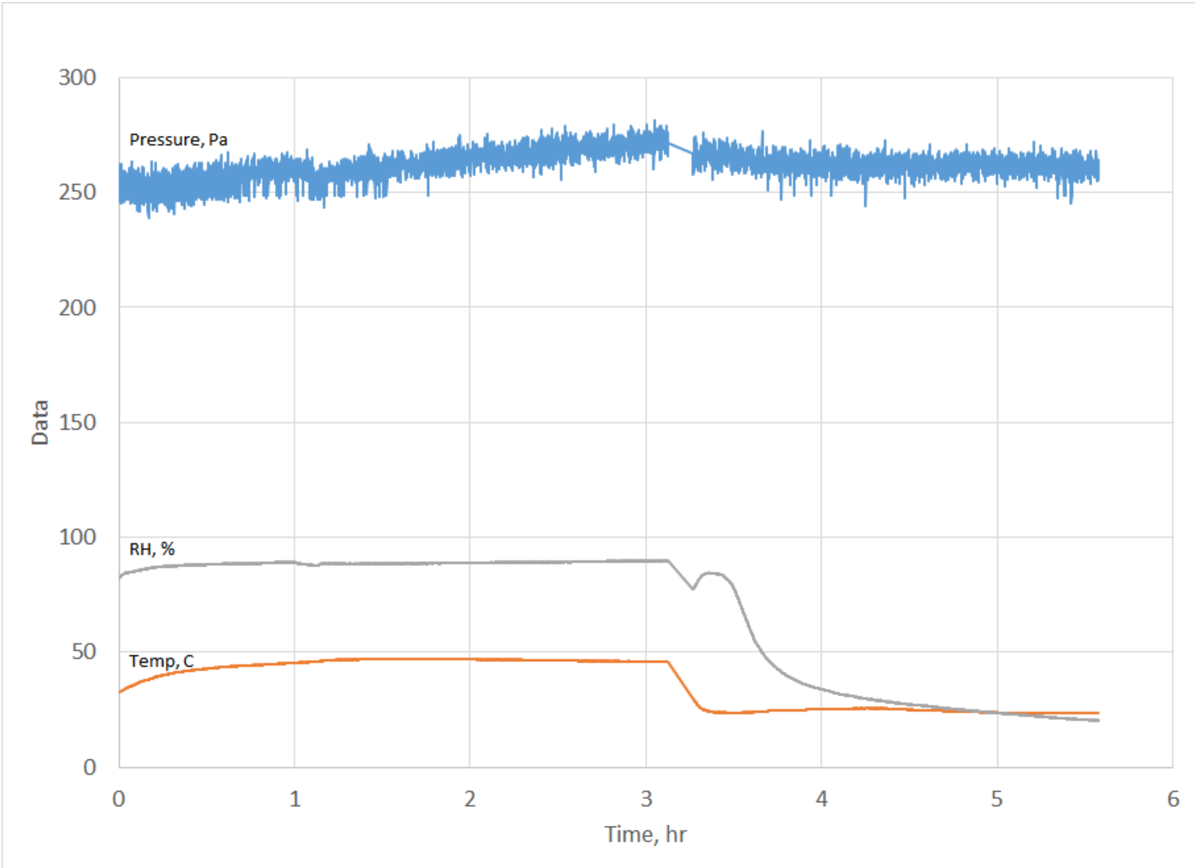
Wet/Dry Cycles Overview

- Salt breach cycle
  - 3 hours wet + 3 hours dry cycles
  - Repeat 4 times
- Aging of filter with dry dust loading
  - 1kPa final dP
- Repeat salt breach test
  - 3 hours wet (stop if dP > 1.5 kPa) + 3 hours dry cycles

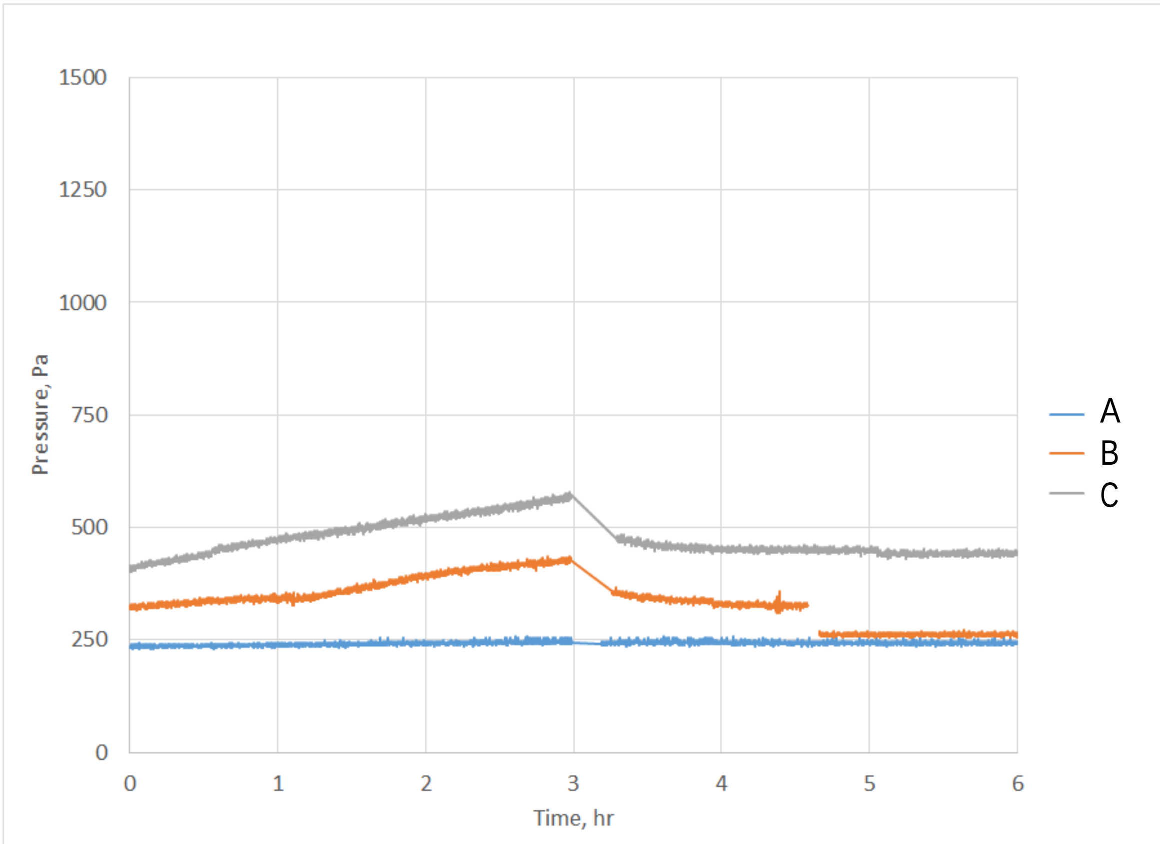
Salt Breach Test



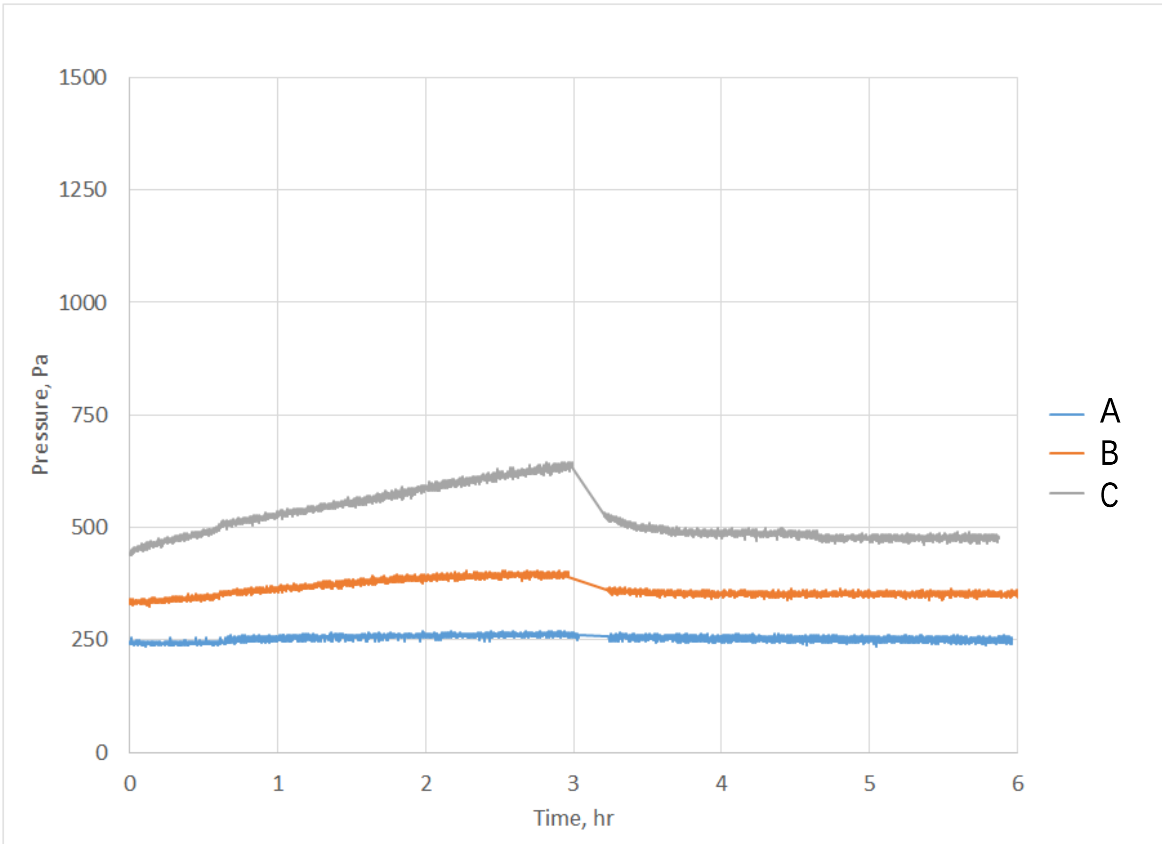
Wet/Dry Cycle 1 – Filter A



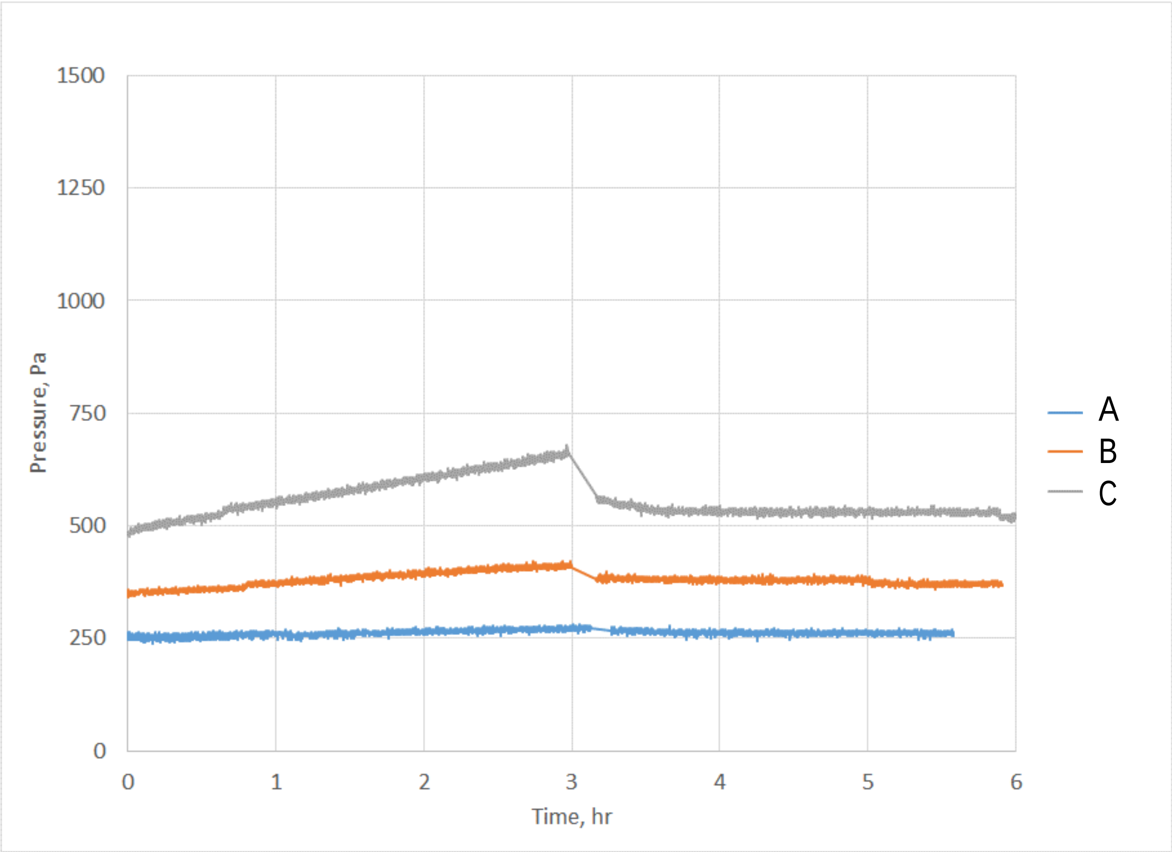
Cycle 1



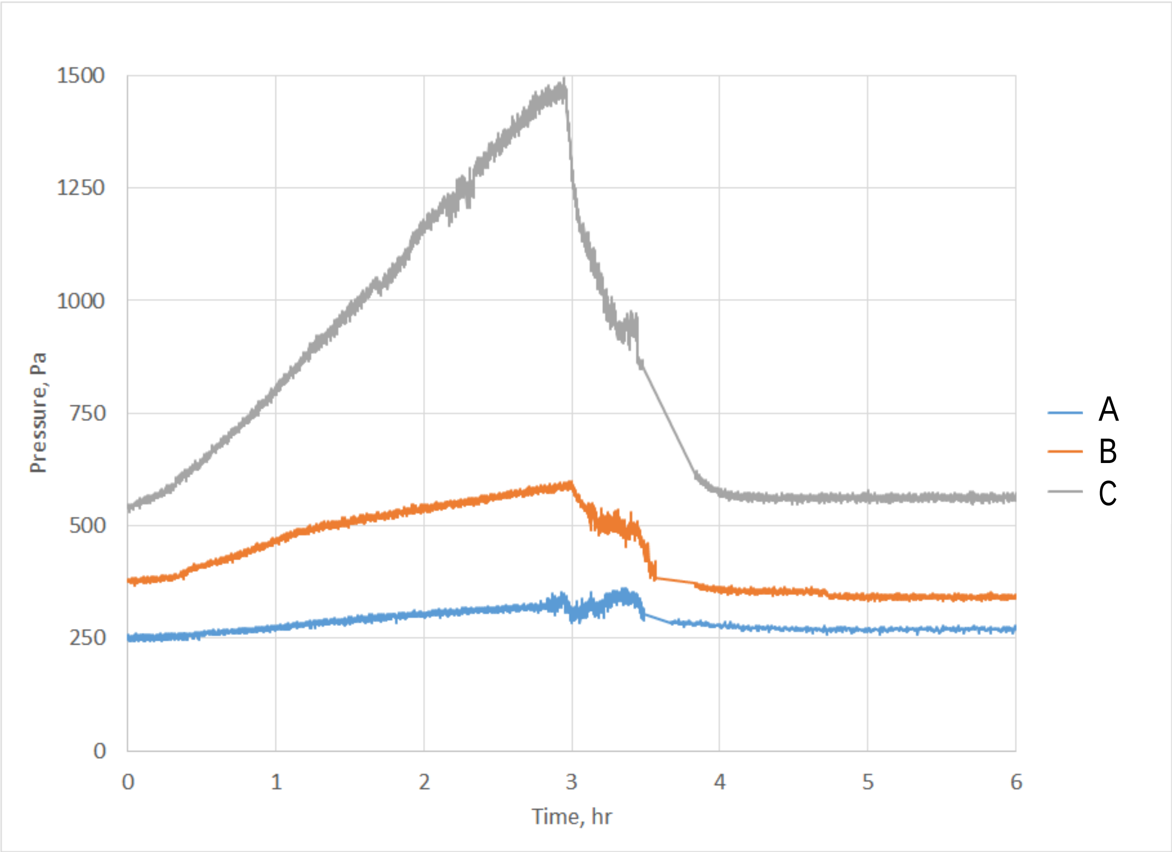
Cycle 2



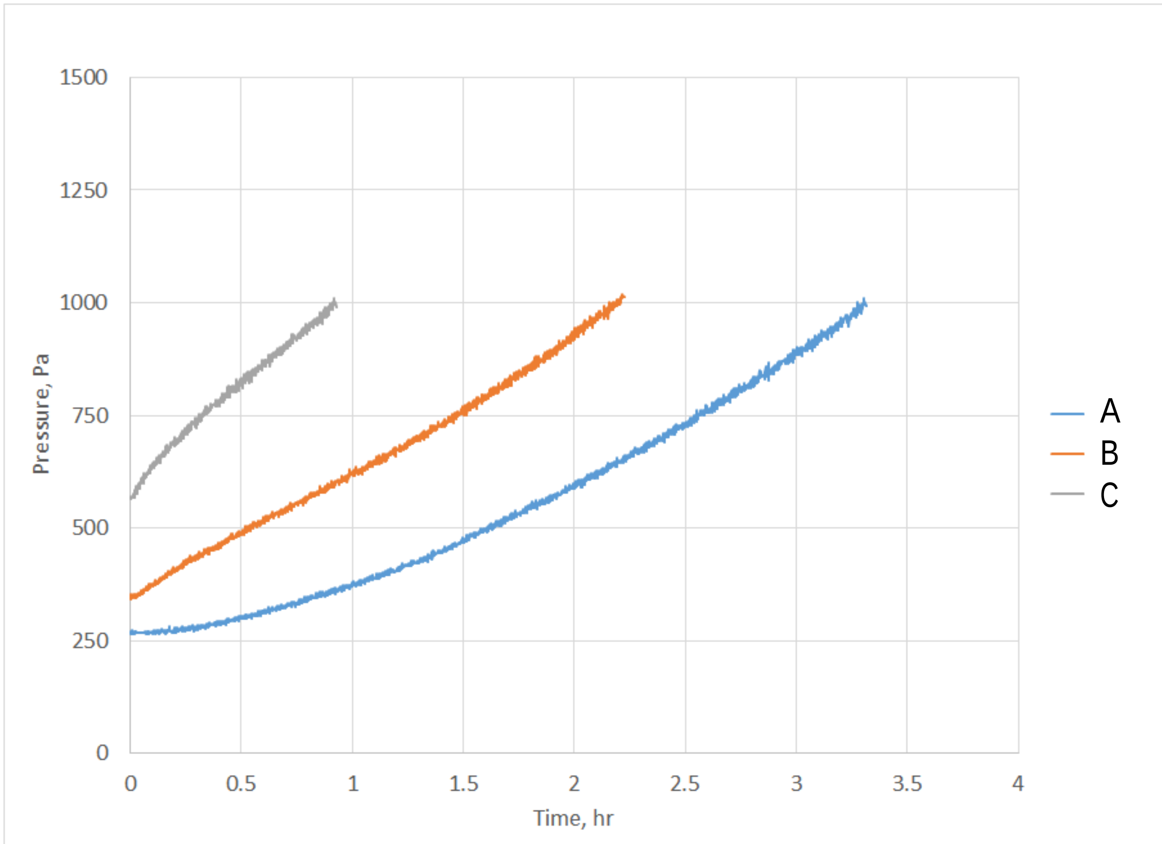
Cycle 3



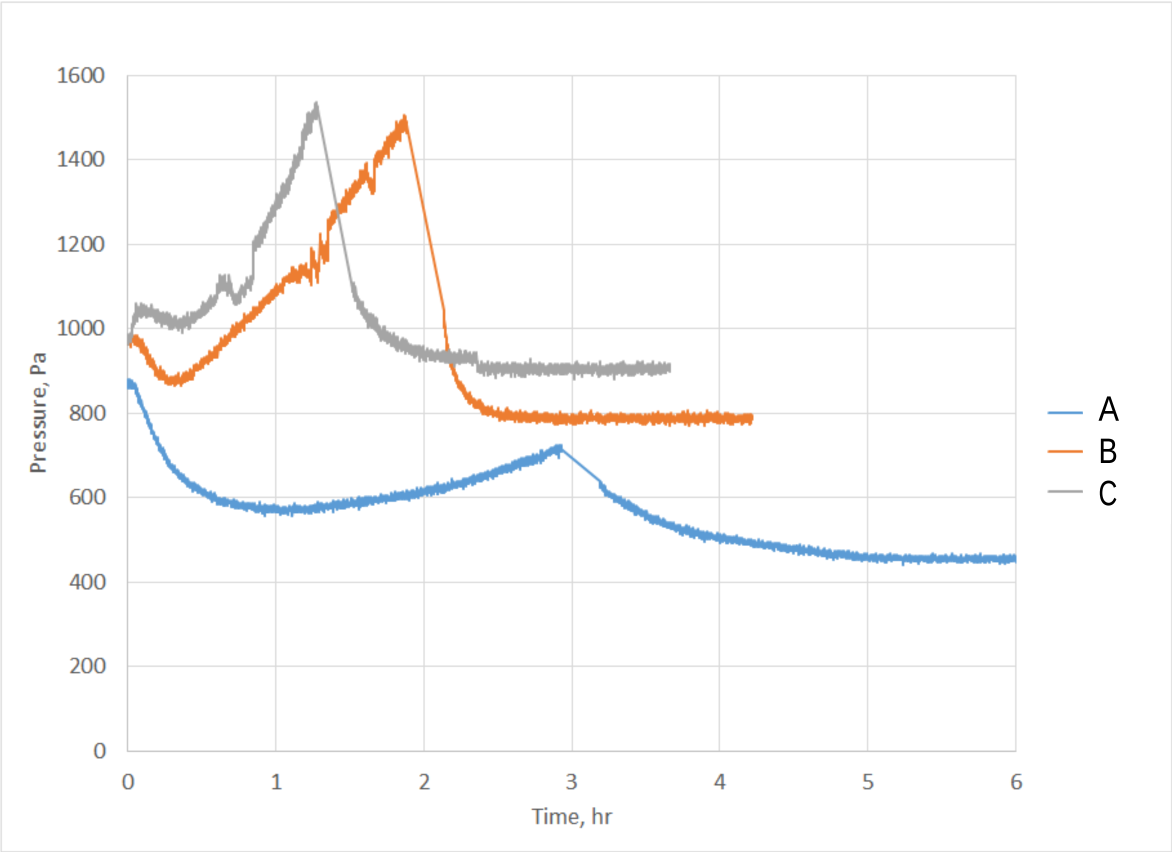
Cycle 4



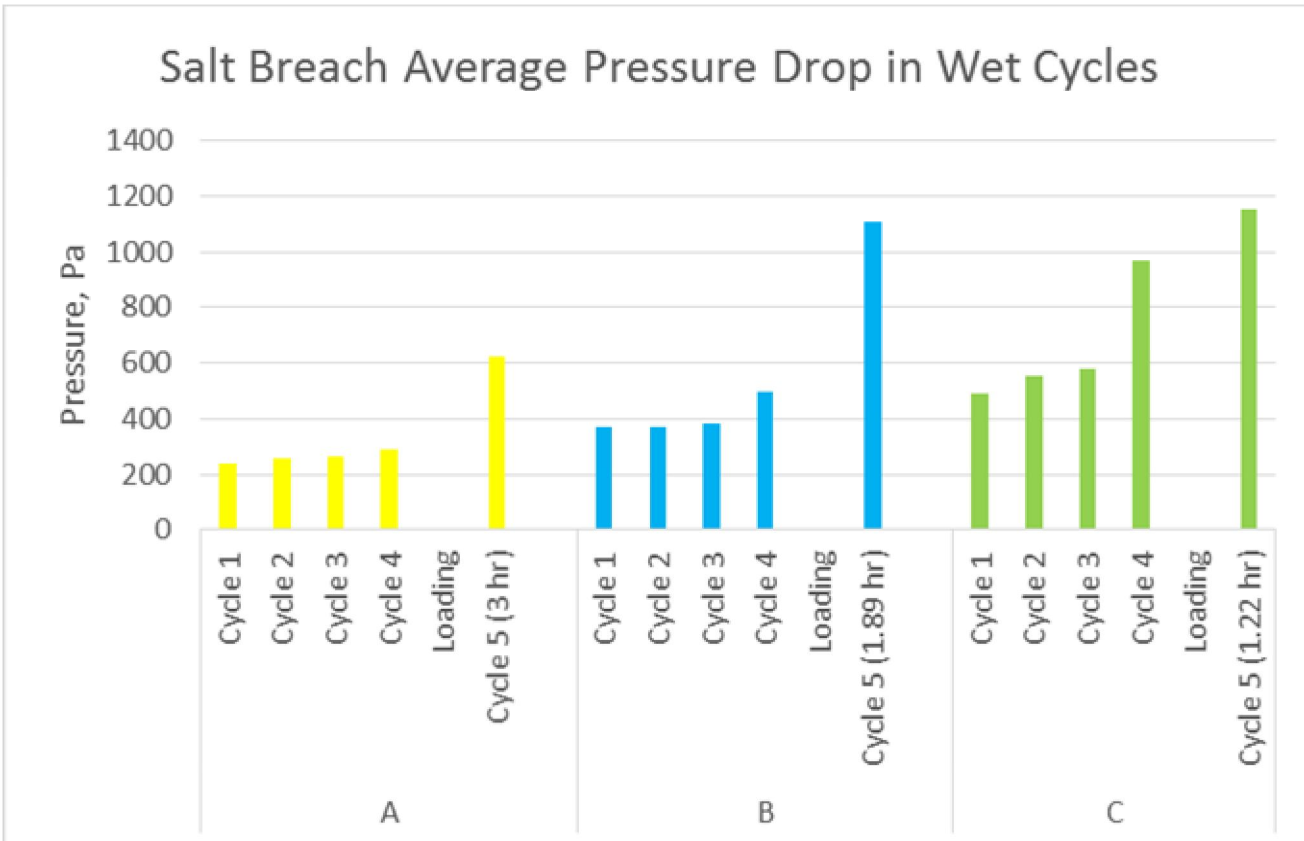
Aging Chart - Time

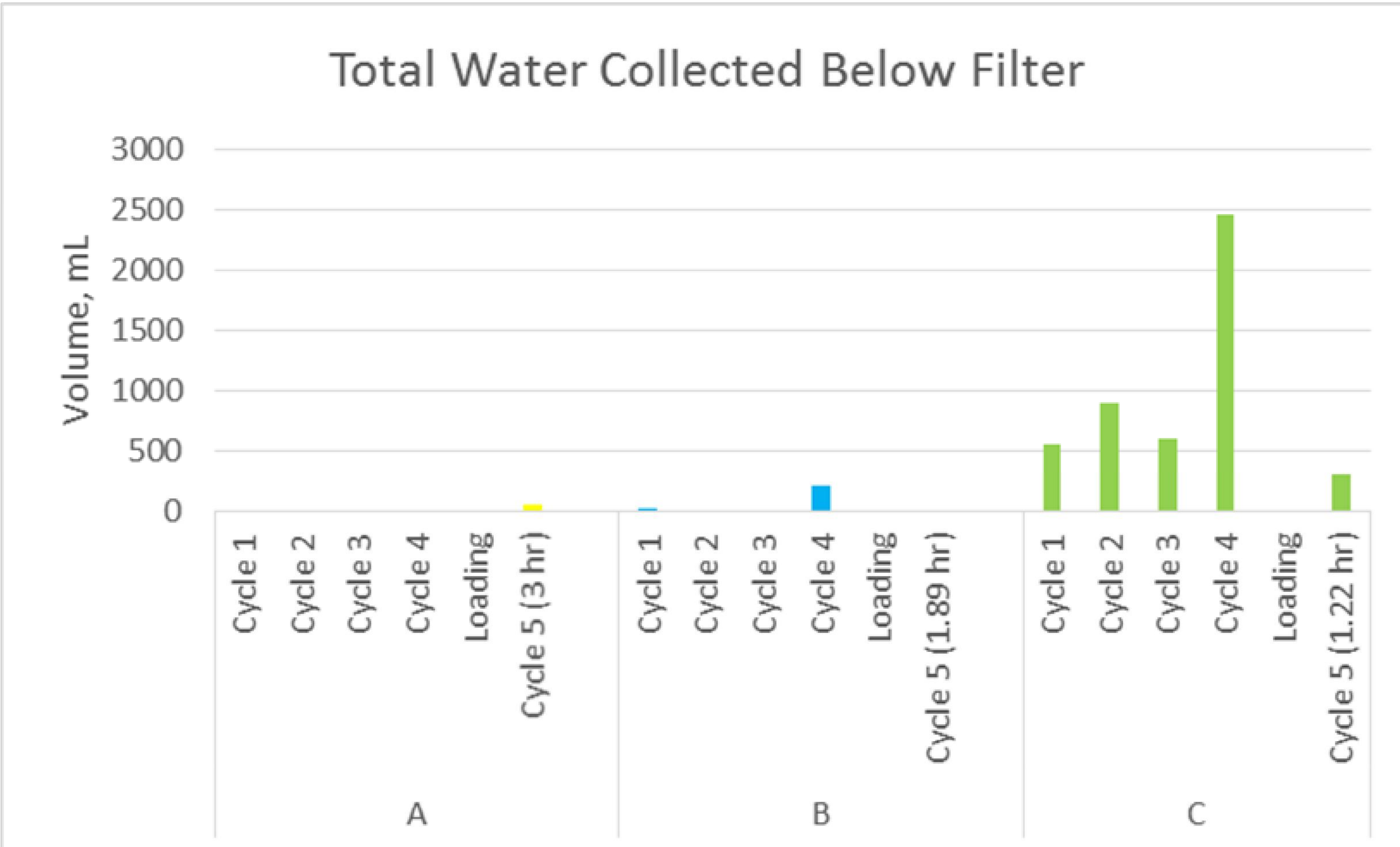


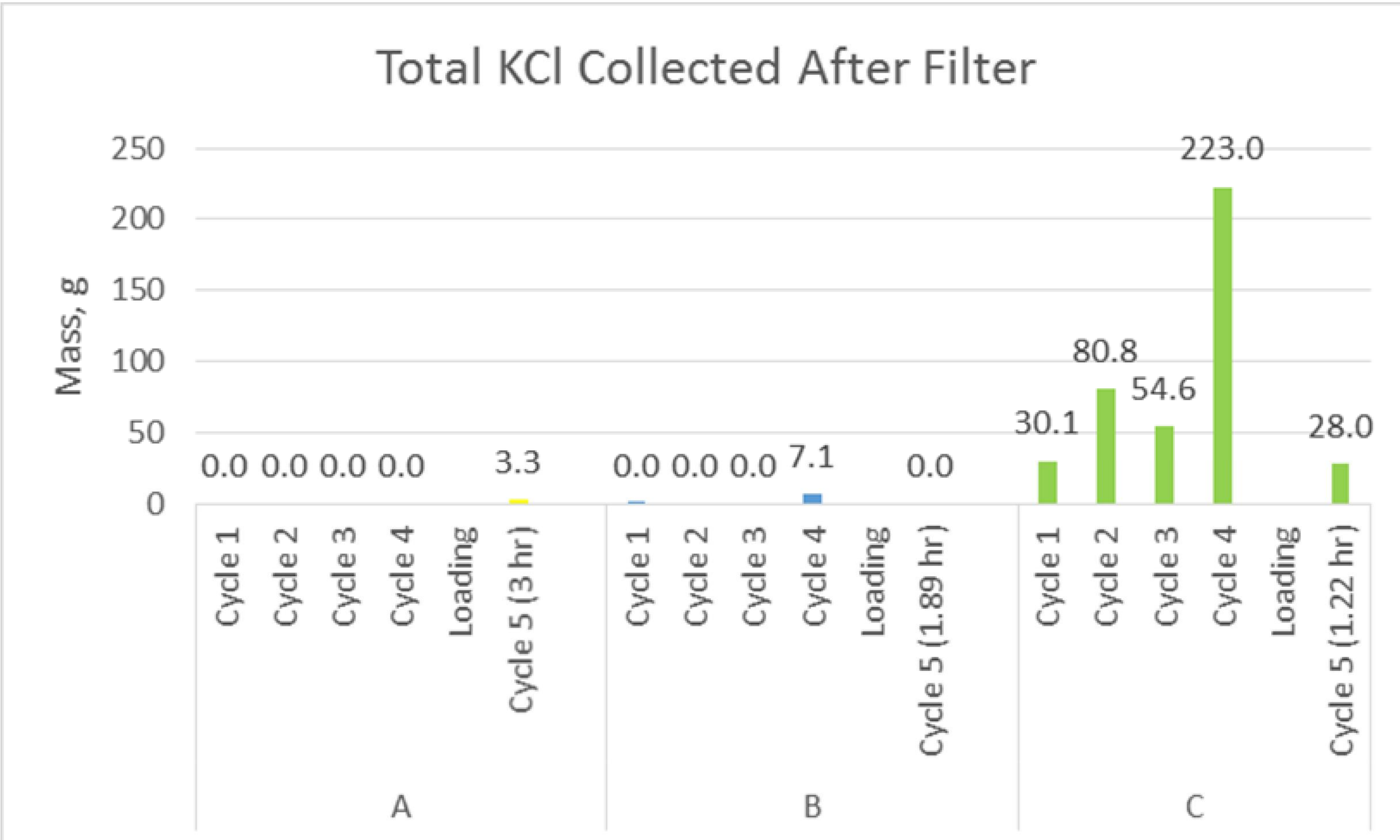
Cycle 5



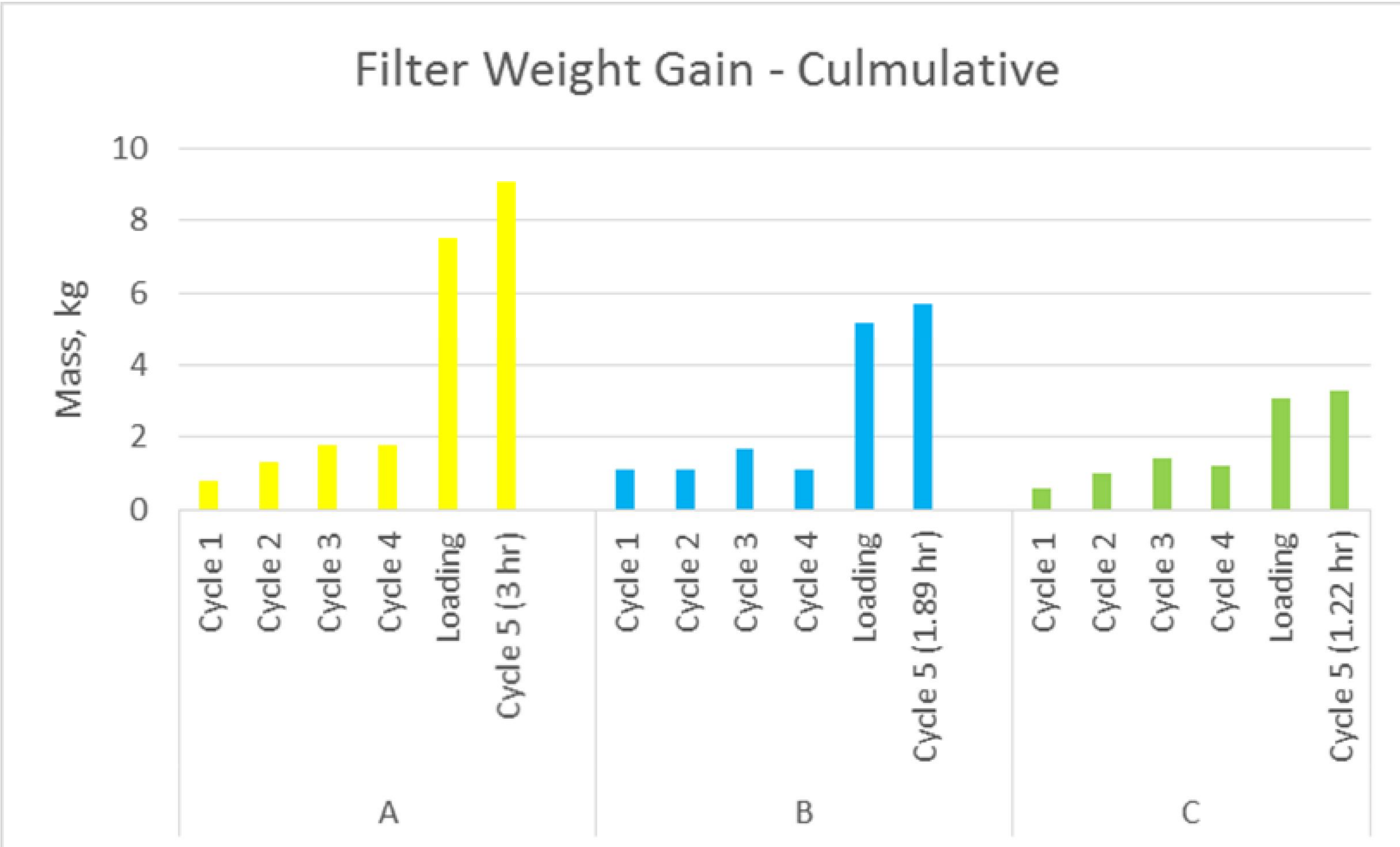
1600
1400
1200
1000
800
600
400
200
0
Pressure, Pa
0
1
2
3
4
5
6
Time, hr
A
B
C

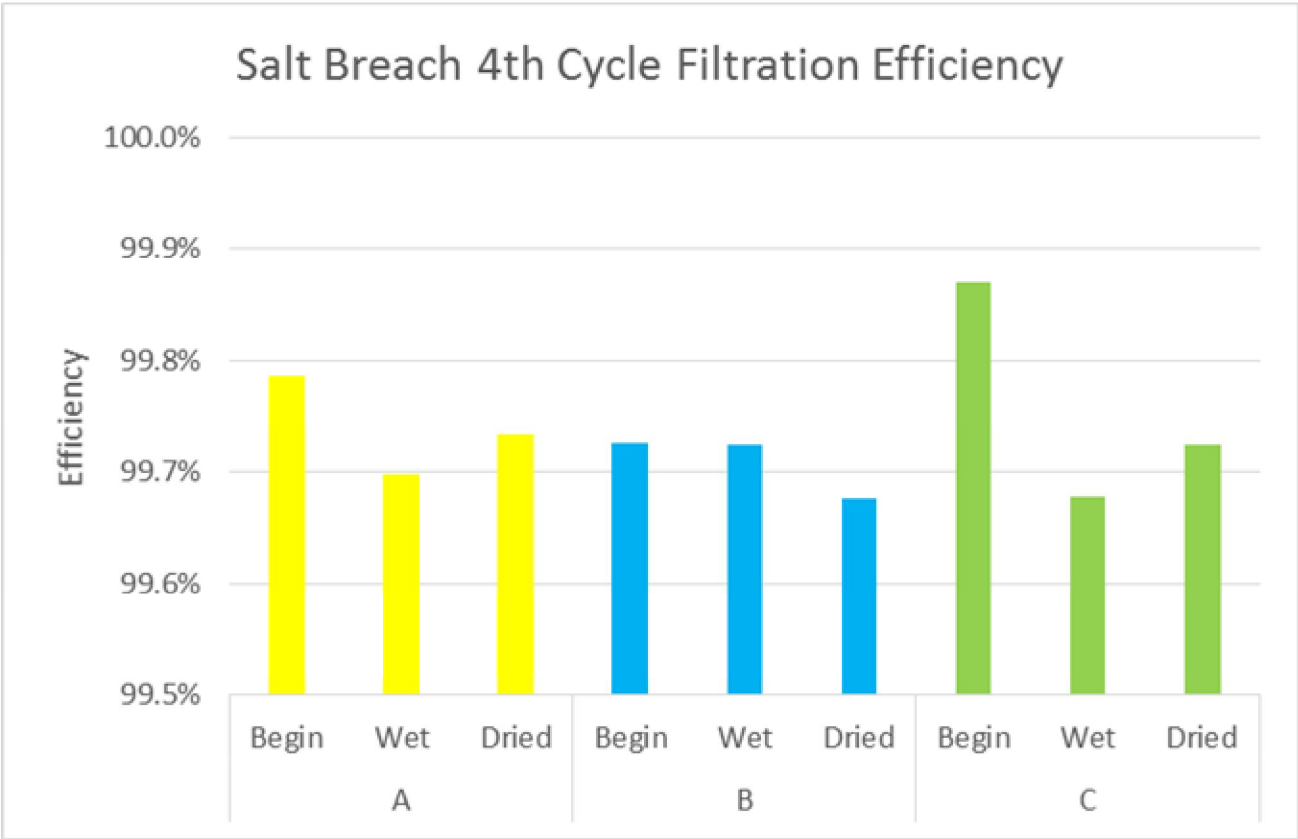

Salt Breach Average Pressure Drop in Wet Cycles
Pressure, Pa
0
200
400
600
800
1000
1200
1400
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (3 hr)
Cycle 5 (1.89 hr)
Cycle 5 (1.22 hr)
A
B
C


Total Water Collected Below Filter
Volume, mL
3000
2500
2000
1500
1000
500
0
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (3 hr)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (1.89 hr)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (1.22 hr)
A
B
C



Total KCl Collected After Filter
Mass, g
250
200
150
100
50
0
0.0
0.0
0.0
0.0
3.3
0.0
0.0
0.0
7.1
0.0
30.1
80.8
54.6
223.0
28.0
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (3 hr)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (1.89 hr)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (1.22 hr)
A
B
C


Filter Weight Gain - Culmulative
Mass, kg
0
2
4
6
8
10
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (3 hr)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (1.89 hr)
Cycle 1
Cycle 2
Cycle 3
Cycle 4
Loading
Cycle 5 (1.22 hr)
A
B
C



All filters maintained efficiency

Filter B Downstream Side

After Cycle 4th Wet Salt

After Dust Loading Cycle

Results

- Tests for Sample B and C were stopped after dP climbed to1,500 Pa, results in shorter test time for last cycle
- Filter C has highest volume of water and salt collected after the filters.
- Filter B showed salt crystals built-up on the clean side after 4^{th} cycle, and dust bypass on the upper side of the filter.
- Filters had E12 efficiency in wet and dry condition.
- KCl concentration in collected water was over 190 g/L, more concentrated than source

Summary

- The operating conditions of atomizing nozzles have big impact on the droplet size distribution. They must be clearly defined
- The performance of the filters changed significantly after 3 wet and dry cycles. More cycles should be included in future work
- Aging the filter to 1kPa caused one sample to leak. The duration of aging is influenced by the seasoned pressure drop of the filter.
- Two filters did not finish the last wet/dry cycle due to dP exceeding 1.5 kPa.
- The test showed different performance of the filters: Filter A (best), followed by B (better) and C (worst)
- Measuring the weight of filter is cumbersome and doesn’t provide useful information.