

CAT 1R-1808 FILTER ANALYSIS

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Caterpillar Surveillance Panel Meeting
October 7th, 2016

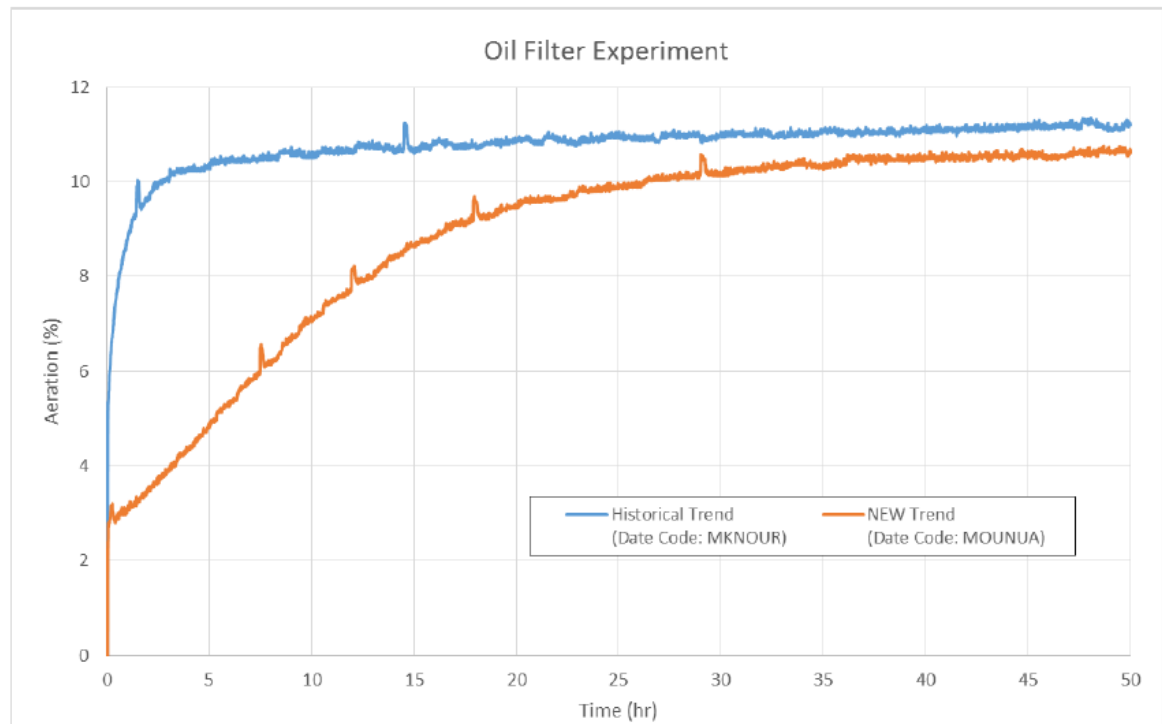
Performance you can rely on.



Concern raised at SP meeting on July 13th

Slide from LZ showing new aeration profile trend (orange line) with new filters. Old filters appeared to produce a different type of profile (blue line) where there is a steep rise and quick plateau.

Test Results (OS265386)



Goal, samples, and methodology

Goal: To examine the filter media and assess if there are reasons that could contribute to the new aeration profile.

Two 1R-1808 samples available to analyze:
NRNAUE/040513 and MDNEUL/290316

Methods:

- Filter housings were cut open for visual observation (number of pleats, color, etc)
- Optical microscopy, digital scale
- Scanning electron microscopy (SEM)
- Energy dispersive spectroscopy (EDS)



Highlights from analysis



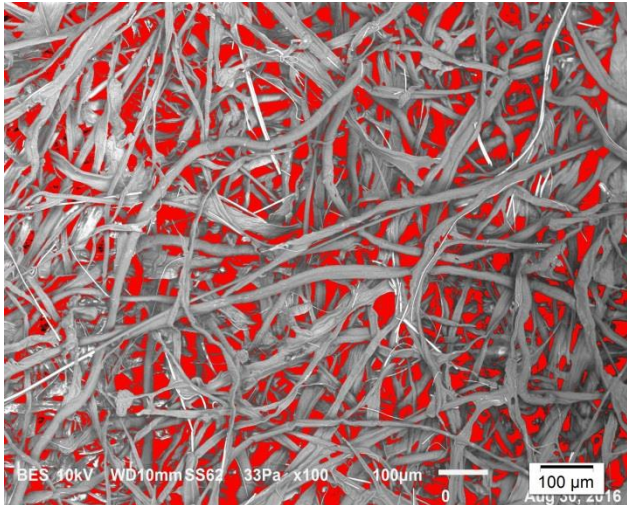
Media attribute	Remark	“old” NRNAUE/ 040513	“new” MDNEUL/ 290316
Open surface area [%]	Pore sizes ranged from about 20-80 microns for both filter samples but were difficult to accurately represent. Instead, open surface area in the first layer of filter media was measured and it was found that the new 2016 filter had more open space than the old 2013 filter sample on the inlet side, which may translate to less bubble breakage. Lower density, more open space was also observed in the cross-section of new 2016 filters.	18-26	27-37
# pleats	More pleats in 2013 mean more surface area of filter per unit oil flow.	78	77
Glass fiber content	2016 filters contained about 50% more glass fibers than the 2013 filters on the inlet and outlet sides. The added stiffness from the extra glass fiber could contribute to why there are less folds in the 2016 filter.	~0.4	~0.6
Glue bead width and depth [mm]	Both glue bead width and depth values were higher for the 2016 filters compared to the 2013 filters. Consistent with remark re: # pleats: less surface area of filter than an oil sees for new 2016 filter.	w 3.7, d 6.8	w 6.5, d 9.6

- Details such as images, raw data, and standard deviations can be found in the Appendix.
- Additional properties such as media thickness and density were also measured but were found to not be significantly different for the two filters.

Summary of key points

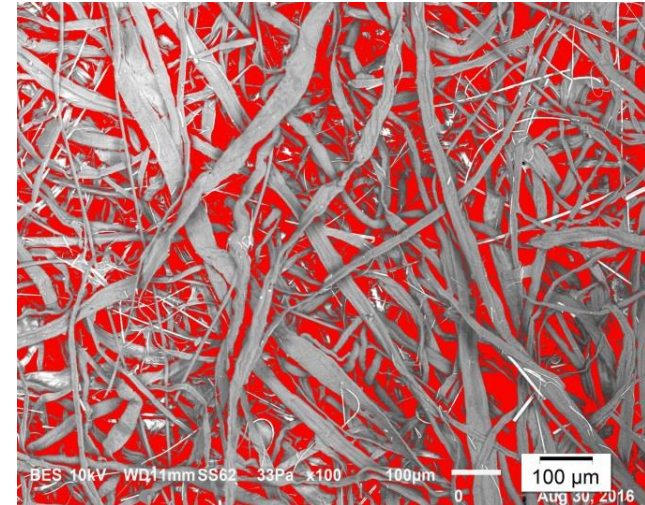
- Open space in first layer of fibers (pictured below, w/ medians of 5 measurements for each filter):

2013: 17.67%



vs.

2016: 27.23%



Cross section measurements of open space show similar trend. See appendix 1g for raw data.

- Less densely packed fibers can contribute to larger post-filter bubble size distribution. Larger bubbles will exit the oil in the sump faster and therefore, steady state aeration will be slower to reach, and could therefore, exhibit a slow-to-rise aeration profile (orange line in slide 2). Conversely, smaller bubbles will have a greater tendency to remain in the oil and therefore, the oil will quickly aerate (see first few hours of blue line in slide 2).
- Recommendation: Understand manufacturing process of filters for improved control of filter properties with target for original properties. Run experiments to confirm/disprove hypothesis.

Appendix

1. Open area fractions
 - a. 2013 inlet area fraction
 - b. 2013 outlet area fraction
 - c. 2013 cross section area fraction
 - d. 2016 inlet area fraction
 - e. 2016 outlet area fraction
 - f. 2016 cross section area fraction
 - g. Summary of open area measurements

2. Glue beading measurements (width and depth)

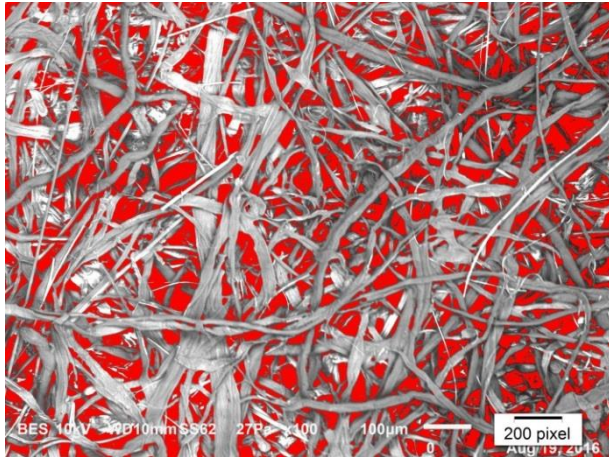
3. Si content from EDS analysis

4. Filter media thickness

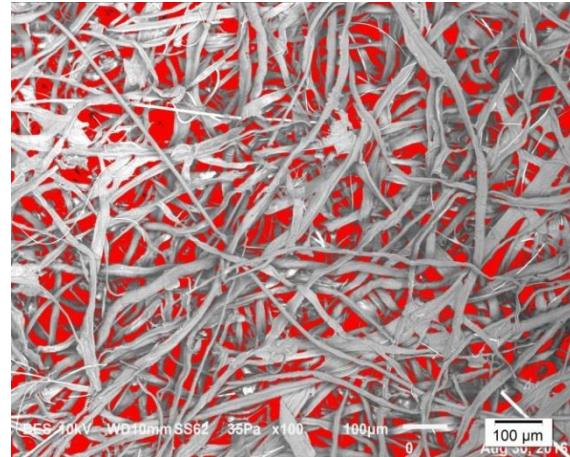
5. Pore size measurements

6. Filter density

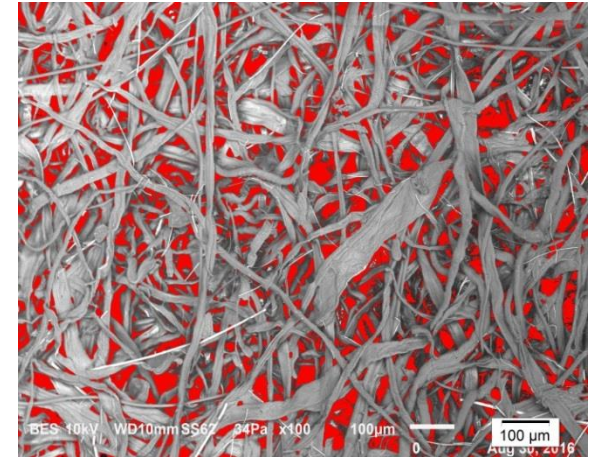
Appendix 1a: 2013 Inlet area fraction



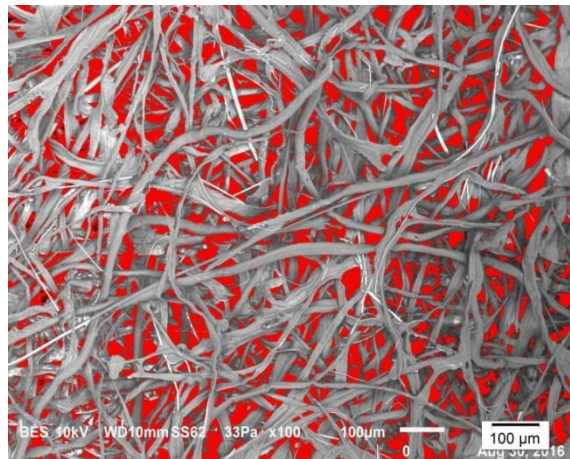
Area Fraction ROI (%)
22.47



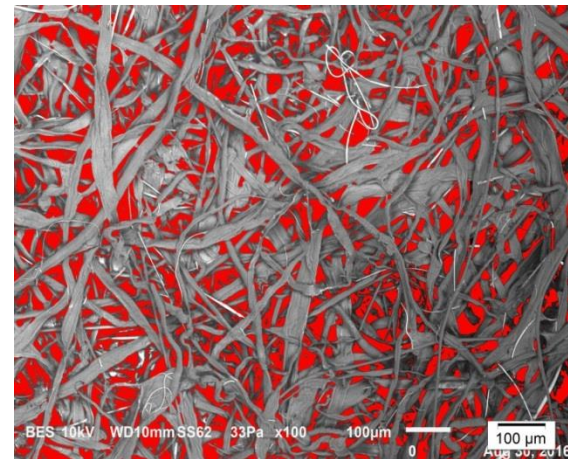
Area Fraction ROI (%)
16.61



Area Fraction ROI (%)
14.59

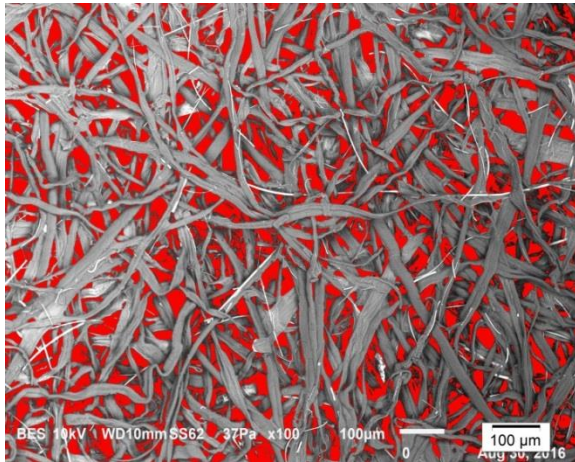


Area Fraction ROI (%)
17.67



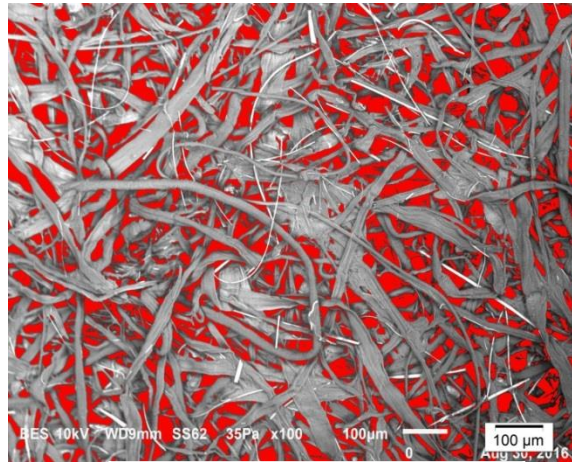
Area Fraction ROI (%)
19.23

Appendix 1b: 2013 Outlet Area Fraction



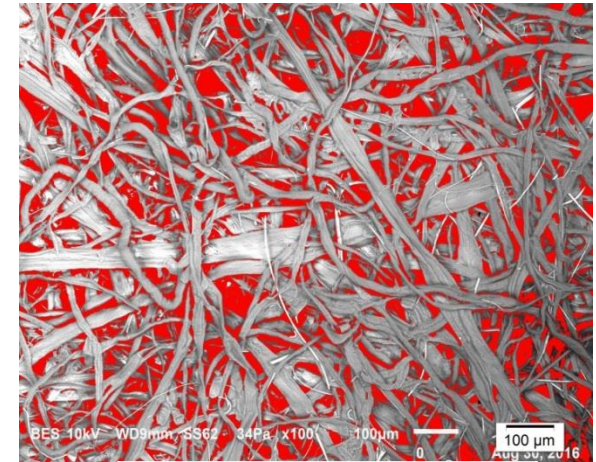
Area Fraction ROI (%)

19.18



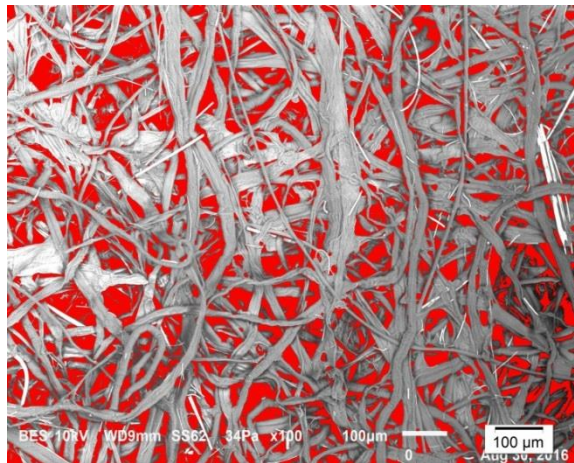
Area Fraction ROI (%)

19.89



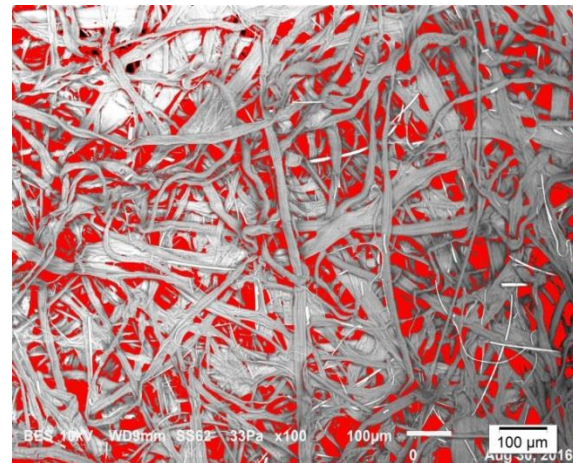
Area Fraction ROI (%)

21.62



Area Fraction ROI (%)

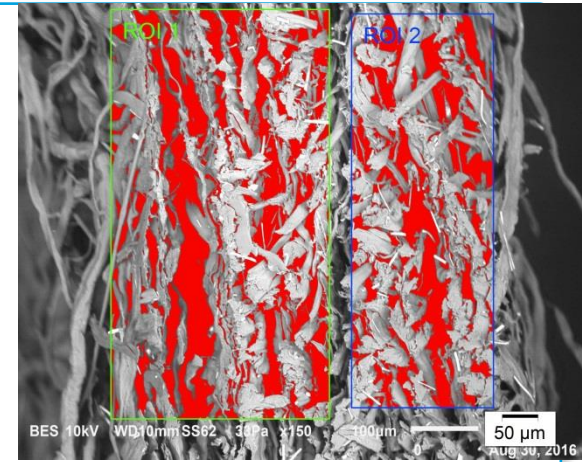
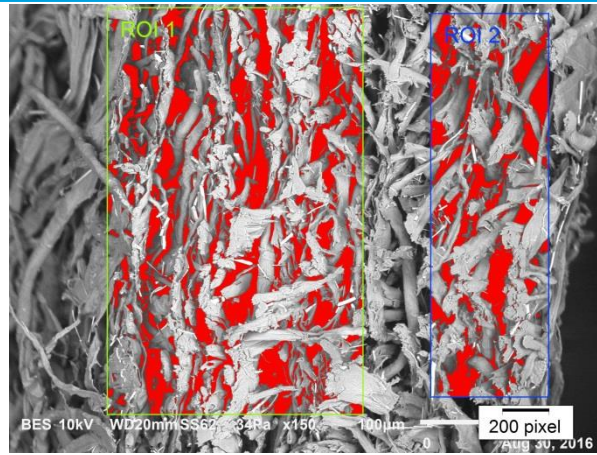
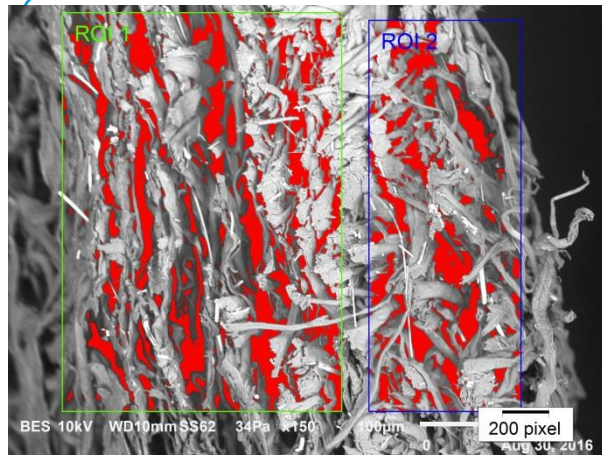
21



Area Fraction ROI (%)

19.4

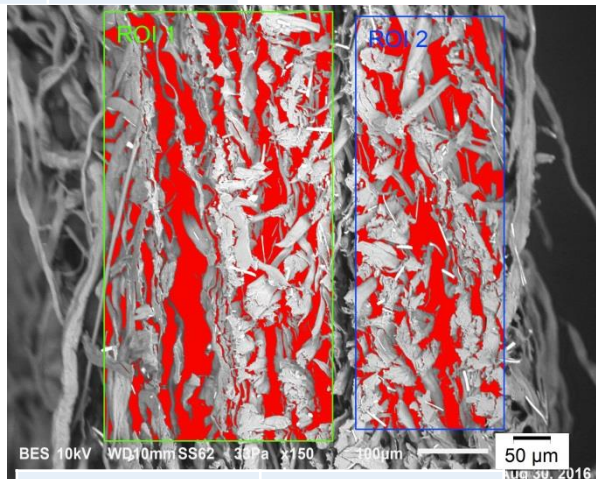
Appendix 1c: 2013 Cross-section Area Fraction



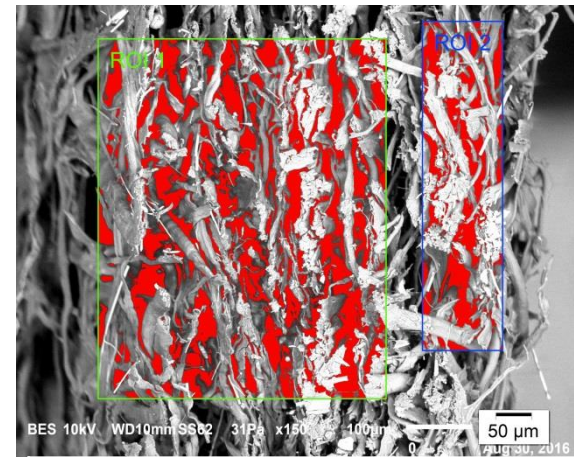
ROI	Area Fraction ROI (%)
ROI 1	19.12
ROI 2	17.54

ROI	Area Fraction ROI (%)
ROI 1	23.69
ROI 2	22.4

ROI	Area Fraction ROI (%)
ROI 1	31.12
ROI 2	28.93

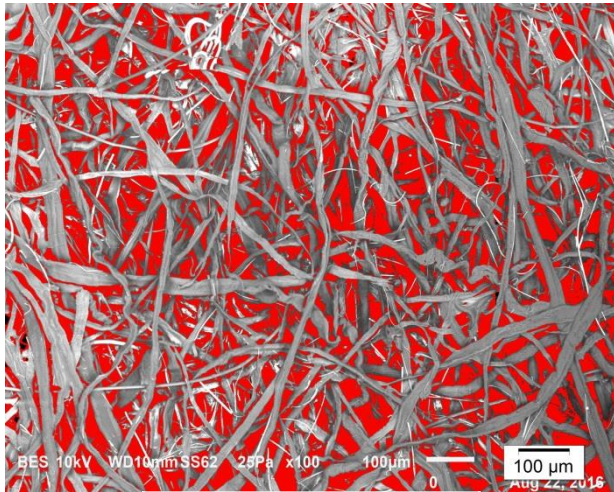


ROI	Area Fraction ROI (%)
ROI 1	31.98
ROI 2	29.17

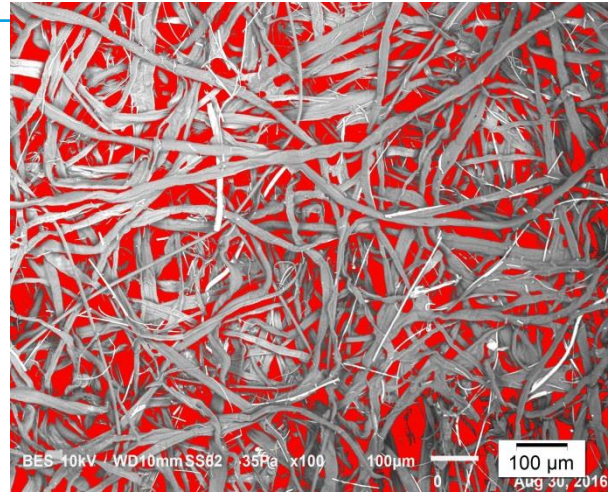


ROI	Area Fraction ROI (%)
ROI 1	27.21
ROI 2	26.27

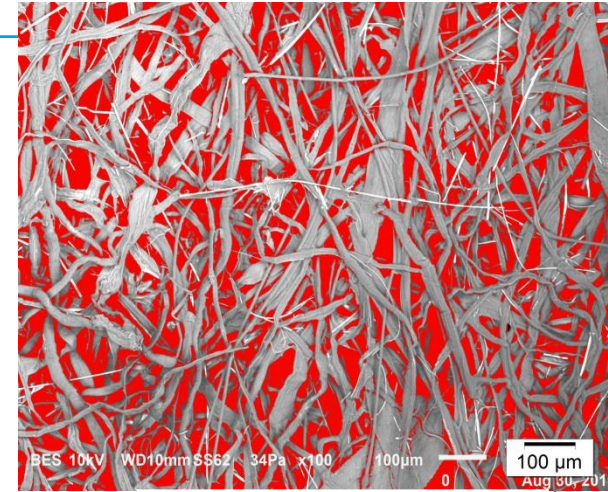
Appendix 1d: 2016 Inlet Area Fraction



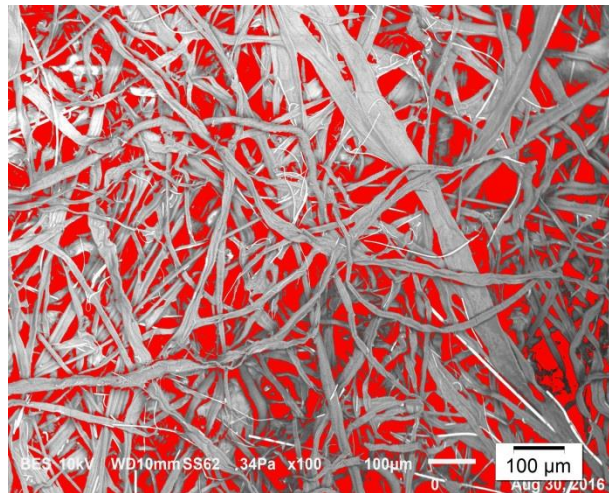
Area Fraction ROI (%)
27.62



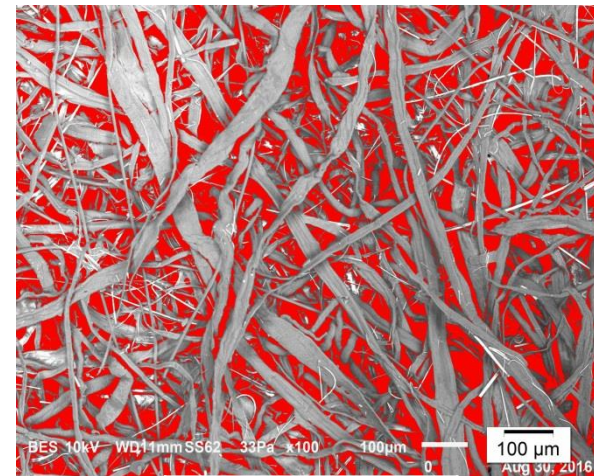
Area Fraction ROI (%)
24.13



Area Fraction ROI (%)
29.53

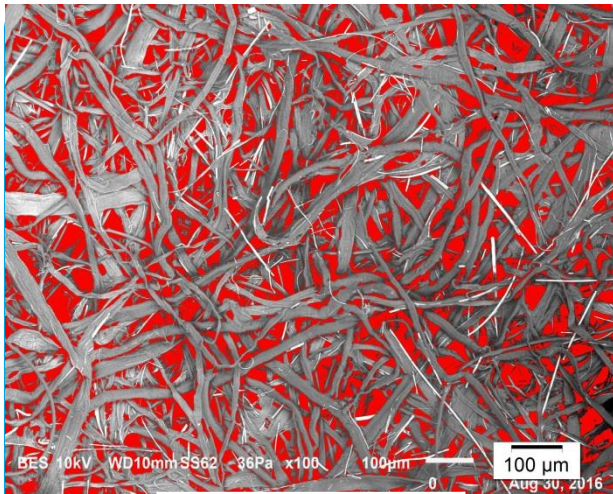


Area Fraction ROI (%)
26.84

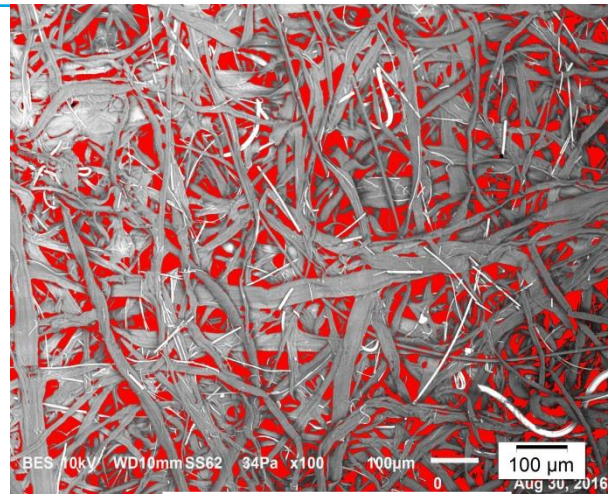


Area Fraction ROI (%)
27.23

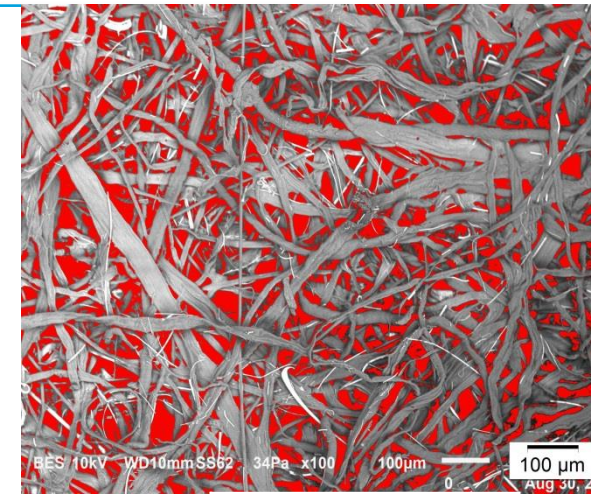
Appendix 1e: 2016 Outlet Area Fraction



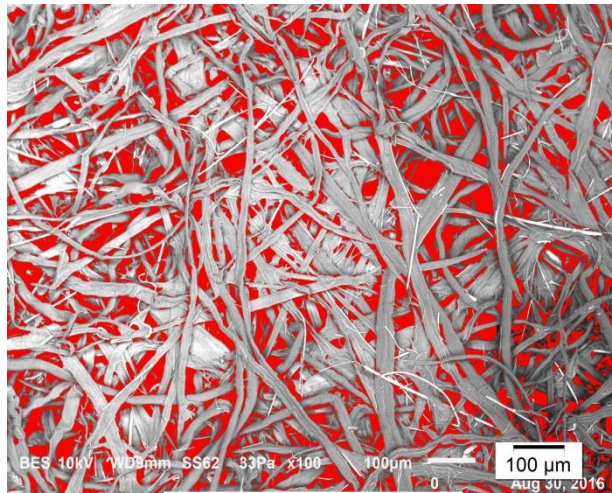
Area Fraction ROI (%)
23.53



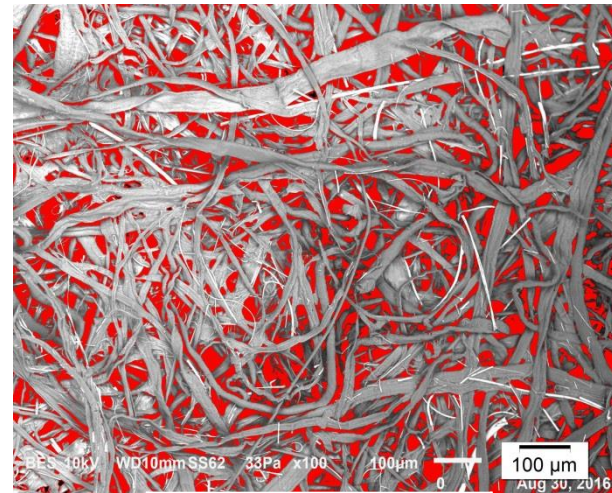
Area Fraction ROI (%)
18.7



Area Fraction ROI (%)
19.9

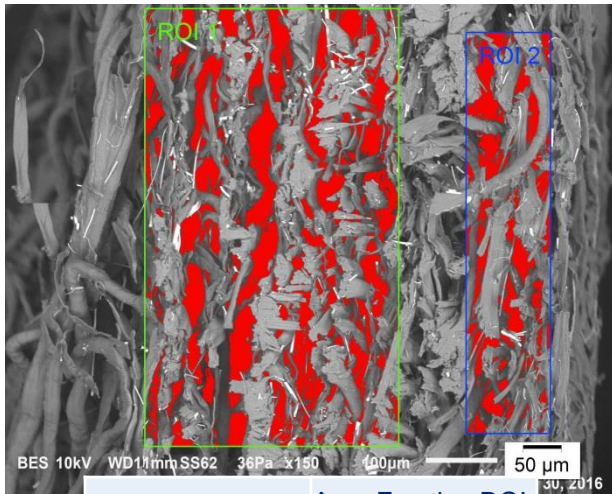


Area Fraction ROI (%)
21.01

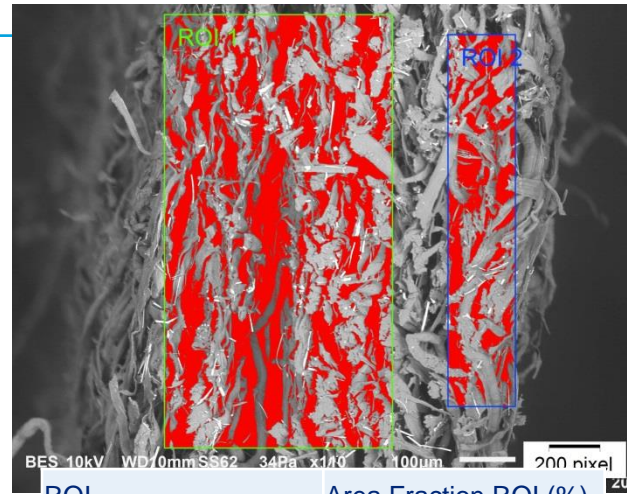


Area Fraction ROI (%)
18.44

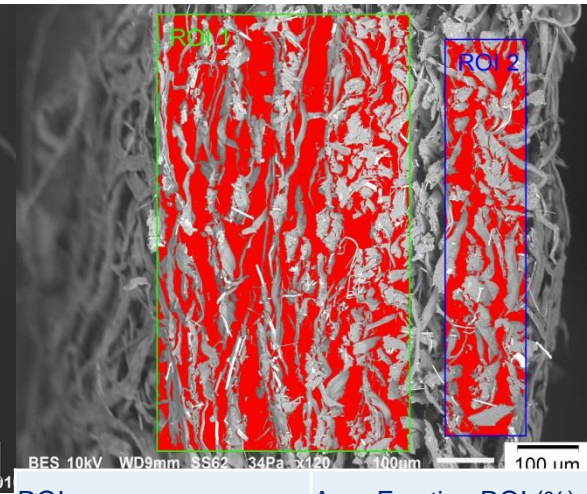
Appendix 1f: 2016 Cross-section Area Fraction



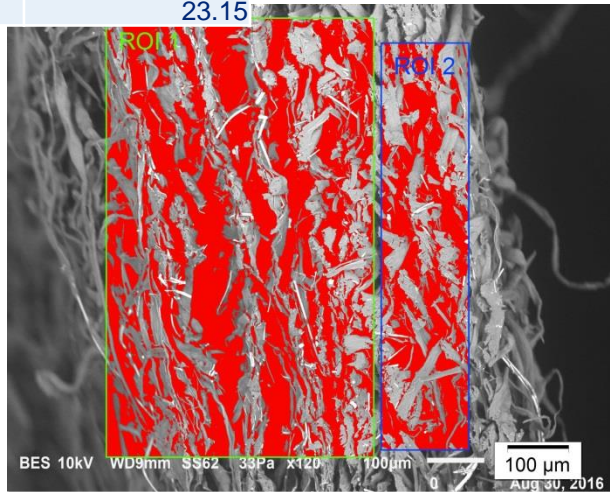
ROI	Area Fraction ROI (%)
ROI 1	25.13
ROI 2	23.15



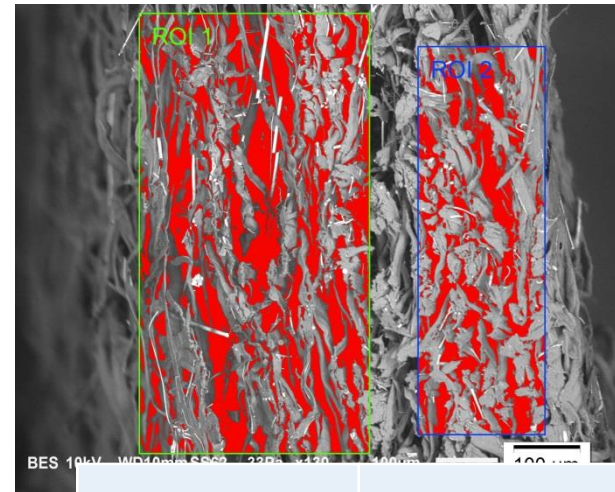
ROI	Area Fraction ROI (%)
ROI 1	41.66
ROI 2	36.78



ROI	Area Fraction ROI (%)
ROI 1	46.11
ROI 2	42.16

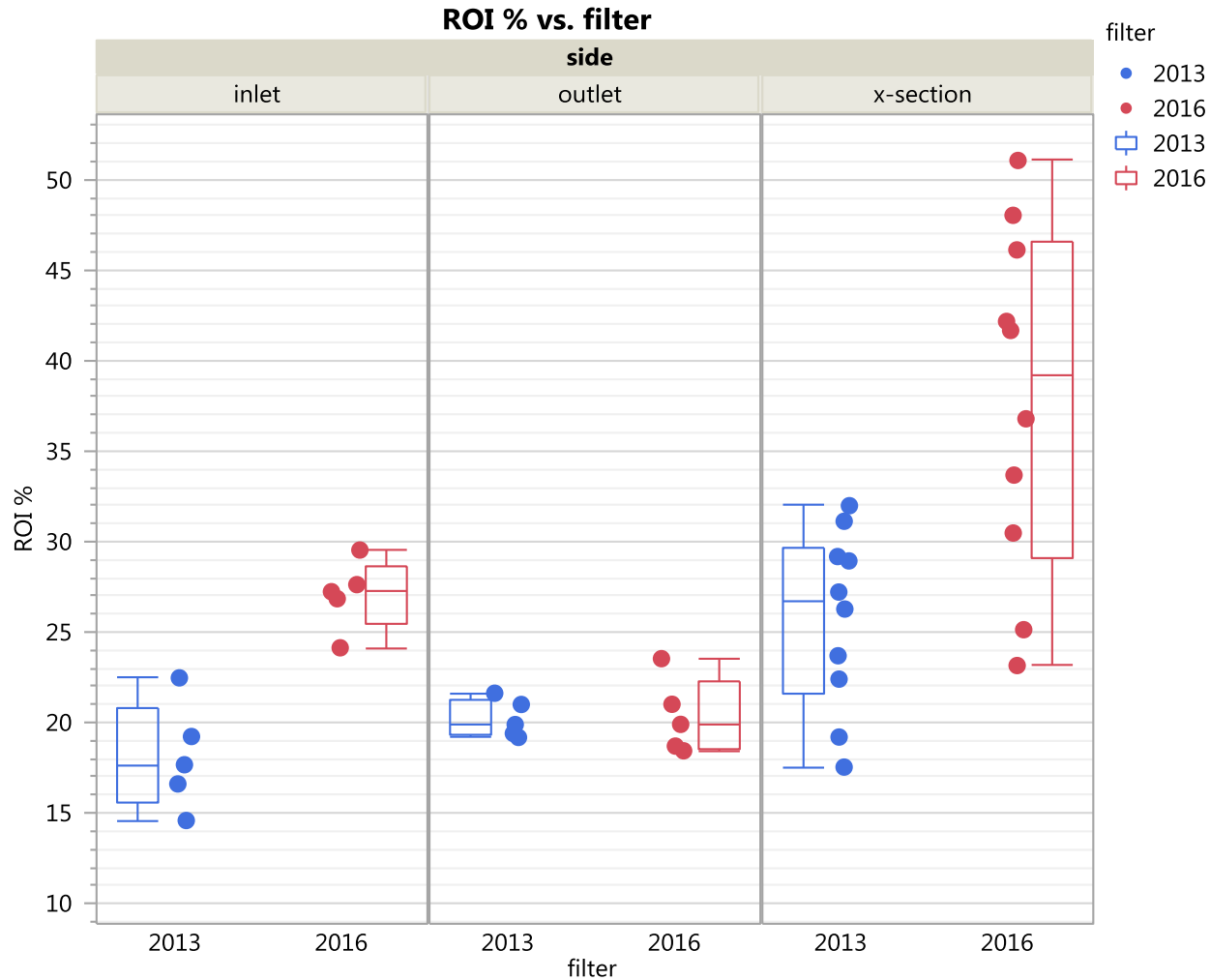


ROI	Area Fraction ROI (%)
ROI 1	51.05
ROI 2	48.02

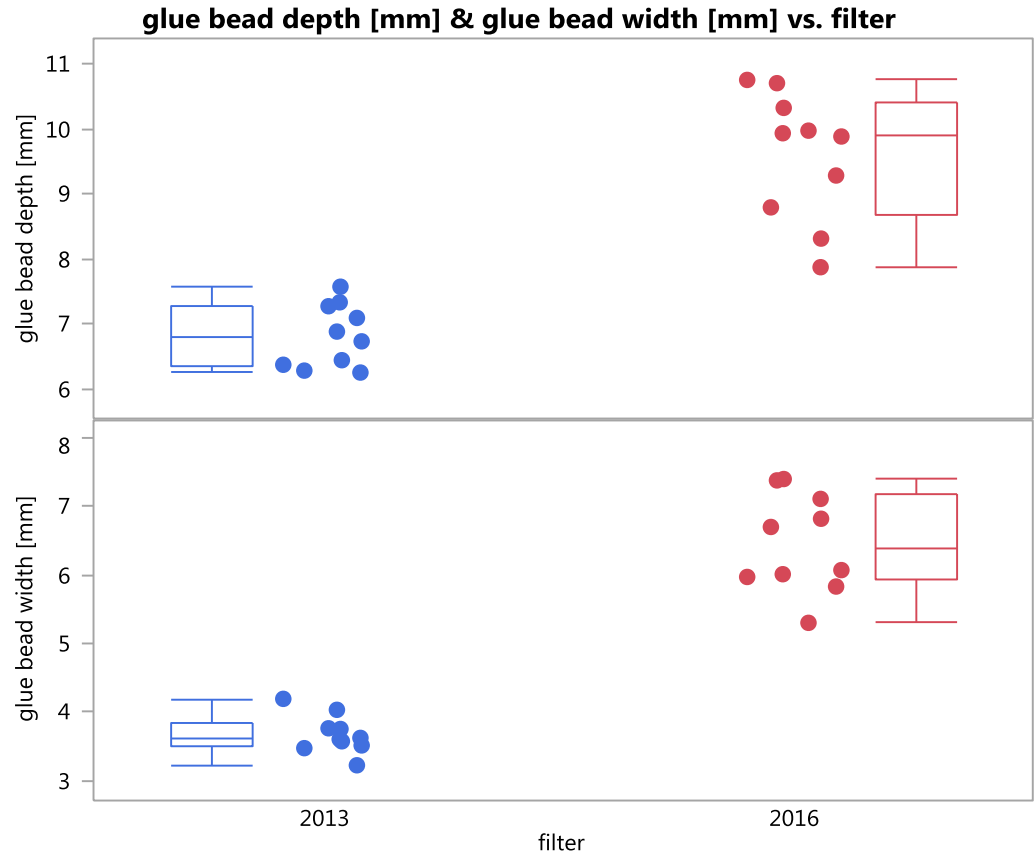
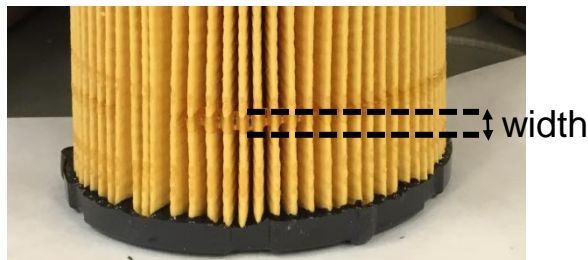
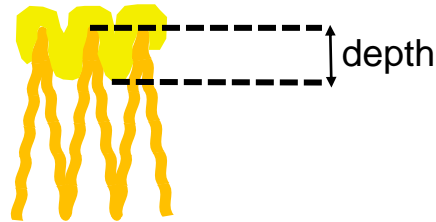


ROI	Area Fraction ROI (%)
ROI 1	33.67
ROI 2	30.47

Appendix 1g: Summary of open area measurements

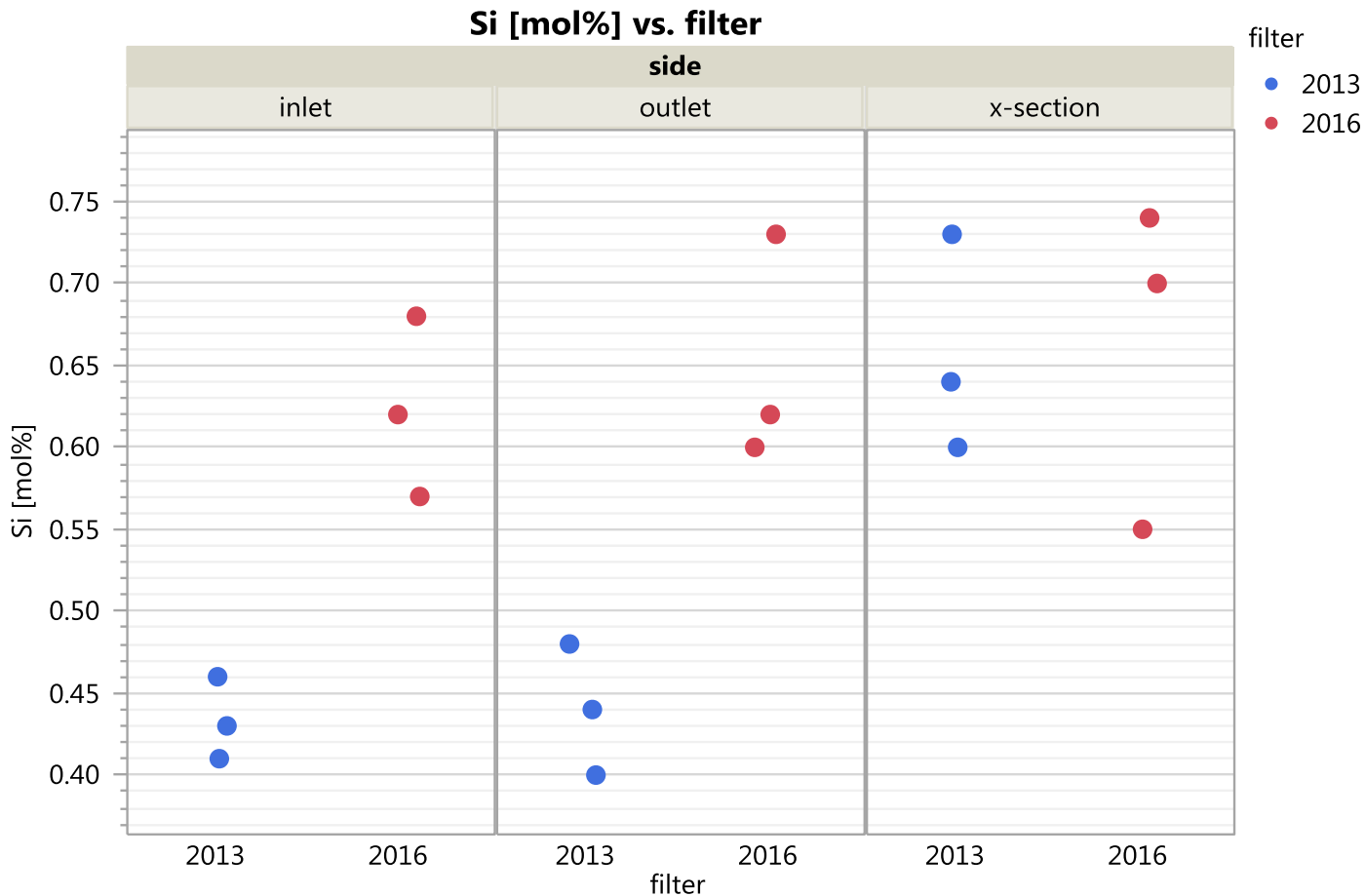


Appendix 2: Glue beading measurements



Glue beading was wider and deeper for 2016 filter compared to 2013 filter. 2016 filter sample may have had glue gun at a hotter temperature during manufacturing? Combined with less pleats, this further decreases available filter surface area for the 2016 filter.

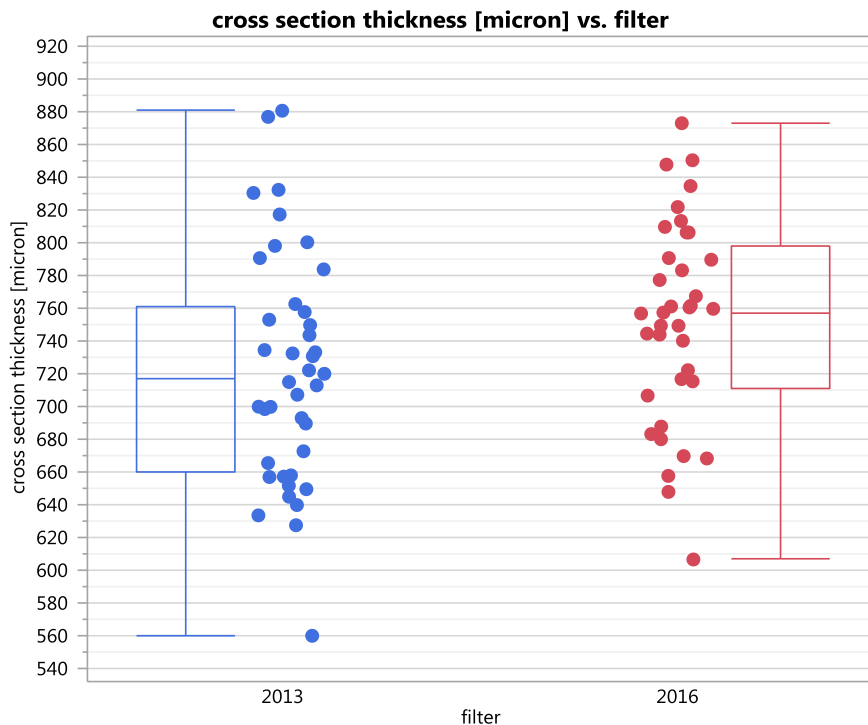
Appendix 3: Si content from EDS analysis



- Inlet and outlet sides of 2016 filter contained about 50% more glass fibers than those of 2013 filter. May have contributed to higher stiffness / less pleats for 2016 filter sample.

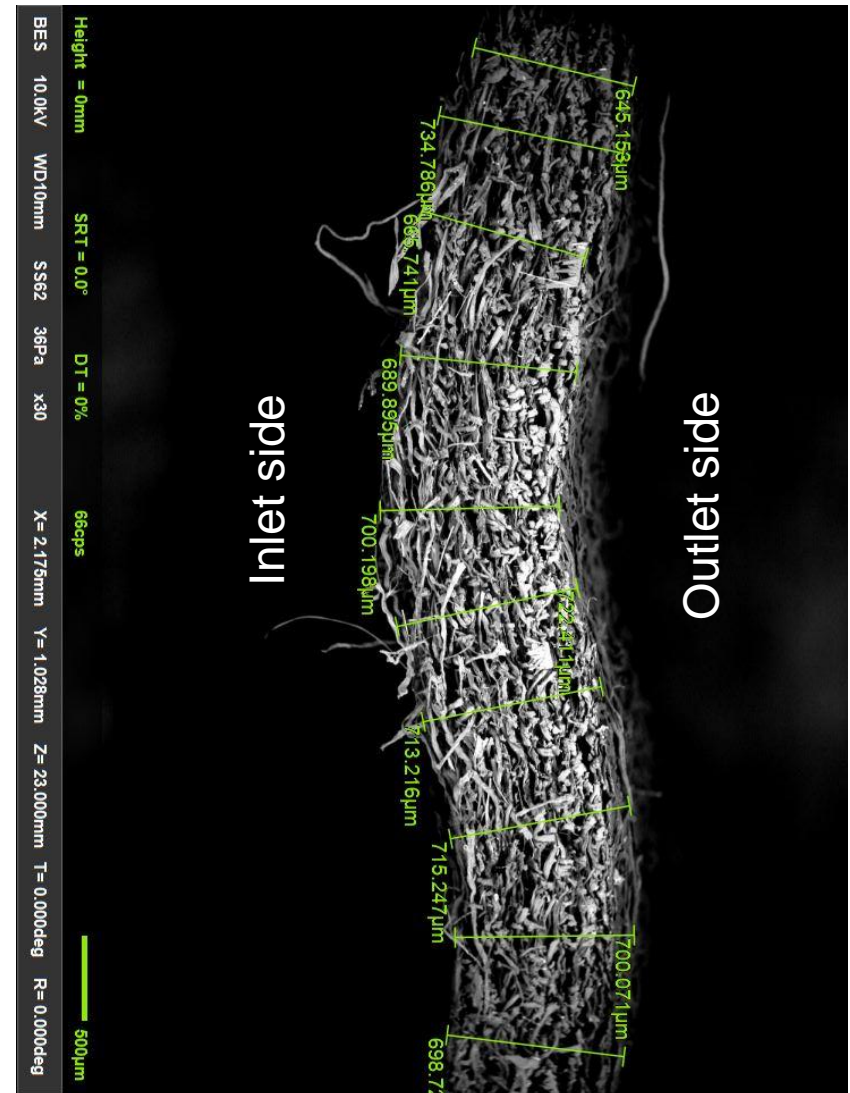
Appendix 4: Filter media thickness

2016 filter media was measured to be only slightly thicker than 2013 filter media sample. 4 samples cut from each filter and about 10 measurements were taken for each sample. Example image shown to right.



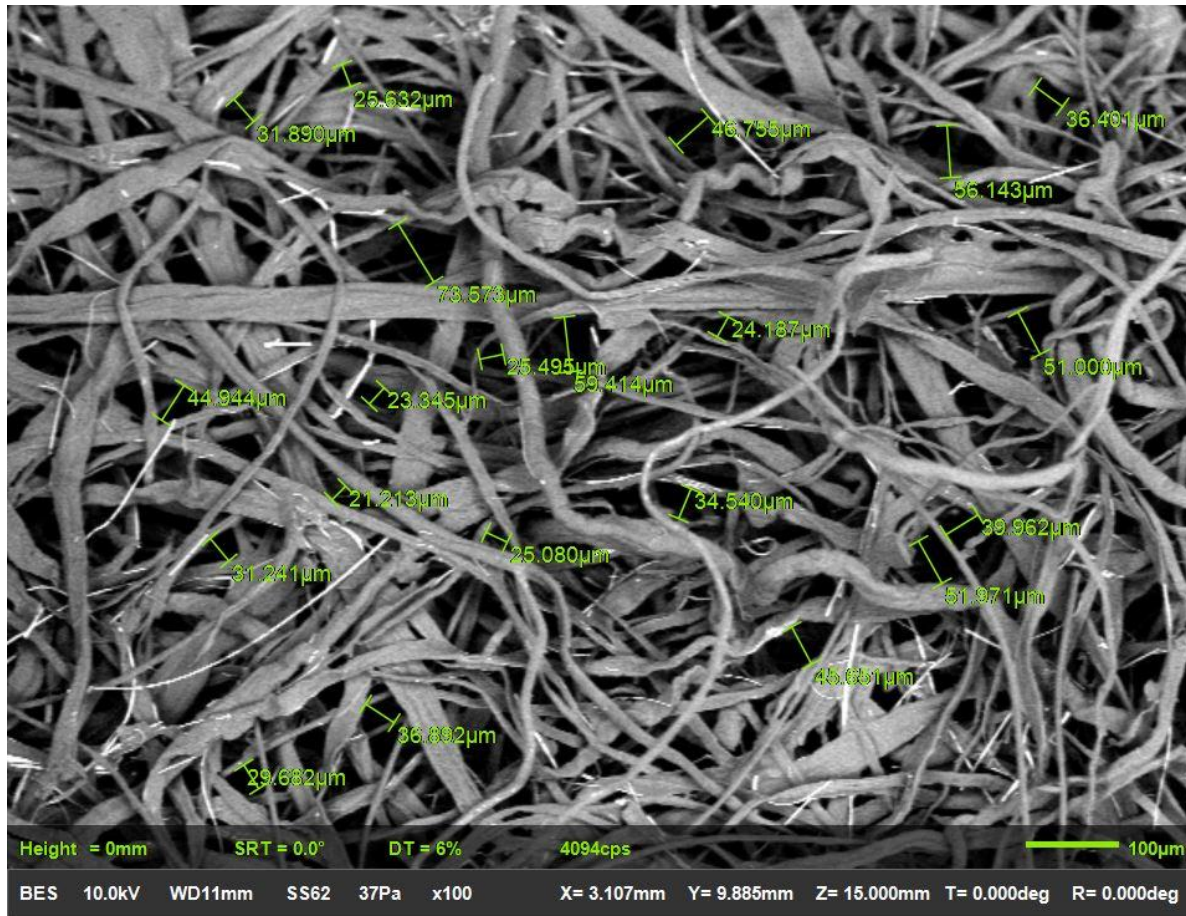
Means for Oneway Anova					
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
2013	40	722.372	10.557	701.34	743.40
2016	37	752.154	10.977	730.29	774.02

Std Error uses a pooled estimate of error variance



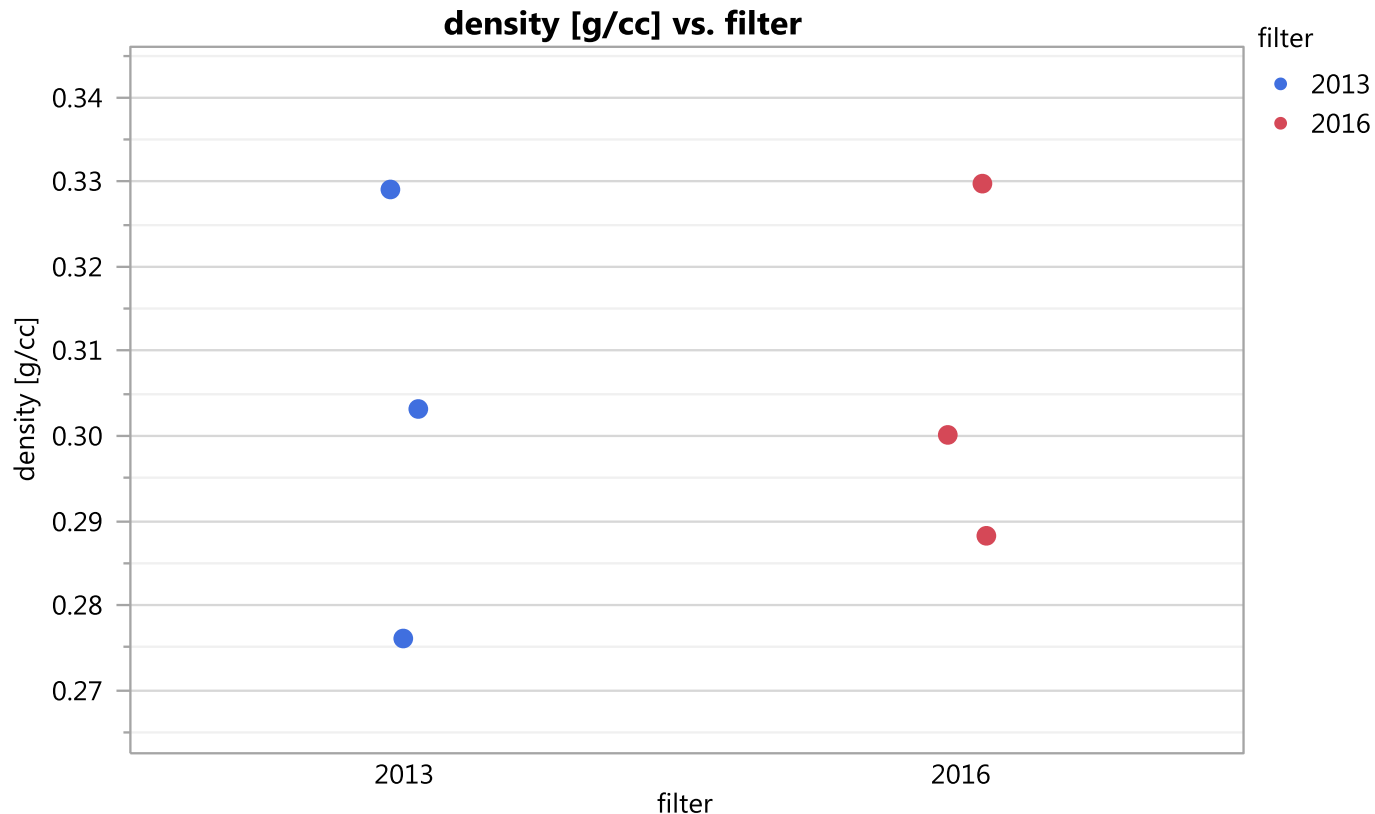
Appendix 5: Pore size measurements

Due to the nature of fibers (non-uniformity, several layers, etc), it was challenging to accurately characterize pore size. An example of how measurements were taken is given in the image below. Openings ranged from about 20 to 80 microns.



Appendix 6: Filter density

- Three 1 cm x 1 cm samples were cut from each filter and weighed. Measurements of length and width were from a handheld micrometer, thickness from SEM measurements, and weight from a digital scale. Densities measured were comparable / very similar for each filter.



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