Naval Fuels & Lubricants
Cross Functional Team
Test Report

Navy Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection

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EXECUTIVE SUMMARY

Four commercial off-the-shelf (COTS) particle counters - Parker Hannifin icount Oil Sampler (iOS), PAMAS S40, Parker Hannifin ACM20, and Stanhope-Seta AvCount - were evaluated at Naval Air Station (NAS) Patuxent River, NAS Jacksonville, and onboard the aircraft carrier USS George H.W. Bush (CVN-77) during an underway deployment. Utilizing a combination of in-line and bottle samples, fuel quality was measured during fueling operations over the span of two weeks at each NAS and one week onboard CVN-77. The PAMAS S40, Parker Hannifin ACM20, and Stanhope-Seta AvCount particle counters were housed in a laboratory environment and used to measure the particle counts and International Organization for Standardization (ISO) 4406:1999 cleanliness code of bottled fuel samples. The Parker Hannifin iOS particle counter measured the ISO 4406:1999 cleanliness code of samples taken in-line. Sediment and free water analysis were conducted on all fuel samples to allow particle counts and ISO codes to be correlated with the fuel's contaminant level.

In total, 216 JP-5 samples and 5 JP-8 samples were measured over the five week evaluation period. Select samples were evaluated using the Iso-proponal and Resolver® cosolvents. Of the 221 samples analyzed, only two samples contained free water (1 ppm & 5 ppm) and 92% of the samples contained less than 0.4 mg/L sediment and 0 ppm free water. High relative standard deviation between particle counts of the same sediment and free water concentration were measured confirming the results of past Navy testing that particle counts are not a feasible alternative to gravimetric sediment and free water analysis but may be a suitable measure of overall fuel cleanliness. Due to the lack of samples near the sediment and free water limits, 2.0 mg/L sediment and 10 ppm free water, a particle count and ISO 4406:1999 cleanliness code specification limit could not be established. The evaluation of the iso-propanol and Resolver® cosolvents was also limited by a lack of fuel samples containing free water and sediment. However, the samples that were tested with iso-proponal and Resolver® consistently measured a higher particle count despite the samples containing no free water.

The ISO codes measured by the in-line iOS particle counter only matched the ISO codes measured by the bottle sampling units six times. On average the difference between the ISO codes measured by the iOS and bottle sampling units was less than one in the >4 µm, >6 µm, and >14 µm channels at each sediment concentration. However there was large variability between the in-line and bottle results; as much as a 10 ISO code variability was observed in the >30 µm channel. Since the iOS particle counter was the only in-line sampling particle counter evaluated, the cause of these differences could not be determined. In-line sampling particle counters would be the most advantageous to the Navy due to the decreased analysis time required but prior to implementing any particle count or ISO code limit, the variability between the in-line and bottle ISO code measurements will need to be addressed.

Further evaluation of the particle counters is recommended to develop an ISO 4406:1999 cleanliness code limit representative for fuel containing 2.0 mg/L sediment and 10 ppm free water. Bottle testing should be completed with bottle samples of known/prepared contamination levels. In-line sampling units should be tested on a test rig capable of injecting controlled levels of sediment and free water contamination. Samples containing 0.5 to 3.0 mg/L and 1 ppm to 15 ppm free water should be tested. The iso-propanol and Resolver® additives should be further tested on fuel samples containing sediment and free water to fully determine their impacts on particle counts. Due to the consistency with which clean fuel samples were measured during this evaluation, further field evaluation of bottle sampling particle counters and in-line particle counters is not recommended.

LIST OF ACRONYMS/ABBREVIATIONS

ASTM……………………………..…. …………….. American Society for Testing and Materials

PPM.... ………………………………..…. ……………………..Parts per million by volume

CCFD……………………………………..…..…………Combined Contaminated Fuel Detector

COTS . ………………………………..…. ………………………..Commercial off-the-shelf

CVN. ………………………………..…. ………………….Nuclear-powered aircraft carrier

EI ………………………………..…. ………………………...…..…….Energy Institute

NAS..……………………………………………………………..…..…. …Naval Air Station

NATOPS ………………………Naval Air Training and Operating Procedures Standardization

IAW..……………………………………………………………………...In accordance with

iOS .... ……………………………………………………………………...icount OS

IP ………………………………………………………...……….Institute of Petroleum

ISO….……………………………...………..International Organization for Standardization

NSTM ………………………………………………………Naval Ship's Technical Manual

NAVAIR... ……………………………………………………Naval Air Systems Command

RSD................……………………………………….………Relative Standard Deviation

DEFINITIONS

Free Water...............water that is not in solution with the fuel i.e. the fuel is above its water saturation point

Navy Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection

1.0 BACKGROUND

Aviation fuel quality assurance is accomplished by routinely collecting fuel samples from various locations within the aviation fuels system and testing for free water and sediment contamination. The primary mission of the aviation fuels system is to provide aircraft-quality fuel to all aircraft and to shipboard support equipment. This is accomplished through rigorous fuel sampling and testing with the combined contaminated fuel detector (CCFD). Additionally, test results are verified at shore-based laboratories to ensure the accuracy of results using established ASTM methods.

Extensive sampling and testing protocols have been implemented to ensure the concentration of free water and sediment in aviation fuel are below the limits specified in Naval Air Training and Operating Procedures Standardization (NATOPS) NAVAIR 00-80T-109 of 10 parts per million (ppm) free water and 2.0 mg/L sediment. Failure to meet these limits can adversely affect safety-of-flight. Sediment contaminants can plug fuel filters and increase fuel pump wear. Sediment contaminants vary in shape and composition but are commonly found in the 5µm to 40 µm range. Common sediment contaminants includes silica, rust, metal shavings, fibrous materials, coatings, and hydrocarbon/oxidation deposits. In addition, free water can potentially freeze and clog fuel lines and fuel pumps. The presence of free water can also facilitate the formation of microbial growth in storage tanks. Free water can appear as fine droplets or slugs of water in the fuel systems.

Present fuel quality assurance practices outlined in numerous directives such as MIL-STD-3004, NATOPS Aircraft Refueling Manual (NAVAIR 00-80T-109), and the Naval Ships Technical Manual (NSTM Chapter 542) require a dedicated group of specifically trained personnel to routinely collect fuel samples from various points in the fuel distribution system. Onboard ships samples are routinely collected from stripping pumps, purifiers, filter/separators, and refueling nozzles. These samples are visually examined and periodically transported to a dedicated onboard aviation fuels laboratory for free water and sediment analysis. At shore stations, fuel samples are collected and analyzed for sediment and water contamination a minimum of once a day from refueler trucks, fueling stations, and other shore-based equipment used to dispense fuel. Fuel received at shore stations via barges, pipelines, and tank trucks are also sampled and tested for free water and sediment contamination. These guidelines represent the minimum sampling requirements and additional samples may be collected if contamination is suspected.

In the hydraulics industry, particle counting and automatic particle counters are widely used to measure the cleanliness of hydraulic fluids. However, particle count analysis for aviation fuel cleanliness is relatively new. Both military and commercial industries have conducted testing to evaluate the feasibility of transitioning particle counter technology to the aviation fuel sector. The Navy previously evaluated four commercial off-the-shelf (COTS) particle counters for fuel contamination detection —Parker Hannifin ACM20, Stanhope-Seta AvCount, PAMAS S40, and HIAC GlyCount[1]. Unlike traditional laboratory methods, particle counters offer the ability to objectively measure fuel quality directly from fuel lines without the use of consumables thereby reducing the total analysis time (sampling time + transport time + test time) and eliminating the subjectivity of visual methods. Previous testing at the Naval Air Station (NAS) Patuxent River Propulsion Systems Evaluation Facility included installing the above four particle counters in a flowing fuel stream test rig while controlled levels of free water and sediment were injected into the fuel stream at various concentrations. Test results showed the particle counters were sensitive to increases in free water and sediment when the two contaminants were injected separately. However, the particle counters were unable to distinguish between free water and sediment when both types of contamination were present. From this test it was concluded that particle counters cannot replace current test methods when separate quantification of both free water and sediment is required. Since the particle counters were sensitive to sediment and free water contamination, they can potentially be used as a tool for the general measure of overall fuel cleanliness. In this capacity, the particle counters would serve as a "go" or "no-go" tool.

Particle counts have already been incorporated in the Jet A-1 specification DEF STAN 91-91 issue 6 as a report only parameter. As noted in DEF STAN 91-91, the specification authority intends to replace test methods American Society for Testing and Materials (ASTM) D5452 and Institute of Petroleum (IP) 423 for the measurement of sediment contamination at the point of fuel manufacturing with particle counts. Similarly, particle counts are listed as a report only parameter in JP-5 specification MIL-DTL-5624V and JP-8 specification MIL-DTL-83133H. Particle counts were included in these specifications to facilitate the collection of particle count data and the identification of a particle count specification limit. In support of this effort, DLA Energy provided funding for the evaluation of particle counters at three U.S. Navy locations—NAS Patuxent River, NAS Jacksonville, and during an underway period onboard the aircraft carrier U.S.S. George H.W. Bush (CVN-77). Utilizing a combination of in-line and laboratory based particle counters, particle counts were measured over the span of two weeks at each land site and one week onboard CVN-77.

2.0 OBJECTIVE

The results of this evaluation will assist in assessing the effectiveness of particle counters at identifying aviation fuel contamination. An assessment will be made based on both operability and technological applicability. In addition, the data collected from this study will provide particle counts representative of those seen in the field. These results may be used to help establish use limit particle counts and International Organization for Standardization (ISO) ISO 4406:1999 cleanliness code limits for Naval aviation fuel.

3.0 APPROACH

3.1 PARTICLE COUNTERS

Four COTS particle counters {1) Parker Hannifin icount Oil Sampler (iOS), 2) Parker Hannifin ACM20, 3) Stanhope-Seta AvCount, and 4) PAMAS S40} were used to measure fuel quality at NAS Patuxent River and NAS Jacksonville. Unlike the other particle counters, the Parker iOS unit lacked a sampling pump and was limited to in-line measurements (i.e. samples drawn directly from fuel lines). The Parker iOS unit's sampling connection, a ¼" male quick-disconnect coupling was incompatible with the CVN-77 sampling ports. Therefore only the ACM20, AvCount, and S40 were used onboard CVN-77 to measure fuel quality.

The AvCount, S40, and ACM20 particle counters are capable of sampling directly from fuel lines but require inlet pressures less than 10 bar, 6 bar, and 420 bar, respectively. With the SA1008-0 option, the AvCount is able to handle inlet pressures up to 310 bar. Due to these inlet pressure limitations, the decision was made by DLA Energy to use the AvCount, S40, and ACM20 units to only measure particle counts of bottle samples. Images of the four particle counters used in this evaluation can be found below in Figure 1. The same ACM20, AvCount, and S40 particle counter was used at each test location. All three units were calibrated in accordance with (IAW) ISO 11171 by each manufacturer prior to conducting this evaluation. Since in-line measurements were made at various points in the fuel distribution system, multiple iOS units were used. Prior to this evaluation each iOS unit was calibrated IAW Parker's IPD-0136 calibration procedure.

Figure 1. Parker Hannifin iOS, Parker Hannifin ACM20, Stanhope-Seta AvCount with SA1008-0 option, and PAMAS S40 Particle Counters (from left to right)

3.2 BOTTLE SAMPLE TEST PROCEDURE

Since particles settle to the bottom of pipes and filter separators during periods of stagnation, collection of bottle samples and in-line measurements were restricted only to fueling operations. When time allowed, an in-line measurement was also made using the iOS particle counter directly before or after collecting the bottle sample.

The Energy Institute (EI) has established test methods IP564, IP 565, and IP577 for particle count determination of bottle samples when using the ACM20, AvCount, and S40 particle counters, respectively. Slight variations were made to the test methods to allow for the simultaneous testing of the three instruments. During fueling operations a minimum of 3L of fuel was collected from the moving fuel stream into a clean borosilicate amber bottle. The samples were then transported to the on-site fuel laboratory for particle count analysis. At the laboratory, each bottle sample was hand rolled end-over-end at a rate of ~1 revolution per second for one minute to produce a homogenous solution and to minimize bubble formation. The sample probes of the ACM20, AvCount, and S40 were tied together and then inserted into the top of the bottle to a point approximately 2 inches from the bottom of the bottle to ensure each unit could simultaneously sample from the same location in the bottle. Next the ACM20's fuel lines were flushed by manually pressing and holding the pump button on the ACM20's external pump until approximately 100 mL of fuel were passed through the unit. Note: the S40 and AvCount units did not require manual flushing because a flush operation is programmed into the software and occurs automatically once a measurement is initiated. Finally, a measurement operation was initiated IAW the instructions provided by each unit's manufacturer. Due to programming differences, each instrument analyzed a different number of sample aliquots. The S40 and AvCount are programmed to measure 5 and 3 aliquots, respectively. For the ACM20 a single measurement is initiated by manually turning the blue dial on the front of the unit. This was performed 3 times for each bottle sample. The particle count and ISO 4406:1999 cleanliness code (herein abbreviated as ISO code) from each measurement were stored in each unit's internal memory and later downloaded for final analyis. In addition a printout of the results was retained. For this analysis, the average of the aliquot measurements is taken as the true particle count for that sample. All values reported in this study are based on these average values.

3.3 IN-LINE SAMPLE TEST PROCEDURE

The Parker iOS in-line particle counters sampled directly from fuel lines via a ¼" quick-disconnect fitting. In-line measurements were collected at various locations in the NAS Patuxent River and NAS Jacksonville fuel distribution system including the inlet and outlet of receipt and issue filter separators, at the refueling nozzle (sampling probe to ¼" quick-disconnect fitting used), and along transfer lines. Unlike the ACM20, AvCount, and S40 particle counters, the iOS unit does not provide absolute particle counts. The iOS provides only an ISO code value for the >4 µm, >6 µm, >14 µm, and >30 µm diameter channels. These cleanliness codes are a simplified representation of particle counts and correspond to a range of particles (See Appendix A).

The iOS units were connected to fuel lines directly prior to fueling operations and measurements initiated manually. A one minute flush period and a two minute sampling period were used for each in-line measurement. Although, the Parker iOS units are able to pump directly back into fuel lines via a ¼" quick disconnect coupling on the outlet, this feature was not utilized during this evaluation to simplify the testing procedure. Fuel used during the flush and measurement periods was discarded into a 5 gallon can. All in-line measurement were taken directly before or after collecting the bottle sample so comparable fuel samples could be evaluated. Due to the varying duration of fueling operations only one in-line measurement was taken for each bottle sample.

3.4 FREE WATER AND SEDIMENT ANALYSIS

Free water and sediment analysis of each bottle sample was also conducted after performing particle count measurements to allow for correlation with particle count and ISO code measurements. At NAS Patuxent River, the free water content of the bottle samples was determined IAW ASTM D3240: Standard Test Method for Free Water in Aviation Turbine Fuels. Due to the short window for collecting bottle samples, in-line sediment analysis IAW ASTM D2276 was not feasible for this evaluation. Instead, the sediment concentration of all bottle samples collected at NAS Patuxent River were analyzed IAW ASTM D5452: Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration using a 1.0 L volume of fuel. Sediment analysis was conducted at the Propulsion Systems Evaluation Facility chemistry laboratory.

At NAS Jacksonville and onboard CVN-77 sediment and free water analysis was determined using a combined contaminated fuel detector (CCFD) conforming to MIL-D-22612. Free water and sediment analysis was conducted IAW NSTM Chapter 542 Procedures 7.4.3.2 and 7.4.2.1, respectively. CCFDs are used onboard Navy vessels and in Navy fuel laboratories to determine the free water and sediment concentrations of JP-5 due to their ease of use and shorter test times as compared to ASTM D3240 and D5452. The sediment concentration is determined by vacuum filtering fuel through two 0.65 µm Millipore filters and then comparing the light absorption of the two filters. The difference in absorption between the two filters is directly related to the sediment concentration. The free water concentration is determined by vacuum filtering fuel through a uranine coated pad that fluoresces when it comes in contact with free water. The free water concentration is determined by visually comparing the level of fluorescence of the test pads to standards. In this study particle counts from fuel samples measured IAW ASTM D3240 and D5452 are analyzed separately from those measured via the CCFD.

3.5 NAS PATUXENT RIVER, MD TEST OVERVIEW

Testing was conducted at NAS Patuxent River, MD over the span of two weeks beginning April 29, 2013 and ending May 13, 2013. Over the evaluation period, a total of 53 bottle samples were collected for particle count, sediment, and free water analysis. Of the 53 bottle samples, 42 in-line particle count measurements were taken in parallel (i.e. in-line particle count measurements taken from the same location during the same fueling operation as a bottle sample). In-line measurements and bottle samples were collected from sampling points throughout the NAS Patuxent River fuel supply system. A breakdown of the sampling locations and fuel type can be found in Table 1. A schematic of the NAS Patuxent River fuel distribution system can be found in Figure 2.

Table 1. NAS Patuxent River, MD Sampling Locations

Legend	Location	Fuel Type	Bottle Sample	In-line Measurement
1	Issue Filter Separator Inlet	JP-5	19	18
2	Issue Filter Separator Outlet	JP-5	18	17
3	Fill Stand Nozzle	JP-5	6	6
4	Refueler Nozzle	JP-5	2	0
5	Barge Receipt Line	JP-5	3	0
6	Fill Stand Nozzle	JP-8	3	1
7	Refueler Nozzle	JP-8	2	0
	Total		**53**	**42**

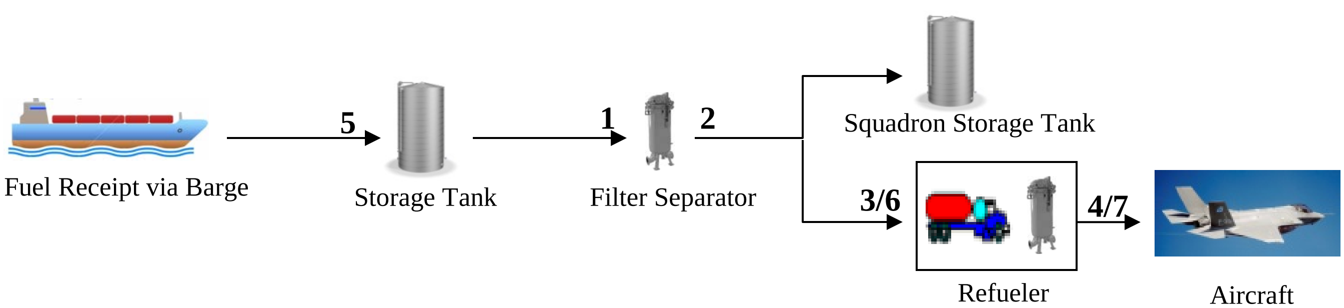

Figure 2. NAS Patuxent River Fuel Distribution System Schematic

Particle count, free water and sediment concentrations were determined IAW sections 3.2, 3.3, and 3.4. In addition, two fuel additives intended to mask particle counts associated with free water, iso-propanol and Resolver®, were tested in 8 bottle samples. The additives were tested by combining 700 mL of the test fuel and 10 mL of iso-propanol or Resolver® in a clean glass quart bottle and vigorously shaking for 30 seconds. The sample was then allowed to sit undisturbed for one minute. Next the jar was tumbled end-over-end at a rate of ~1 revolution per second for 1 minute and then tested using the bottle sampling particle counters as described in Section 3.2.

3.6 NAS JACKSONVILLE, FL TEST OVERVIEW

Testing was conducted at NAS Jacksonville, FL over the span of two weeks beginning May 20, 2013 and ending May 31, 2013. Over the evaluation period a total of 85 bottle samples were collected for particle count, sediment, and free water analysis. Of the 85 bottle samples, 84 in-line particle count measurements were taken in parallel. Samples were collected at the inlet and outlet of issue and receipt filter separators. The locations are listed in Table 2. A schematic of the NAS Jacksonville fuel distribution system can be found in Figure 3.

Table 2. NAS Jacksonville, FL Sampling Locations

Legend	Location	Fuel Type	Bottle Sample	In-line Measurement
1	Issue Filter Separator Inlet	JP-5	16	16
2	Issue Filter Separator Outlet	JP-5	17	16
3	Receipt Filter Separator Inlet	JP-5	26	26
4	Receipt Filter Separator Outlet	JP-5	26	26
	Total		**85**	**84**

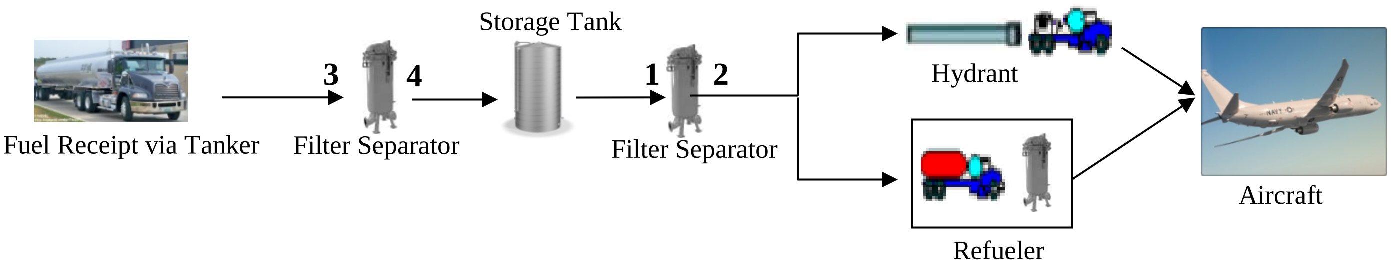

Figure 3. NAS Jacksonville Fuel Distribution System Schematic

Particle count measurements of in-line and bottle samples were measured as described in Sections 3.2 and 3.3. Free water and sediment concentrations were measured as described in Section 3.4. Resolver® and iso-propanol were not tested at NAS Jacksonville, FL.

3.7 CVN-77 USN AIRCRAFT CARRIER TEST OVERVIEW

Testing was conducted onboard CVN-77 while underway over the span of five days beginning August 26, 2013 and ending August 30, 2013. A total of 83 bottle samples were collected for particle count, sediment, and free water analysis while onboard the vessel. The CVN-77 fuel system lacked the appropriate pipe fittings to test the Parker iOS in-line particle counter; therefore no in-line particle count measurements were made. Bottle samples were collected during a wide array of fueling operations including filter separator flushes, nozzle flushes, service tank hand stripping, and issuances to aircraft. The locations of where bottle samples were collected can be found in Table 3 and Figure 4.

Table 3. CVN-77 Underway Sampling Locations

Legend	Location	Fuel Type	Bottle Sample
1	Service Filter Separator Inlet	JP-5	20
2	Service Filter Separator Outlet	JP-5	19
3	Service Filter Separator Outlet (Hand-Stripping)	JP-5	12
4	Transfer Filter Separator Outlet	JP-5	7
5	Fueling Station Hose Nozzle	JP-5	25
	Total		**83**

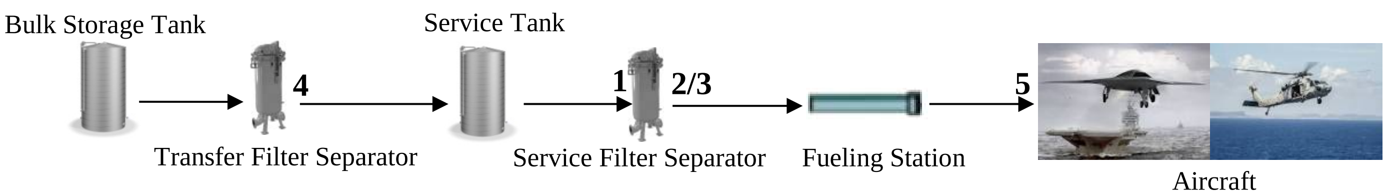

Figure 4. CVN-77 Fuel Distribution System Schematic

Particle count measurements of bottle samples were tested as described in Sections 3.2. Free water and sediment concentrations were determined as described in Section 3.4 by CVN-77 V-4 division personnel.

4.0 RESULTS AND DISCUSSION

Only two samples collected during the five week evaluation period contained free water. One sample collected from the outlet of an issue filter at NAS Jacksonville, FL contained a free water concentration of 1 ppm. Additionally, a sample collected onboard CVN-77 from the outlet of a service filter during hand stripping of a service tank contained 5 ppm of free water. All samples measured at NAS Patuxent River, MD had a free water concentration of 0 ppm. Between the three sites, the sediment concentration varied from 0.0 mg/L to 2.7 mg/L; the average sediment concentration was 0.2 mg/L. All but one sample collected at the test sites were below the maximum allowable sediment and free water concentrations stated in NAVAIR 00-80T-109, 2.0 mg/L and 10 ppm. A site-by-site breakdown of the sediment levels measured at each test site can be found in Table 4. In this study particle counts from fuel samples measured IAW ASTM D3240 and D5452 are analyzed separately from those measured via the CCFD.

Table 4. Fuel Sediment Levels by Test Site

Test Site	Bottle Samples	Average Sediment Concentration, mg/L	Minimum, mg/L	Maximum, mg/L
NAS Patuxent River, MD	53	0.2	0.0	2.7
NAS Jacksonville, FL	85	0.1	0.0	0.4
CVN-77 Underway	83	0.2	0.0	1.2

4.1 BOTTLE SAMPLING PARTICLE COUNTER RESULTS

4.1.1. ASTM D5452 & ASTM D3240

The average >4 µm particle count of the 53 samples analyzed IAW ASTM D5452 and ASTM D3240 can be seen in Figure 5. All samples shown have a free water concentration of 0 ppm.

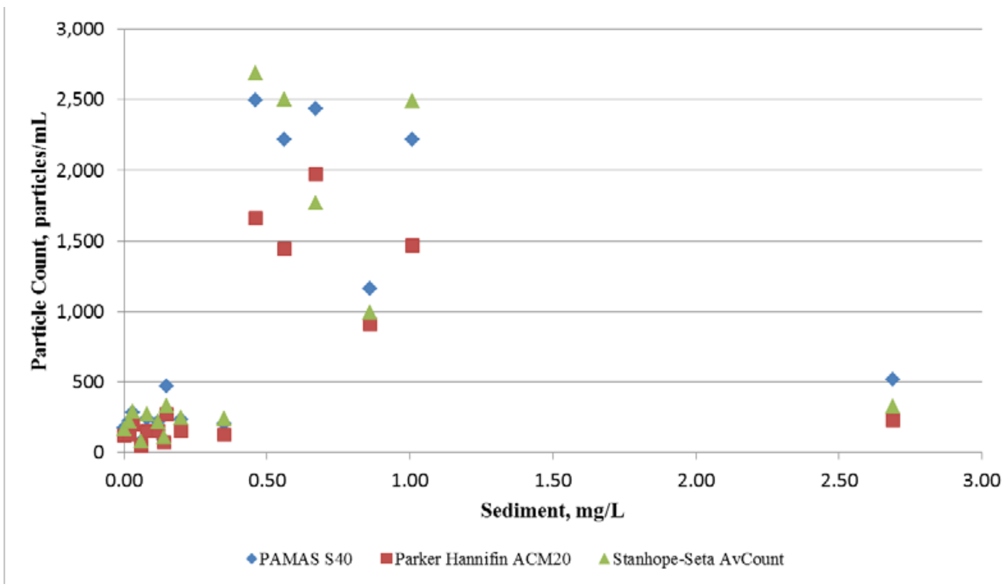

Figure 5. Average >4 µm Particle Count: Free Water and Sediment Determined IAW ASTM D3240 and D5452

As can be seen in Figure 5, the particle count in the >4 µm channel does not trend with sediment concentration and the >4 µm particle counts vary at a given sediment concentration, most notably at a sediment concentration of 0.0 mg/L. This may be attributed to variations between the 10 mL aliquots measured by the particle counters and 1L aliquots used to analytically measure the sediment concentration (ASTM D5452). The units are also highly sensitive and inconsistent particle counts may also be the result of random sample variations due to imperfect mixing within the bottle.

The relative standard deviation (equation 1) of each unit can be seen below in Figure 6. Some data points found in Figure 5 are omitted from Figure 6 due to only a single sample being measured at that sediment concentration.

$$Relative\ Standard\ Deviation\ (RSD)\ \% = \frac{standard\ deviation}{average\ particle\ count} \times 100 \quad (1)$$

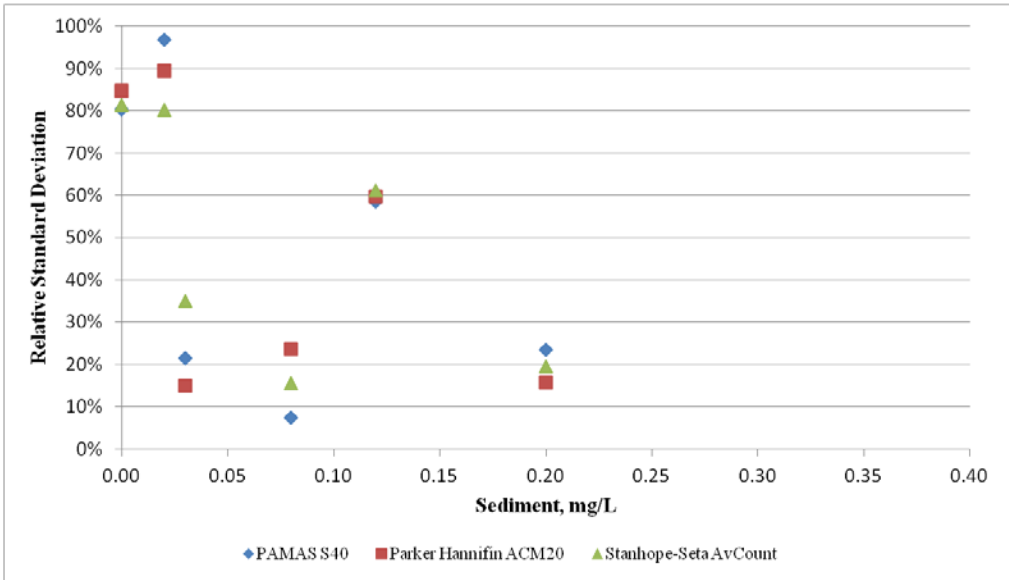

Figure 6. Relative Standard Deviation of >4 µm Particle Count

The high RSD between particle counts of the same sediment and free water concentrations are consistent with the conclusion from past studies completed by the Navy that particle counts are not a feasible alternative to gravimetric sediment analysis (1). Particle counts vary too widely to precisely measure sediment and free water concentrations, especially at low sediment concentrations (i.e. 0.0 mg/L). ISO codes help compensate for variability between fuel samples by assigning a numerical value based on the number of particles measured (see Appendix A). Figure 7 presents the same data from Figure 5 transcribed in ISO codes. Error bars correspond to the range of ISO codes (i.e. maximum and minimum ISO code) measured at that sediment concentration. Error bars are omitted from samples containing greater than 0.4 mg/L because only one sample was collected at those concentrations. Similar ISO code results for the >6 µm, >14 µm, >21 µm, >25 µm and >30 µm diameter channels can be found in Appendix B.

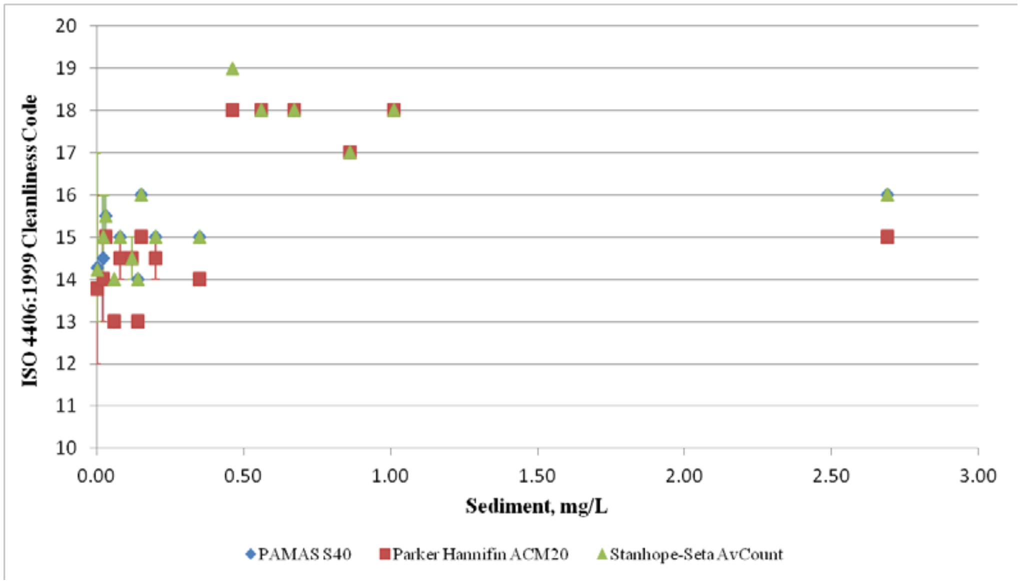

Figure 7. Average >4 µm ISO Code: Free Water and Sediment Determined IAW ASTM D3240 and D5452

Due to the absence of samples in the 2.0±1.0 mg/L sediment range and the lack of samples containing free water, an accurate ISO code specification limit cannot be established solely from the data collected during this evaluation. However, 89% of the bottle samples analyzed at NAS Patuxent River had a sediment concentration less than 0.4 mg/L and a free water concentration of 0 ppm. Average, maximum, minimum, 50^{th} percentile and 90^{th} percentile ISO code of samples containing <0.4 mg/L sediment can be found in Table 5.

Table 5. ISO Codes of Samples Containing <0.4 mg/L Sediment and 0 ppm Free Water as Determined by ASTM Methods

Particle Counter	Maximum	Minimum	Average (Std. Dev)	90^{th} Percentile	50^{th} Percentile
			>4 µm		
PAMAS S40	17	12	14.4 (1.1)	16	15
Parker Hannifin ACM20	16	12	13.9 (1.0)	15	14
Stanhope-Seta AvCount	17	13	14.4 (1.0)	15	14
			>6 µm		
PAMAS S40	15	11	12.7 (1.0)	14	13
Parker Hannifin ACM20	14	10	12.1 (0.9)	13	12
Stanhope-Seta AvCount	15	11	12.8 (0.9)	14	13
			>14 µm		
PAMAS S40	13	8	9.6(1.1)	10	10
Parker Hannifin ACM20	12	7	8.6 (1.1)	10	8
Stanhope-Seta AvCount	12	7	9.7 (1.1)	11	9
			>30 µm		
PAMAS S40*	-	-	-	-	-
Parker Hannifin ACM20	7	2	4.7 (1.2)	6	5
Stanhope-Seta AvCount	9	3	5.9 (1.2)	7	6

*The PAMAS S40 unit lacks a >30 µm channel

4.1.2 COMBINED CONTAMINATED FUEL DETECTOR

CCFDs were used to determine the sediment and free water concentration of fuel samples collected at NAS Jacksonville and onboard CVN-77. Between the two sites 168 fuel samples were evaluated, two of which contained free water. The average >4 µm particle count of the 166 samples analyzed containing no free water can be seen in Figure 8. The error bars found in Figure 8 correspond to the range of particle counts measured.

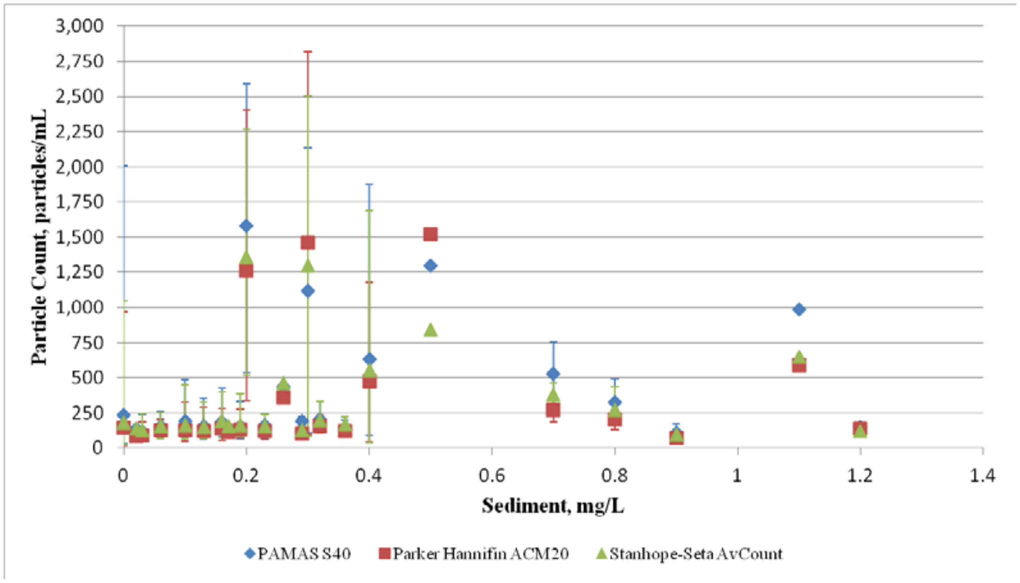

Figure 8. Average >4 µm Particle Count: Free Water and Sediment Determined IAW Chapter 542 of NSTM

A broader range of particle counts were measured at each CCFD determined sediment concentration than ASTM D5452 determined sediment concentration. For example, >4 µm particle counts between 18 and 2010 particles/mL were measured at a CCFD determined sediment concentration of 0.0 mg/L while fuel samples containing 0.0 mg/L as measured IAW ASTM D5452 ranged between 30 and 759 particles/mL. This increase in variability may be the result of the precision of the CCFD. In Figure 9 below, Figure 8 results are transcribed into ISO codes. Similar ISO code results for the >6 µm, >14 µm, >21 µm, >25 µm and >30 µm diameter channels can be found in Appendix C.

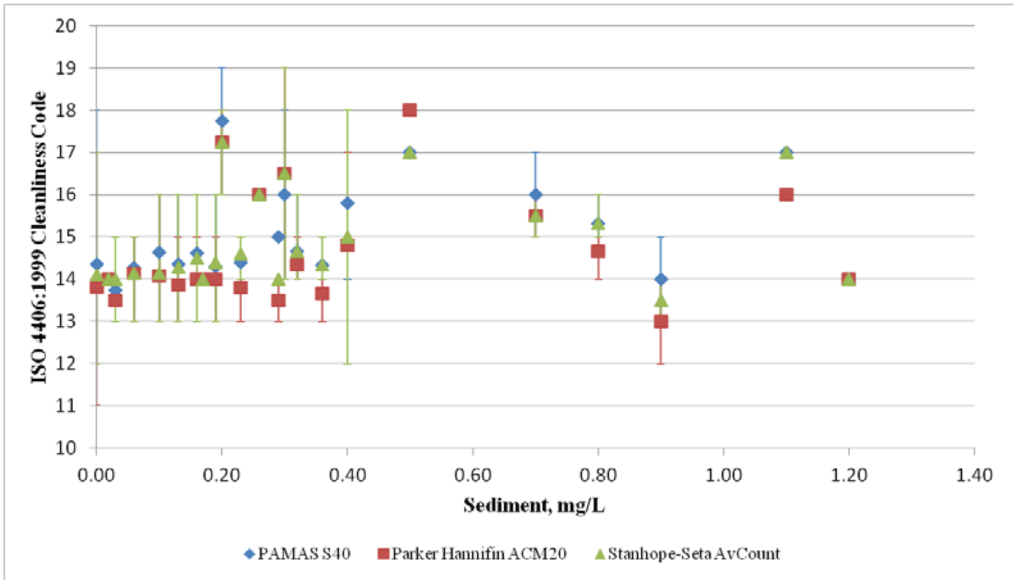

Figure 9. Average >4 µm ISO Code: Free Water and Sediment Determined IAW Chapter 542 of NSTM

Of the 168 samples measured at NAS Jacksonville and onboard CVN-77, 93% of the samples contained <0.4 mg/L sediment and 0 ppm free water. The maximum, minimum, 90th percentile, and average ISO code of these samples can be found in Table 6. As expected, similar ISO code results were measured for samples containing 0.4 mg/L sediment and 0 ppm free water no matter which sediment and free water test method was used. A larger sample pool is needed to verify consistent ISO codes are measured for samples containing similar levels of contamination.

Table 6. ISO Codes of Samples Containing ≤0.4 mg/L Sediment and 0 ppm Free Water as Determined by NSTM Methods

Particle Counter	Maximum	Minimum	90th Percentile	CCFD: Average (Std. Dev)	ASTM: Average (Std. Dev)
	>4 µm				
PAMAS S40	19	12	16	14.6(1.3)	14.4 (1.1)
Parker Hannifin ACM20	19	11	15	14.0(1.3)	13.9 (1.0)
Stanhope-Seta AvCount	19	12	16	14.3(1.2)	14.4 (1.0)
	>6 µm				
PAMAS S40	17	11	15	13.1(1.1)	12.7 (1.0)
Parker Hannifin ACM20	16	8	14	12.5(1.1)	12.1 (0.9)
Stanhope-Seta AvCount	17	11	14	13.0(1.0)	12.8 (0.9)
	>14 µm				
PAMAS S40	13	8	11	10.1(1.0)	9.6(1.1)
Parker Hannifin ACM20	12	6	10	9.1(1.0)	8.6 (1.1)
Stanhope-Seta AvCount	13	7	11	9.9(1.0)	9.7 (1.1)
	>30 µm				
PAMAS S40*	-	-	-	-	-
Parker Hannifin ACM20	8	0	7	5.2(1.5)	4.7 (1.2)
Stanhope-Seta AvCount	9	3	7	6.2(1.1)	5.9 (1.2)

*The PAMAS S40 unit lacks a >30 µm channel

Between the three locations only two samples were measured to contain free water. One sample contained 1 ppm of free water and 0.0 mg/L of sediment; the other, 5 ppm of free water and 0.1 mg/L of sediment. The contaminant levels of both samples were determined via a CCFD. A comparison of the particle counts of the sample containing 1 ppm free water and 72 samples containing no free water can be seen in Figures 10 and 11. Only samples analyzed via a CCFD are included in Figures 10 and 11. Error bars corresponding to the range of particle counts measured are included.

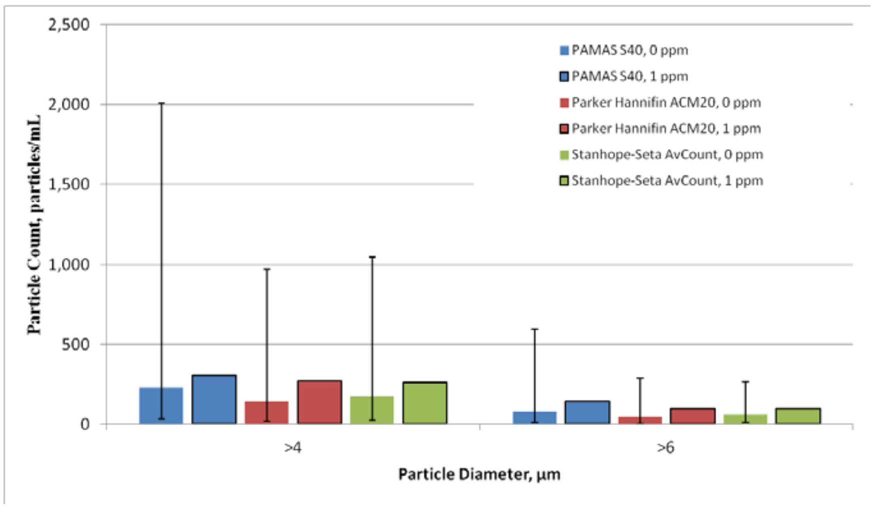

Figure 10. Particle Counts of Fuel Samples Containing 0 ppm and 1 ppm Free Water: >4 µm & >6 µm

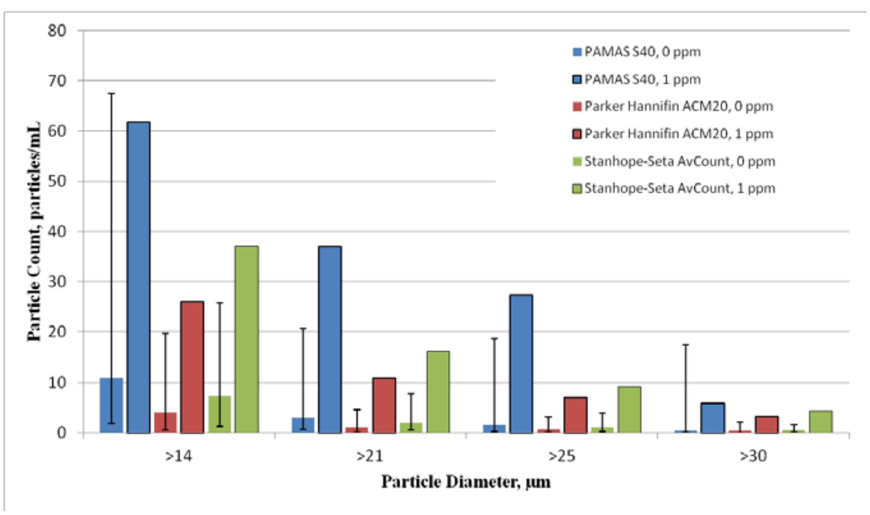

Figure 11. Particle Counts of Fuel Samples Containing 0 ppm and 1 ppm Free Water: >14 µm, >21 µm, >25 µm, and >30 µm

As can be seen in Figure 10, the 1 ppm free water sample's >4 µm and >6 µm particle counts were consistent with those seen in the 0 ppm free water samples. However, the >14 µm, >21 µm, and >30 µm particle counts of the sample containing 1 ppm free water were consistently higher than those of samples containing 0 ppm free water. Across all diameter channels the 1 ppm free water sample's ISO codes were above the average 0 ppm free water ISO code. In the >21 µm, >25 µm, and >30 µm channels the 1 ppm sample contained as many as one ISO code more particles than any of the 0 ppm free water samples measured (Figure 12).

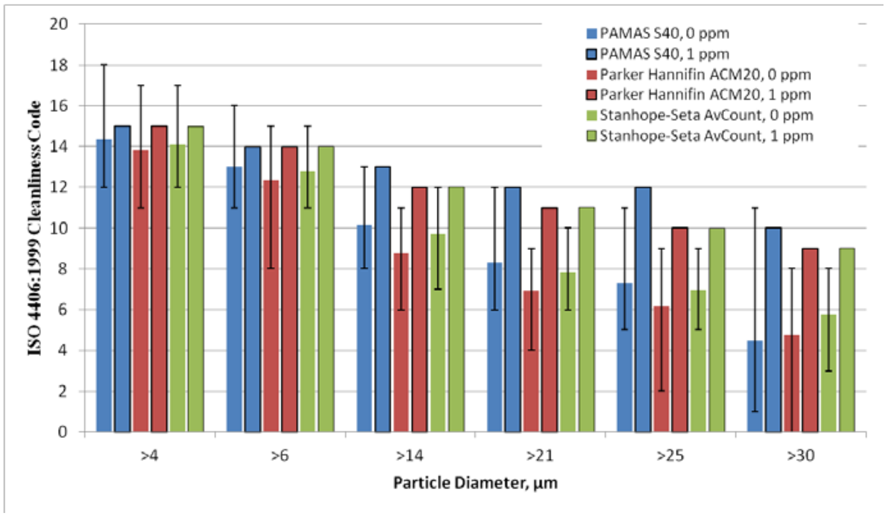

Figure 12. ISO Codes of Fuel Samples Containing 0 ppm and 1 ppm Free Water: >4 µm, >6 µm, >14 µm, >21 µm, >25 µm, and >30 µm

A particle count and ISO code comparison of fuel samples containing 5 ppm free water and 0 ppm free water can be found in Figures 13 and 14, respectively. All samples included in Figures 13 and 14 contain 0.1 mg/L of sediment contamination as measured by a CCFD. 14 samples were measured to have a sediment concentration of 0.1 mg/L and a free water concentration of 0 ppm. The 5 ppm free water sample consistently contained more particles and a greater ISO code in each channel than the samples containing 0 ppm free water. Based on these two results, free water contributes more counts to each channel and has a more prominent impact on the ISO code of channels ≥ 14 µm. More fuel samples containing free water will need to be analyzed to better characterize free water's effect on particle counts.

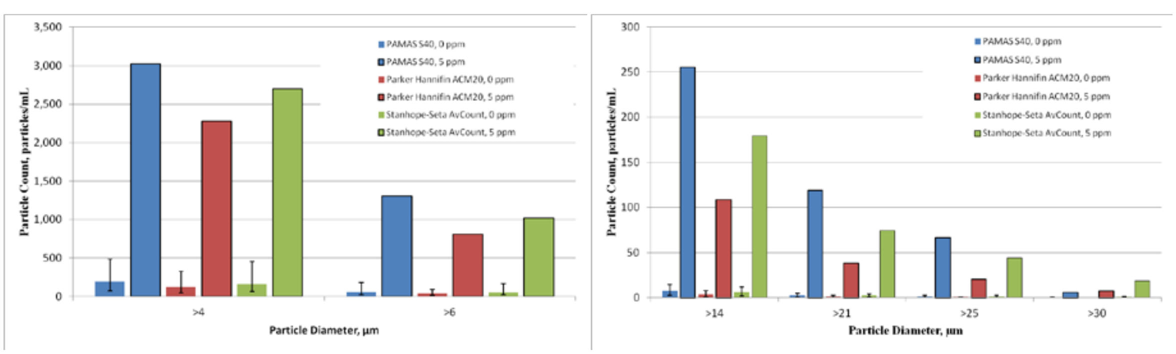

Figure 13. Particle Counts of Samples Containing 0 ppm and 5 ppm Free Water

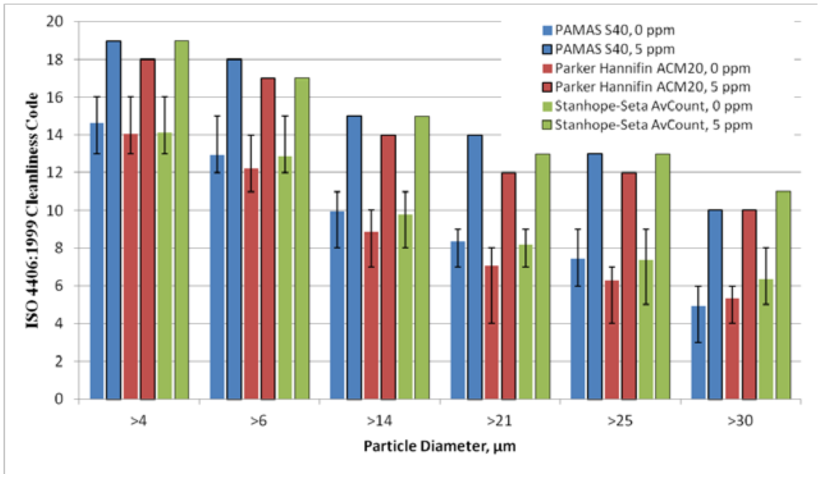

Figure 14. ISO Codes of Samples Containing 0 ppm and 5 ppm Free Water

4.2 BOTTLE SAMPLING PARTICLE COUNTER COMPARISON

Prior to conducting this evaluation, the S40, ACM20, and AvCount particle counters were calibrated by their respective manufacturers IAW ISO 11171. Despite doing so, particle count variations still existed between each of the three units. On average, the ACM20 measured fewer counts in each of the particle channels than the S40 and AvCount. A comparison of the S40 and AvCount particle counts relative to the ACM20 particle counts can be found in Figure 15. No distinction is made between contaminant levels since each bottle sample was simultaneously tested by the three units at the same sampling point. The relative particle counts were calculated using equation 2.

$$relative\ particle\ count = \sum_{i=1}^{N} \frac{\frac{(S40\ or\ AvCount\ Particle\ Count)_i}{(ACM20\ Particle\ Count)_i}}{N} - 1 \qquad (2)$$

N= total number of bottom samples measured= 221
i= individual bottle sample

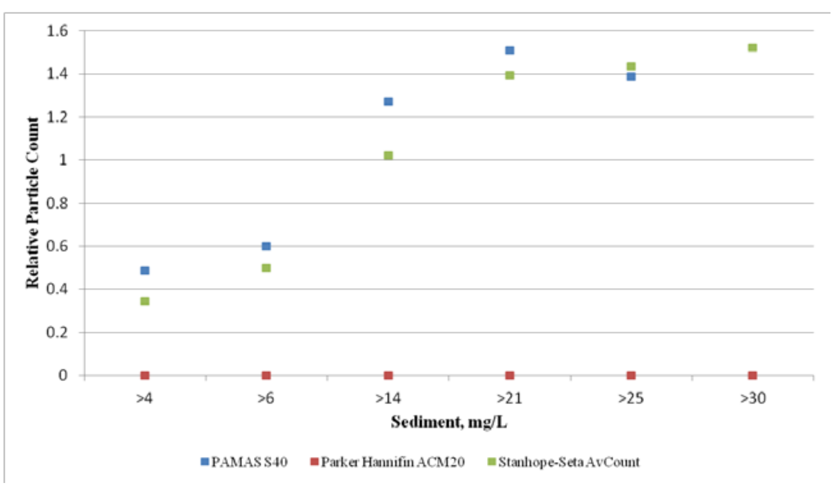

Figure 15. Relative Particle Count of S40, ACM20, and AvCount Particle Counters

4.3 IN-LINE VS. BOTTLE SAMPLING PARTICLE COUNTERS

The Parker iOS in-line particle counter and bottle sampling particle counters (S40, ACM20, and AvCount) were used to measure the ISO code of 126 samples— 42 samples at NAS Patuxent River and 84 samples at NAS Jacksonville. The ISO codes measured by the Parker Hannifin iOS and laboratory based particle counters were not consistent with one another. Plots of the ISO codes measured by the in-line and bottle sampling particle counters can be found in Appendix D. Appendix D only includes data for samples containing 0 ppm free water.

Of the 126 samples measured by the iOS and S40, only 4 samples gave identical ISO code values in the >4 µm, >6 µm, and >14 µm channels (PAMAS S40 does not have a >30 µm channel). The iOS and ACM20 gave identical ISO code values in the >4 µm, >6 µm, >14 µm, and >30 µm channels for two samples. The iOS and AvCount failed to produce identical ISO code values in all four channels for any of the 126 samples. A similar comparison between the 126 samples measured by both the Parker Hannifin iOS and bottle sampling particle counters allowing for a ±1 and ±2 ISO code variation in the >4 µm, >6 µm, >14 µm and, if applicable, >30 µm channels can be found in Table 7.

Table 7. ISO Code Agreeability of In-line and Bottle Samples

In-line Particle Counter	Laboratory Based Particle Counter	Samples within ±1 ISO Code		Samples within ±2 ISO Code	
		#	% of Samples Analyzed	#	% of Samples Analyzed
Parker Hannifin iOS	PAMAS S40	30	23.8%	56	44.4%
Parker Hannifin iOS	Parker Hannifin ACM20	13	10.3%	39	31.0%
Parker Hannifin iOS	Stanhope-Seta AvCount	17	13.5%	46	36.5%

The discrepancies between the in-line and laboratory results may be associated to a number of factors including differences in calibration, contamination from improper cleaning of the sampling bottles, inadequate mixing prior to performing the laboratory tests, and variations between in-line and bottle fuel samples. The risk of contamination from dirty bottles was mitigated by using clean bottles and triple rinsing each bottle with a minimum of 500 mL per rinse of the fuel being sampled prior to collecting the 3L test sample. Likewise, the test samples were tumbled end-over-end for at least one minute directly prior to performing laboratory measurements to ensure each test sample was thoroughly mixed. Bottle samples were also collected immediately before or after performing an in-line ISO code measurement in order to minimize sample variation. Nonetheless the bottle and in-line particle counters did not measure the same fuel sample and variations may have existed. Without an additional in-line unit to compare the iOS results to, the cause of the differences between the bottle and in-line measurements cannot be determined.

Despite the variations between the in-line and bottle measurements, on average the iOS and laboratory based particle counters were within one ISO code of one another in the >4 µm, >6 µm, and >14 µm channels. Descriptive statistics for the difference between the laboratory and iOS particle counters (Laboratory Particle Counter ISO code – In-line Particle Counter ISO code) for each paired sample can be found in Table 8.

Table 8. ISO Code Comparison of In-line and Bottle Samples

	Parameter	>4 µm	>6 µm	>14 µm	>30 µm
PAMAS S40	Average Difference	0.97	0.87	0.97	-
	Maximum ISO Code Difference	6	6	6	-
	Minimum ISO Code Difference	-5	-6	-6	-
	Standard Deviation of Average Difference	2.41	2.57	2.79	-
	Number of Paired Samples	126	126	126	0
Parker Hannifin ACM20	Average Difference	0.54	0.29	0.10	-1.30
	Maximum ISO Code Difference	5	6	5	6
	Minimum ISO Code Difference	-5	-8	-7	-10
	Standard Deviation of Average Difference	2.51	2.68	2.89	3.43
	Number of Paired Samples	125	125	125	125
Stanhope-Seta AvCount	Average Difference	0.95	0.91	0.91	-0.17
	Maximum ISO Code Difference	6	6	6	7
	Minimum ISO Code Difference	-4	-5	-6	-9
	Standard Deviation of Average Difference	2.42	2.49	2.73	3.31
	Number of Paired Samples	126	126	126	126

4.4 ISO-PROPANOL AND RESOLVER® EVALUATION

Since particle counts are a collective measure of sediment and free water, particle counters are unable to directly distinguish between sediment and free water. Iso-propanol and Resolver® have been proposed as cosolvents to mask the presence of free water particles thereby allowing a particle count solely comprised of sediment to be measured. The iso-propanol and Resolver® cosolvents were tested IAW the procedure described in section 3.5. Despite the lack of free water at the NAS Patuxent River test site, 8 samples of JP-5 were tested with each cosolvent to examine the effect of the cosolvents in the absence of free water. The type of fuel, sampling location, free water concentration and sediment concentration of these 8 samples can be found in Table 9. The particle counts measured by the S40, ACM20, and AvCount particle counters can be found in Appendix E.

Table 9. Iso-Propanol and Resolver® Test Samples

				PAMAS S40 Particle Count (see Appendix E for ACM20 and AvCount Particle Counts)		
Sample ID	Location	Free Water, ppm	Sediment, mg/L	>4 µm No Additive	>4 µm Iso-Propanol	>4 µm Resolver®
1	Filter Separator Inlet	0.0	0.67	2,437	3,370	3,334
2	Filter Separator Inlet	0.0	0.00	200	1,350	580
3	Filter Separator Outlet	0.0	0.00	63	685	1,039
4	Barge Receipt Line	0.0	0.46	2,498	4,706	3,823
5	Barge Receipt Line	0.0	0.56	2,219	3,127	3,595
6	Barge Receipt Line	0.0	1.01	2,217	3,197	2,408
7	Filter Separator Inlet	0.0	0.00	463	1,055	669
8	Filter Separator Inlet	0.0	0.86	1,164	3,278	908

Overall, the addition of iso-propanol and Resolver® to the test samples resulted in an increase in particle counts across all channels. On average, the samples additized with iso-propanol contained 1,188 (PAMAS S40), 489 (Parker Hannifin ACM20), and 702 (Stanhope-Seta AvCount) more particles in the >4 µm diameter channel than the non-additized sample. Samples additized with Resolver® contained on average 637 (PAMAS S40), 284 (Parker Hannifin ACM20), and 554 (Stanhope-Seta AvCount) more particles in the >4 µm diameter channel than the non-additized sample. Depending on the original contamination level of the sample, the particle count variation due to the additive was significant enough to increase the ISO code of the samples.

5.0 CONCLUSIONS

Particle counters remain a viable option for monitoring overall fuel quality. The high variability between particle counts of the same sediment and free water concentration support previous Navy testing which concluded particle counts cannot replace gravimetric sediment and free water analysis and should only be used to provide a general measure of overall fuel cleanliness. An ISO code specification limit could not be established due to a lack of samples near the contamination limits of 2.0 mg/L sediment and 10 ppm free water. Similar particle counts were measured for bottle samples containing <0.4 mg/L sediment and 0 ppm free water but more data is required to determine if a significant and consistent difference in particle counts or ISO codes exist between fuels of different contaminant levels. The 8 samples analyzed with the iso-propanol and Resolver® cosolvents increased the sample's particle count. Additional samples containing sediment and free water will also need to be analyzed in order to fully assess the utility of iso-propanol and Resolver®.

Despite being calibrated IAW ISO 11171, the S40, ACM20, and AvCount particle counters did not produce identical results. The ISO codes measured by the in-line iOS particle counter only matched the ISO codes measured by the bottle sampling units six times. On average the difference between the ISO codes measured by the iOS and bottle sampling units was less than one in the >4 µm, >6 µm, and >14 µm channels at each sediment concentration. However there was large variability between the in-line and bottle results, as much as a 10 ISO code variability in the >30 µm channel. Since only the iOS in-line particle counter was tested, the cause of these differences cannot be identified as due to the iOS's inaccuracy or differences between the in-line and bottle samples analyzed. Prior to implementing any particle count or ISO code limit, the variability between the in-line and bottle ISO code measurements will need to be addressed. High variability between in-line and bottle sampling units increases the likelihood of inaccurately screening Naval aviation fuel, which is an unacceptable risk.

The particle counters were easy to operate and required minimal training. One concern that will need to be addressed is test time, especially for bottle sampling particle counters that may be used onboard sea vessels. Fuel samples are continuously tested onboard CVN vessels; therefore it is very important for potential replacements to test fuel samples at a comparable if not faster rate than current test methods. During this evaluation, the CCFD was able to analyze more samples in a shorter period of time than the bottle sampling particle counters. A longer test time will negatively impact fleet readiness; therefore the duration of a bottle sampling particle count test needs to be shortened, ideally less than two minutes per sample. The greatest benefits particle counter technology offers the Navy is the ability to drastically reduce bottle sampling and eliminate analysis delays associated with transporting the bottles to a fuels laboratory. For these reasons, particle counters capable of sampling directly from fuel lines are most advantageous to the Navy. By sampling directly from fuel lines, the overall test time (sampling time + transport time + contaminant detection time + cleanup) is shortened by effectively eliminating the sampling, transport, and cleanup steps.

6.0 RECOMMENDATIONS

Further evaluation of particle counters is recommended so that a particle count or ISO code limit representative of the Navy's aviation fuel containing 2.0 mg/L sediment and 10 ppm free water can be identified. Laboratory testing should be utilized to determine ISO code limits since current Navy fuel quality assurance methods produce clean fuel throughout the distribution system.

Additional work should also be completed to compare the ISO code measurements made by the in-line particle counters and bottle sampling particle counters to ensure the two methods agree. At least two in-line sampling particle counters, preferably by two different manufacturers, should be tested simultaneously to verify the accuracy of in-line particle counter technology. This testing should be completed in a manner that allows for controlled levels of sediment and free water contamination (i.e. test rig with water and sediment injection capabilities). The iso-propanol and Resolver® additives should be further tested on fuel samples containing sediment and free water to fully determine their impacts on particle counts.

7.0 REFERENCES

1. Evaluation of Particle Counters for Field Determination of Aviation Fuel Contamination, NF&LCFT Report 441/12-004, 9 February 2012

8.0 ACKNOWLEDGEMENTS

The Navy would like to thank DLA Energy for funding this study. The Navy would also like to thank NAS Patuxent River MD fuel supply point, NAS Jacksonville FL fuel supply point, and CVN-77 Division V-4 personnel for making their sites available for this evaluation and for all of the assistance they provided throughout the duration of testing.

APPENDIX A: ISO 4406:1999 CLEANLINESS CODES

Table A-1. ISO 4406:1999 Cleanliness Codes

ISO Code	>	≤
0	0	0.01
1	0.01	0.02
2	0.02	0.04
3	0.04	0.08
4	0.08	0.16
5	0.16	0.32
6	0.32	0.64
7	0.64	1.3
8	1.3	2.5
9	2.5	5
10	5	10
11	10	20
12	20	40
13	40	80
14	80	160
15	160	320
16	320	640
17	640	1,300
18	1,300	2,500
19	2,500	5,000
20	5,000	10,000
21	10,000	20,000
22	20,000	40,000
23	40,000	80,000
24	80,000	160,000

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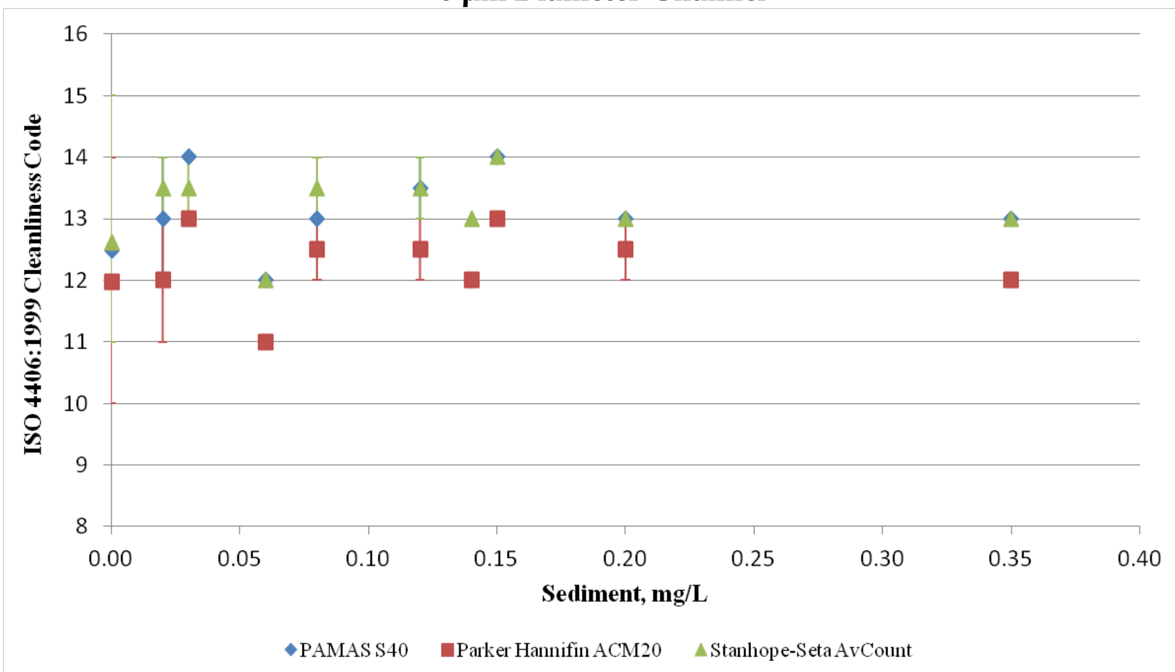
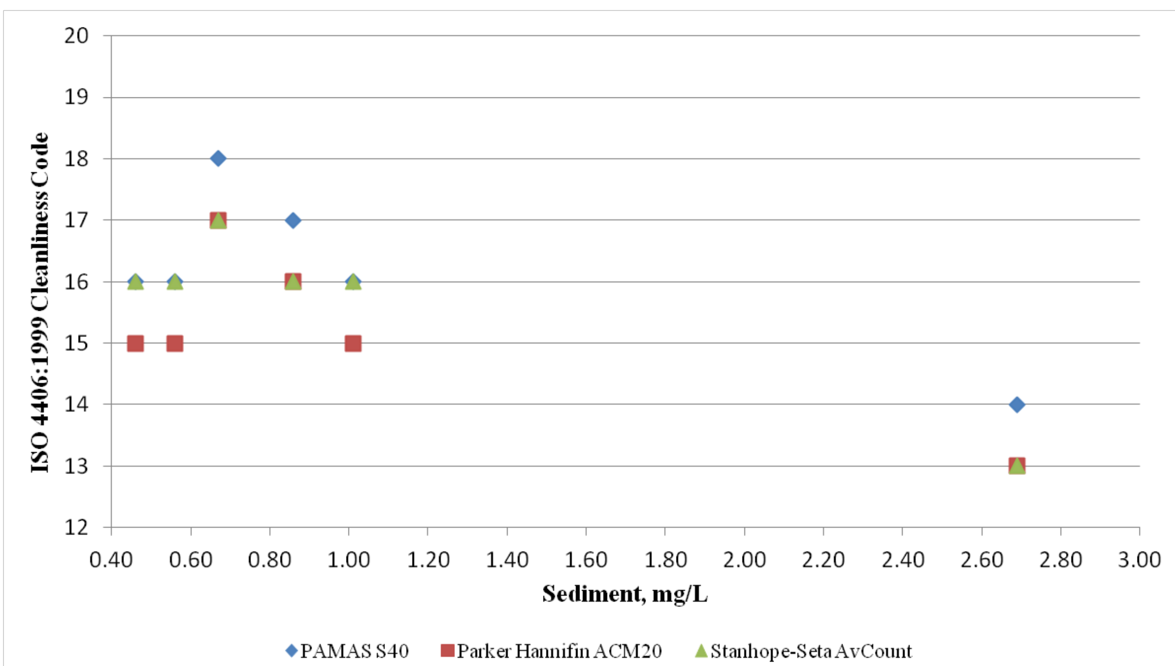
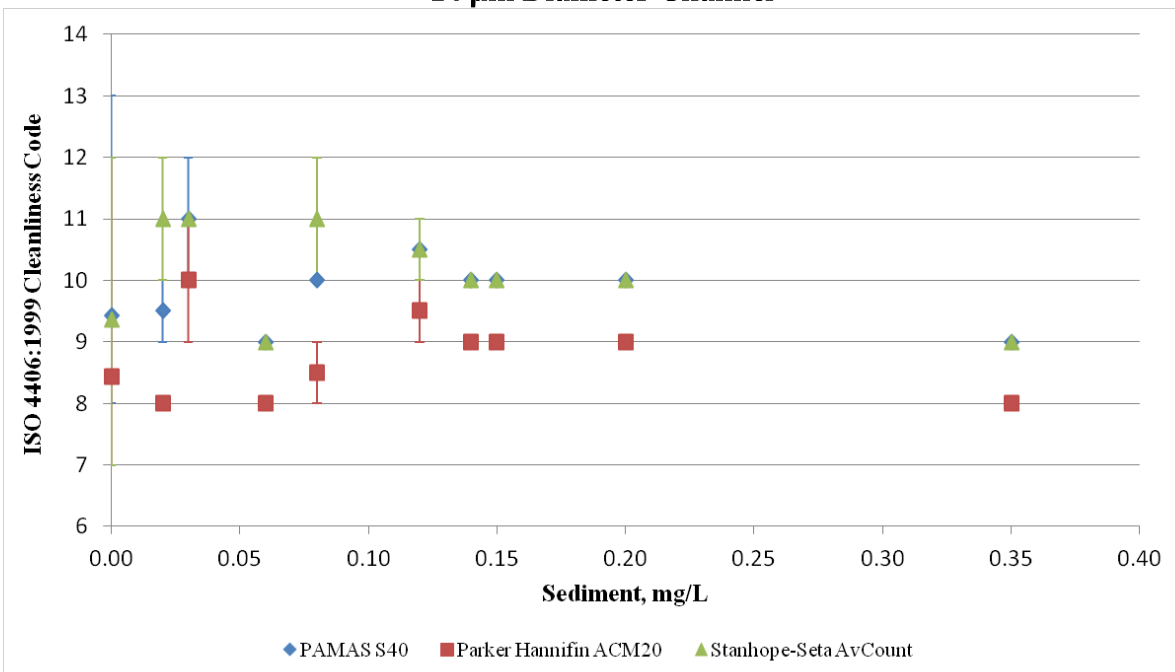
Appendix B: Average ISO Code Results for >6 µm, >14 µm, >21 µm, >25 µm and >30 µm Particle Channels: ASTM D3240 & ASTM D5452

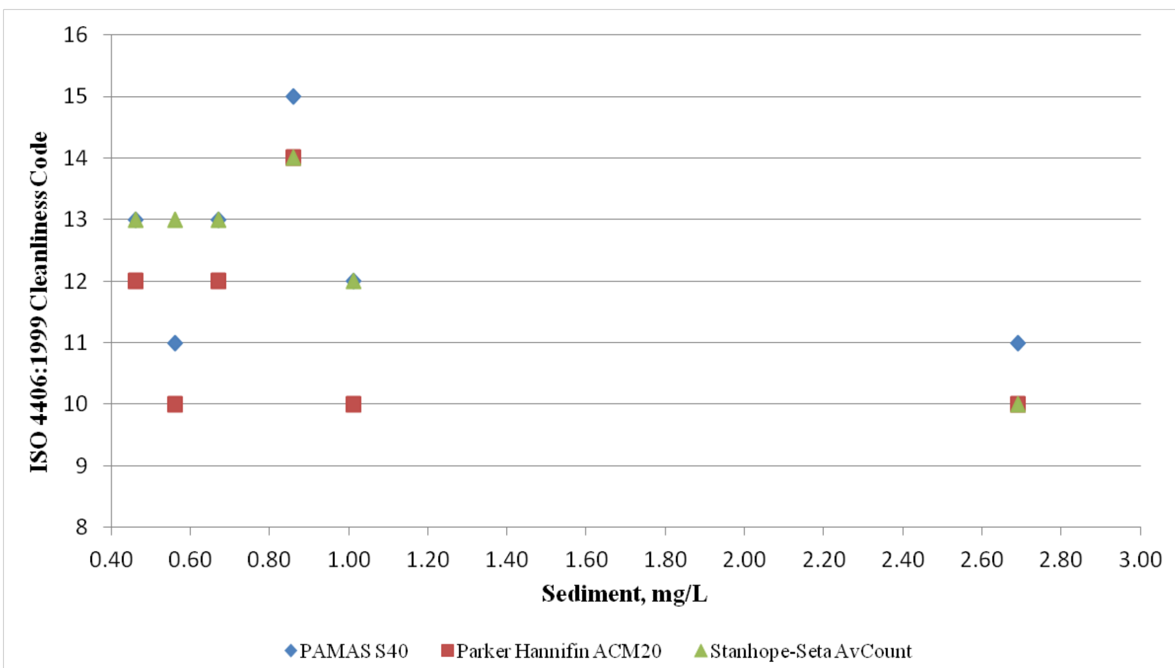
>6 µm Diameter Channel



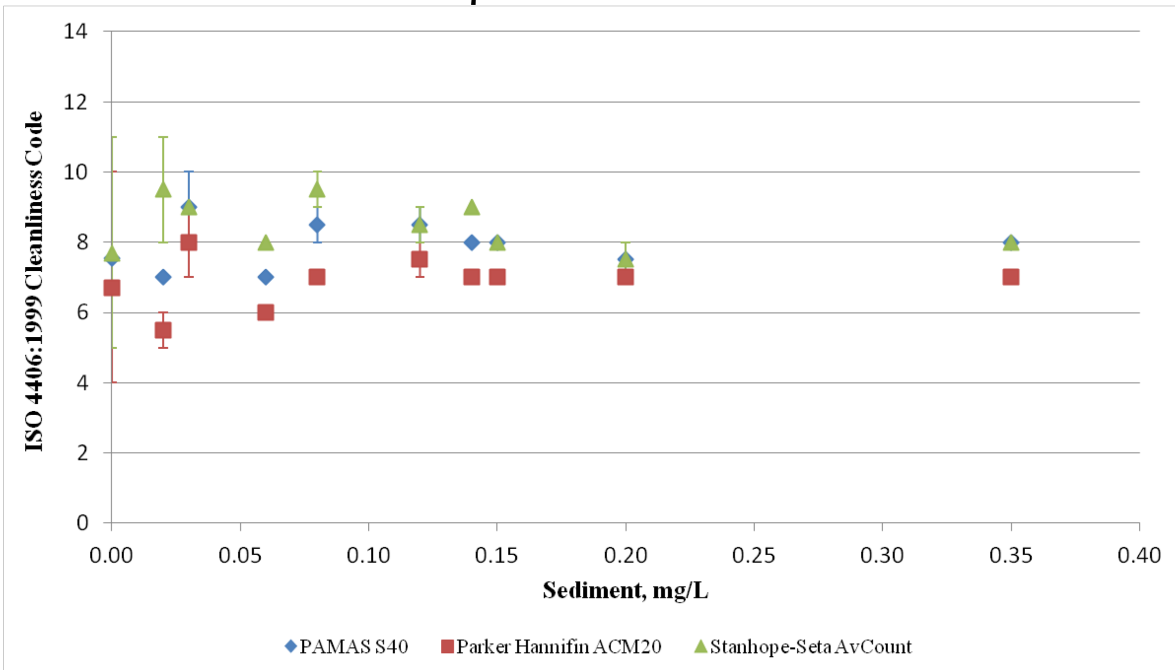


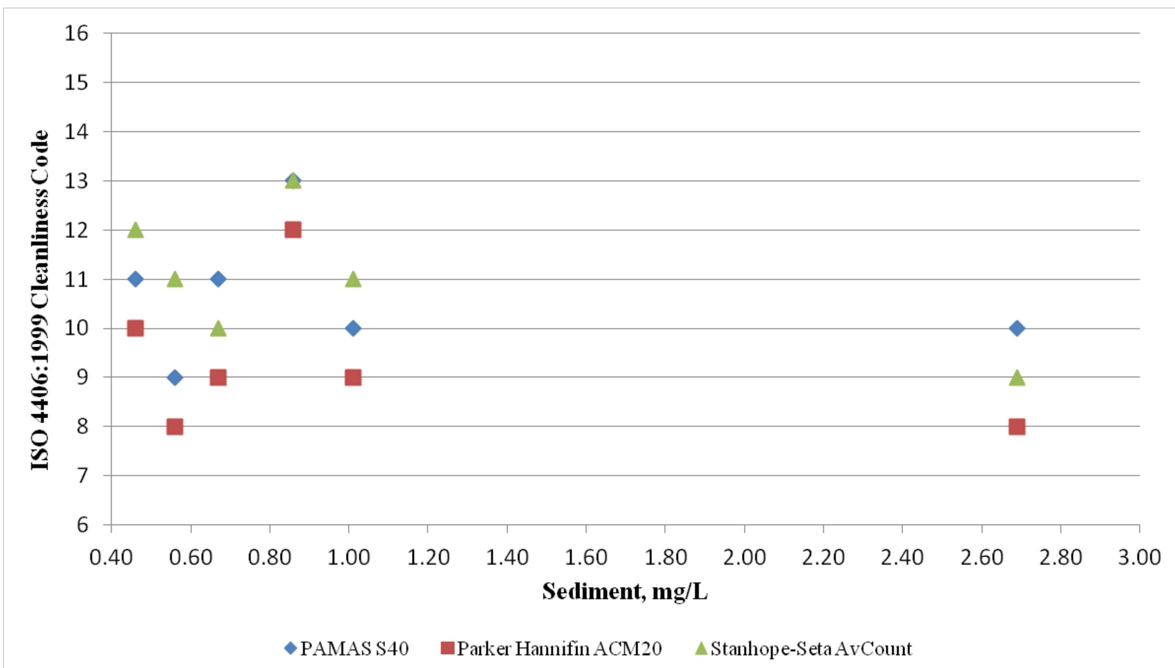
>14 µm Diameter Channel

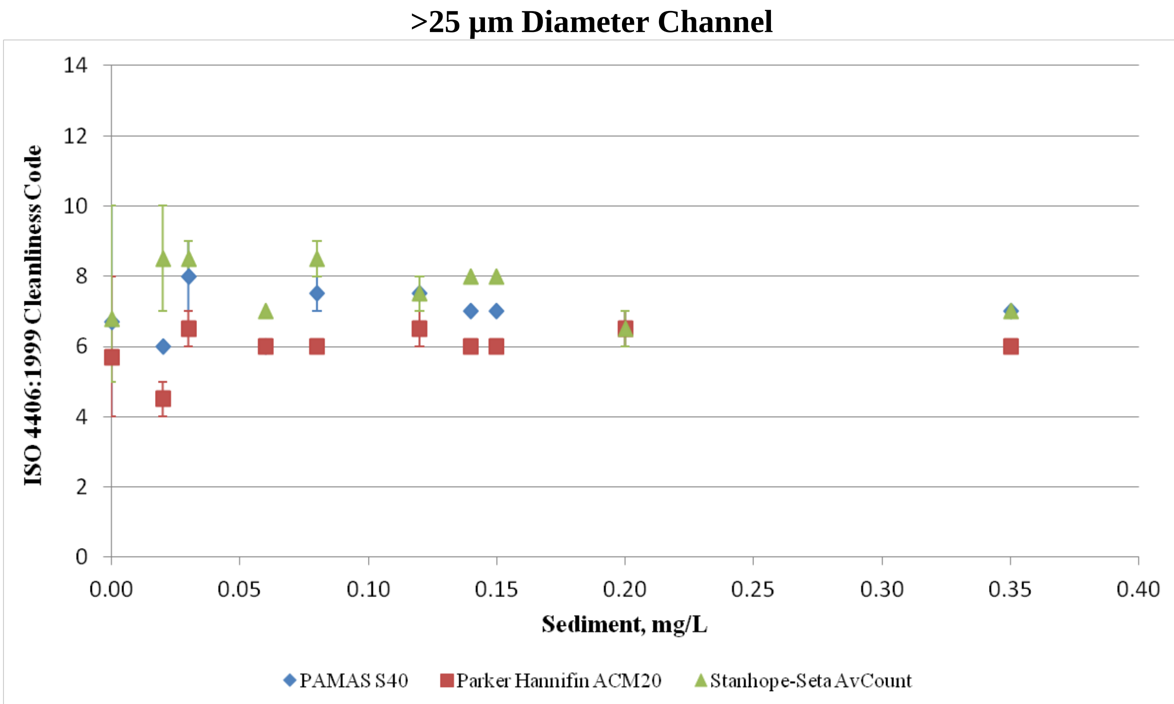


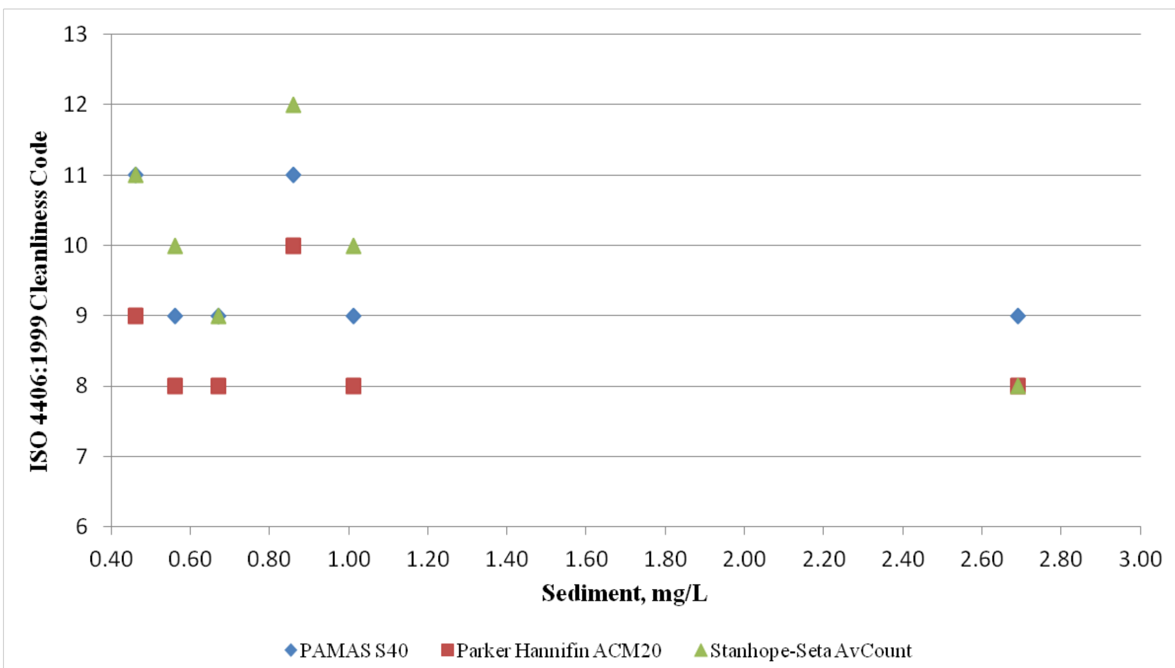


>21 µm Diameter Channel






>25 µm Diameter Channel
ISO 4406:1999 Cleanliness Code
Sediment, mg/L
PAMAS S40
Parker Hannifin ACM20
Stanhope-Seta AvCount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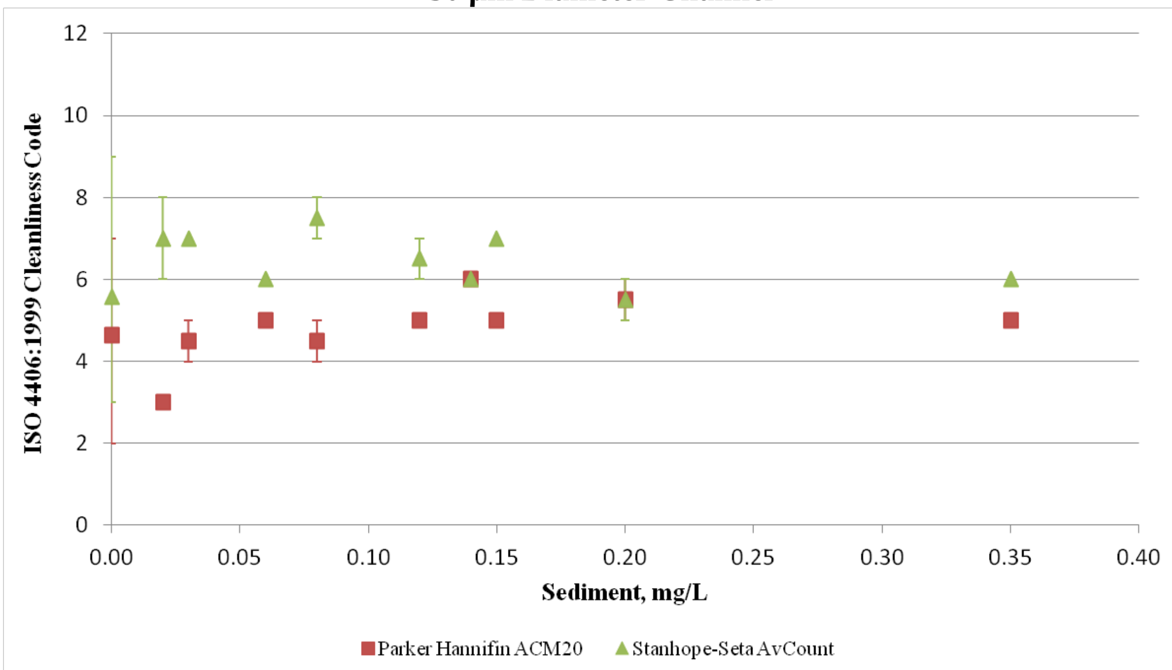
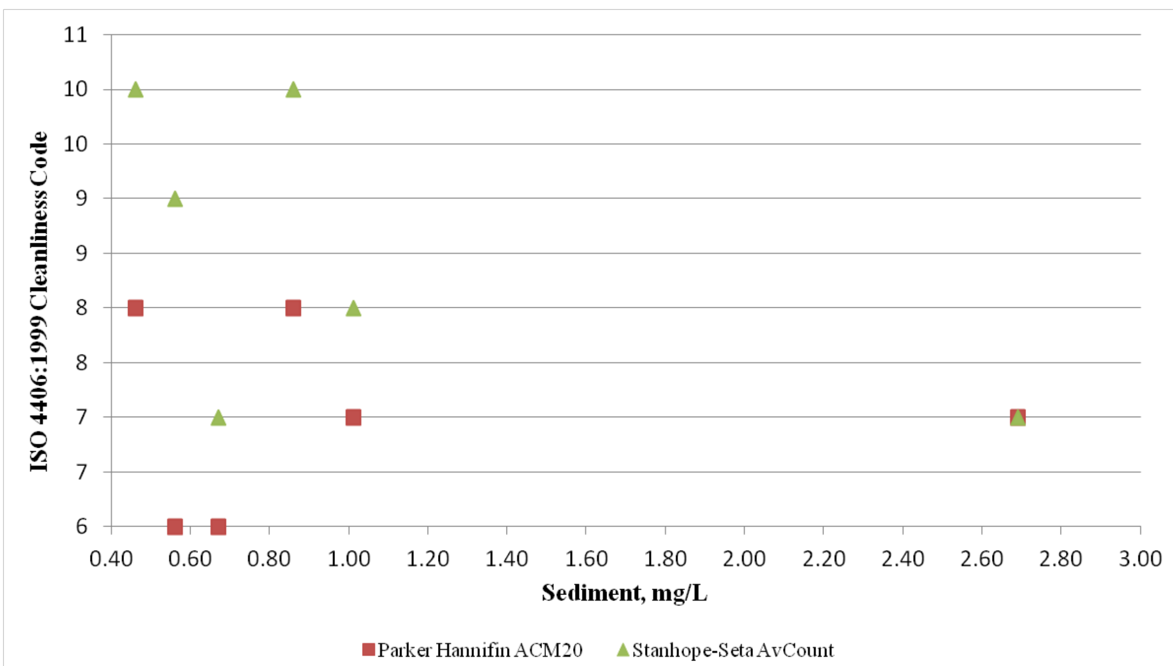
Sediment, mg/L
PAMAS S40
Parker Hannifin ACM20
Stanhope-Seta AvCount

>30 µm Diameter Channel





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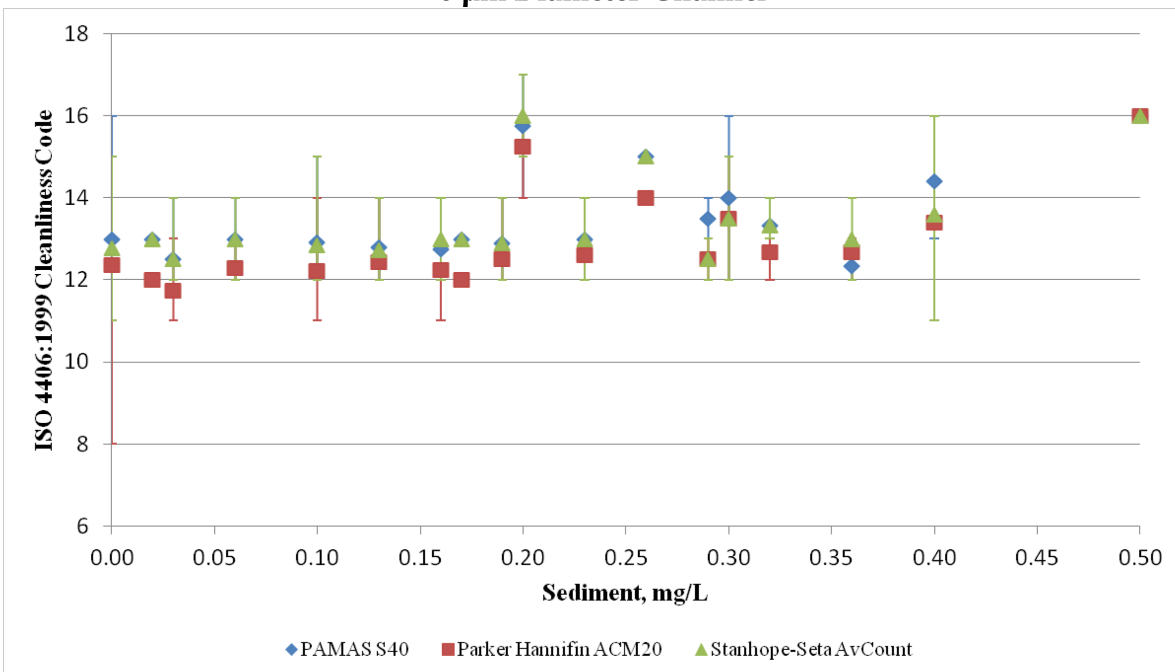
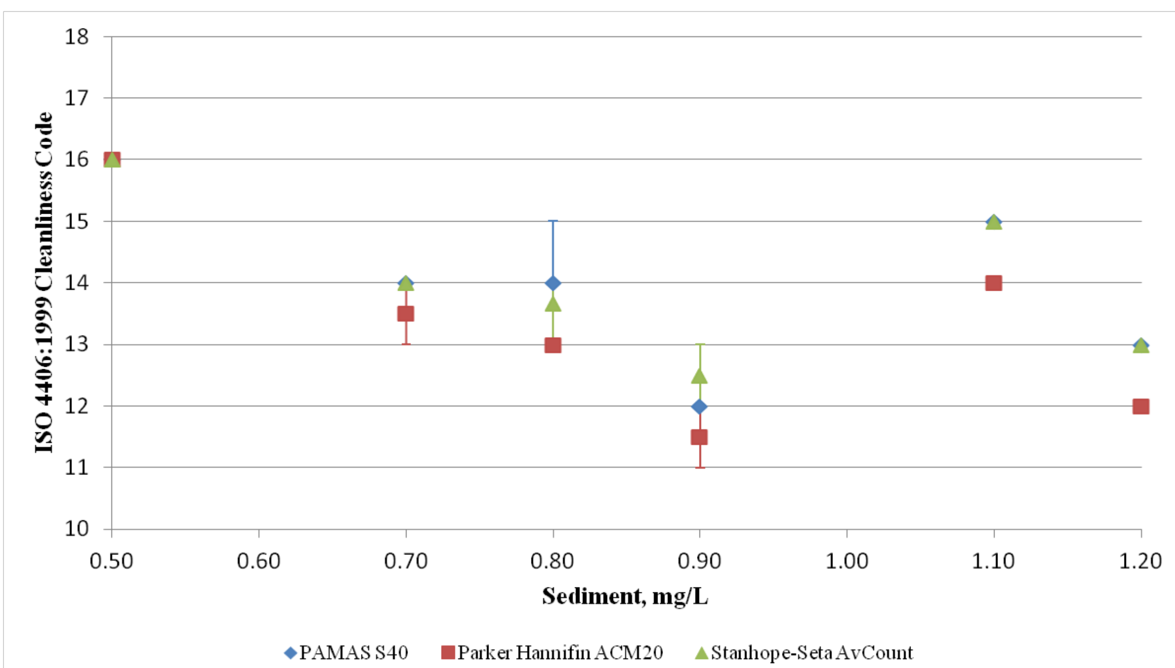
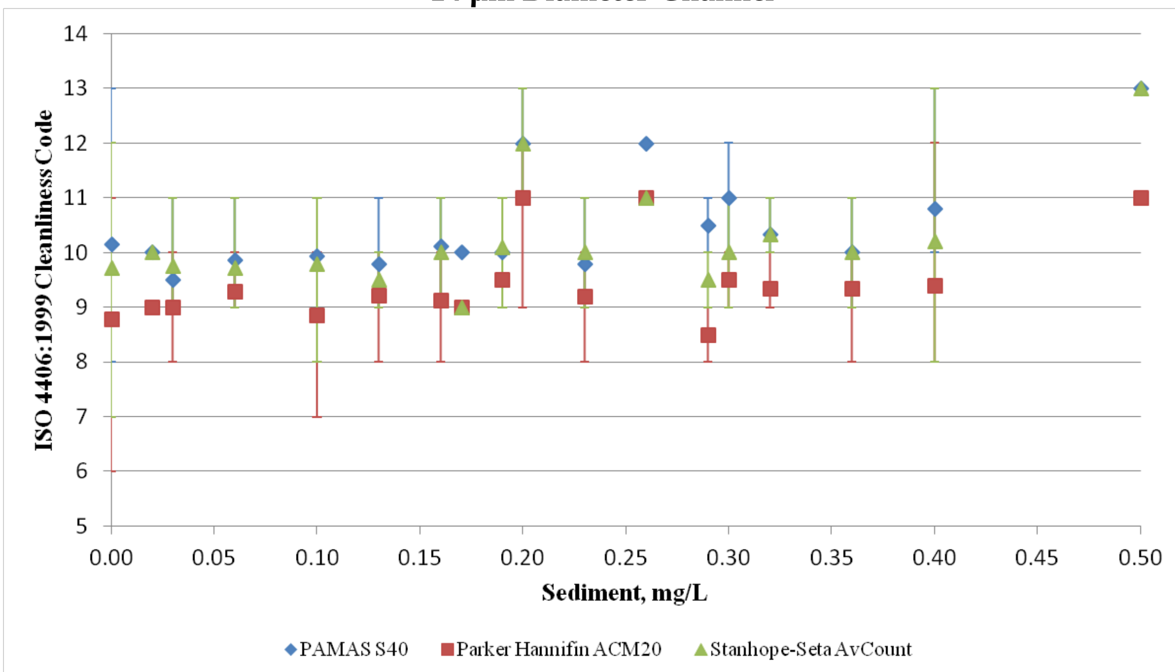
Appendix C: Average ISO Code Results for >6 µm, >14 µm, >21 µm, >25 µm and >30 µm Particle Channels: NSTM Methods

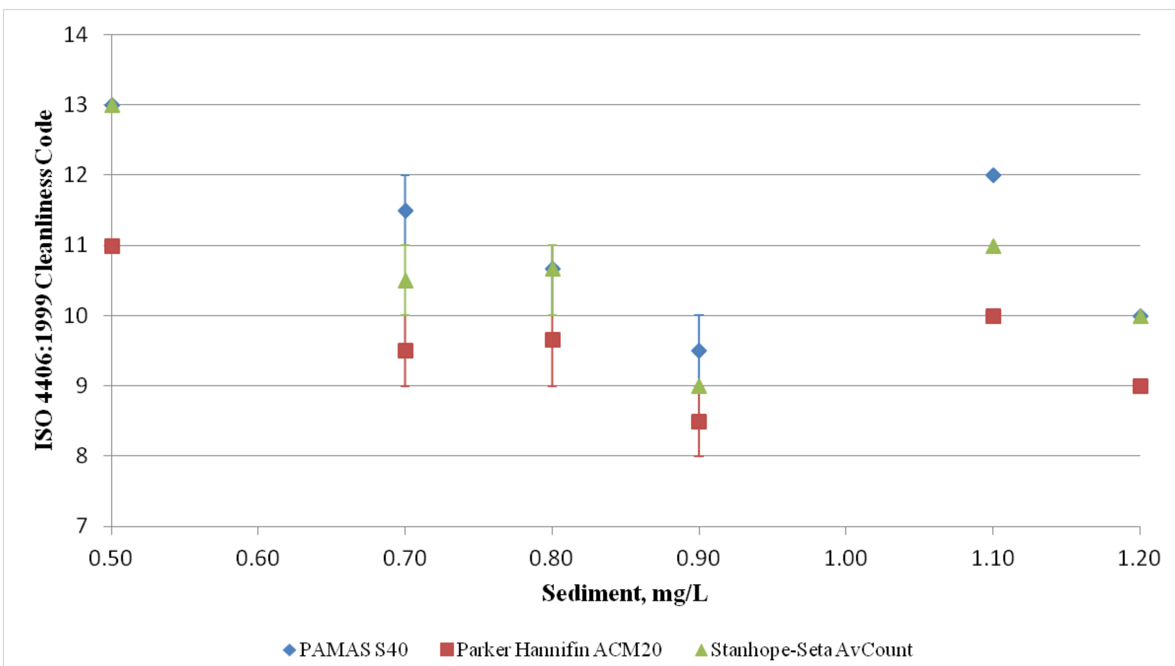
>6 µm Diameter Channel



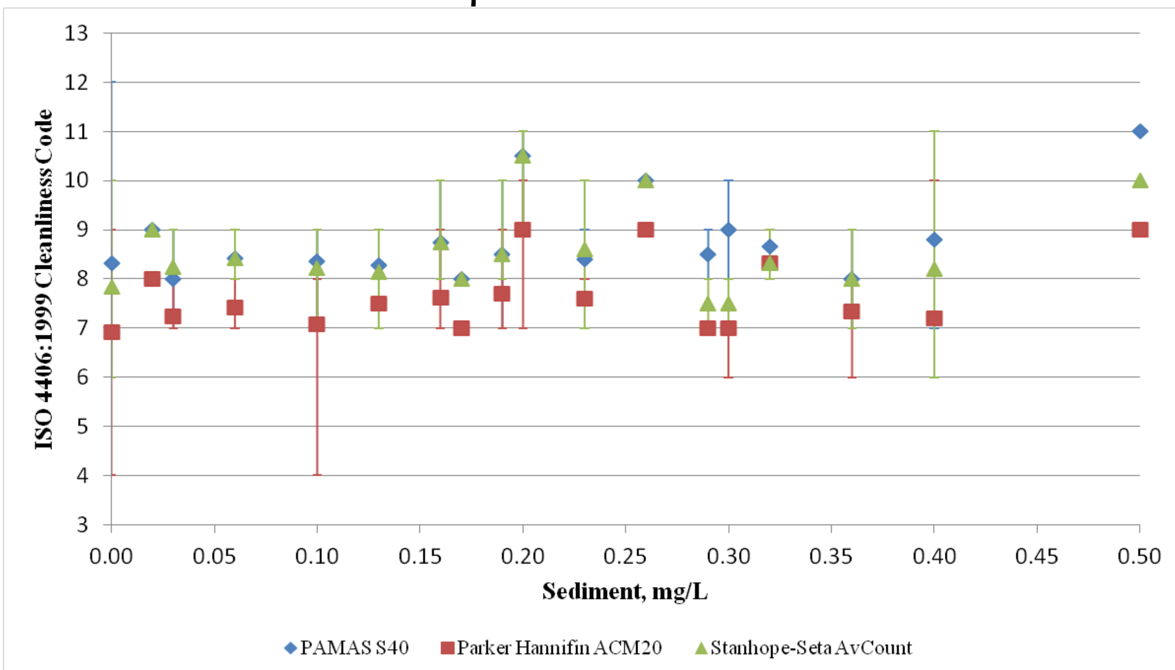


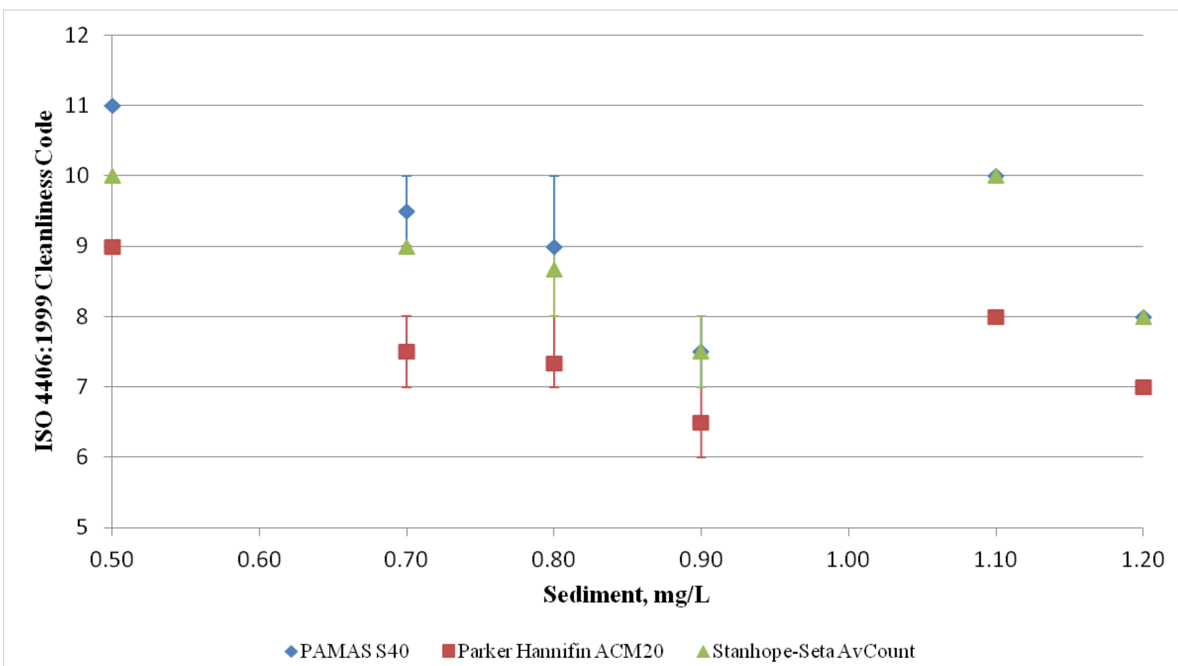
>14 µm Diameter Channel



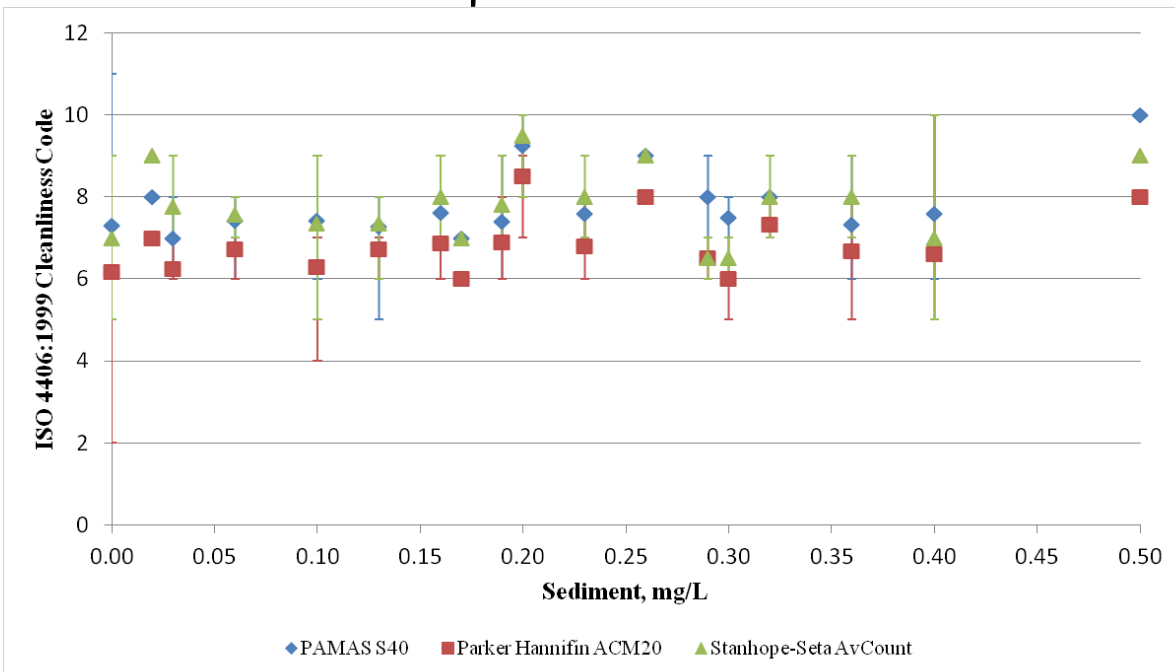


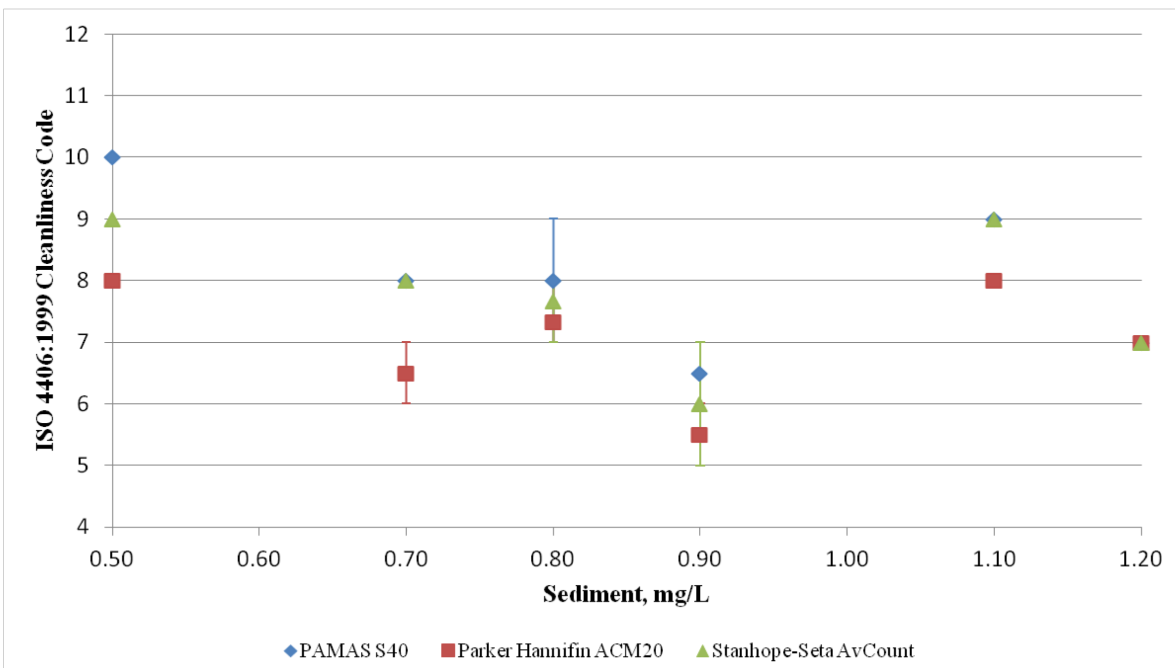
>21 µm Diameter Channel



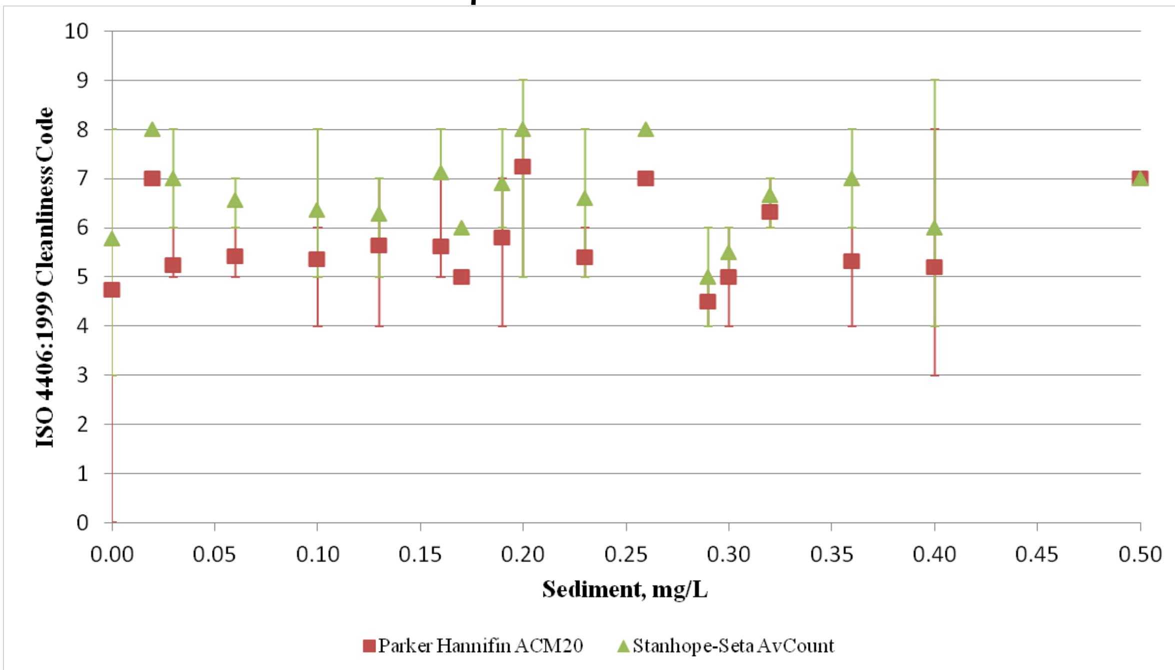


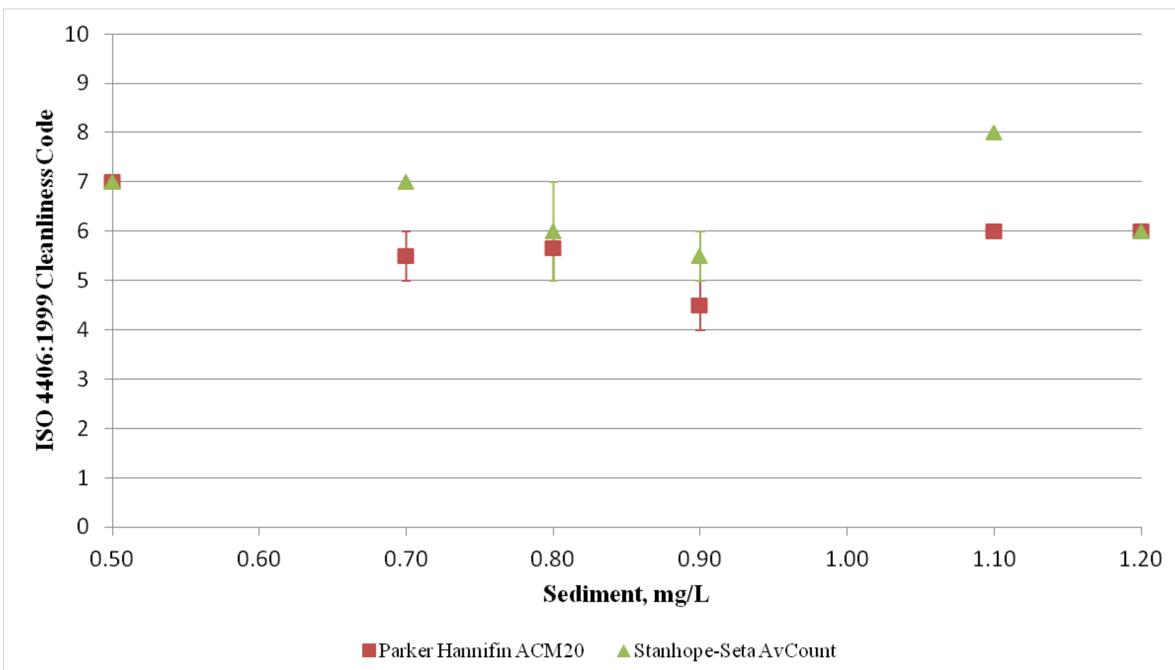
>25 µm Diameter Channel





>30 µm Diameter Channel





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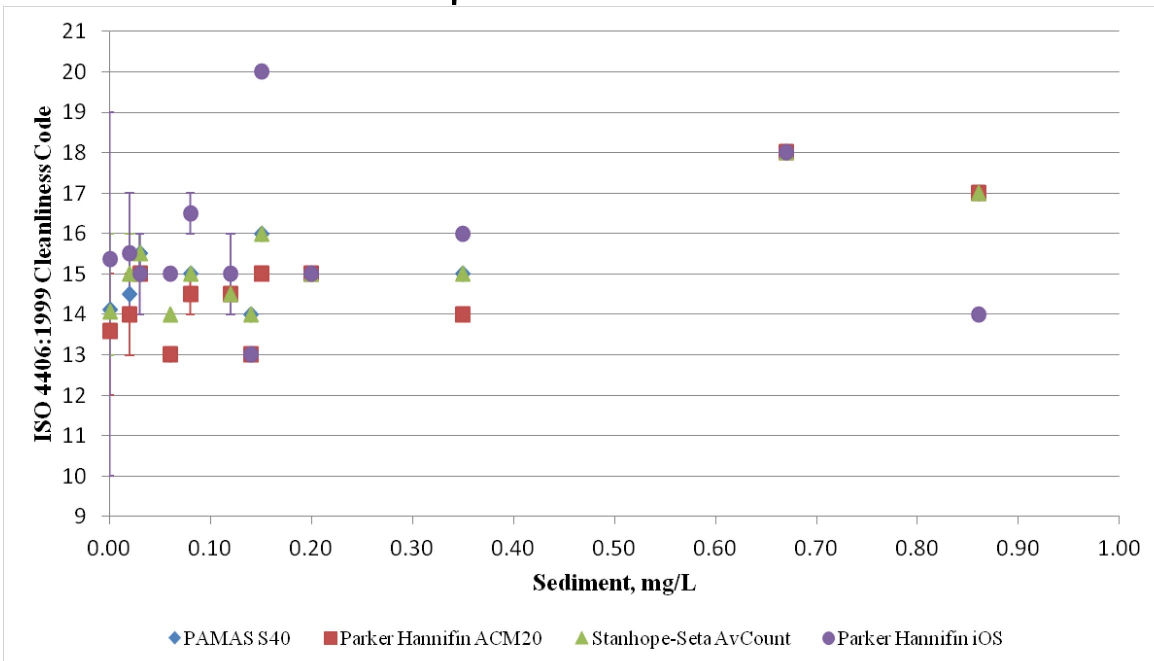
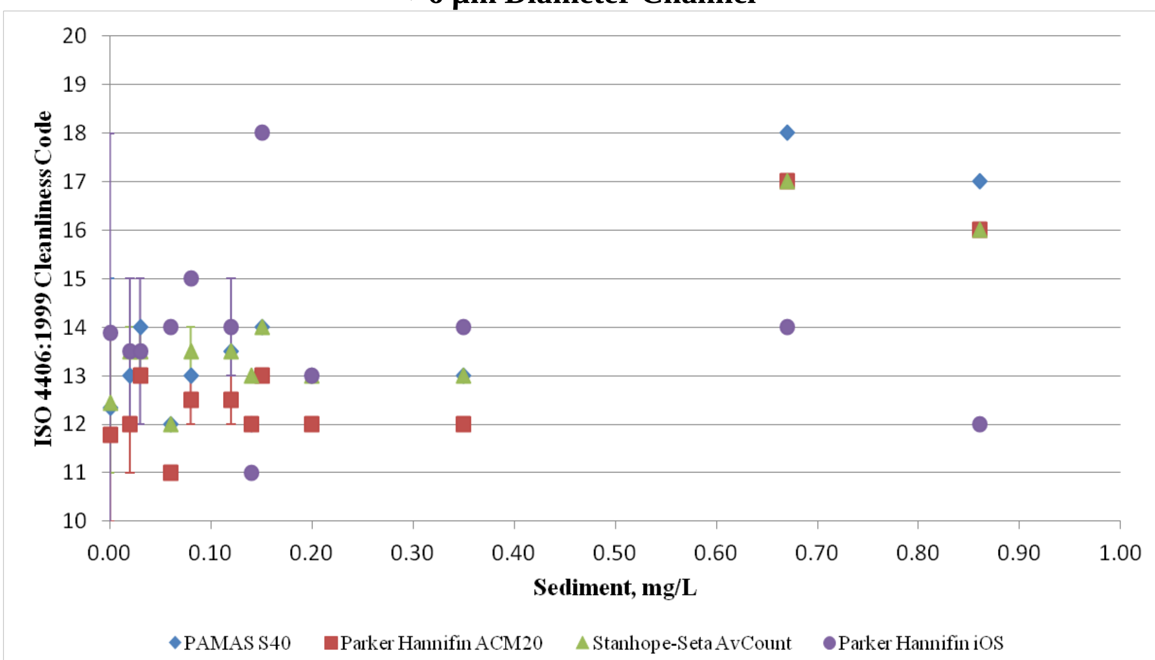
APPENDIX D: IN-LINE AND BOTTLE SAMPLE ISO CODES FOR >4 µm, >6 µm, >14 µm, AND >30 µm PARTICLE CHANNELS

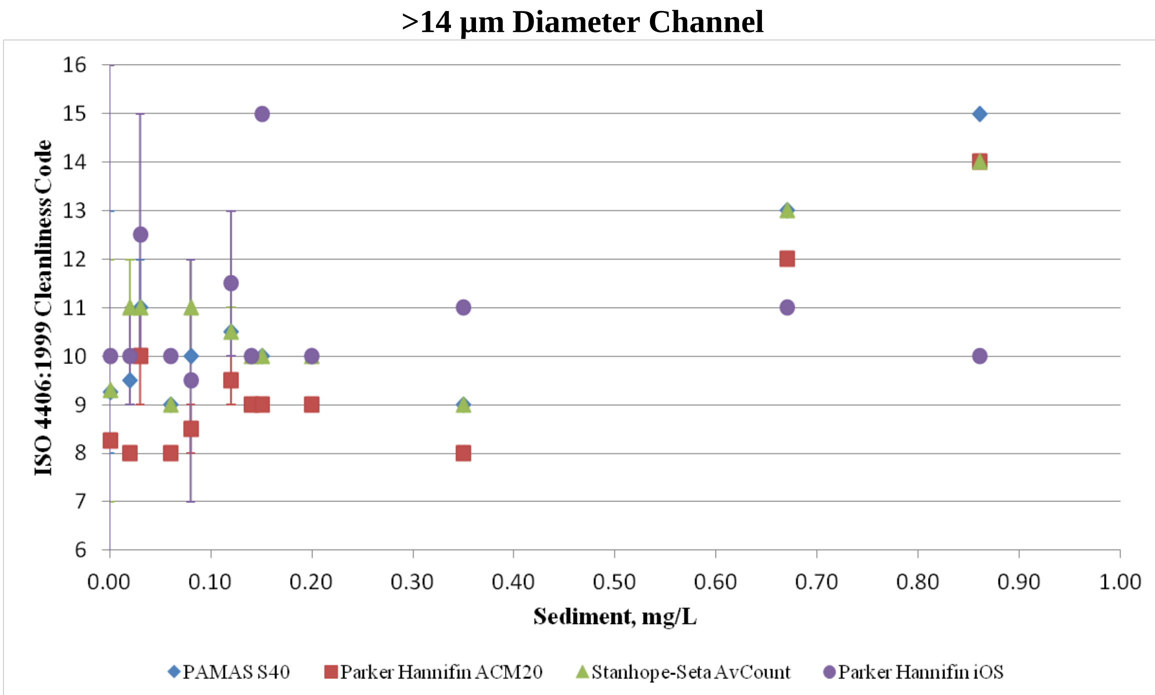
ASTM D5452 & ASTM D3240

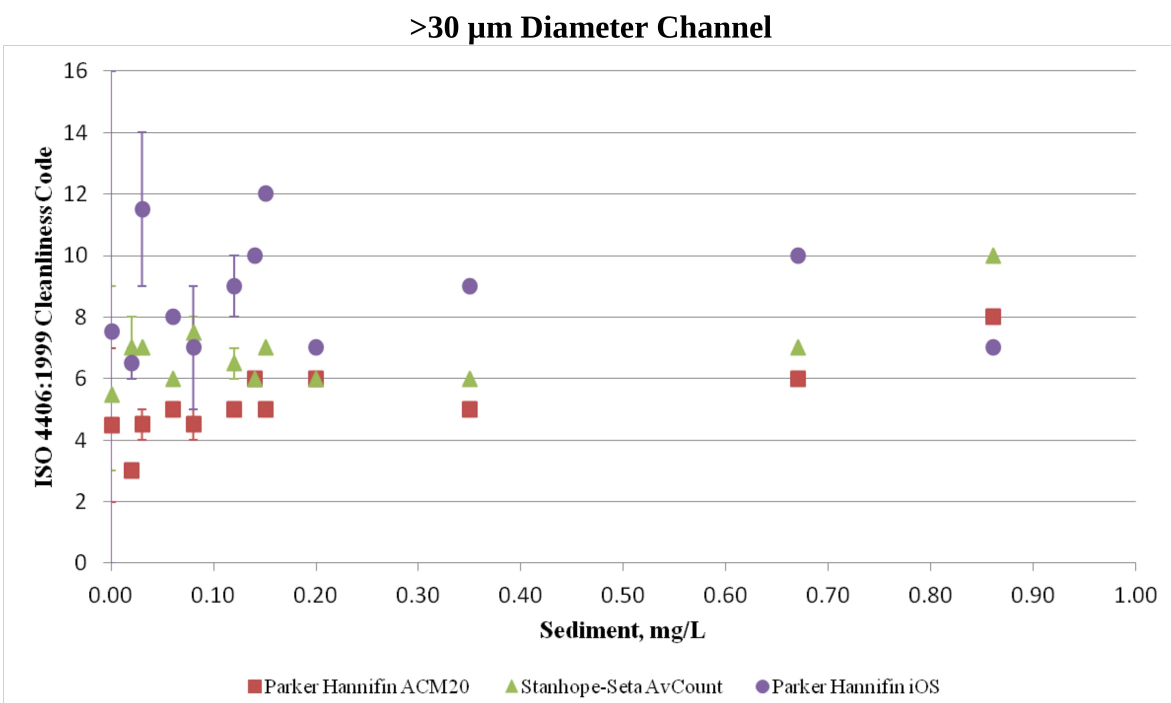
>4 µm Diameter Channel



>6 µm Diameter Channel

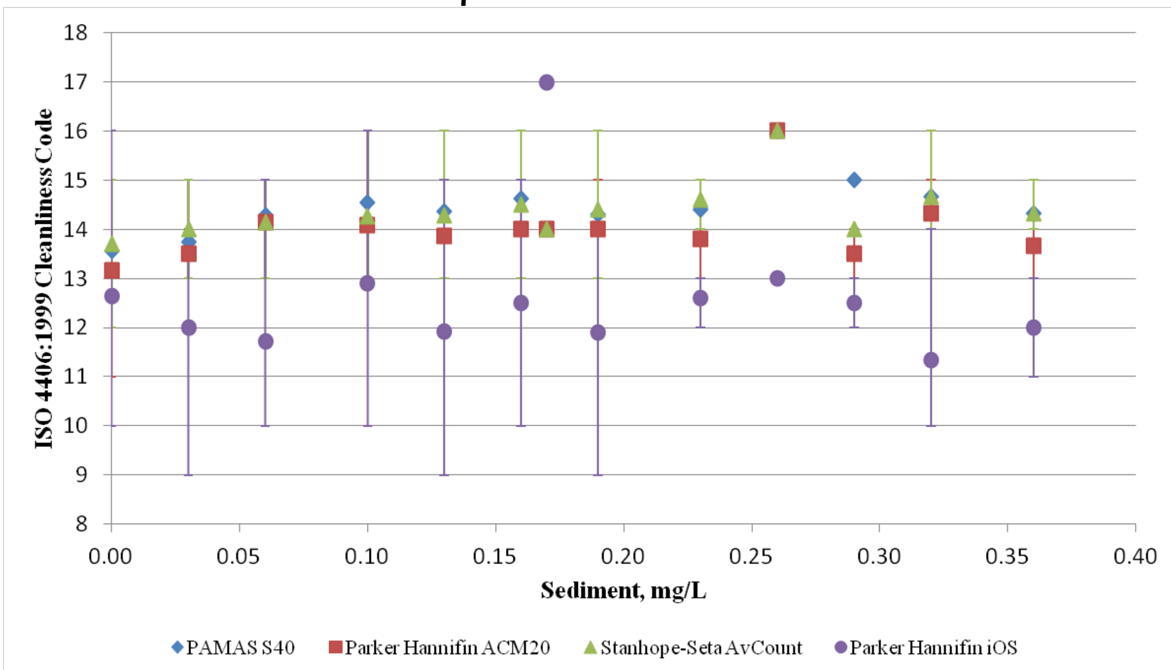



>14 µm Diameter Channel
ISO 4406:1999 Cleanliness Code
16
15
14
13
12
11
10
9
8
7
6
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Sediment, mg/L
PAMAS S40
Parker Hannifin ACM20
Stanhope-Seta AvCount
Parker Hannifin iOS

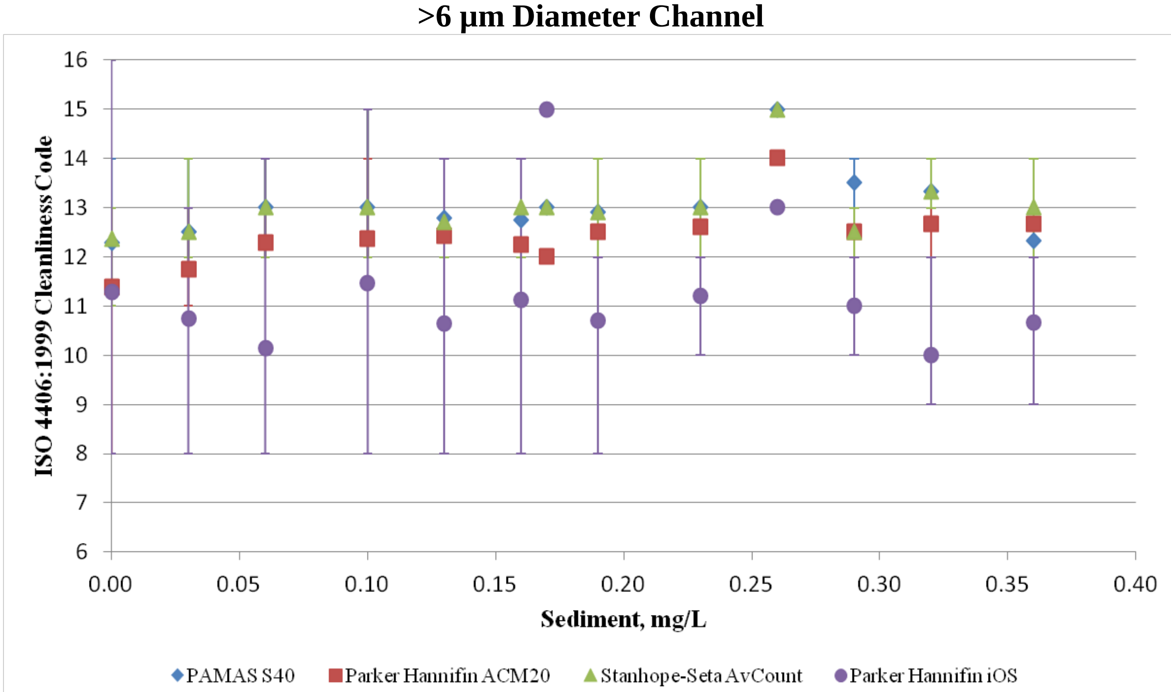

>30 µm Diameter Channel
ISO 4406:1999 Cleanliness Code
16
14
12
10
8
6
4
2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Sediment, mg/L
Parker Hannifin ACM20
Stanhope-Seta AvCount
Parker Hannifin iOS

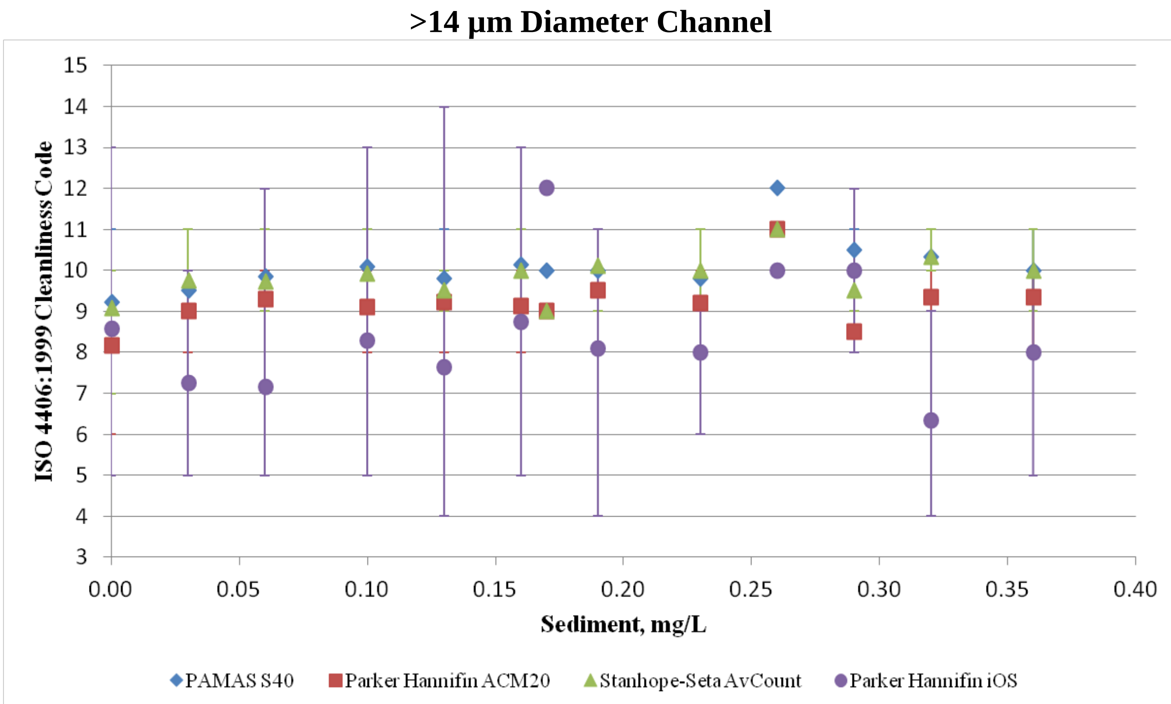
CCFD IAW Chapter 542 of NSTM

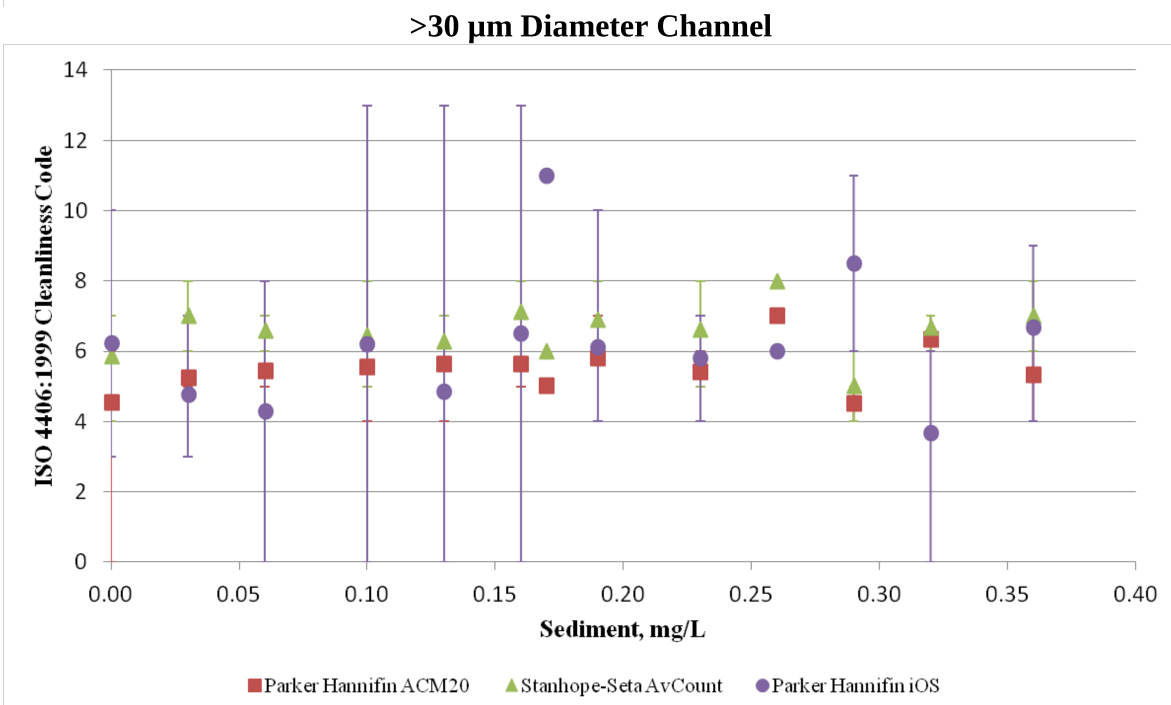
>4 µm Diameter Channel



>6 µm Diameter Channel




>14 µm Diameter Channel
ISO 4406:1999 Cleanliness Code
15
14
13
12
11
10
9
8
7
6
5
4
3
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Sediment, mg/L
PAMAS S40
Parker Hannifin ACM20
Stanhope-Seta AvCount
Parker Hannifin iOS

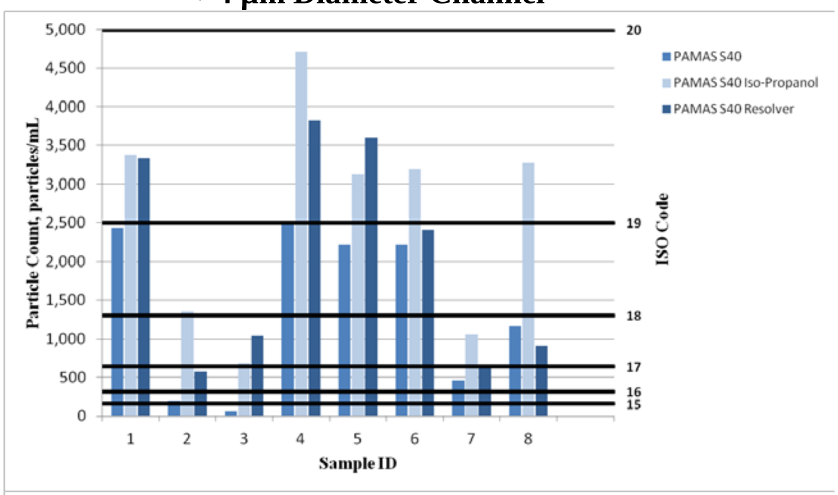

>30 µm Diameter Channel
ISO 4406:1999 Cleanliness Code
14
12
10
8
6
4
2
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Sediment, mg/L
Parker Hannifin ACM20
Stanhope-Seta AvCount
Parker Hannifin iOS

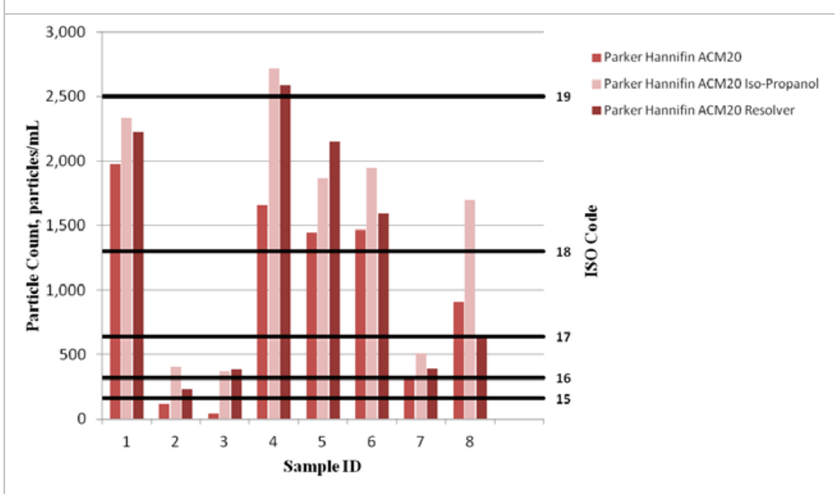
APPENDIX E: ISO-PROPANOL AND RESOLVER® PARTICLE COUNTS FOR >4 µm, >6 µm, >14 µm, AND >30 µm PARTICLE CHANNELS

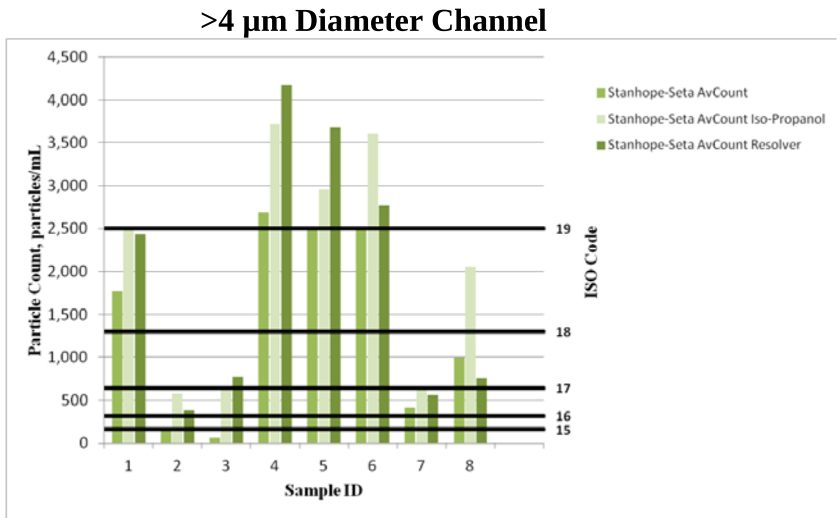
Iso-Propanol and Resolver® Test Samples

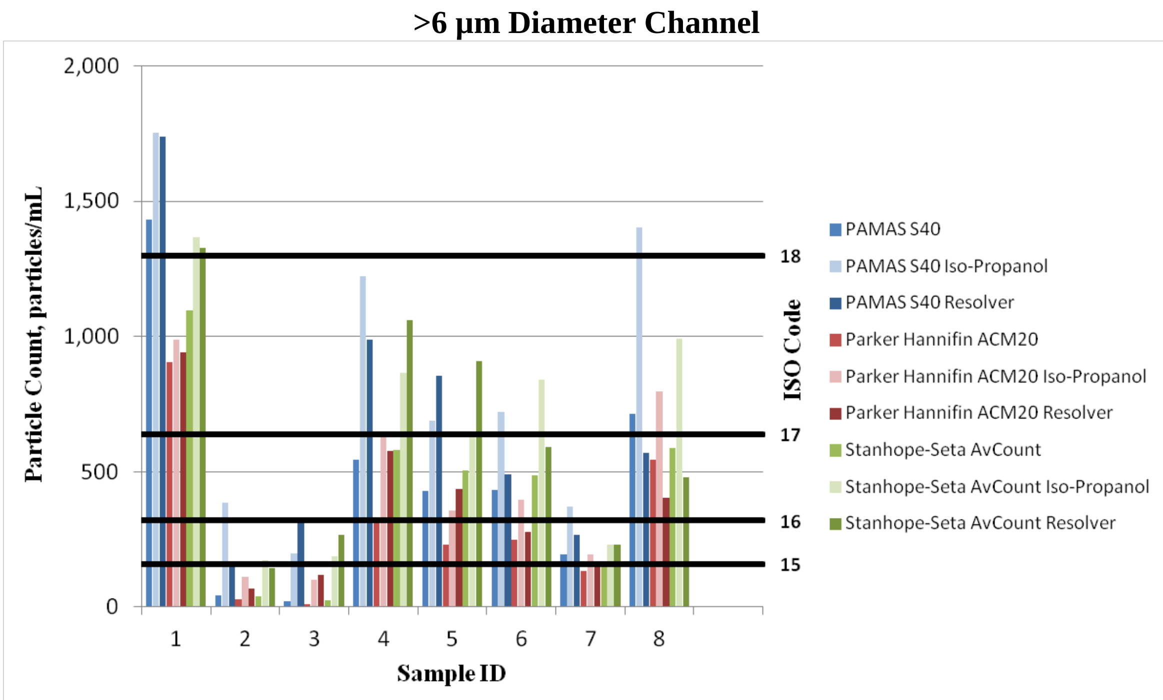
Sample ID	Fuel	Location	Free Water, ppm	Sediment, mg/L
1	JP-5	Filter Separator Inlet	0.0	0.67
2	JP-5	Filter Separator Inlet	0.0	0.00
3	JP-5	Filter Separator Outlet	0.0	0.00
4	JP-5	Barge Receipt Line	0.0	0.46
5	JP-5	Barge Receipt Line	0.0	0.56
6	JP-5	Barge Receipt Line	0.0	1.01
7	JP-5	Filter Separator Inlet	0.0	0.00
8	JP-5	Filter Separator Inlet	0.0	0.86

>4 µm Diameter Channel

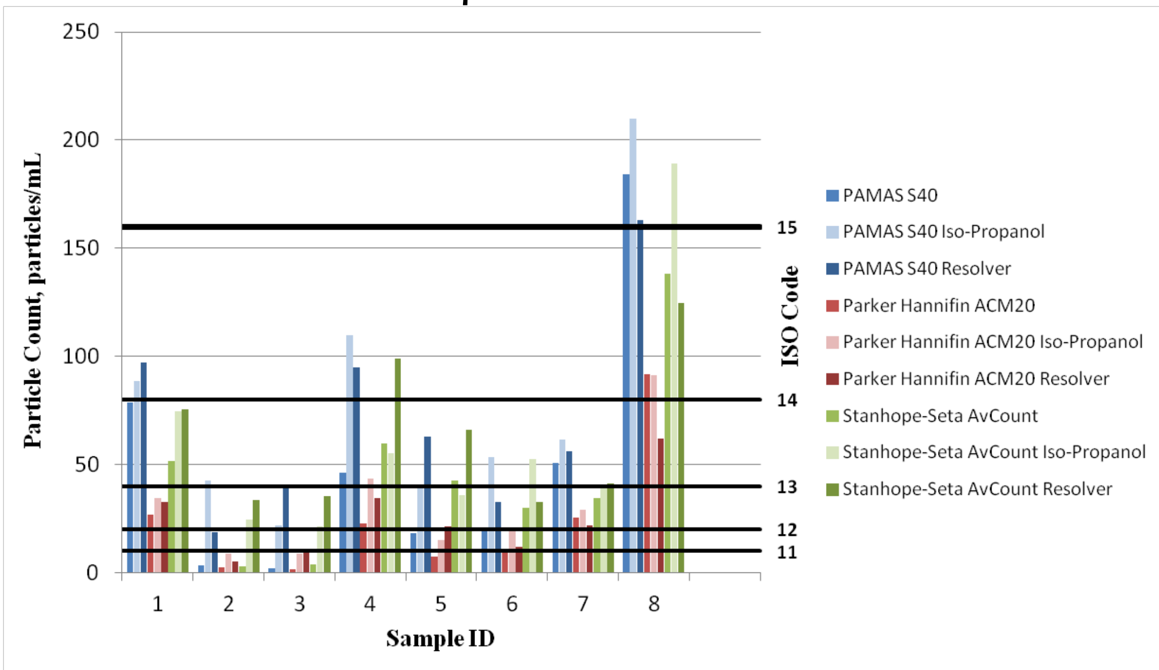




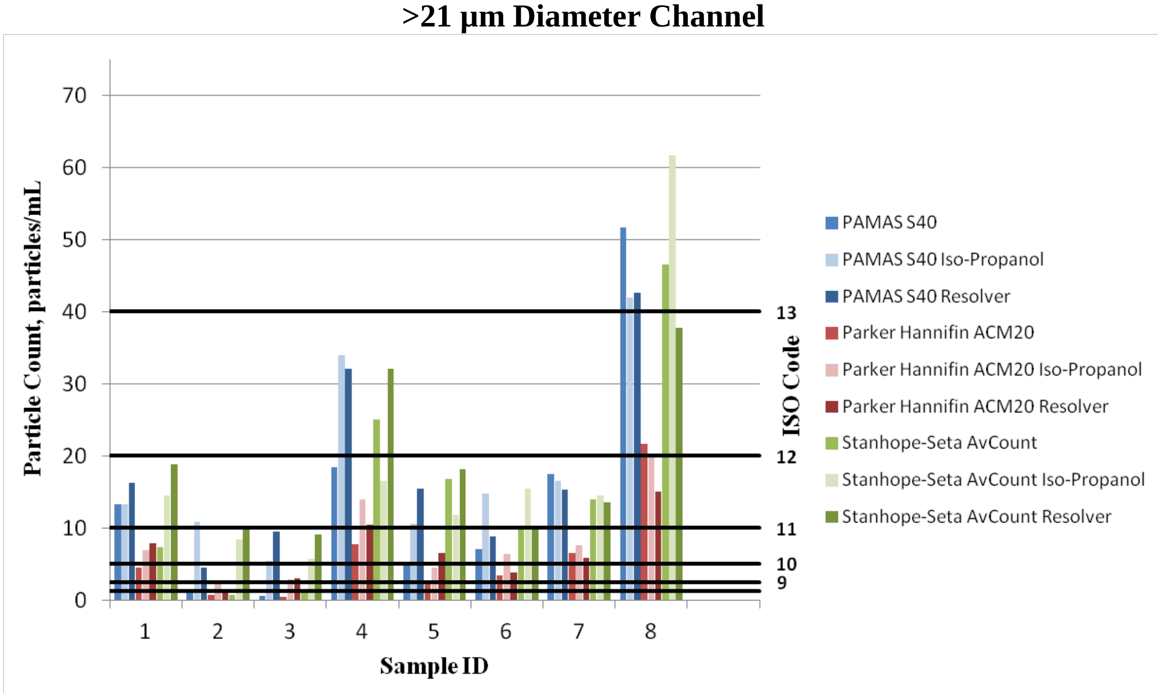

>4 µm Diameter Channel
Particle Count, particles/mL
ISO Code
Sample ID
Stanhope-Seta AvCount
Stanhope-Seta AvCount Iso-Propanol
Stanhope-Seta AvCount Resolver


>6 µm Diameter Channel
Particle Count, particles/mL
ISO Code
Sample ID
PAMAS S40
PAMAS S40 Iso-Propanol
PAMAS S40 Resolver
Parker Hannifin ACM20
Parker Hannifin ACM20 Iso-Propanol
Parker Hannifin ACM20 Resolver
Stanhope-Seta AvCount
Stanhope-Seta AvCount Iso-Propanol
Stanhope-Seta AvCount Resolver

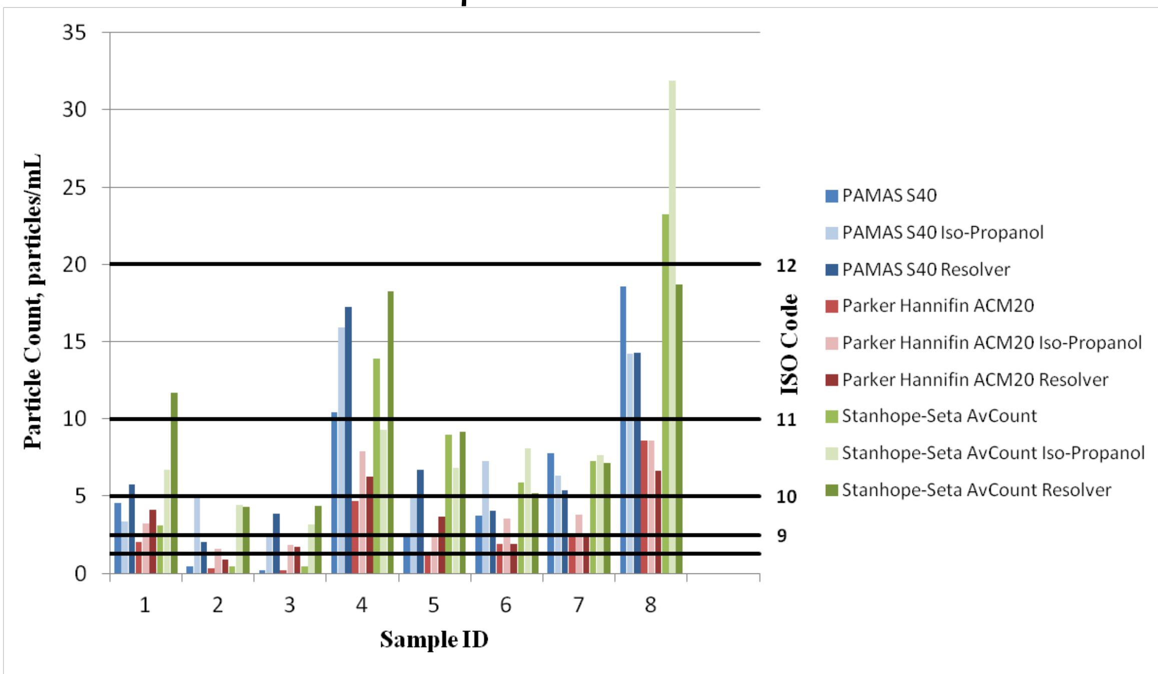
>14 µm Diameter Channel



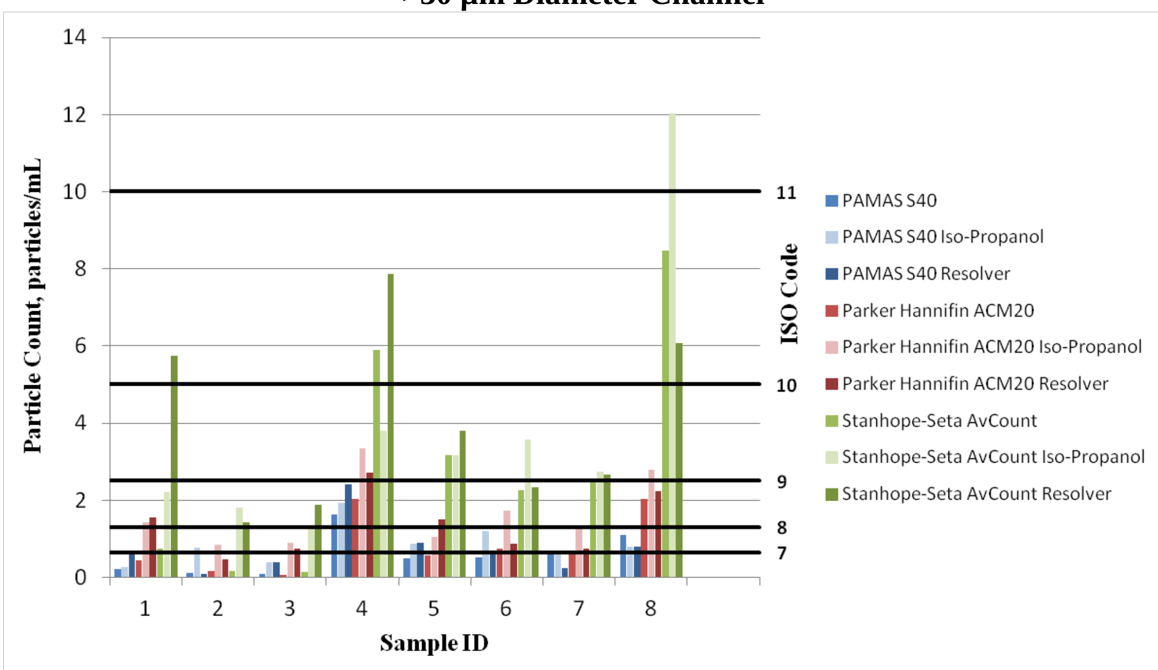
>21 µm Diameter Channel



>25 µm Diameter Channel



>30 µm Diameter Channel



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14. ABSTRACT
In an effort to improve current fuel quality surveillance practices, the Navy evaluated four commercial off-the-shelf (COTS) particle counters at two shore stations and onboard the aircraft carrier USS George H.W. Bush (CVN-77) during an underway deployment. Utilizing a combination of in-line and bottle samples, fuel quality was measured during fueling operations. Sediment and free water analysis were conducted on all fuel samples to allow particle counts and ISO codes to be correlated with the fuel's contaminant level.

In total, 216 JP-5 samples and 5 JP-8 samples were measured over the five week evaluation period. Select samples were evaluated using the Iso-proponal and Resolver® cosolvents. High relative standard deviation between particle counts of the same sediment and free water concentration were measured confirming the results of past Navy testing that particle counts are not a feasible alternative to gravimetric sediment and free water analysis but may be a suitable measure of overall fuel cleanliness. Due to the lack of samples near the sediment and free water limits, 2.0 mg/L sediment and 10 ppm free water, a particle count and ISO 4406:1999 cleanliness code specification limit could not be established. In-line sampling particle counters would be the most advantageous to the Navy due to the decreased analysis time required but prior to implementing any particle count or ISO code limit, the variability between the in-line and bottle ISO code measurements will need to be addressed.

15. SUBJECT TERMS
Fuel quality, particle counters, COTS, ISO code, particle count, JP-5

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