

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 19-08-2014		2. REPORT TYPE Technical		3. DATES COVERED (From - To) Nov 2013 - Aug 2014	
4. TITLE AND SUBTITLE Evaluation of On-line Light Obscuration Particle Counters for Detection of Fuel Contamination				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Joel Schmitigal				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army TARDEC RDTA SIE-ES-FPT 6501 E. 11 Mile Road Warren, MI 48397-5000				8. PERFORMING ORGANIZATION REPORT NUMBER 25587	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army TARDEC RDTA SIE-ES-FPT 6501 E. 11 Mile Road Warren, MI 48397-5000				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The objective of this effort was to evaluate on-line light obscuration particle counters against standard test dusts and free water to verify proposed particle counter limits, and evaluate the correlation between the two instruments tested.					
15. SUBJECT TERMS Fuel, On-line Automatic Particle Counter, particles, cleanliness, free water, Diesel					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT none	18. NUMBER OF PAGES 29	19a. NAME OF RESPONSIBLE PERSON Joel Schmitigal
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 586-282-4235

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g., 30-06-1998; xx-08-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. 1F665702D1257.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. AFOSR-82-1234.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORS AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

Registration No.

25587



Evaluation of On-line Light Obscuration Particle Counters for Detection of Fuel Contamination

Joel Schmitigal

DISTRIBUTION STATEMENT A. Approved for public
release; distribution is unlimited.

August 2014

U.S. Army Tank Automotive Research,
Development, and Engineering Center
Detroit Arsenal
Warren, Michigan 48397-5000

UNCLASSIFIED

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

UNCLASSIFIED

UNCLASSIFIED

U.S. Army Tank Automotive Research Development and Engineering Center

Warren, Michigan 48397-5000

Evaluation of On-line Light Obscuration Particle Counters for Detection of Fuel Contamination

Joel Schmitigal
Force Projection Technology

**DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.
Standard Form 298 (Rev. 8/98)**

Prescribed by ANSI Std. Z39

UNCLASSIFIED

List of Figures	iii
List of Tables	iv
1. Introduction	1
2. Project Background	2
3. Approach	2
4. Analysis	4
12103-1 A3 medium test dust evaluation	4
ISO 12103-1 A2 fine test dust evaluation	8
ISO 12103-1 A1 ultrafine test dust evaluation	13
Red Iron Oxide test dust evaluation	17
Free water evaluation	20
ISO 12103-1 A2 fine test dust and free water test dust evaluation	24
5. Conclusions	27
References	28
List of Symbols, Abbreviations, and Acronyms	29

List of Figures

Figure 1. Parker icountOS ISO Code data, 12103-1 A3 medium test dust $\geq 4\mu\text{m}$ channel. 5

Figure 2. ACM 20 particle count ISO Code data, 12103-1 A3 medium test dust $\geq 4\mu\text{m}$ channel. . 6

Figure 3. ACM 20 particle counts, 12103-1 A3 medium test dust $\geq 4\mu\text{m}$ channel. 6

Figure 4. Parker icountOS ISO Code data, ISO 12103-1 A2 fine test dust $\geq 4\mu\text{m}$ channel. 10

Figure 5. ACM 20 particle count ISO Code data, ISO 12103-1 A2 fine test dust $\geq 4\mu\text{m}$ channel.
..... 10

Figure 6. ACM 20 particle counts, ISO 12103-1 A2 fine test dust $\geq 4\mu\text{m}$ channel. 11

Figure 7. Parker icountOS ISO Code data, ISO 12103-1 A1 ultrafine test dust $\geq 4\mu\text{m}$ channel. . 14

Figure 8. ACM 20 particle count ISO Code data, ISO 12103-1 A1 ultrafine test dust $\geq 4\mu\text{m}$
channel. 14

Figure 9. ACM 20 particle counts, ISO 12103-1 A1 ultrafine test dust $\geq 4\mu\text{m}$ channel. 15

Figure 10. Parker icountOS ISO Code data, red iron oxide test dust $\geq 4\mu\text{m}$ channel. 18

Figure 11. ACM 20 particle count ISO Code data, red iron oxide test dust $\geq 4\mu\text{m}$ channel. 18

Figure 12. ACM 20 particle counts, red iron oxide test dust $\geq 4\mu\text{m}$ channel. 19

Figure 13. Parker icountOS ISO Code data, free water $\geq 4\mu\text{m}$ channel. 21

Figure 14. ACM 20 particle count ISO Code data, free water $\geq 4\mu\text{m}$ channel. 21

Figure 15. ACM 20 particle counts, free water $\geq 4\mu\text{m}$ channel. 22

Figure 16. Particle count size distribution for test dusts and free water. 22

Figure 17. Parker icountOS ISO Code data, ISO 12103-1 A2 fine test dust and free water $\geq 4\mu\text{m}$
channel. 25

Figure 18. ACM 20 ISO Code data, ISO 12103-1 A2 fine test dust and free water $\geq 4\mu\text{m}$ channel.
..... 25

Figure 19. ACM 20 particle counts, ISO 12103-1 A2 fine test dust and free water $\geq 4\mu\text{m}$ channel.
..... 26

List of Tables

Table 1 ISO 12103-1 test dust particle size distribution.....	4
Table 2. ISO 12103-1 A3 medium test dust gravimetric analysis results.....	4
Table 3. ACM 20 particle count ISO Code data for 1.0 mg/L, 12103-1 A3 medium test dust.....	6
Table 4. Parker icountOS particle count ISO Code data for 1.0 mg/L, 12103-1 A3 medium test dust.....	7
Table 5. ACM 20 particle count ISO Code data for 0.5 mg/L, 12103-1 A3 medium test dust.....	7
Table 6. Parker icountOS particle count ISO Code data for 0.5 mg/L, 12103-1 A3 medium test dust.....	7
Table 7. ACM 20 particle count ISO Code data for 0.25 mg/L, 12103-1 A3 medium test dust....	7
Table 8. Parker icountOS particle count ISO Code data for 0.25 mg/L, 12103-1 A3 medium test dust.....	7
Table 9. ISO 12103-1 A3 medium test dust test dust gravimetric and particle count data	8
Table 10. ISO 12103-1 A2 fine test dust gravimetric analysis results.....	9
Table 11. ACM 20 particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A2 fine test dust .	11
Table 12. Parker icountOS particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A2 fine test dust.....	11
Table 13. ACM 20 particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A2 fine test dust .	11
Table 14. Parker icountOS particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A2 fine test dust.....	12
Table 15. ACM 20 particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A2 fine test dust	12
Table 16. Parker icountOS particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A2 fine test dust.....	12
Table 17. ISO 12103-1 A2 fine test dust test dust gravimetric and particle count data	13
Table 18. ISO 12103-1 A1 ultrafine test dust gravimetric analysis results.	13
Table 19. ACM 20 particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A1 ultrafine test dust.....	15
Table 20. Parker icountOS particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A1 ultrafine test dust	15
Table 21. ACM 20 particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A1 ultrafine test dust.....	16
Table 22. Parker icountOS particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A1 ultrafine test dust	16
Table 23. ACM 20 particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A1 ultrafine test dust.....	16
Table 24. Parker icountOS particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A1 ultrafine test dust.....	16
Table 25. ISO 12103-1 A1 ultrafine test dust test dust gravimetric and particle count data	17
Table 26. Red Iron Oxide test dust gravimetric analysis results.....	17
Table 27. ACM 20 particle count ISO Code data for red iron oxide test dust.....	19
Table 28. Parker icountOS particle count ISO Code data for red iron oxide test dust.	20
Table 29. Parker ACM-20 particle count ISO Code data free water.	23
Table 30. Parker icountOS particle count ISO Code data for free water.....	24

UNCLASSIFIED

Table 31. Parker ACM 20 particle count ISO Code data for free water..... 26
Table 32. Parker icountOS particle count ISO Code data for free water..... 26

1. Introduction

The U.S. Army maintains the mission of providing quality fuel to all U.S. and Allied troops in tactical environments. Presently, requirements as outlined require a dedicated group of specifically trained fuels personnel to perform several tests per day per installation looking for traces of sediment and water in the fuel (1) (2) (3).

The Army utilizes several techniques to ensure that aviation fuels are clean and dry. Despite the best of intentions the current test methods utilized by the Army have several drawbacks including: timeliness of data due to the turn-around time needed to get the test results, operator subjectivity, lack of detailed analysis, and limitations in providing reliable data. For these reasons the Army has been actively working to develop new methods for monitoring fuel contamination (4) (5).

The Army utilizes ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures), as a final check of fuel to ensure aviation fuel is clear and bright before flight operations.

Fuel filter effectiveness is evaluated by quality assurance testing though conducting periodic fuel sampling for gravimetric analysis. The Army currently utilizes two methods for measuring particulate contamination by gravimetric analysis: ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling, and ASTM D5452 - Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration. Additionally free water content is determined by performing ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels, commonly termed AquaGlo testing.

Current standards, such as MIL-STD-3004, Department of Defense Standard Practice for Quality Assurance/Surveillance for Fuels, Lubricants, and Related Products and Field Manual No. 10-67-2, Department of the Army Manual for Petroleum Laboratory Testing and Operations, specifies limits for free water and particulate matter in aviation fuels. Specifically, free water contamination in jet fuel cannot exceed 10 parts per million (PPM) (1) and particulate matter contamination cannot exceed 2.0 mg/L for Intra-Governmental transfer receipts and 1.0 mg/L on issue to aircraft, or up to 10 mg/L for product used as a diesel product for ground use (1). Free water contamination (droplets) may appear as fine droplets or slugs of water in the fuel systems. The particulate matter found in field fuel systems varies in shape and is commonly found in the 5 to 40 micron size range. Common particulate matter includes silica, rust, metal shavings, fibrous materials, coatings material including paint, elastomeric materials, hydrocarbon/oxidation materials, and other solid matter. At a minimum free water and particulate by color (as specified in the appendix of ASTM D2276) are checked daily, while filter effectiveness is checked every 30 days by gravimetric analysis (ASTM D2276).

One of the problems with the gravimetric methods is the poor repeatability and reproducibility of the methods, ASTM D2276 has a repeatability of 0.25 mg/L and reproducibility of 0.62 mg/L at the 1.0 mg/L contaminate level based on a 5 liter sample, where as the Army utilizes 1 liter

samples increasing the associated error. While the published repeatability and reproducibility of ASTM D5452 only spans from 0 to 0.6 mg/L applying the provided formulas to the 1.0 mg/L contaminate level provides a repeatability of 0.42 mg/L and reproducibility of 0.73 mg/L, sample volume used to calculate these values is not provided in ASTM D5452, but again 5 liter samples were used to develop these formulas used for these calculations.

2. Project Background

The U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) has been actively perusing advanced technologies to monitor aviation fuel for particulate and water contamination. The application of light obscuration particle counters for this purpose has risen to the top of available technologies in terms of performance and availability.

In 2013 Defense Logistics Agency – Energy funded a Tri-Service Field Evaluation of Automatic Particle Counters. Each service chose two locations to conduct testing (6) (7). The U.S. Army chose to conduct testing at Campbell Army Airfield at Fort Campbell, KY (8), and three Army Heliports at Fort Rucker, AL (9).

The test results at Fort Rucker and Fort Campbell verified the on-line particle counters susceptibility to providing erroneous results in the presence of air bubbles in the fuel stream. Later testing at Redstone Test Center showed that the fuel stream of an Advanced Aviation Forward Area Refueling System (AAFARS) and Fuel System Supply Point (FSSP) lacked the air bubbles that have been shown to be problematic for particle counter applications, showing that the utilization of light obscuration particle counters with tactical equipment may be an acceptable solution for monitoring aviation fuel for particulate and water contamination (10) (11).

3. Approach

The test plan for evaluating the selected light obscuration particle counters was modified from the concepts found in Energy Institute (EI) 1598 – Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel (12). The test purpose was to compare the performance of the Parker icountOS aviation fuel contamination monitoring instrument as an instrument calibrated to ISO 11171, and determine if previous differences seen between the two instruments was a result of instrument calibration or sampling procedures. The Parker icountOS instrument which contains similar internal optics and fluid path geometry as the Parker ACM 20 which is specified in IP 564, Determination of the level of cleanliness of aviation turbine fuel - Laboratory automatic particle counter method, is traceable to ISO 11171, Hydraulic fluid power - Calibration of automatic particle counters for liquids via ISO 11943.1999 - On-Line automatic particle-counting systems for liquids - Methods of calibration and validation, and reports ISO 4406.1999, Hydraulic fluid power - Fluids - Method for coding the level of contamination by solid particles, codes directly. The water distribution was generated using the centrifugal pump specified in EI 1581,

UNCLASSIFIED

Specification and qualification procedures for aviation jet fuel filter/separators. The testing was performed at a high flow rate to ensure turbulent flow and no filtration devices were used between the contaminant injection and the electronic sensors. The test protocol for evaluating the various sensors is provided below:

1. Operate the system at approximately 105.7 gpm (400 lpm) in a single pass flow loop (contaminant is removed after electronic sensors)
2. Using clean, dry, Jet A, obtain baseline data for 30 minutes
3. Upon completion of baseline, obtain data when injecting ISO 12103-1 A1 ultrafine test dust at approximately 1 mg/L, 0.5 mg/L, and 0.25 mg/L
4. Upon completion of ISO 12103-1 A1 ultrafine test dust evaluation, perform analysis using ISO 12103-1 A2 fine test dust at approximately 1 mg/L, 0.5 mg/L, and 0.25 mg/L
5. Upon completion of the ISO 12103-1 A2 fine test dust evaluation, perform analysis using ISO 12103-1 A3 medium test dust at approximately 1 mg/L, 0.5 mg/L, and 0.25 mg/L
6. Upon completion of ISO 12103-1 A3 medium test dust evaluation, perform same analysis using Red Iron Oxide (RIO) at approximately 1 mg/L, 0.5 mg/L, and 0.25 mg/L
7. Upon completion of dirt tests, verify fuel is dry (Aqua-glo)
8. Obtain electronic sensor data using water contamination at approximately 5, 10, 20, and 40 ppm. Verify water contamination levels using Aqua-glo (both Gammon and D2 readers)
9. Upon completion of water tests, test ISO 12103-1 A2 fine test dust and free water at 5, 10, and 20ppm.

The particle size distribution for evaluated test dusts is provided in Table 1.

	A3 Medium Test Dust	A2 Fine Test Dust	A1 Ultrafine Test Dust	Red Iron Oxide
micron	% Less Than	% Less Than	% Less Than	
1	1.0 – 3.0	2.5 – 3.5	1.0 – 3.0	96.0
2	4.0 – 5.5	10.5 – 12.5	9.0 – 13.0	
3	7.5 – 9.5	18.5 – 22.0	21.0 – 27.0	
4	10.5 – 13.0	25.5 – 29.5	36.0 – 44.0	
5	15.0 – 19.0	31.0 – 36.0	56.0 – 64.0	
7	28.0 – 33.0	41.0 – 46.0	83.0 – 88.0	
10	40.0 – 45.0	50.0 – 54.0	97.0 – 100	
20	65.0 – 69.0	70.0 – 74.0	100	
40	84.0 – 88.0	88.0 – 91.0		
80	99.0 – 100	99.5 – 100		
120	100	100		

Table 1 ISO 12103-1 test dust particle size distribution

4. Analysis

12103-1 A3 medium test dust evaluation

ISO 12103-1 A3 medium test dust, having a particle size distribution found in Table 1, with 55% of its particulate content being larger than 10 μm , provides a good representation of what would be clear evidence of a failed filter separator if particles of this size were found downstream of a filter separator as EI 1581 filters, which have an approximate nominal micron rating of 0.4-1.0 μm , and are qualified with a 90% A1 ultrafine test dust – 10% red iron oxide mixture. Following a 30 minute baseline run the fuel was determined to be clean with a particle count ISO code of 14/11/1/1 with a total average of ~94 particles per mL in the $\geq 4\mu\text{m}$ (c) channel and dry per ASTM D3240 with a Gammon Technical Products Aqua-Glo reading of 1 ppm, and a D-2 Incorporated JF-WA1 Hydro-Light reading of 0.4 ppm free water. Test conditions were established and maintained for 30 minutes each, with gravimetric samples taken at the 5 and 20 minute marks, per ASTM D2276, for each evaluation as detailed in Table 2.

Theoretical Gravimetric mg/L	Measured Gravimetric mg/L
1.00	0.25
1.00	0.27
0.50	0.08
0.50	0.10
0.25	0.08
0.25	0.10

Table 2. ISO 12103-1 A3 medium test dust gravimetric analysis results.

The Parker icountOS (IOS) was utilized to collect data throughout the ISO 12103-1 A3 medium test dust evaluation at the 1.0 mg/L, 0.5 mg/L, 0.25 mg/L, as well as at the baseline concentration

levels as seen in Figure 1. The Parker IOS instrument was found to provide ISO code readings commensurate with the Parker ACM20 performing to IP 564 Figure 2. A detailed analysis of the $\geq 4\mu\text{m}$ channel ACM20 data, in Figure 3, shows a clear delineation between the 0.5 mg/L and 0.25 mg/L A3 test dust contamination levels, not seen when simply just reporting the ISO codes. The particle count ISO codes for the 12103-1 A3 medium test dust at the 1.0 mg/L level for the Parker ACM 20 and Parker IOS instruments is provided in Table 3 and Table 4 respectively this data supports the 19/17/14/13 limits proposed for use by TARDEC (5). Additional analysis of the particle counting data for the A3 medium test is provided in Table 5 -Table 8. The correlation between the two instruments shows that both calibration methods provide agreement in reported ISO codes and the variation seen in previous evaluations, at Fort Campbell (8), between the two technologies was a results of the sampling methods, on-line vs bottle samples, rather than instrument calibration.

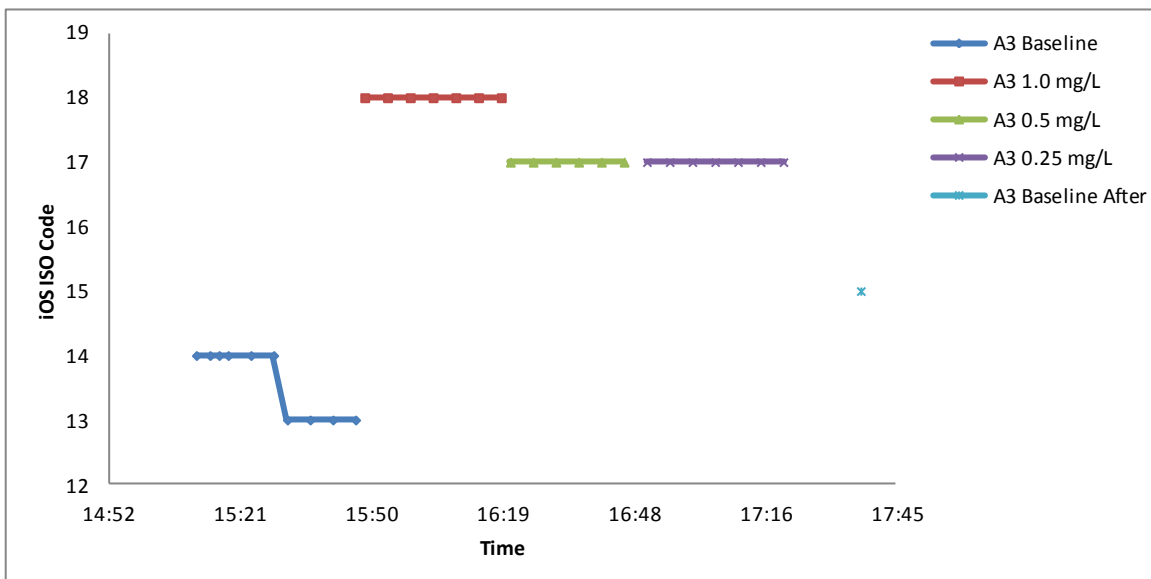


Figure 1. Parker icountOS ISO Code data, 12103-1 A3 medium test dust $\geq 4\mu\text{m}$ channel.

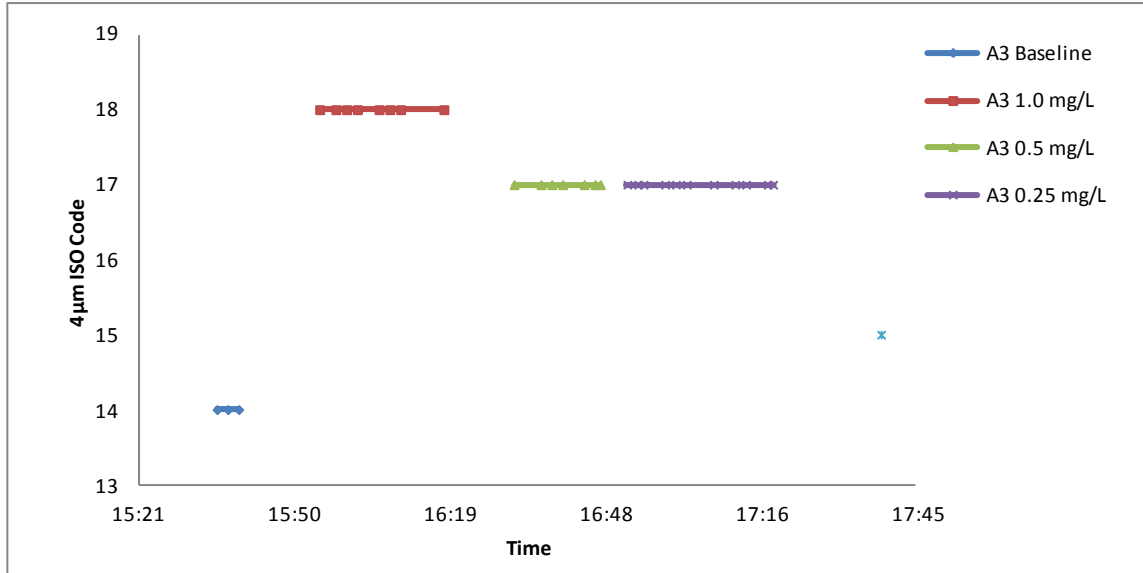


Figure 2. ACM 20 particle count ISO Code data, 12103-1 A3 medium test dust $\geq 4\mu\text{m}$ channel.

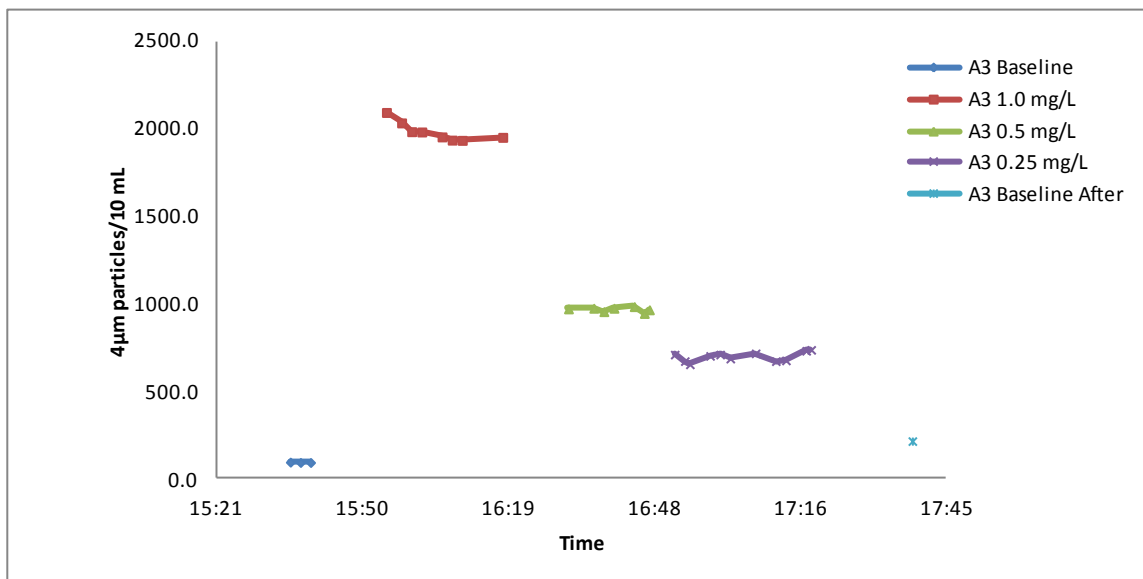


Figure 3. ACM 20 particle counts, 12103-1 A3 medium test dust $\geq 4\mu\text{m}$ channel.

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
15:55	18	17	12	7
15:58	18	17	12	7
16:00	18	17	12	6
16:02	18	17	12	7
16:06	18	17	12	7
16:08	18	17	12	7
16:10	18	17	12	7
16:18	18	17	12	6

Table 3. ACM 20 particle count ISO Code data for 1.0 mg/L, 12103-1 A3 medium test dust

UNCLASSIFIED

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
15:49	18	17	13	8
15:54	18	17	13	8
15:59	18	17	13	8
16:04	18	17	13	8
16:09	18	17	13	8
16:14	18	17	13	8
16:19	18	17	12	>7

Table 4. Parker icountOS particle count ISO Code data for 1.0 mg/L, 12103-1 A3 medium test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
16:31	17	16	11	5
16:36	17	16	11	6
16:38	17	16	11	6
16:40	17	16	11	5
16:44	17	16	11	4
16:46	17	15	11	5
16:47	17	16	11	5

Table 5. ACM 20 particle count ISO Code data for 0.5 mg/L, 12103-1 A3 medium test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
16:21	17	16	12	>6
16:26	17	16	11	>7
16:31	17	16	11	7
16:36	17	16	12	>7
16:41	17	16	11	>6
16:46	17	16	11	>6

Table 6. Parker icountOS particle count ISO Code data for 0.5 mg/L, 12103-1 A3 medium test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
16:52	17	15	10	5
16:54	17	15	10	4
16:55	17	15	10	4
16:59	17	15	10	6
17:01	17	15	10	5
17:03	17	15	10	4
17:08	17	15	10	6
17:12	17	15	10	5
17:14	17	15	10	1
17:18	17	15	10	1
17:19	17	15	10	5

Table 7. ACM 20 particle count ISO Code data for 0.25 mg/L, 12103-1 A3 medium test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
16:51	17	15	11	>6
16:56	17	15	11	>5
17:01	17	15	11	>6
17:06	17	15	11	>6
17:11	17	15	11	>6
17:16	17	15	11	>5
17:21	17	15	11	>6

Table 8. Parker icountOS particle count ISO Code data for 0.25 mg/L, 12103-1 A3 medium test dust

To verify the particle counts obtained via the EI 1581 test rig bottle samples of fuel were prepared with known a concentration of 1.0 mg/L of 12103-1 A3 medium test dust, these bottle samples were then particle counted via IP 564 and had their gravimetric loading tested via ASTM D5452. The data generated, provided in Table 9, showed that the gravimetric weight of dust reflected greater adherence to theoretical values during the bottle sample tests versus the tests performed on the EI 1581 test rig. This data suggests that the EI 1581 gravimetric error is associated with the ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling testing and sampling or the EI 1581 testing. The particle count data for the bottle samples fell relatively close to the values obtained with the equivalent EI 1581 test rig theoretical gravimetric loads validating the EI 1581 slurry injection. 1.0 mg/L of A3 test dust with the EI 1581 test rig had an average of 1984.2 particles $\geq 4\mu$ in size; whereas the average for 1.0mg/L of A1 test dust for the bottle samples was 1823.3 particles $\geq 4\mu$ in size, validating the particle count data taken on the EI 1581 test rig in accordance with the amount of test dust theoretically injected (theoretical gravimetric readings).

On-line EI 1581 - A3 test dust				Bottle Sample - A3 test dust			
	Theoretical	Actual	Particle 4(c)		Theoretical	Actual	Particle 4(c)
	1	-	2094.3		1	0.8	2210.7
	1	-	2034.5		1	0.4	2017
	1	0.25	1984.3		1	0.6	1685.1
	1	-	1982.7		1	0.8	1653.5
	1	-	1954.4		1	1.2	2223.8
	1	-	1936.2		1	0.6	1867.8
	1	0.27	1934.8		1	0.8	1434.5
	1	-	1952.1		1	0.9	1375.7
Average			1984.2		1	0.7	1687.6
SD			55.18		1	1.5	2077.3
Range			159.5	Average			1823.3
				SD			304.1
				Range			848.1

Table 9. ISO 12103-1 A3 medium test dust test dust gravimetric and particle count data

ISO 12103-1 A2 fine test dust evaluation

ISO 12103-1 A2 fine test dust, having a particle size distribution found in Table 1, has a slight shift from the A3 distribution toward a higher concentration of particles smaller than 10 μm . Following a 30 minute baseline run the fuel was determined to be clean with a particle count ISO code of 13/11/6/4 with a total average of ~51 particles per mL in the $\geq 4\mu\text{m}$ (c) channel and dry with a Gammon Technical Products Aqua-Glo reading of 1.2 ppm, and a D-2 Incorporated JF-WA1 Hydro-Light reading of 0.6 ppm free water. Test conditions were established and maintained for 30 minutes each, with gravimetric samples per ASTM D2276 taken at the 5 and 20 minute marks for each evaluation as detailed in Table 10.

UNCLASSIFIED

Theoretical Gravimetric mg/L	Measured Gravimetric mg/L
1.00	0.275
1.00	0.225
0.50	0.125
0.50	0.125
0.25	0.075
0.25	0.125

Table 10. ISO 12103-1 A2 fine test dust gravimetric analysis results.

The Parker IOS and ACM20 instruments collected data throughout the ISO 12103-1 A2 fine test dust evaluation at the 1.0 mg/L, 0.5 mg/L, 0.25 mg/L, and at the baseline contamination levels, the ISO code readings for the $\geq 4\mu\text{m}$ channel are provided in Figure 4 and Figure 5. The variation seen in the 0.5 mg/L contamination levels between the 17 and 18 ISO code is seen as minimal. A mechanical failure seen in the Parker ACM20 during testing prevented this instrument from taking data during this time period, so an actual change in fuel contaminate levels is not verifiable. The gravimetric data does not support a shift in particulate content but a particulate level content shift at this low level is probably not detectable via ASTM D2276. The shift in ISO code from 17 to 20 during the 0.25 mg/L evaluation is unexplained; again the Parker ACM20 mechanical failure prevented duplicate data from being taken during this occurrence. A detailed analysis of the $\geq 4\mu\text{m}$ channel ACM20 data, in Figure 6, shows a clear delineation between the 0.5 mg/L and 0.25 mg/L A2 test dust contamination levels, not seen when simply just reporting the ISO codes. The particle count ISO codes for the 12103-1 A2 fine test dust at the 1.0 mg/L level for the Parker ACM 20 and Parker IOS instruments is provided in Table 11 and Table 12 respectively. The particle count ISO code data provided in Table 11 and Table 12 supports the 19/17/14/13 limits proposed for use by TARDEC, as tighter ISO code limits would provide an unrealistic constraint on military filtration systems (5). Additional ISO code particle counting data for the A2 fine at the 0.5 mg/L and 0.25 mg/L contamination levels is provided in Table 13 Table 16. Again the correlation between the two instruments shows that both calibration methods provide agreement in reported ISO codes and the variation seen in previous evaluations, at Fort Campbell (8), between the two technologies was a results of the sampling methods, on-line vs bottle samples, rather than instrument calibration.

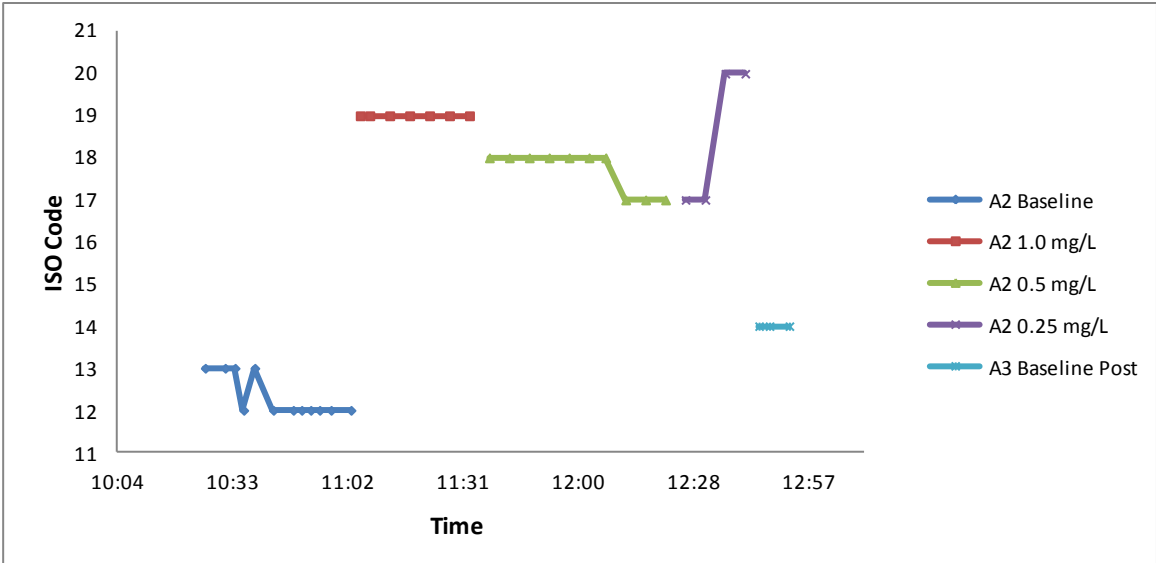


Figure 4. Parker icountOS ISO Code data, ISO 12103-1 A2 fine test dust $\geq 4\mu\text{m}$ channel.

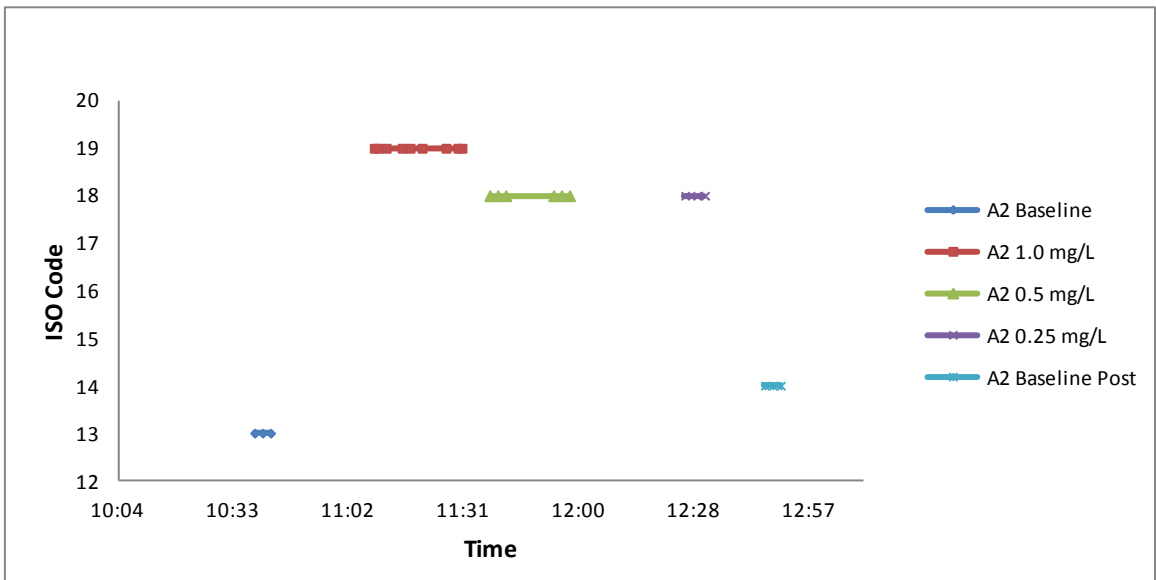


Figure 5. ACM 20 particle count ISO Code data, ISO 12103-1 A2 fine test dust $\geq 4\mu\text{m}$ channel.

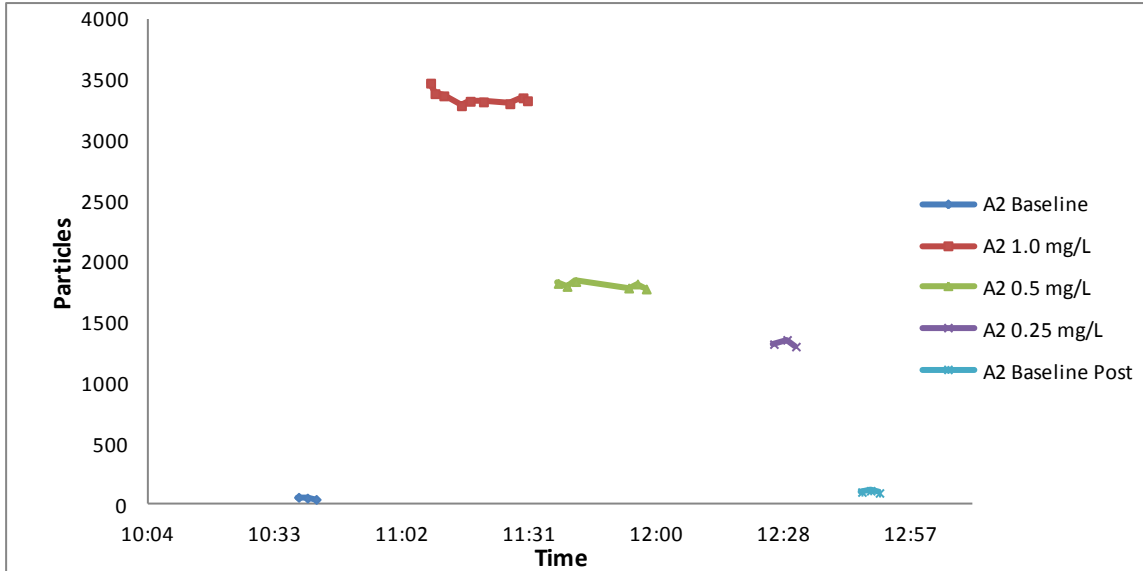


Figure 6. ACM 20 particle counts, ISO 12103-1 A2 fine test dust $\geq 4\mu\text{m}$ channel.

Time	ISO 4 μm	ISO 6 μm	ISO 14 μm	ISO 30 μm
11:09	19	17	11	7
11:10	19	17	12	6
11:12	19	17	12	7
11:16	19	17	12	7
11:18	19	17	12	6
11:21	19	17	11	7
11:27	19	17	12	6
11:30	19	17	11	6
11:31	19	17	12	6

Table 11. ACM 20 particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A2 fine test dust

Time	ISO 4 μm	ISO 6 μm	ISO 14 μm	ISO 30 μm
11:05	19	17	12	7
11:08	19	17	12	8
11:13	19	17	12	8
11:18	19	17	12	8
11:23	19	17	12	8
11:28	19	17	12	8
11:33	19	17	12	8

Table 12. Parker icountOS particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A2 fine test dust

Time	ISO 4 μm	ISO 6 μm	ISO 14 μm	ISO 30 μm
11:38	18	16	11	6
11:40	18	16	11	5
11:42	18	16	11	6
11:54	18	16	11	6
11:56	18	16	11	5
11:58	18	16	11	4

Table 13. ACM 20 particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A2 fine test dust

UNCLASSIFIED

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
11:38	18	16	11	8
11:43	18	16	11	7
11:48	18	16	11	7
11:53	18	16	11	7
11:58	18	16	11	7
12:03	18	16	11	6
12:07	18	16	11	7
12:12	17	16	11	6
12:17	17	16	11	7
12:22	17	16	11	6

Table 14. Parker icountOS particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A2 fine test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
12:27	18	15	10	5
12:30	18	16	10	4
12:32	18	15	10	1

Table 15. ACM 20 particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A2 fine test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
12:27	17	16	10	6
12:32	17	16	11	7
12:37	20	19	14	10
12:42	20	18	14	10

Table 16. Parker icountOS particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A2 fine test dust

To verify the particle counts obtained via the EI 1581 test rig bottle samples of fuel were prepared with known a concentration of 1.0 mg/L of ISO 12103-1 A2 fine test dust, these bottle samples were then particle counted via IP 564 and had their gravimetric loading tested via ASTM D5452. The particle count data generated, provided in Table 17, for the bottle samples fell relatively close to the values obtained with the equivalent EI 1581 test rig theoretical gravimetric loads. 1.0 mg/L of A2 test dust with the EI 1581 test rig had an average of 3355.5 particles $\geq 4\mu$ in size; whereas the average for 1.0mg/L of A2 test dust for the bottle samples was 2889.3 particles $\geq 4\mu$ in size, validating the particle count data taken on the EI 1581 test rig in accordance with the amount of test dust theoretically injected (theoretical gravimetric readings). The gravimetric weight of dust in the bottle samples showed a greater adherence to the theoretical values during the bottle sample tests versus the tests performed on the EI 1581 test rig. This data supports the theory that the EI 1581 gravimetric error is associated with the ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling testing and sampling or the EI 1581 testing.

On-Line EI-1581 - A2 test dust			
	Theoretical	Actual	Particle 4(c)
	1	-	3480
	1	-	3393.1
	1	0.275	3374.9
	1	-	3293.4
	1	-	3330.2
	1		3325.2
	1	0.225	3309.8
	1	-	3358.6
	1	-	3334.4
Average			3355.5
SD			56.18
Range			186.6

Bottle Samples- A2 test dust			
	Theoretical	Actual	Particle 4(c)
	1.0	0.90	3329.9
	1.0	0.54	3045.9
	1.0	0.39	2910.5
	1.0	1.70	3484.8
	1.0	1.30	2939.9
	1.0	1.70	2706.2
	1.0	1.00	2462.0
	1.0	1.50	2645.9
	1.0	1.40	3366.8
	1.0	0.70	2769.1
Average			2966.1
SD			339.1
Range			1022.8

Table 17. ISO 12103-1 A2 fine test dust test dust gravimetric and particle count data

ISO 12103-1 A1 ultrafine test dust evaluation

ISO 12103-1 A1 ultrafine test dust, having a particle size distribution found in Table 1, is the test dust used in a 90-10 mixture with red iron oxide in the qualification of EI 1581 filters and is composed of 97-100% sub 10 µm particles. Following a 30 minute baseline run the fuel was determined to be clean with and dry with a Gammon Technical Products Aqua-Glo reading of 1.2 ppm, and a D-2 Incorporated JF-WA1 Hydro-Light reading of 0.6 ppm free water. Test conditions were established and maintained for 30 minutes each, with gravimetric samples per ASTM D2276 taken at the 5 and 20 minute marks for each evaluation as detailed in Table 18.

Theoretical Gravimetric mg/L	Measured Gravimetric mg/L
1.00	0.2750
1.00	0.1250
0.50	0.0500
0.50	0.1250
0.25	0.1500
0.25	0.1000

Table 18. ISO 12103-1 A1 ultrafine test dust gravimetric analysis results.

The Parker IOS and ACM20 instruments collected data throughout the ISO 12103-1 A1 ultrafine test dust evaluation at the 1.0 mg/L, 0.5 mg/L, 0.25 mg/L, and at the baseline contamination levels, the ISO code readings for the ≥4µm channel are provided in Figure 7 and Figure 8. The cause of the shift seen in the 0.25 mg/L contamination levels between the 19 and 21 ISO code in the final data point for the Parker IOS instrument data is unknown, this jump is seen as questionable as it would represent a minimal 2 fold increase in particles present from 5000-10,000 particles, a test point with the Parker ACM20 was not take at this time period so an actual change in fuel contaminate levels is not verifiable. The gravimetric data does not support a shift in particulate content. A detailed analysis of the ≥4µm channel ACM20 data, in Figure 9, shows clear distinction between the 0.5 mg/L and 0.25 mg/L test dust contamination levels, not seen when simply just reporting the ISO codes. The particle count ISO codes for the 12103-1 A1

ultrafine test dust at the 1.0 mg/L level for the Parker ACM 20 and Parker IOS instruments is provided in Table 19 and Table 20 respectively. The particle count data shows that A1 test dust at 1.0 mg/L exceeds the Army's proposed 19/17/14/13 threshold limits with an ISO code value of 20/18/9/1, due to hits high level of sub 10µm particles. Additional ISO code particle counting data for the A2 fine at the 0.5 mg/L and 0.25 mg/L contamination levels is provided in Table 21 Table 24.

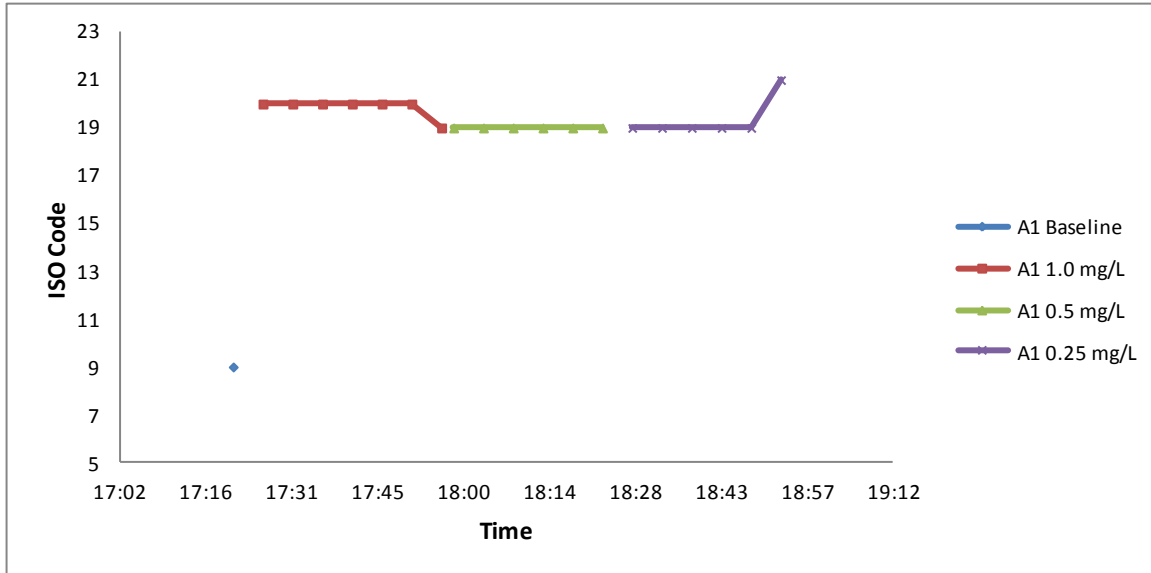


Figure 7. Parker icountOS ISO Code data, ISO 12103-1 A1 ultrafine test dust $\geq 4\mu\text{m}$ channel.

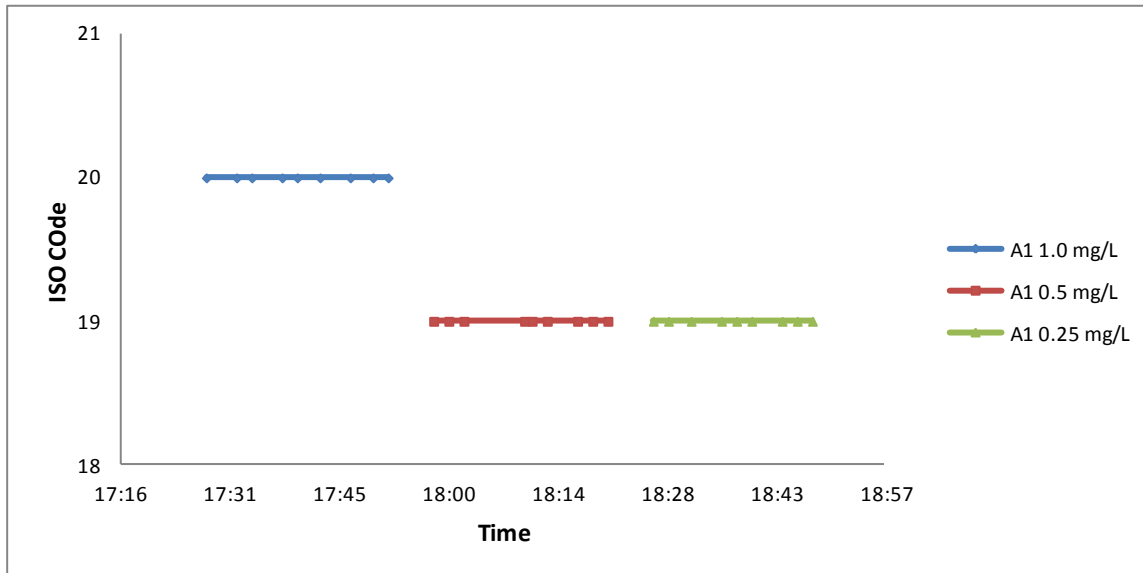


Figure 8. ACM 20 particle count ISO Code data, ISO 12103-1 A1 ultrafine test dust $\geq 4\mu\text{m}$ channel.

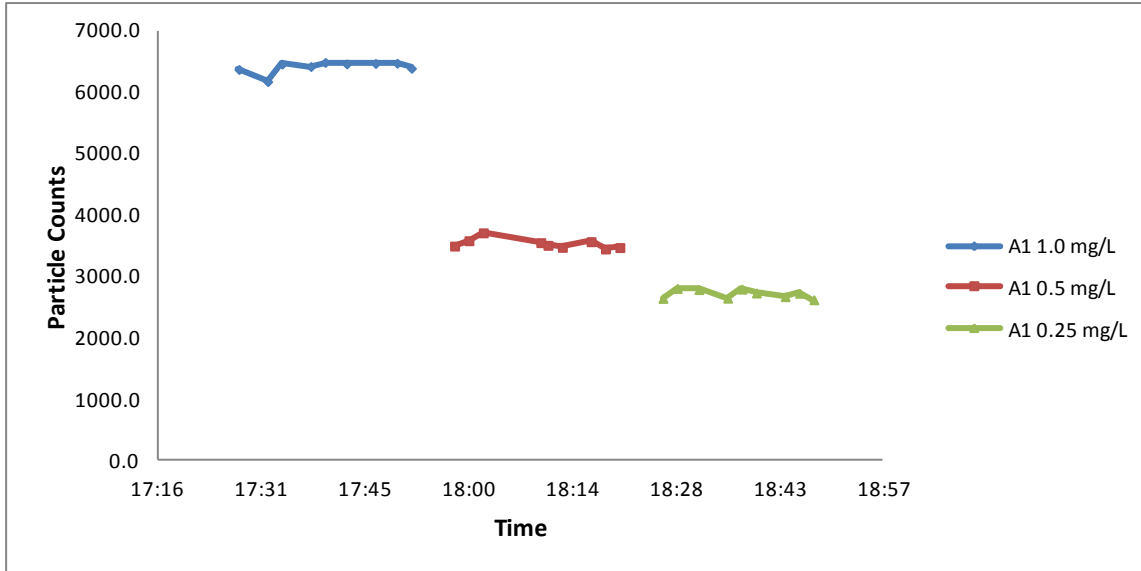


Figure 9. ACM 20 particle counts, ISO 12103-1 A1 ultrafine test dust ≥4μm channel.

Time	ISO 4μm	ISO 6μm	ISO 14μm	ISO 30μm
17:28	20	18	10	1
17:32	20	18	9	1
17:34	20	18	9	1
17:38	20	18	10	1
17:40	20	18	9	1
17:43	20	18	9	1
17:47	20	18	9	1
17:50	20	18	10	4
17:52	19	17	12	6

Table 19. ACM 20 particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A1 ultrafine test dust

Time	ISO 4μm	ISO 6μm	ISO 14μm	ISO 30μm
17:26	20	18	11	9
17:31	20	18	9	>4
17:36	20	18	9	>5
17:41	20	18	9	>4
17:46	20	19	9	>3
17:51	20	18	9	>5
17:56	19	18	9	>5

Table 20. Parker icountOS particle count ISO Code data for 1.0 mg/L, ISO 12103-1 A1 ultrafine test dust

UNCLASSIFIED

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
17:58	19	17	8	4
18:00	19	17	9	1
18:02	19	17	9	1
18:10	19	17	9	1
18:11	19	17	8	4
18:13	19	17	8	4
18:17	19	17	10	1
18:19	19	17	9	4
18:21	19	17	9	1

Table 21. ACM 20 particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A1 ultrafine test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
17:58	19	17	9	6
18:03	19	18	7	0
18:08	19	18	9	5
18:13	19	18	9	6
18:18	19	18	9	4
18:23	19	17	9	6

Table 22. Parker icountOS particle count ISO Code data for 0.5 mg/L, ISO 12103-1 A1 ultrafine test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
18:27	19	17	8	1
18:29	19	17	9	4
18:32	19	17	8	1
18:36	19	17	8	1
18:38	19	17	8	1
18:40	19	17	9	1
18:44	19	17	8	1
18:46	19	17	8	1
18:48	19	17	8	1

Table 23. ACM 20 particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A1 ultrafine test dust

Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
18:28	19	17	9	6
18:33	19	17	8	5
18:38	19	17	9	4
18:43	19	17	8	4
18:48	19	18	9	3
18:53	21	20	10	6

Table 24. Parker icountOS particle count ISO Code data for 0.25 mg/L, ISO 12103-1 A1 ultrafine test dust

To verify the particle counts obtained via the EI 1581 test rig bottle samples of fuel were prepared with a known concentration of 1.0 mg/L, these bottle samples were then particle counted via IP 564 and had their gravimetric loading tested via ASTM D5452. The data generated, provided in Table 25, for the gravimetric weight of dust reflected greater adherence to theoretical values during the bottle sample tests versus the tests performed on the EI 1581 test rig. This data suggests that the EI 1581 gravimetric error is associated with the ASTM D2276 sampling and testing or the EI 1581 testing. The particle count data for the bottle samples fell close, within the same ISO code, to the values obtained with the equivalent EI 1581 test rig theoretical gravimetric loads. 1.0 mg/L of A1 test dust with the EI 1581 test rig had an average of 6423.4 particles $\geq 4\mu$ in size; whereas the average for 1.0mg/L of A1 test dust for the bottle

samples was 6065.5 particles $\geq 4\mu$ in size, validating the particle count data taken on the EI 1581 test rig in accordance with the amount of test dust theoretically injected (theoretical gravimetric readings).

Online EI 1581- A1 test dust			
	Theoretical	Actual	Particle 4(c)
	1	-	6382.8
	1	0.275	6184.2
	1	-	6470.7
	1	-	6431.7
	1	-	6498.2
	1		6473.9
	1	0.125	6481.4
	1	-	6485.3
	1	-	6402.1
Average			6423.4
SD			98.09
Range			314

Bottle Samples- A1 test dust			
	Theoretical	Actual	Particle 4(c)
	1	1.3	5553.2
	1	1.2	5562.2
	1	1	5830.9
	1	1.4	5452.5
	1	1.3	6843.2
	1	1.4	7035.8
	1	0.8	5722.9
	1	1.4	5279.8
	1	1.4	6412.6
	1	0.4	6961.9
Average			6065.5
SD			679.2
Range			1756

Table 25. ISO 12103-1 A1 ultrafine test dust test dust gravimetric and particle count data

Red Iron Oxide test dust evaluation

Red Iron Oxide test dust, having a particle size distribution composed of sub 10 μm particles similar to that of ISO 12103-1 A1 ultrafine test dust detailed in Table 1. Following a 30 minute baseline run the fuel was determined to be clean with a particle count ISO code of 15/13/6/1 with a total average of ~ 210 particles per mL in the $\geq 4\mu\text{m}$ channel with and dry with a Gammon Technical Products Aqua-Glo reading of 1 ppm, and a D-2 Incorporated JF-WA1 Hydro-Light reading of 0.7 ppm free water. Test conditions were established and maintained for 30 minutes each, with gravimetric samples per ASTM D2276 taken at the 5 and 20 minute marks for each evaluation as detailed in Table 26.

Theoretical Gravimetric mg/L	Measured Gravimetric mg/L
1.00	0.27
1.00	0.20
0.50	0.18
0.50	0.20
0.25	0.15
0.25	0.17

Table 26. Red Iron Oxide test dust gravimetric analysis results.

The Parker IOS and ACM20 instruments data collected during the Red Iron Oxide test dust evaluation at the 1.0 mg/L, 0.5 mg/L, 0.25 mg/L, and the baseline contamination levels detailed in Figure 10 and Figure 11, detail the ability of the light obscuration particle counters to detect and quantify the Red Iron Oxide test contaminate. An analysis of the $\geq 4\mu\text{m}$ channel ACM20

particle counts, in Figure 12, shows clear distinction between the 0.5 mg/L and 0.25 mg/L test dust contamination levels, not seen when simply just reporting the ISO codes. The particle count ISO codes for the Red Iron Oxide test dust for the Parker ACM 20 and Parker IOS instruments is provided in Table 27 and Table 28 respectively, the red iron oxide tests even down to 0.25mg/L of the sub 10 μ m particulate would exceed the particle counter limits of 19/17/14/13.

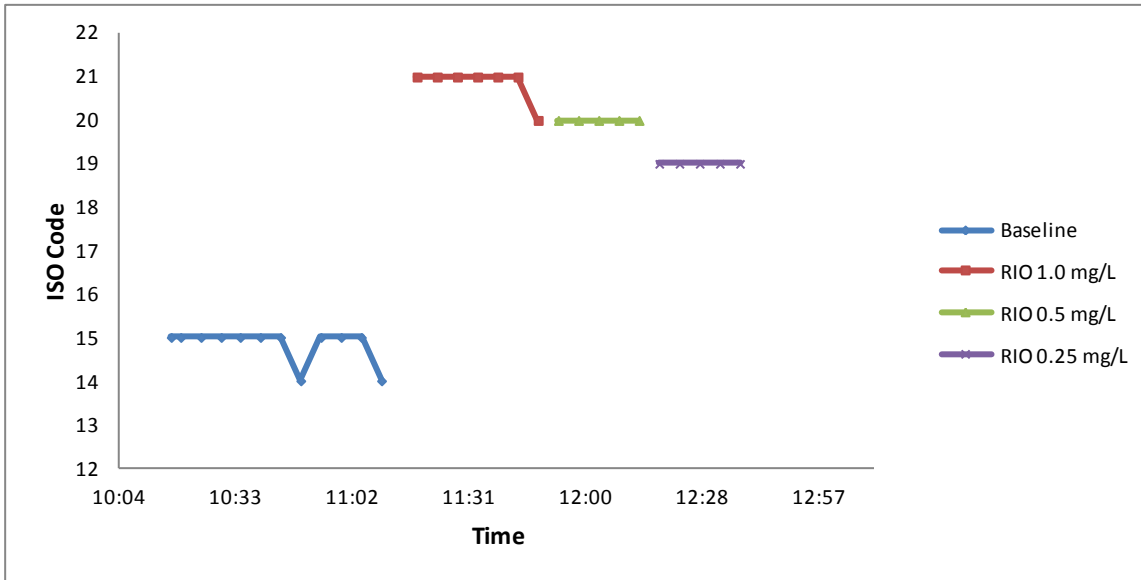


Figure 10. Parker icountOS ISO Code data, red iron oxide test dust $\geq 4\mu$ m channel.

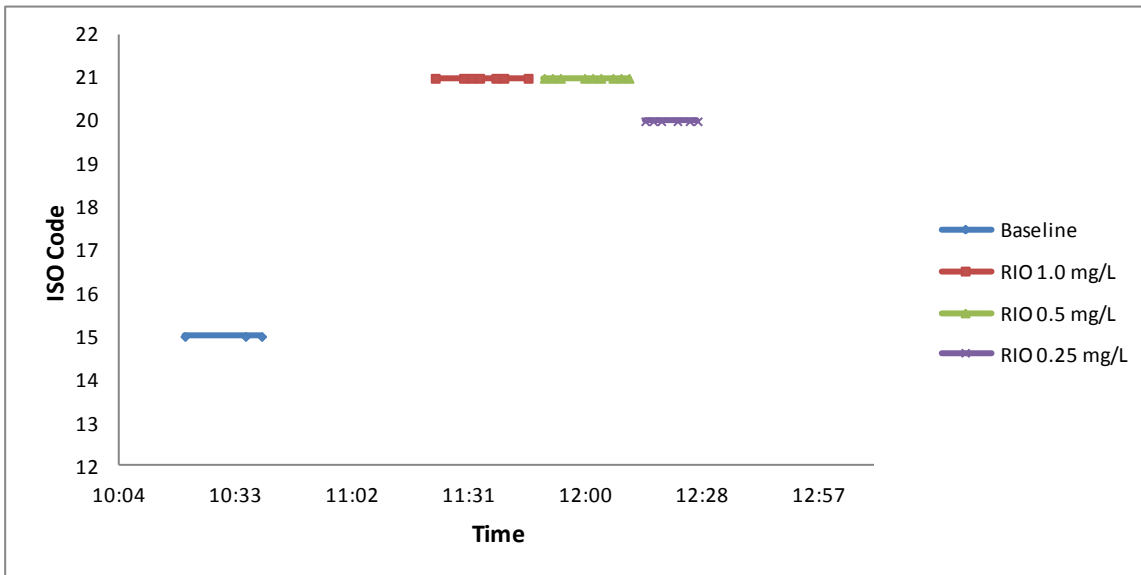


Figure 11. ACM 20 particle count ISO Code data, red iron oxide test dust $\geq 4\mu$ m channel.

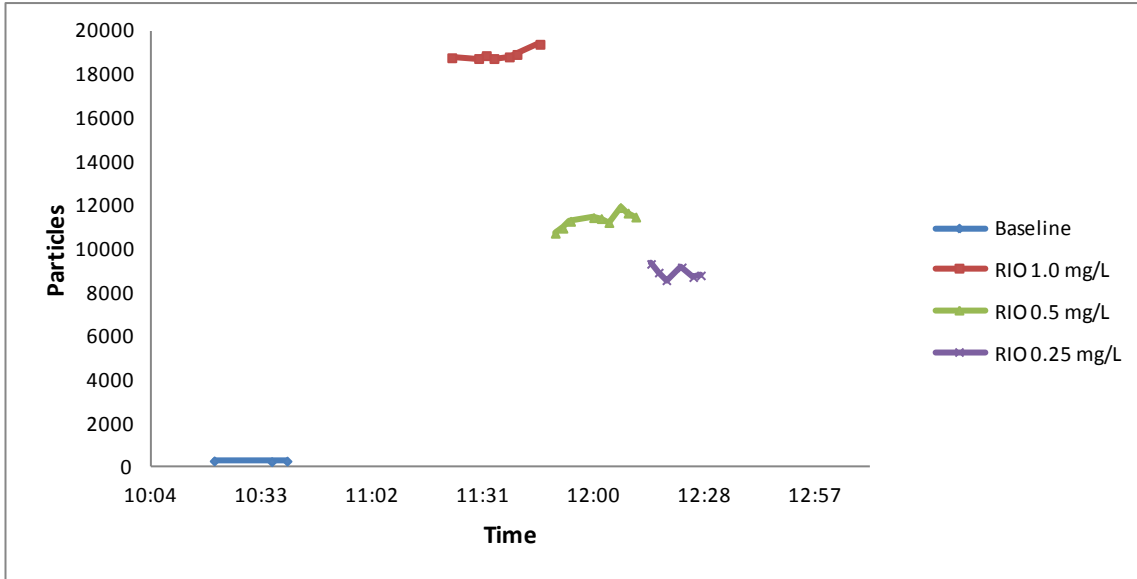


Figure 12. ACM 20 particle counts, red iron oxide test dust $\geq 4\mu\text{m}$ channel.

	test condition	ISO 4 μm	ISO 6 μm	ISO 14 μm	ISO 30 μm
11:23	1.0 mg/L	21	19	10	1
11:30	1.0 mg/L	21	19	10	1
11:32	1.0 mg/L	21	19	10	4
11:34	1.0 mg/L	21	19	10	1
11:38	1.0 mg/L	21	19	10	1
11:40	1.0 mg/L	21	19	10	1
11:46	1.0 mg/L	21	19	10	4
11:50	0.5 mg/L	21	18	8	1
11:52	0.5 mg/L	21	18	9	1
11:54	0.5 mg/L	21	18	9	1
12:00	0.5 mg/L	21	18	10	1
12:02	0.5 mg/L	21	18	9	1
12:04	0.5 mg/L	21	18	9	1
12:07	0.5 mg/L	21	18	9	1
12:09	0.5 mg/L	21	18	9	1
12:11	0.5 mg/L	21	18	9	1
12:15	0.25 mg/L	20	17	9	4
12:17	0.25 mg/L	20	17	10	4
12:19	0.25 mg/L	20	17	8	1
12:23	0.25 mg/L	20	17	8	1
12:26	0.25 mg/L	20	17	9	4
12:28	0.25 mg/L	20	17	8	5

Table 27. ACM 20 particle count ISO Code data for red iron oxide test dust.

	test condition	ISO 4 μ m	ISO 6 μ m	ISO 14 μ m	ISO 30 μ m
11:18	1.0 mg/L	21	18	11	>6
11:23	1.0 mg/L	21	18	10	>6
11:28	1.0 mg/L	21	18	9	>4
11:33	1.0 mg/L	21	18	10	>5
11:38	1.0 mg/L	21	18	10	>6
11:43	1.0 mg/L	21	18	10	>5
11:48	1.0 mg/L	20	16	8	>0
10:53	0.5 mg/L	20	16	9	>5
10:58	0.5 mg/L	20	16	9	>4
11:03	0.5 mg/L	20	16	9	>5
11:08	0.5 mg/L	20	16	9	>4
11:13	0.5 mg/L	20	16	9	>5
11:18	0.25 mg/L	19	16	8	>4
11:23	0.25 mg/L	19	16	10	>6
11:28	0.25 mg/L	19	16	11	7
11:33	0.25 mg/L	19	16	9	>6
11:38	0.25 mg/L	19	15	8	>0

Table 28. Parker icountOS particle count ISO Code data for red iron oxide test dust.

Free water evaluation

To test the light obscuration particle counters capability to detect free water droplets in jet fuel, water was injected into the fuel flow per the requirements of EI 1581. Following a 30 minute baseline run the fuel was determined to be clean with a particle count ISO code of 14/12/7/4 with a total average of ~104 particles per mL in the $\geq 4\mu$ m channel with and dry with a Gammon Technical Products Aqua-Glo reading of 1.5 ppm, and a D-2 Incorporated JF-WA1 Hydro-Light reading of 0.7 ppm free water. Test conditions were established and maintained for 25 minutes each, with undissolved water samples per ASTM D3240 taken every 5 minutes.

The Parker IOS and ACM20 instruments data collected during the free water evaluation is detailed in Figure 13 and Figure 14 respectively, these graphs clearly demonstrate the ability of the light obscuration particle counters to detect and quantify free water. An analysis of the $\geq 4\mu$ m channel ACM20 particle counts, in Figure 15, shows clear distinction between the 5.6, 7.1, 12.6, and 16.2 free water contamination levels, this distinction is not seen by the IOS when reporting the ISO codes only. Analysis of the particle counter data reveals that free water causes a higher than normal reading in the 6 μ m channel, than is seen with test dust contamination, this reveals that the free water is showing up in the 6-14 μ m region at a higher rate than in the 4-6 μ m size channel, and at a higher percentage in the 14-21 μ m region than seen in the test dust evaluations, this particle distribution shift can be clearly illustrated in Figure 16. The particle count ISO codes for the free water evaluation for the Parker ACM 20 and Parker IOS instruments is provided in Table 29 and Table 30 respectively of particular interest in this data is the high ISO codes in the 6 μ m, 14 μ m, and 30 μ m channels, particularly when compared to the ratio of particles in the 4 μ m channel.

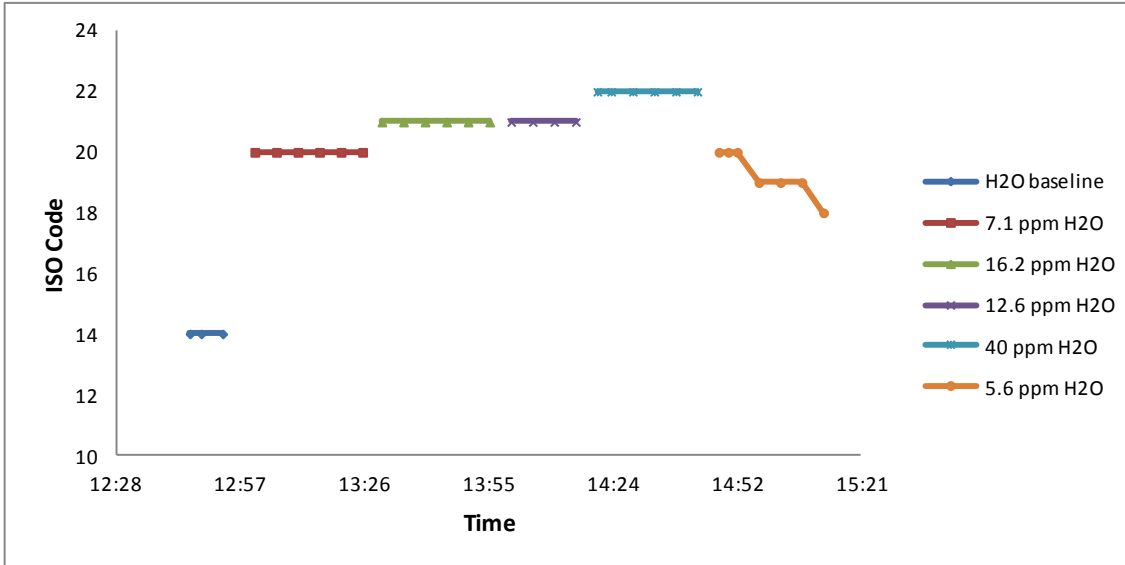


Figure 13. Parker icountOS ISO Code data, free water $\geq 4\mu\text{m}$ channel.

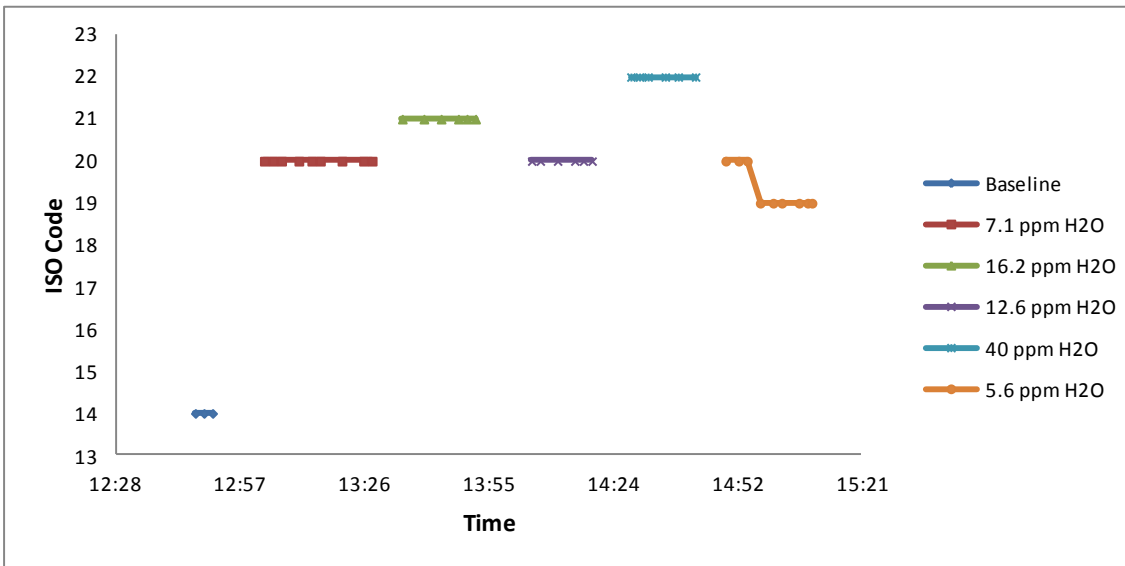


Figure 14. ACM 20 particle count ISO Code data, free water $\geq 4\mu\text{m}$ channel.

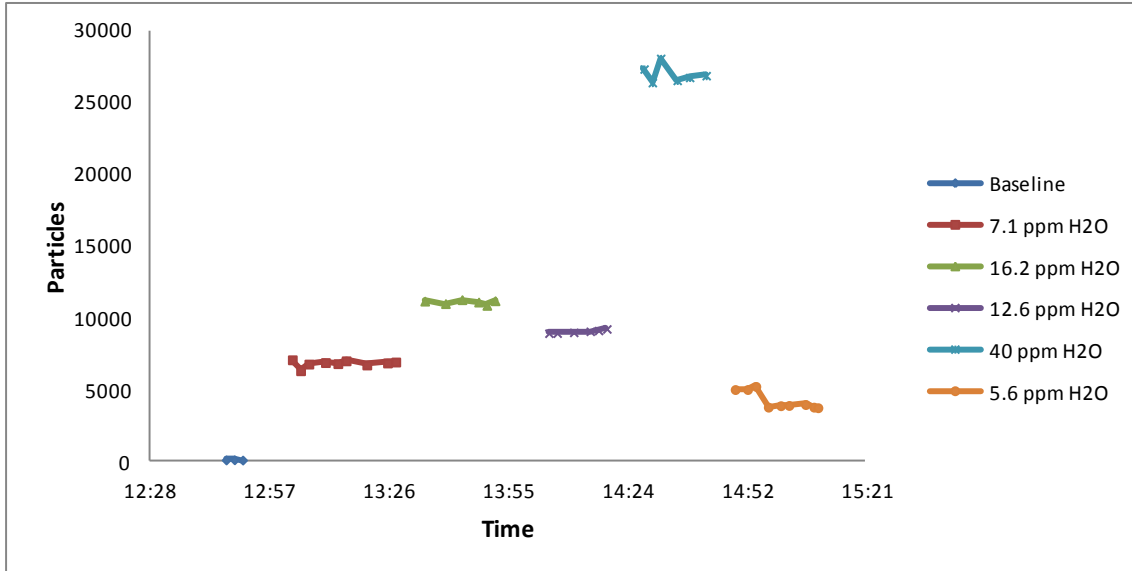


Figure 15. ACM 20 particle counts, free water $\geq 4\mu\text{m}$ channel.

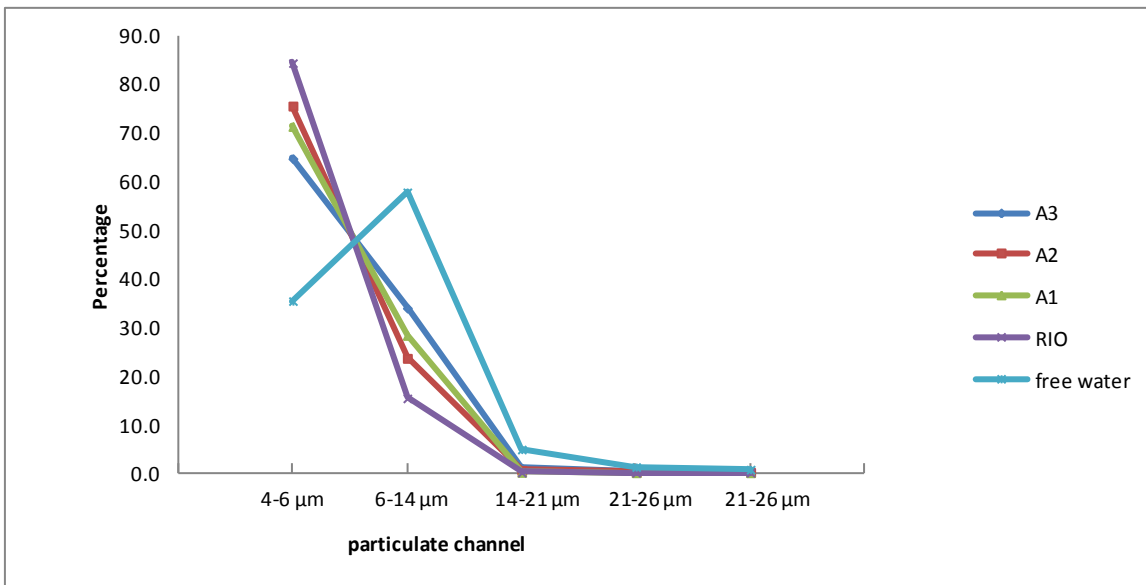


Figure 16. Particle count size distribution for test dusts and free water.

UNCLASSIFIED

	Water	Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
Baseline	0.7	12:47	14	12	7	4
	0.7	12:49	14	12	7	4
	0.7	12:51	14	12	4	1
7.1 ppm	6.7	13:05	20	19	16	10
		13:07	20	19	16	10
	7.2	13:11	20	19	16	10
		13:14	20	19	16	10
	8.1	13:16	20	19	16	10
	7.5	13:21	20	19	16	10
		13:26	20	19	16	10
	6.2	13:28	20	19	16	10
16.2 ppm		13:35	21	20	17	11
	16.9	13:40	21	20	17	11
	17.2	13:44	21	20	17	11
		13:48	21	20	17	11
	14.5	13:50	21	20	17	11
	16.1	13:52	21	20	17	11
12.6 ppm	12.9	14:05	20	20	16	11
		14:07	20	20	16	11
	8.2	14:11	20	20	16	11
	12.4	14:15	20	20	16	10
	12.3	14:17	20	20	16	11
	12.9	14:19	20	20	16	11
40 ppm	39.6	14:28	22	21	18	13
		14:30	22	21	18	13
	40.7	14:32	22	21	18	13
	39.9	14:36	22	21	18	13
	40.6	14:39	22	21	18	13
	38.2	14:43	22	21	18	13
5.6 ppm		14:50	20	19	15	10
		14:53	20	19	15	10
	6.9	14:55	20	19	16	10
		14:58	19	18	15	9
	6.7	15:01	19	18	15	9
		15:03	19	18	15	10
	4.1	15:07	19	19	15	9
	5.0	15:09	19	18	15	10
5.1	15:10	19	18	15	10	

Table 29. Parker ACM-20 particle count ISO Code data free water.

	Water	Time	ISO 4µm	ISO 6µm	ISO 14µm	ISO 30µm
baseline	0.7	12:45	14	12	8	>4
	0.7	12:48	14	12	8	>4
	0.7	12:53	14	12	>5	>3
7.1 ppm		12:58	16	15	12	8
		13:00	20	20	17	13
	6.7	13:05	20	20	17	13
	7.2	13:10	20	20	17	13
	8.1	13:15	20	20	17	13
	7.5	13:20	20	20	17	13
	6.2	13:25	20	20	17	13
16.2 ppm		13:30	21	20	18	14
		13:35	21	21	18	14
	16.9	13:40	21	21	18	14
	17.2	13:45	21	20	17	14
	14.5	13:50	21	20	18	14
	16.1	13:55	21	20	17	14
12.6 ppm		14:00	21	20	17	14
	12.9	14:05	21	20	17	14
	8.2	14:10	21	20	17	14
	12.4	14:15	21	20	17	14
40 ppm		14:20	22	21	19	15
		14:23	22	22	19	16
	39.6	14:28	22	22	19	16
	40.7	14:33	22	22	19	16
	40.6	14:38	22	22	19	16
	38.2	14:43	22	22	19	16

Table 30. Parker icountOS particle count ISO Code data for free water.

ISO 12103-1 A2 fine test dust and free water test dust evaluation

The Parker IOS and ACM20 instruments data collected during the ISO 12103-1 A2 particulate and free water combined contamination evaluation is graphically displayed in Figure 17 and Figure 18 respectively, these graphs clearly demonstrate the ability of the light obscuration particle counters to detect free water in the presence of particulate contamination. An analysis of the $\geq 4\mu\text{m}$ channel ACM20 particle counts, in Figure 19, shows clear distinction between the 7.6 and 8.8 ppm free water contamination levels, this distinction is not seen by the IOS when reporting the ISO codes only. The particle count ISO codes for the particulate and free water combined contamination evaluation for the Parker ACM 20 and Parker IOS instruments is provided in Table 31 and Table 32 respectively of particular interest in this data is the high ISO codes in the 6µm, 14µm, and 30µm channels, particularly when compared to the ratio of particles in the 4µm channel.

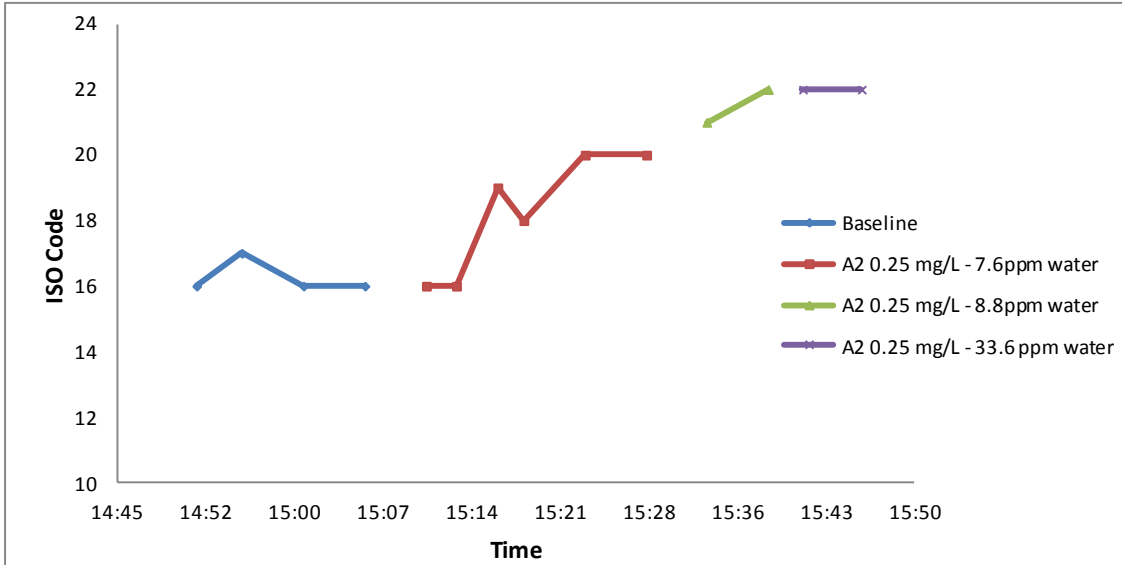


Figure 17. Parker icountOS ISO Code data, ISO 12103-1 A2 fine test dust and free water $\geq 4\mu\text{m}$ channel.

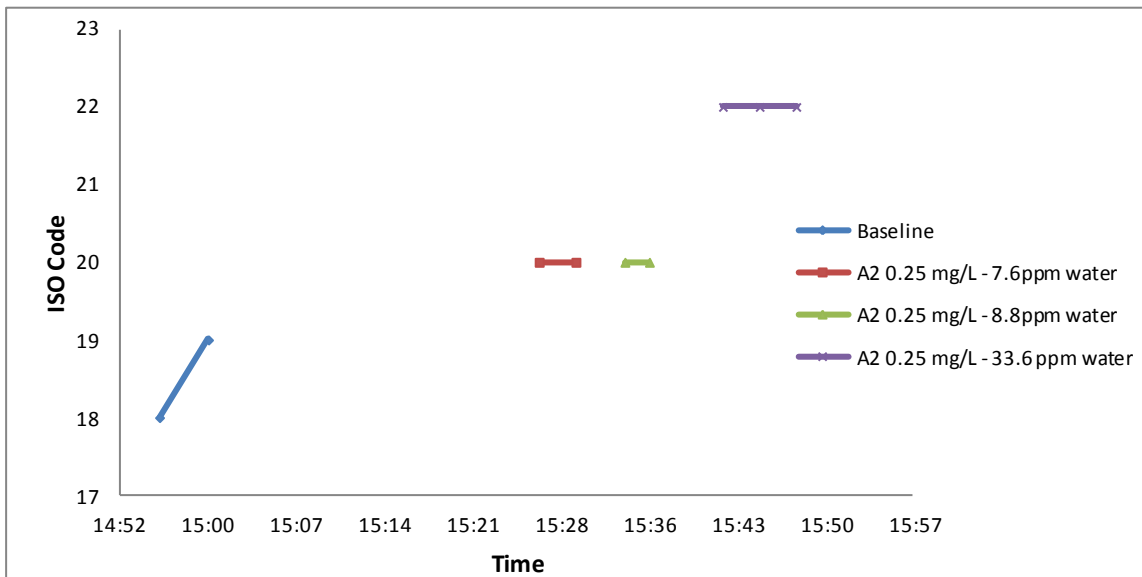


Figure 18. ACM 20 ISO Code data, ISO 12103-1 A2 fine test dust and free water $\geq 4\mu\text{m}$ channel.

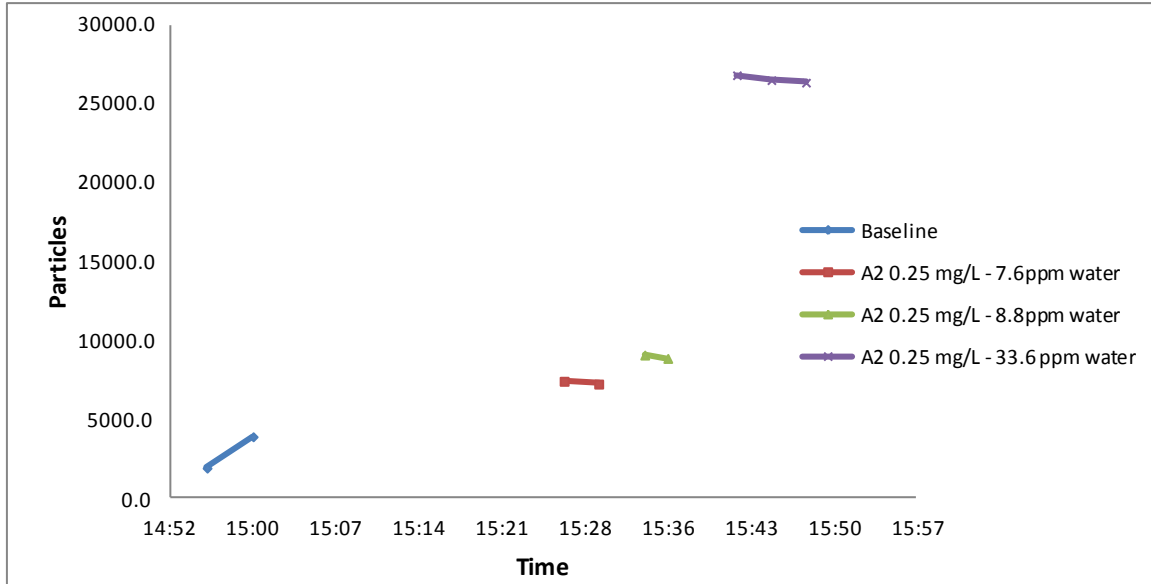


Figure 19. ACM 20 particle counts, ISO 12103-1 A2 fine test dust and free water $\geq 4\mu\text{m}$ channel.

	Water	Time	ISO 4 μm	ISO 6 μm	ISO 14 μm	ISO 30 μm
Baseline	1.5	14:56	18	15	11	9
	1.5	15:00	19	17	14	12
	1.5	15:10	20	18	14	11
A2 0.25 mg/L - 7.6ppm water	8.0	15:27	20	19	16	10
	7.2	15:30	20	19	15	10
A2 0.25 mg/L - 8.8ppm water	8.8	15:34	20	19	16	10
		15:36	20	19	16	10
A2 0.25 mg/L - 33.6 ppm water	33.9	15:42	22	21	18	12
	33.3	15:45	22	21	18	12
		15:48	22	21	18	12

Table 31. Parker ACM 20 particle count ISO Code data for free water.

	Water	Time	ISO 4 μm	ISO 6 μm	ISO 14 μm	ISO 30 μm
Baseline		14:52	16	13	9	9
	1.5	14:55	17	13	9	9
	1.5	15:00	16	13	8	8
	1.5	15:05	16	13	8	8
A2 0.25 mg/L - 7.6ppm water		15:10	16	12	9	9
		15:13	16	13	8	8
		15:16	19	17	12	8
		15:18	18	17	12	7
	8.0	15:23	20	20	16	13
A2 0.25 mg/L - 8.8ppm water	7.2	15:28	20	20	16	13
	8.8	15:33	21	20	17	13
A2 0.25 mg/L - 33.6 ppm water		15:38	22	21	18	15
	33.9	15:41	22	22	19	15
	33.3	15:46	22	22	19	15

Table 32. Parker icountOS particle count ISO Code data for free water.

5. Conclusions

The laboratory data collected supports the proposed ISO code limits of 19/17/14/13, at the 1.0 mg/L concentration levels for the A1 and A2 test dusts, and down to a 5 ppm free water presence. The Parker icountOS instrument providing ISO Code data per ISO 4406.1999 correlates well with the data provided from the Parker ACM 20 instrument. The utilization of ISO code groupings does reduce the depth of information available from the particle count measurements as seen in the transitions between 0.25mg/L and 0.50 mg/L where the ISO codes reported are the same, but does provide a sound basis for comparison multiple particle counts back to gravimetric measurements. Both light obscuration particle counter technologies evaluated were able to properly measure solid particulate contamination and provide an indication of the presence of free water down to the 5 ppm level.

The correlation between the two instruments shows that both calibration methods provide agreement in reported ISO codes and the variation seen in previous evaluations between the two technologies was a results of the sampling methods, on-line vs bottle samples, rather than instrument calibration.

References

1. **Department of Defense Standard Practice.** Quality Assurance/Surveillance for Fuels, Lubricants and Related Products. *MIL-STD-3004C w/change 1*. December 7, 2012.
2. **Headquarters Department of the Army.** Petroleum Laboratory Testing and Operations. *Field Manual No. 10-67-2*. Washington DC : s.n., April 2, 1997.
3. —. Concepts and Equipment of Petroleum Operations. *Field Manual No. 10-67-1*. Washington DC : s.n., April 2, 1998.
4. **Schmitigal, J., Cox, D., Boenker, M., Krizovensky, J.O.** Update on the US Army's Fuel Contamination Detection Efforts. Seattle, Washington : Coordinating Research Council, Inc. 2011 Aviation Technical Committee Meetings, May 2011.
5. **Besse, G., Schmitigal, J.** Army's Evaluation of Aviation Fuel Contaminants Using Electronic Sensors. Alexandria VA : Coordinating Research Council, Inc. Vols. 2013 Aviation Technical Committee Meetings, May 2012.
6. **Dickerson, T.** Navy Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection. *NF&LCFT REPORT 441/14-003*. Patuxent River, MD : Naval Air Systems Command, February 6, 2014.
7. **Bessee, G.** Procurement of Instruments and Limited Comparison Study for Field Evaluation of Automatic Particle Counters. 2014. Vol. SwRI® Project No. 08.15954.08.001.
8. **Schmitigal, J and Bramer, J.** Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection – Fort Campbell. *TARDEC Technical Report 23967*. June 2013.
9. —. Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection – Fort Rucker. *TARDEC Technical Report 23966*. 2013.
10. **Schmitigal, J.** Evaluation of Particle Counter Technology for Detection of Fuel Contamination Detection utilizing Advanced Aviation Forward Area Refueling System. *TARDEC technical report*. Warren : s.n., 2014.
11. —. Evaluation of Particle Counter Technology for Detection of Fuel Contamination utilizing Fuel System Supply Point. *TARDEC Technical Report 24971*. Warren, Michigan : s.n., 2014.
12. **Energy Institute.** Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel. 2nd London : Energy Institute, February 2012.

List of Symbols, Abbreviations, and Acronyms

µm	Micrometer
AAFARS	Advanced Aviation Forward Area Refueling System
AL	Alabama
ASTM	ASTM International
AUST	Australia
EI	Energy Institute
FSSP	Fuel System Supply Point
IOS	icountOS
ISO	International Organization for Standardization
L	Liter
mg/L	Milligrams per Liter
MIL	Military
mL	Milliliter
PPM	Parts Per Million
RIO	Red Iron Oxide
STD	Standard
TARDEC	Tank Automotive Research Development and Engineering Center
U.S.	United States