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Evaluation of Particle Counter Technology for Detection of Fuel Contamination Detection utilizing Fuel System Supply Point

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In June 2013 TARDEC evaluated an online light obscuration particle counter plumbed into a Fuel System Supply Point (FSSP) in conjunction with the Effective Energy for Expeditionary Operations Limited Objective Experiment (E2X LOE) at Fort A.P. Hill during the 2014 Quartermaster Liquid Logistics Exercise (QLLEX '14), to determine if air entrained in the fuel during the FSSP operation would affect the particle counter operation.

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Force Projection Technology

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1. **Introduction**

Fuel quality assurance is accomplished by conducting periodic fuel sampling for the condition monitoring of aviation fuel by detecting, measuring, and reporting the levels of contaminants in the fuel. The currently accepted methods for measuring particulate and free water contamination of fuel supplies include:

- ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
- ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels
- ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)

The current methods have several drawbacks including operator subjectivity, lack of detailed analysis, limitations in providing reliable data, and the turn-around time needed to get the test results.

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).

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 (2) 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 any 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).

The use of particle counting and automatic particle counters is prevalent in the hydraulics/hydraulic fluid industry. The International Organization for Standardization (ISO) has published several methods and test procedures for the calibration and use of automatic particle counters. The transition of this technology to the fuel industry is relatively new and several organizations (military and commercial) have conducted testing to ensure the transition from the hydraulic fluid market to fuels is viable.

In recent years, the United Kingdom (UK) based, Energy Institute (EI) published standards relating to fuel quality measurement using sensors. The first edition of EI 1570 Handbook on electronic sensors for the detection of particulate and/or free water during aircraft refueling was published in August 2012, and the second edition of EI 1598 Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel was published in February 2012. In addition to the handbooks, the EI has also developed three (3) standard test procedures and methods for evaluating the particulate matter of fuels using electronic sensors; IP 564, IP 565, and IP 577.

- IP 564 – Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method
- IP 565 – Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method
- IP 577 – Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction

Military aviation fuels meeting the requirements of DEF STAN 91-91 (UK) (4) and MIL-DTL-83133 (US) (5) both include a report only requirement for particle counting. Particulate contaminate limits using particle counters are being developed as test programs and field demonstrations are in progress.

The U.S. Army and U.S. Navy have conducted laboratory evaluations of particle counter technologies for fuel contamination monitoring. The particle counters tested were unable to adequately distinguish between free water and sediment contamination. Conclusions from the laboratory evaluation indicated that particle counters cannot replace current technology where quantification of both free water and sediment contamination is required. However, this technology showed significant promise for monitoring overall fuel quality. To simplify the reporting of particle counter data, the International Organization for Standardization created Cleanliness code 4406:1999 (6). Several interested parties, both commercial and military, have proposed limits based on light obscuration particle counting technologies based on ISO 4406, provided in Table 1 and references (7)(8)(9)(10)(11)(12)(13)(14). As a result of the laboratory testing conducted, the U.S. Army has proposed a working cleanliness limit (based on ISO 4406) of 19/17/14/13 utilizing the 4µm (c)/ 6µm (c)/ 14µm (c)/ 30µm (c) size channels (9). The U.S. Army has included the 30µm size to detect free water in the fuel.

	Receipt	Vehicle Fuel Tank	Fuel Injector
Aviation Fuel			
DEF (AUST) 5695B		18/16/13	
Parker	18/16/13	14/10/7	
Pamas/Parker/Particle Solutions	19/17/12		
U.S. Army	19/17/14/13*		
Diesel Fuel			
World Wide Fuel Charter 4th		18/16/13	
DEF (AUST) 5695B		18/16/13	
Caterpillar		18/16/13	
Detroit Diesel		18/16/13	
MTU		18/17/14	
Bosch/Cummins		18/16/13	
Donaldson	22/21/18	14/13/11	12/9/6
Pall	17/15/12	15/14/11	12/9/6 11/8/7

Table 1. Proposed Particle Counter Limits
***addition of 30 micron channel proposed by U.S. Army for detection of free water.**

2. **Project Background**

In 2013 Defense Logistics Agency – Energy funded a Tri-Service Field Evaluation of Automatic Particle Counters. Each Service chose two locations to conduct testing. The U.S. Army chose to conduct testing at Campbell Army Airfield at Fort Campbell, KY(15), and three Army Heliports (AHP) at Fort Rucker, AL(16).

The test results at Fort Rucker clearly demonstrated the on-line particle counters susceptibility to providing erroneous results in the presence of air bubbles in the fuel stream. In addition to the light obscuration particle counters displaying these erroneous results when air bubbles were known to be in the fuel stream during fuel receipt operations the test results at Monielli Stagefield Army Heliport's Pad 11, which is at the furthest point away from the bulk fuel storage facility at Molinelli Stagefield AHP fed by a 1/3 mile underground fuel line. The data seen at Monielli Stagefield Army Heliport had spikes corresponding to the fuel pump at the airfield automatically shutting off every 10 minutes and were theorized as being caused due to a "water hammer" effect in the fuel system that shook water free from pockets within the fuel system piping(16).

To follow up on the Fort Rucker testing additional tests were conducted at Redstone Test Center while AMRDEC was conducting Alcohol to Jet (ATJ) fuel flight tests (17). The test results indicated that on-line particle counters, while susceptible to the presence of air found in fueling systems, appear to be compatible to the Army's tactical fueling systems. It should be noted the ATJ testing utilized a commercial fuel tanker to house the bulk petroleum product and not the fuel drums or collapsible fuel storage bags/tanks which may induce more air into the fuel stream than the commercial fuel tanks. The Army's tactical fuel storage drums and collapsible fuel storage bags/tanks are more likely to cause air entrainment in the fueling stream due to the location of fill or discharge port than is seen in commercial fuel tanks with bottom discharge points, and additional testing is recommended on tactical fueling equipment.

In June 2014 the Army conducted a the Effective Energy for Expeditionary Operations Limited Objective Experiment (E2X LOE) at Fort A.P. Hill during the 2014 Quartermaster Liquid Logistics Exercise (QLLEX '14), which included the operation of a Fuel System Supply Point (FSSP) manned by the 439th Quartermaster Company, with afforded an opportunity to evaluate the online particle counter technologies.

3. **Approach**

The FSSP utilized for the QLLEX '14 at Fort A.P. Hill consisted of three 20,000 gallon fuel bladders, two containing 10,000 gallons of fuel and the third bladder was held in reserve as shown in

. Fuel sample ports were inserted upstream and downstream of the fuel filter separator to sample the fuel for the presence of contamination and determination of if the presence of air bubbles in the fuel flow would obscure particle counter readings as shown in **Error! Reference source not found.**.

Figure 1. Fuel System Supply Point (FSSP) set up at POL Site 4 at Fort A.P. Hill during the 2014 Quartermaster Liquid Logistics Exercise (QLLEX '14).

Figure 2. Parker icountOS light obscuration particle counter, BB-2590 battery box accessory, and fuel sampling port.

Initial fuel receipt for the E2X LOE during QLLEX '14 consisted of 20,000 gallons of fuel downloaded into one fuel bladder, 10,000 gallons of fuel was later transferred through the filter separator to the second bladder. During this fuel transfer particle count data was collected at the sample ports upstream and downstream of the filter separator.

The instrumentation utilized for the evaluation was an online instrument Parker icountOS, **Error! Reference source not found.**, the same online instrumentation for previous evaluations. The Parker icountOS instrument contains the similar internal optics and fluid path geometry as the Parker ACM 20 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 iOS instruments are capable of pumping the fuel back into the supply lines; thus creating no waste fuel. Ideally, these instruments can be left in the field to monitor and collect data for fuel transfers. For this demonstration the iOS units were configured to pull fuel samples when manually initiated by the operators for each data set.

4. **Analysis**

The data obtained during the 10,000 gallon fuel transfer indicates that air bubbles are not present in the fuel stream as there are not a large number of particles, as shown in Figure 3, nor are there large particle present as shown in Figure 4 and Figure 5, which is indicative of the presence of air bubbles.

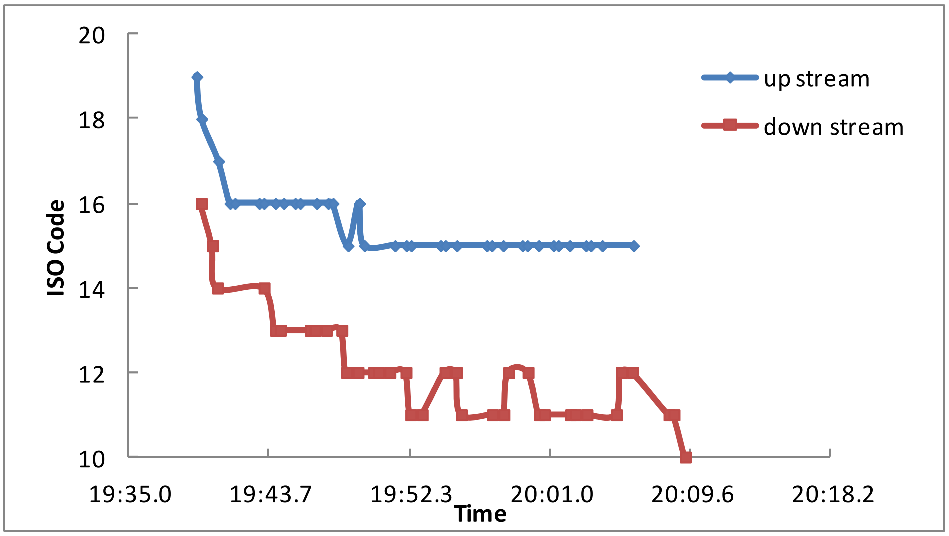

Figure 3. 4µm (c) ISO code particle count data for 10,000 gallon fuel transfer.

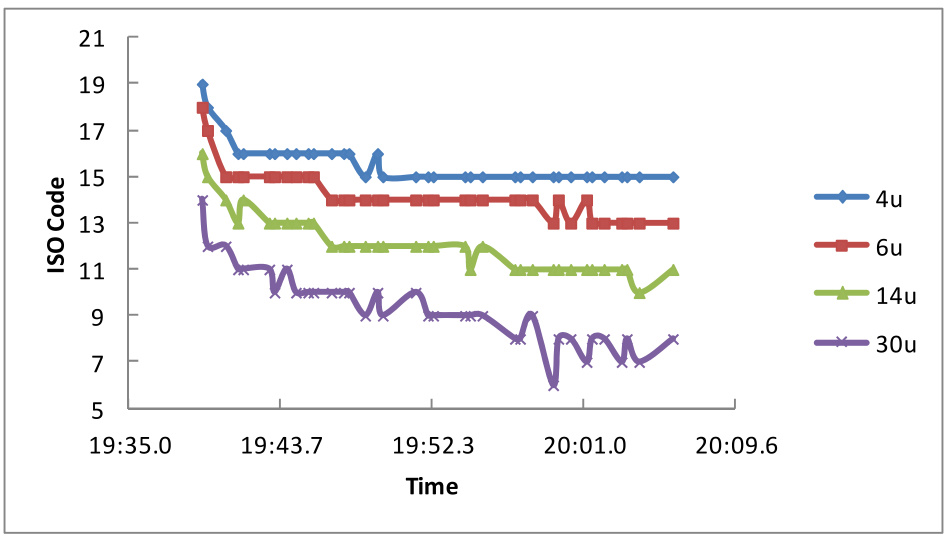

Figure 4. Upstream ISO code particle count data for 10,000 gallon fuel transfer.

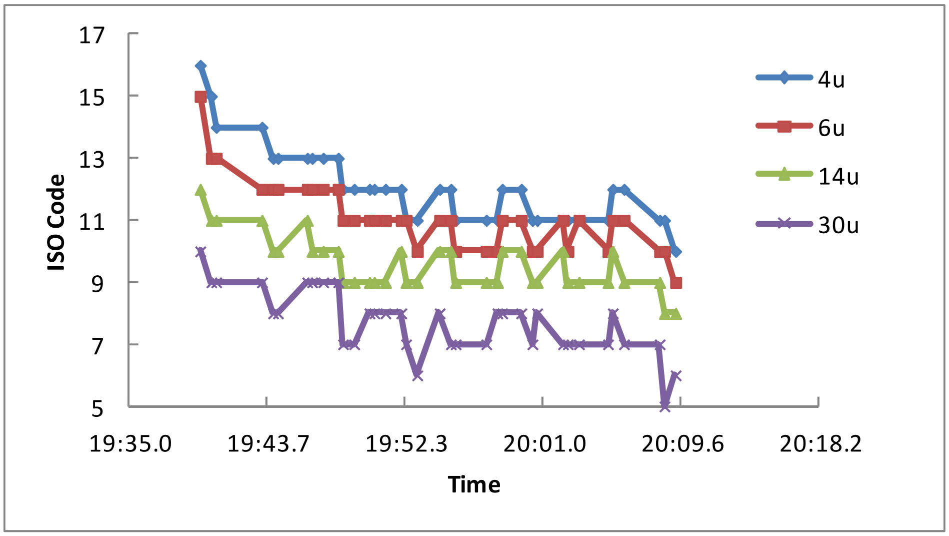

Figure 5. Downstream ISO code particle count data for 10,000 gallon fuel transfer.

5. Conclusion

The test results indicate that on-line particle counters appear to be compatible to the Army's tactical fueling systems. It should be noted that only a limited data set was collected during the 10,000 gallon fuel transfer. A long term evaluation of online particle counter instruments on the Army's tactical fuel storage drums and collapsible fuel storage bags/tanks would give a better indication of the likelihood air entrainment in the fueling stream due to the location of fill or discharge port.

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List of Symbols, Abbreviations, and Acronyms

µm	Micrometer
ASTM	ASTM International
AUST	Australia
DEF	Defence/Defense
DTL	Detail
EI	Energy Institute
FSSP	Fuel System Supply Point
iOS	icountOS
ISO	International Organization for Standardization
MIL	Military
STAN	Standard
STD	Standard
TARDEC	Tank Automotive Research Development and Engineering Center
U.S.	United States
UK	United Kingdom