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Field Demonstration of Light Obscuration Particle Counting Technologies to Detect Fuel Contaminates

Joel Schmitigal

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January 2016

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Field Demonstration of Light Obscuration Particle Counting Technologies to Detect Fuel Contaminates

Joel Schmitigal
Force Projection Technology

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Introduction

The U.S. Army maintains the mission of providing quality fuel to 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).

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 (3) (4).

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 specify limits for free water and particulate matter in aviation fuels. Specifically, free water contamination in jet fuel cannot exceed 10 parts per million (PPM) while 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 sediment and 10ppm water for product to be used in ground equipment (1) (2) (5). 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, whereas 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 in not provided in ASTM D5452, but again, 5 liter samples were used to develop these formulas used for these calculations.

The use of particle counting and automatic particle counters for monitoring contamination is frequently used in the hydraulics/hydraulic fluid industry. In 1999 ISO adopted ISO 11171

Hydraulic fluid power — Calibration of automatic particle counters for liquids (7), replacing ISO 4402, as an international standard for the calibration of liquid particle counters giving NIST traceability to particle size measurement, and providing an area equivalent diameter of particles measured. International standard ISO 4406:1999 *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles* (8) simplifies the reporting of particle counter data by grouping the numbers of particles into broad classes or codes. Generally an increase in one ISO code number is caused by a doubling of the contamination level. EI has also published three standard test methods for evaluating the particulate matter of fuels using light obscuration particle counters; IP 564 – *Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method* (9); IP 565 – *Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method* (10)*;* IP 577 – *Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction* (11). ASTM International adopted ASTM D7619 *Standard Test Method for Sizing and Counting Particles in Light and Middle Distillate Fuels, by Automatic Particle Counter* (12), which utilizes the same instrumentation as IP 565.

As a result of laboratory testing, the Department of Defense has implemented a cleanliness limit (modified from ISO 4406) of 19/17/14/13 utilizing the 4µm (c)/ 6µm (c)/ 14µm (c)/ 30µm (c) size channels (12). The 30µm (c) size is included for the detection of free water in the fuel. The proposed ISO code limits of 19/17/14/13 are based on the 1.0 mg/L concentration levels for the A1 and A2 test dusts, and down to a 5 ppm free water presence.

Approach and Findings

The Parker icount Oil Sampler (IOS) light obscuration particle counter was deployed for a 6 day period of time to demonstrate fuel condition monitoring capabilities by monitoring fuel coming into and out of a Brigade Support Area (BSA). The Brigade Support Battalion maintained a refueling mission by receiving fuel from a rear fuel supply point and staging the fuel in 5000 gallon M969 semitrailer tankers for the refueling of Heavy Expanded Mobility Tactical Truck (HEMTT) M978s. The IOS instrument was installed on a 4” hose connected to the discharge port of one of M969 semitrailer tanker. The Brigade Support Battalion (BSB) personnel pushed all fuel into and out of this semitrailer throughout a 6 day period as the mission would allow at the BSA.

The IOS instrument was set up to run three 30 mL samples in succession every 5 minutes. The instrument was turned on after the hose line was attached between the two trucks and fuel flow had progressed. All fuel used during the evaluation was F-24 aviation fuel.

Day 1

On 24 September, one upload of approximately 2500 gallons of F-24 fuel from the M969 to a HEMTT refueler was observed (Table 1). The initial high readings from the 16:20, are from air in the hydraulic lines running from the sample port to the instrument. Once the air has cleared from the hoses the fuel is clean and in good condition with ISO codes averaging around 16/14/13/13. The ISO code of 13 in the 30 micron channel indicates that there are between 30-80 particles (or water droplets) per mL 30μm or greater in size present in the fuel, falling just under the Department of Defense's 19/17/14/13 limit. Having the same ISO code in the 14μm and 30μm channels indicates that there is not a linear dispersion of particulates (or water droplets) but a high level of contaminate that is ≥30μm equal to or higher than is seen at the 14μm channel.

Date	Time	≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 30 μm
dispense					
9/24/2015	16:09.2	20	19	16	14
9/24/2015	16:09.5	18	17	15	12
9/24/2015	16:10.2	17	16	14	11
9/24/2015	16:14.2	16	15	13	10
9/24/2015	16:14.5	16	15	13	13
9/24/2015	16:15.2	15	15	13	13
9/24/2015	16:19.2	15	14	13	13
9/24/2015	16:19.5	16	14	10	9
9/24/2015	16:20.2	16	14	11	10

Table 1. One upload of approximately 2500 gallons of F-24 fuel from the M969 semitrailer tanker to a HEMTT refueler.

Day 2

On 25 September, six fuel transfers from the M969 semitrailer tanker to HEMTT fuelers were observed (Table 1). Three of these fuel transfers were low volume and short duration, less than five minutes, so only 3 data points were obtained. One was just over 5 minutes and 4 data points were collected, and one was 10 minutes with 8 data points collected. Again the transferred fuel is clean to very clean for the majority of the fuel transfer, but at times the ISO codes in the 14μm and 30μm channels are the same indicative of nonlinear dispersion of particulates or water droplets in the fuel are seen. This nonlinear dispersion is indicative of the presence of objects that are ≥30μm in size. Additionally the 30μm channel is approaching its ISO code limit of 13.

Date	Time	≥ 4 µm	≥ 6 µm	≥ 14 µm	≥ 30 µm
dispense					
9/25/2015	09:13.1	16	14	11	11
9/25/2015	09:13.4	16	14	10	9
9/25/2015	09:14.1	16	14	10	9
dispense					
9/25/2015	10:46.2	16	14	11	>8
9/25/2015	10:46.5	14	13	10	>5
9/25/2015	10:47.2	14	12	>8	>4
dispense					
9/25/2015	11:11.1	15	13	9	>6
9/25/2015	11:11.4	14	11	>9	>5
9/25/2015	11:12.1	14	12	>8	>4
9/25/2015	11:16.1	14	12	>8	>5
9/25/2015	11:16.4	14	12	>8	>5
9/25/2015	11:17.1	14	12	>7	>5
9/25/2015	11:21.1	14	14	13	13
9/25/2015	11:21.4	16	14	12	12
dispense					
9/25/2015	12:06.6	16	14	11	9
9/25/2015	12:07.3	14	12	>9	>6
9/25/2015	12:07.6	14	12	9	>5
dispense					
9/25/2015	12:18.3	14	13	12	12
9/25/2015	12:19.0	15	14	12	12
9/25/2015	12:19.3	15	13	11	10
dispense					
9/25/2015	17:04.2	16	15	12	11
9/25/2015	17:04.5	16	15	13	13
9/25/2015	17:05.2	16	14	11	>9
9/25/2015	17:09.2	15	13	12	12

Table 2. Six fuel transfers from M969 semitrailer tanker to a HEMTT fueler.

Day 4

Following a day of fuel movement inactivity at the BSA on 27 September, 5000 gallons of fuel were received from the fuel point. The fuel transfer took over 20 minutes to complete. There are several instances where the 14µm and 30µm channels exceed the prescribed limits. Having these limits exceeded while the 4µm and 6µm channels remain within the limits is indicative of free water contamination where the water droplets are found to be ≥14µm and/or 30µm. The BSB does not have any quality surveillance capability so free water content could not be verified for the fuel.

Date	Time	≥ 4 µm	≥ 6 µm	≥ 14 µm	≥ 30 µm
receipt					
9/27/2015	10:03.2	18	16	13	12
9/27/2015	10:03.5	17	15	14	13
9/27/2015	10:04.2	16	15	14	14
9/27/2015	10:08.2	15	14	13	13
9/27/2015	10:08.5	16	16	15	15
9/27/2015	10:09.2	16	16	16	16
9/27/2015	10:13.2	15	15	14	14
9/27/2015	10:13.5	16	16	16	16
9/27/2015	10:14.2	16	15	15	15
9/27/2015	10:18.2	16	15	15	15
9/27/2015	10:18.5	16	16	16	16
9/27/2015	10:19.2	16	15	15	15
9/27/2015	10:23.2	15	14	14	14
9/27/2015	10:23.5	15	15	15	14
9/27/2015	10:24.2	14	13	10	>6

Table 3. Fuel receipt transferred into M969 semitrailer tanker.

Day 5

The fuel in the M969 settled for 22 hours before it was transferred to 3 separate HEMMT tankers on 28 September (Table 4). The initial transfer exceeded the 30µm limit on its second measurement and the 14µm and 30µm channel limits in the third measurement. Again these measurements are a nonlinear response, where the same ISO code is provided for 6µm, 14µm, and 30µm channels indicating that the particulates or water droplets are predominately ≥30µm which would indicate free water contamination. The increase in contaminate concentration from what was seen on 27 September when the fuel was received is attributed to the 22 hours of settling time, and water coalescence in the fuel trailer from the time of receipt. Subsequent fuel dispensed from the M969 to HEMMT tankers throughout the day is clean and dry fuel.

Date	Time	≥ 4 µm	≥ 6 µm	≥ 14 µm	≥ 30 µm
dispense					
9/28/2015	08:42.6	15	13	11	10
9/28/2015	08:43.2	15	14	14	14
9/28/2015	08:43.6	18	17	17	17
dispense					
9/28/2015	09:47.2	15	12	>8	>5
9/28/2015	09:47.5	14	11	>6	>0
9/28/2015	09:48.2	14	11	>6	>0
9/28/2015	09:52.2	14	11	>6	>4
9/28/2015	09:52.5	14	11	>5	>4
9/28/2015	09:53.2	14	11	>5	>0
9/28/2015	09:57.2	14	11	>0	>0
9/28/2015	09:57.5	14	11	>5	>0
9/28/2015	09:58.2	14	11	>0	>0
dispense					
9/28/2015	22:30.5	14	11	>7	>7
9/28/2015	22:31.2	13	11	>6	>4
9/28/2015	22:31.5	13	10	>5	>0
9/28/2015	22:35.5	14	13	13	13
9/28/2015	22:36.2	15	14	14	14
9/28/2015	22:36.5	14	11	9	>9
9/28/2015	22:40.5	13	11	>4	>0
9/28/2015	22:41.2	13	10	>4	>0
9/28/2015	22:41.5	13	10	>0	>0

Table 4. Day 5 transfers to HEMMT tankers

Day 6

Fuel received on 29 September was high in the 4µm, 6µm and 14µm channels. It is unknown if this was sediment or free water contamination.

Date	Time	≥ 4 µm	≥ 6 µm	≥ 14 µm	≥ 30 µm
receipt					
9/29/2015	10:35.4	19	18	14	10
9/29/2015	10:36.1	20	18	15	11
9/29/2015	10:36.4	20	18	15	11

Table 5. Day 6 fuel receipt

Free Water Contamination

Free water content was not able to be quantified due to the BSB not having any fuel quality surveillance capability. Fuel that was received at the Expeditionary Base Camp (EBC) less than 7 miles away was receiving its fuel from the same rear fuel point. They were able to confirm that water contamination in fuel used in high pressure common rail fuel injected engines running generators caused system failures (Figure 1). It was verified that the two locations were receiving their fuel from the same fuel point.

Figure 1. Water contaminated fuel

Conclusions

Although the lack of quality surveillance testing performed by the BSB prevented the verification that the light obscuration particle counters were reacting to free water in the fuel, the observation of water contamination in the generators at the second basecamp provides empirical evidence that the particle counter data was high due to free water droplets in the fuel.

The lack of quality surveillance and quality control procedures affecting the generators employing high pressure common rail fuel injected engines is not surprising in that these systems are more sensitive to fuel contamination than the engines utilized in the Army's legacy systems. It is recommended that systems that utilize these components and their compatibility with the Army's fuel handling hardware, procedures, and quality surveillance protocols be further investigated.

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List of Symbols, Abbreviations, and Acronym

µm	Micrometer
ASTM	ASTM International
BSB	Brigade Support Battalion
BSA	Brigade Support Area
HEMMT	Heavy Expanded Mobility Tactical Truck
IOS	icountOS
ISO	International Organization for Standardization
mg/L	Milligrams per Liter
MIL	Military
mL	Milliliter
PPM	Parts Per Million
STD	Standard
U.S.	United States