TECHNOLOGY EVALUATION SUMMARY

AUGUST 2020

FAUDI DIRT DEFENSE FILTER + FAUDI AFGUARD® ELECTRONIC WATER SENSOR

This document outlines the main observations and conclusions from the now completed field evaluations made with the FAUDI 2" and 6" Dirt Defence Filters coupled with the FAUDI AFGUARD® Electronic Water Sensor.

The Joint Inspection Group (JIG) Operations Committee, the Airlines for America (A4A) Fuel Technical Committee, and the International Air Transport Association (IATA) Technical Fuel Working Group concur that the combination has met the operating criteria set out in the Field Trial Protocol for New Filtration/Sensing Technologies[1]. The Joint Industry Filtration Field Trial Group is recommending the Dirt Defence Filter and Electronic Water Sensor combinations listed below may be adopted into standards such as the JIG, ATA103, and IFQP, under defined operating procedures.

Technology Evaluated in the Joint Industry Filtration Field Trial		
Dirt Defense Element, 2" Out-to-In Flow Format	FAUDI Aviation GmbH	Model: DDO2.2-xx-2
Dirt Defense Element, 6" Out-to-In Flow Format	FAUDI Aviation GmbH	Model: DDO6.4-xx-2
Electronic Water Sensor (EWS)	FAUDI Aviation GmbH	Model: AFGUARD® Firmware Version: 01.19
Programmable Logic Controller (PLC)	FAUDI Aviation GmbH	Model: Contamination Control System (CCS) Gold

This technology evaluation summary does not constitute an endorsement, certification or approval of any product by the Joint Inspection Group (JIG), Airlines for America (A4A), or the International Air Transport Association (IATA). Neither is this summary intended to replace an operator's own assessment and evaluation of the technology to determine its appropriateness for its operating environment(s) and standards, nor replace the opinions and expert advice that the operator may receive from third parties.

[1] Field Trial Protocol Issue 2, dated March 2020

TECHNOLOGY EVALUATION SUMMARY

Key Results of FAUDI Dirt Defence Filter with FAUDI AFGUARD Sensor

Throughout the Joint Industry Filtration Field Trials:

- Approximately 11,000 Chemical Water Detector (CWD) tests corresponding to field trial operations
- Sensors detected water going to aircraft and successfully shutdown fuelling while always assuring the fuel delivered met specification
- The 12 successful shutdowns accounted for 0.1% of all fuellings
- No reported mechanical or electronic failures of the EWS
- No anomalies revealed on EWS testing (i.e. loop testing and recertification checks)
- No evidence to suggest that EWS was not correctly measuring water in fuel
- No structural failure of dirt defence elements
- No evidence of dirt passing downstream of filter
- No difference observed between laboratory and real world performance

The FAUDI dirt defence filter (DDF) and FAUDI AFGUARD® electronic water sensor (EWS) combination, fitted downstream of the filter vessel, was tested for up to 12-months, in 8 vehicles, at 7 airports. For data collection purposes associated with the trial, an additional EWS was installed upstream of the filter vessel, along with an electronic bulk water detector and an electronic differential pressure (dP) transducer. All were connected to the CCS Gold PLC. The 8 vehicles were different ages and designs; manufacturer authorised technicians installed all equipment needed to safely integrate the systems. These individual installations required specialised knowledge of all components to achieve correct functionality.

The inlet EWS show the vehicles were generally exposed to clean, dry fuel conditions. The 7 locations measured on average less than 5 ppm free water in fuel upstream of the filter vessel. The measured water content downstream of the DDF was also less than 5 ppm average. The AFGUARD's stated accuracy is +/- 3 ppm water, which can explain variations in some sensor readings. The measured water content can be summarized as:

Average Water Measured During Field Trial *(expressed as a % of total fuellings)*			
	UPSTREAM	DOWNSTREAM	CWD PASSED
<15 ppm water	99.7%	99.9%	100%
15 – 30 ppm water	0.3%	0.1%	100%
>30 ppm water	0.0%	0.0%	N/A

The differential pressure (dP) across the DDF filters remained essentially unchanged from the initial start-up dP (c.2psi) in all vehicles, with throughput between 4 and 50 million litres. The consistently low dP observed suggest that filter elements can last several years in environments with relatively clean and dry fuel, while

TECHNOLOGY EVALUATION SUMMARY

exhibiting adequate performance. Following the field trial, a select number of used elements and all used sensors were returned for laboratory testing, which all passed the protocol performance criteria.

Finally, a Failure Modes and Effects Analysis (FMEA) study of the combined filter and sensor technology in fuelling equipment was conducted. The results substantiated the end-to-end system functionality and can be used to develop appropriate operating parameters. The FMEA noted, that certain deadman override designs could disactivate the EWS during fueling operations. In real world use, full EWS functionality should be verified with each vehicle's deadman override system prior to commissioning the DDF + EWS system, in particular during the retrofit of existing vehicle fleets.

Observations of DDF + EWS performance when free water is present

Whilst the average water content was less than 5 ppm, the AFGUARD detected 12 water events (0.1% of the 11,000 fuellings) where free water exceeded 30 ppm for more than 10 seconds or exceeded 50 ppm for more than 5 seconds. Fuelling was successfully shutdown in all 12 events.

Details of Shutdown Events

Location	Average filter monitor element life	Shutdowns as a % of overall number of fuellings	Shutdown Date	Upstream Sensor		Downstream Sensor		Description of shutdown cause
				peak† ppm free water	avg† ppm free water	peak† ppm free water	avg† ppm free water	
A	3-4 weeks in spring months	0.4%	March	50.3*	3.0	50.3*	7.6	Seasonal free water in the system combined with possibility of overnight condensation in vehicle
			March	50.3*	3.9	50.3*	6.8	
			March	50.3*	4.7	50.3*	10.9	
			May	50.3*	2.5	50.3*	4.3	
B	12 months	0.6%	February	0.1	0.1	50.3*	0.5	Small amounts of free water accumulating on the upstream side of filter at low flow, pushed through at high flow
			February	6.9	0.1	50.3*	1.6	
			March	50.3*	0.1	50.3*	1.6	
			March	0.1	0.1	50.3*	1.3§	
C	12 months	1.4%	January	0.7	0.1§	50.3*	3.2§	Large day-to-night temperature swing while equipment was out of use for a few days without flushing first
			January	0.1	0.0§	50.3*	3.5§	
			February	0.1	0.1§	50.3*	3.3§	
			March	0.1	0.1§	50.3*	3.2§	

*The AFGUARD sensor maximum reading is 50.3 ppm

†Peak is the highest value detected over a 2-second interval; Average is the cumulative average free water content for the entire delivery

§Approximate average. After shutdown, fuelling was discontinued with DDF and finished with equipment fitted with filter monitors

TECHNOLOGY EVALUATION SUMMARY

No water slugs were observed during the trial; therefore, the DDF and EWS performance in a severe real-world upset cannot be stated. However, laboratory data demonstrate that AFGUARD can detect a water slug using a PLC programmable shutdown time. Given that all other field trial data showed no difference from laboratory data, it is expected that a water slug would be detected.

In the laboratory, the FAUDI DDFs demonstrated a low flow ability to temporarily hold back water (typically <50% of rated flow). During the trial, some temporary increases, including 1- or 2-second spikes, in upstream water did not transfer across the filter. Additionally, occasional overnight water condensation in the filter vessel was detected by the downstream sensor. Given these sensor reading differences, and the filter's limited ability to hold some water, the trial data supports a single downstream EWS will provide sufficient protection against elevated levels of free water in the jet fuel.

Recommendations Derived from the Field Trial

1. **The combination of FAUDI dirt defence filters and FAUDI AFGUARD electronic water sensor should be adopted into the operating standards.**

   Almost 11,000 fuellings were conducted during the Joint Industry Filtration Field Trials, throughout which all fuel deliveries met the free water specification. Although the dirt defence filter is not intended to remove free water from fuel, when free water was present the AFGUARD EWS detected that water and successfully shut-down fuelling to prevent increased levels of water from reaching aircraft. The combination was confirmed to be durable in mobile applications and to have sufficient life for routine operations. ***The Field Trials have demonstrated that the combination technology prevents dirt and free water from reaching the aircraft in the environments in which they were tested.***

   This recommendation is conditional upon the system settings detailed in item 7 below being used.

2. **Operators should note the potential limitations of this combination.**

   Although the Field Trials indicate the technology can ensure delivery of fuel meeting the free water specification, it may not be suitable in all airports due to operational considerations. Operators with known free water challenges should note the potential for service disruption due to increased number of EWS warnings and shutdowns. We recommend that operators conduct their own evaluation of the technology to determine the operational impacts at their location before adopting the technology on a large-scale. Such an evaluation might be more meaningful at periods when free water in fuel is more likely to be observed. Operators should weigh this potential impact against the limitations of other technologies. It is our collective experience that other filtration technologies have limitations in locations with water challenges, such as frequent filter monitor change-outs or filter water separators with microbiological growth.

3. **The relationship between Filter Monitor change-out frequency and operability of dirt defence filter with EWS.**

   Most field trial locations did not experience any warnings or shutdowns when their EI1583 filter monitor service life was typically 12-months. Field trial locations that historically replace filter monitors more

TECHNOLOGY EVALUATION SUMMARY

frequently during the winter to spring ambient temperature change experienced more warnings and shutdowns during that period. Users should consider this factor during any potential wet season usage.

4. AFGUARD EWS should be installed downstream of filter vessel.

Throughout the trial, the AFGUARD performed consistently both in the upstream and downstream positions. However, given the observed differences in the amount of water present upstream vs downstream and the water retaining characteristics of DDF elements, we recommend installing the EWS downstream to get the most accurate reading of the fuel "as-delivered" to aircraft.

5. No evidence that Dirt defence filters are susceptible to microbial growth (MBG).

The trial confirmed that the FAUDI dirt defence filters have limited water retaining properties in certain operating conditions. The field trial did not generate any data to suggest that dirt defence filters are susceptible to MBG. Although there was no evidence of MBG issues from this field trial, good housekeeping is critical, see item 6 below.

6. Dirt defence filter vessels should be checked daily for water and particulates.

Due to the coalescence and small water holding capability, good housekeeping and application of routine filter drain procedures are still essential to be applied. Dirt defence filter vessels should be sumped or drained daily under pressure.

7. The FAUDI CCS (Gold) PLC can be utilized in the DDF with AFGUARD configuration. Other PLCs may be compatible with this system, but only the FAUDI PLC was evaluated during the trial.

Only the FAUDI CCS (Gold) PLC has been trialled together with the FAUDI DDF and FAUDI AFGUARD EWS combination. Other PLCs may be compatible with this system but were not evaluated in the trial.

The PLC settings on which the field trials were based are as follows:

- Downstream reading of 50 ppm free water in fuel for 5 seconds triggers shutdown of fuelling
- Downstream reading of 30 ppm free water in fuel for 10 seconds triggers shutdown of fuelling

8. Individual operations should conduct their own process hazard analysis.

Although a Failure Modes and Effects Analysis (FMEA) was conducted on typical refuelling equipment types, individual operating environments and equipment do vary. It is recommended that operators conduct their own site-specific assessment to ensure successful integration of the dirt defence filter with EWS combination with existing equipment. Particular attention should be paid to the design of the deadman override to ensure that the EWS system remains active at all times.

9. No conclusions can be reached about the suitability of the AFGUARD as a slug control device.

No water slugs were observed during the trial; therefore, the dirt defence filter and FAUDI AFGUARD performance in the presence of a severe real-world upset cannot be stated. However, based on the laboratory data, it is expected that the AFGUARD will successfully detect a water slug, but the shut-

TECHNOLOGY EVALUATION SUMMARY

down time will depend on how the PLC is programmed. The CCS Gold allows the response time to be adjusted as required.

10. Electronic water sensors and associated electronics should be installed by manufacturer-authorised technicians and commissioned by competent technicians.

Electronic water sensors and other associated electronics should be installed by manufacturer-trained and competent technicians. The manufacturer's installation requirements must be followed to achieve proper functionality. A Management of Change (MOC) process, that includes equipment suitability, and connection and interface with the specific vehicle, should be utilized. As part of the MOC, a detailed EWS system commissioning procedure should be followed by competent technicians, to verify that the EWS system is configured properly and functions as expected and that no unauthorized bypass routes are allowed by the vehicle design (e.g. by the deadman override design)

11. Internal inspection of dirt defence filter vessels should be done annually.

At the conclusion of the field trial, there was no evidence for internal vessel degradation, or element deterioration that support more frequent internal checks.

12. PLC set points should be programmed to shutdown fuelling when the downstream AFGUARD detects >30ppm water for 10 seconds, or >50ppm water for 5 seconds, minimum.

The trial utilized three set points for the downstream AFGUARD:

- Warning at ≥15ppm free water, for 10 seconds
- Alarm at ≥30ppm free water, for 10 seconds
- Alarm at ≥50ppm free water, for 5 seconds

The Field Trial showed that these setpoints were sufficient to ensure all fuel delivered to aircraft met the free water specification. The alarm setpoints listed should be considered the minimum values to program into the PLC. The warning setpoint should be considered as good practice when it prompts another method of confirming free water meets the specification, such as conducting a CWD check when a warning setpoint is reached.

13. Conclusions only apply to the test environments included in this field trial.

While there was no evidence suggesting these conclusions could not broadly apply, the field trial can only confirm these conclusions in the tested environments. For example, FAUDI states the AFGUARD operates from -30 °C to +60 °C ambient temperatures; however, the field trial only included ambient environments from -7 °C to +38 °C.

These conclusions are not intended to replace an operator's own assessment and evaluation of the technology to determine its appropriateness for its operating environment(s) and standards, nor replace the opinions and expert advice that the operator may receive from third parties.

TECHNOLOGY EVALUATION SUMMARY

Appendix A
Technology Background

The FAUDI AFGUARD® Electronic Water Sensor conforming to EI 1598 2nd edition

The FAUDI AFGUARD Sensor was developed in 2009 to measure free water in aviation fuels. It works by pulsing infrared light into the fuel stream. This light will be scattered by water droplets and other debris in the system. The AFGUARD then measures the amount of light transmitted through the fuel and comparing to the amount of light reflected back to the sensor. FAUDI states the AFGUARD can measure 0-50 ppm of free water in aviation fuel with a +/- 3 ppm accuracy and can also detect water slugs. The AFGUARD is to be operated from -30 °C to +60 °C (-22 °F to +140 °F).

The Energy Institute (EI) published a specification, EI 1598, for devices capable of detecting free water and/or dirt. The FAUDI AFGUARD® Electronic Water Sensor is within the scope of EI 1598 and was self-tested by FAUDI against the EI1598 1st edition requirements in 2009. Shell Aviation subsequently conducted a field study which concluded that the AFGUARD was effective at detecting free water in jet fuel downstream of existing filters (report dated 19/5/2017). Based on this industry work, the JIG and IFQP Standards adopted the EWS as an alternative for chemical water tests. A new firmware version (01.19) of the AFGUARD was confirmed to meet the EI 1598 2nd edition requirements in April 2019.

The FAUDI EI 1599 2nd edition qualified DDO Dirt Defence Filter

The EI first published the EI 1599 dirt defence filter specification in 2007, but in 2019 updated to the 2nd edition with Addendum. Dirt defence filters are similar in construction and basic use to EI 1590 microfilters. The filters are designed to remove dirt and solid debris from aviation fuel, but water will pass through. FAUDI successfully qualified their 2” DDO elements in July 2019 and qualified their 6” DDO elements in March 2018. Finally, DDO elements were subjected to electrostatic charge testing, which was successfully completed in 2019 for both the 2” and 6” systems.

The FAUDI DDO and AFGUARD Combination

The EI conducted Robustness Testing of the 2” and 6” FAUDI DDO and FAUDI AFGUARD® combination, completed in 2019, after which the EI’s Aviation Fuel Filtration Committee recommended that the combination was suitable for into-plane field trial.

TECHNOLOGY EVALUATION SUMMARY

Appendix B
Field Trial Equipment Configuration

Below represents the principles of equipment configuration. The specific individual configurations varied due to equipment design differences.