Persistence of Bleed Air Contaminants on High Efficiency Particulate Absorption Filters

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I. Introduction

Commercial aircraft are normally pressurized and ventilated by bleed air from propulsion engine compressors. In certain situations, contaminants from an engine-related source, likely oil from leaky seals, can be introduced into bleed air supplied to the cabin—e.g. (Murawski & Supplee, 2008; Senate, 2000; Van Netten, 2005). When contamination occurs, it is very difficult to exactly identify the nature of the contamination, sometimes requiring multiple occurrences of contamination before the cause is identified or properly addressed. Of primary interest, then, is the ability to detect and determine the source of contamination following a bleed air contamination event. In a previous study, Eckels et al. proposed to determine the nature of the contamination after an event by analyzing the cabin recirculation HEPA filters present in nearly all commercial aircraft (Eckels, Jones, Mann, Mohan, & Weisel, 2014). Using gas chromatography/mass spectrometry (GC/MS), they show a statistically significant elevation in synthetic oil and certain isomers of tricresyl phosphate (TCP), an additive of jet engine oil, on recirculation filters removed from aircraft identified by the operator as potentially having air quality problems. They concluded that, while further research is necessary to validate the method, using GC/MS to analyze HEPA filter specimens from problem aircraft provides useful information as to the likely contamination source.

Key factors in the validity of this type of analysis are the length of time the oil remains on the filters after deposition and whether or not the constituents evaporate at different rates causing a change in relative concentrations. Filters present during contamination events may be left in place for unknown periods of time before being removed. There may also be a time lapse after the filters are removed from service but before the filters can be analyzed. These factors pose a risk to the accuracy of the data collected and impact the applicability of the method proposed by Eckels et al. If the oil dissipates very quickly, e.g. in a few days, then time is of the essence in removing the filters and collecting filter media specimens for analysis. However, such a short life would allow the method to be very

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time specific. That is, any evidence of oil contamination would be evidence of a recent event. On the other hand, if the oil is very stable on the filters, e.g. stays on for months, then removal and sampling is not time critical, but any evidence of oil contamination is not time specific. It could have occurred recently or weeks or months prior. It could be the result of continuous low level contamination or it could be the result of one or a few significant events. Knowledge of the stability of the oil on HEPA filter media is, thus, an important question in the application of the Eckels et al. research.

Similar to the work by Eckels et al., Lamb et al. studied contaminants in aircraft cabins by taking swabbed samples from surfaces in the cabin and similarly analyzing them for organophosphates using GC/MS (Lamb, McGonagle, Cowie, & Cherrie, 2002). In the validation of their study, they measured the degradation of various organophosphates over time both in vials and on various plastic surfaces. Their data indicated that vials not exposed to light have a significant amount of the organophosphate (including TCP) present for longer than 21 days. However, surface samples showed significant decrease in amount, reducing over 90% in 21 days. In their report, they indicate that more porous surfaces showed a much greater persistence of the material than the less porous surfaces.

The research reported in this paper was designed to answer the oil stability on filter media question by measuring the persistence and makeup of jet engine oil on HEPA filters over time. This research differs from the Lamb et al. study because the material on which the oil is absorbed is HEPA filter media with a very different composition than plastic surfaces and it is not exposed to light. Additionally, the data were collected with air flow through the HEPA filter simulating an actual HEPA filter in use.

II. Materials and Methods

A. Summary of Methodology

A test stand was built in order to simulate the conditions of in-use recirculation filters. Clean HEPA filter media were contaminated with oil and exposed to a continuous stream of air at a media velocity comparable to the flow through actual aircraft HEPA filters. After various time intervals, specimens were removed, weighed, placed in sealed containers, and placed in cold storage for later chemical analysis evaluation. At the conclusion of 32 weeks of exposure, specimens were analyzed with GC/MS.

B. Specimen Preparation

Twenty five millimeter diameter specimens were cut from clean HEPA filter media from a standard cabin aircraft filter. The specimens were conditioned in an environmental chamber at 40% RH and 25°C for approximately 24 hours and were then weighed on a scale with an accuracy of ±0.1 mg prior to contamination. Pipettes were then used to place three drops of Mobile Jet Oil II oil on each filter specimens. Each specimens was carefully squeezed between thumb and forefinger (gloved) in order to aid with the even distribution of oil across the filter specimen. These specimens were then weighed again prior to being placed within the test stand. The average weight of the clean filter specimens was 37.6mg. The average amount of oil deposited on the filters was 92.8mg.

C. **Test Stand Description**

A test stand was designed and constructed to simulate the airflow through an in-use HEPA filter. Figure 1 shows a diagram of the test stand. A rotary vane pump pulled air through the filter specimens mounted in filter cassettes. Each filter cassette also contained an additional filter upstream of the doped specimen to act as a prefilter for the air. The first set of specimens used in the test stand did not use pre-filters. Further modification of the setup implemented pre-filters for all subsequent steps. Air flow meters and needle valves were used to accurately regulate the air velocity. The estimated face velocity for the air through the specimens on the test stand was 6.14cm/s and was estimated from typical face velocity of a Pall Inc. CD00973F2 filter for McDonnell-Douglas (MD-82) aircraft from (Xu, Liu, Ren, Yin, & Chen, 2013). The test stand accommodated twelve specimens. During operation, the test stand was placed in an environmental chamber to allow humidity conditioning of the filters before weighing.

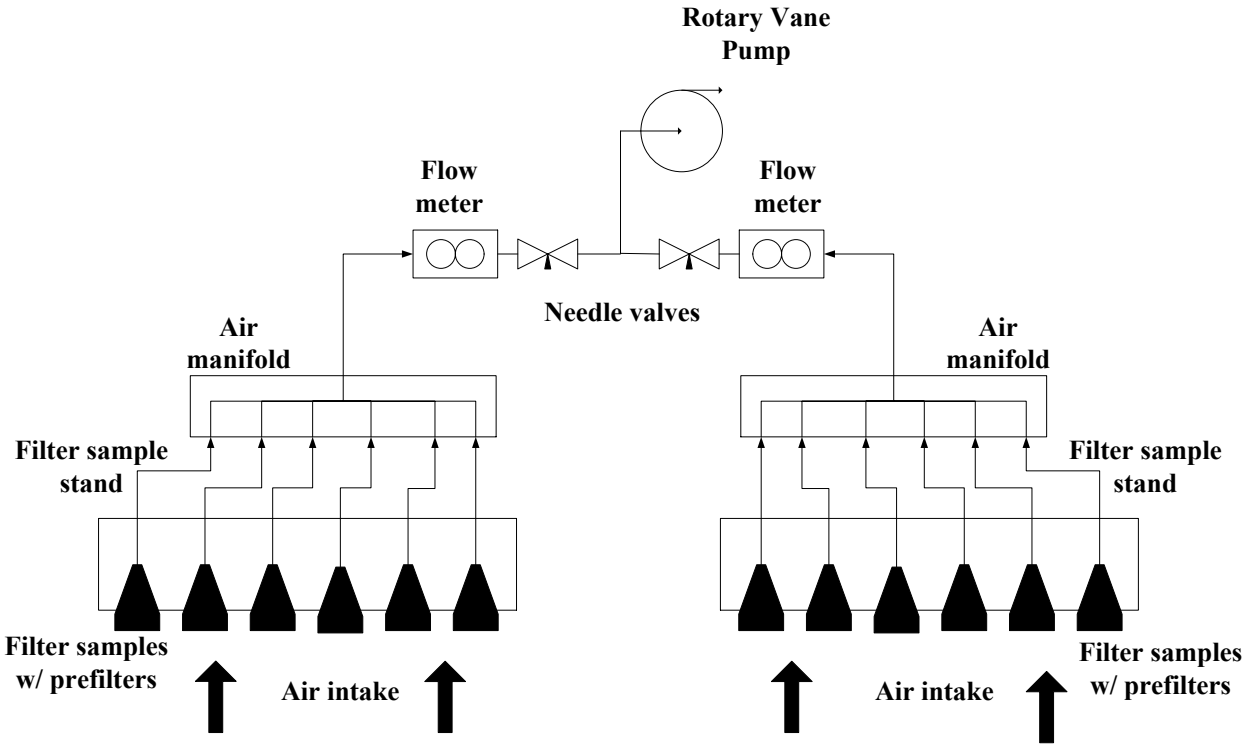

Figure 1: Test stand schematic.

D. **Test Matrix and Conditions**

Two sets of eighteen specimens were used in the testing. For each set of eighteen, four specimens were placed in sealed plastic bags and stored in a freezer (to prevent loss of VOCs) as control specimens. Twelve were placed in the test stand and subjected to the airflow continuously for various time intervals as specified in Table 1. Two additional

specimens were placed in cartridges and left in the same chamber, without air motion. The chamber was not environmentally controlled during the entirety of the test; the ambient temperature varied between approximately 15-30°C.

After removal, specimens were stored in sealed plastic bags in a freezer. New clean filter specimens were placed in the filter cassettes replacing the extracted specimens in order to prevent an imbalance of flow from the manifolds. This process was repeated until all specimens had been removed.

Table 1: Removal times for specimens.

Time Lapse (weeks)	0	1	2	4	8	16	32
Number of Specimens	4	2	2	2	2	2	2+2
Type of Specimens	control	exposed	exposed	exposed	exposed	exposed	exposed/ambient

E. **Gravimetric Measurements and Specimen Handling**

Twenty four hours prior to a specimen extraction, the environmental chamber was conditioned at 40% RH and 25°C to minimize humidity variations affecting the gravimetric measurements. Specimens were extracted in pairs, with one specimen coming from each manifold. Specimen extraction required the test stand to be temporarily shut off. Using nitrile gloves, the desired specimen cartridges were removed from the test stand. Cartridges were then opened, and with tweezers, specimens individually weighed. After measurements were completed, specimen was placed in a sealed plastic bag and placed in the freezer. Clean specimens were then used to replace extracted specimens. The test stand was turned on, and each needle valve readjusted to set the correct face velocity. Gravimetric measurements are not reported for the non-prefiltered specimens because they are invalidated by the accumulation of ambient particulates.

F. **GC/MS Measurements**

Twelve exposed, two ambient, and one control specimens from the non-prefiltered set along with ten exposed (all but the 32 week specimens) and one control from the prefiltered set were sent to Environmental and Occupational Health Sciences Institute, Robert Wood Johnson Medical School at Rutgers University for GC/MS analysis. The GC/MS analysis procedure was the same as that described in (Eckels et al., 2014). Four different isomers of TCP were found in all specimens: meta-TCP, para-TCP, and two unknown but differentiable isomers of TCP designated

unknown 1 and unknown 2. The GC/MS also gave the mass of the particular isomer that was found in each filter specimen. The accuracy of the analysis was given by the laboratory to be ±20%.

III. Results and Discussion

Figure 2 shows the change in oil mass present on the prefiltered specimens versus exposure time. While there is some variation in weight and all specimens experienced some loss of mass, there was not a substantial or noticeable oil decrease with time. Even for the specimens that were exposed to a constant air velocity for the full 32 weeks, the change in oil mass was not greater than 3%. Additionally, the ambient specimens showed no change in weight after the 32 week exposure time.

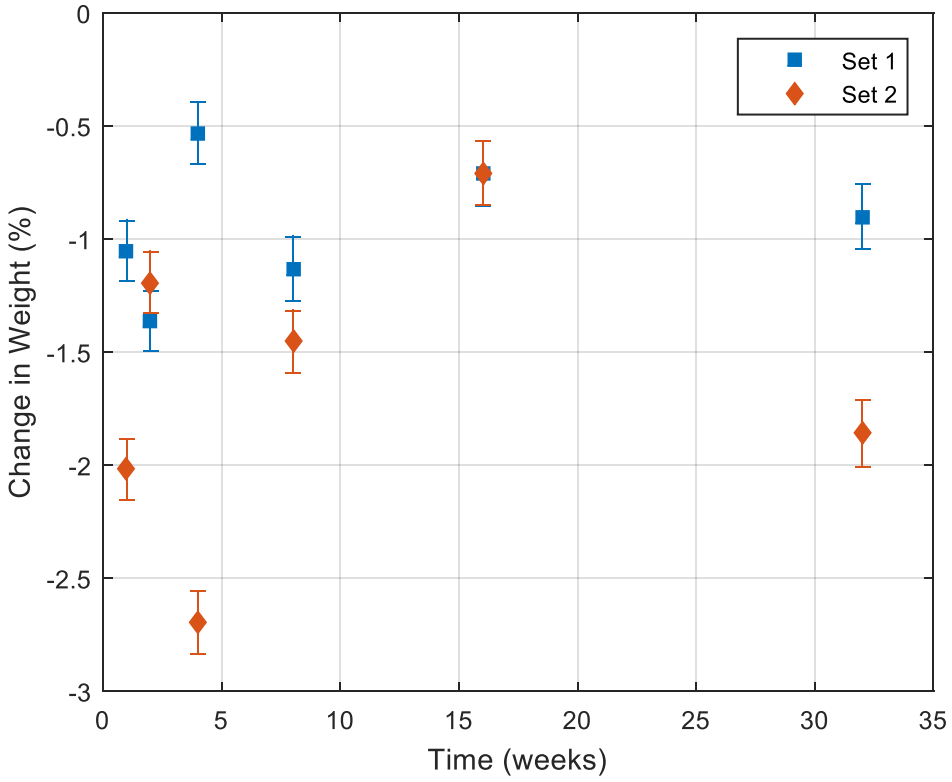

Figure 2: Weight loss over time

Figure 3 shows the mass of four different TCP isomers present on the filter specimens as a function of time from GC/MS analysis. While there is variation in the data, there also is no significant trend with time. Regression analysis shows that the 95% confidence intervals of the slope of a regression line for all isomers includes zero. This result indicates that the TCPs are persisting on the filter specimens

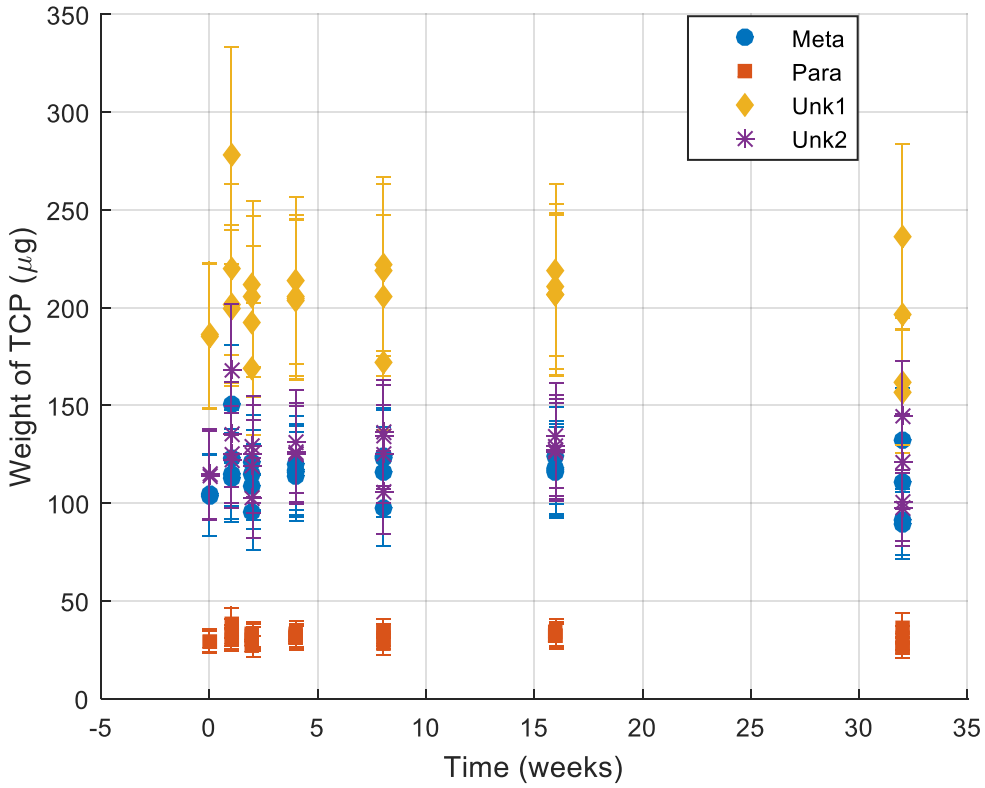

Figure 3: Weight of TCP detected versus exposure time

In Figure 4, the amounts of the four detected TCPs for all the analyzed specimens are plotted versus the weight of oil initially added to the specimens. There is a clear correlation between these variables, which regression analysis confirms to be statistically significant, indicating that the amount of oil initially present on the filter more significantly contributed to the variation in TCP than the exposure time. This outcome reaffirms the results from the gravimetric measurements that oil initially imparted upon a HEPA filter during a contamination event will remain there regardless of continued use. Lastly, Figure 5 shows the ratio between two pairs of the TCP isomers over time for all of the specimens. Once again these results are constant with time, indicating that there is not a shift in TCP composition with continued exposure.

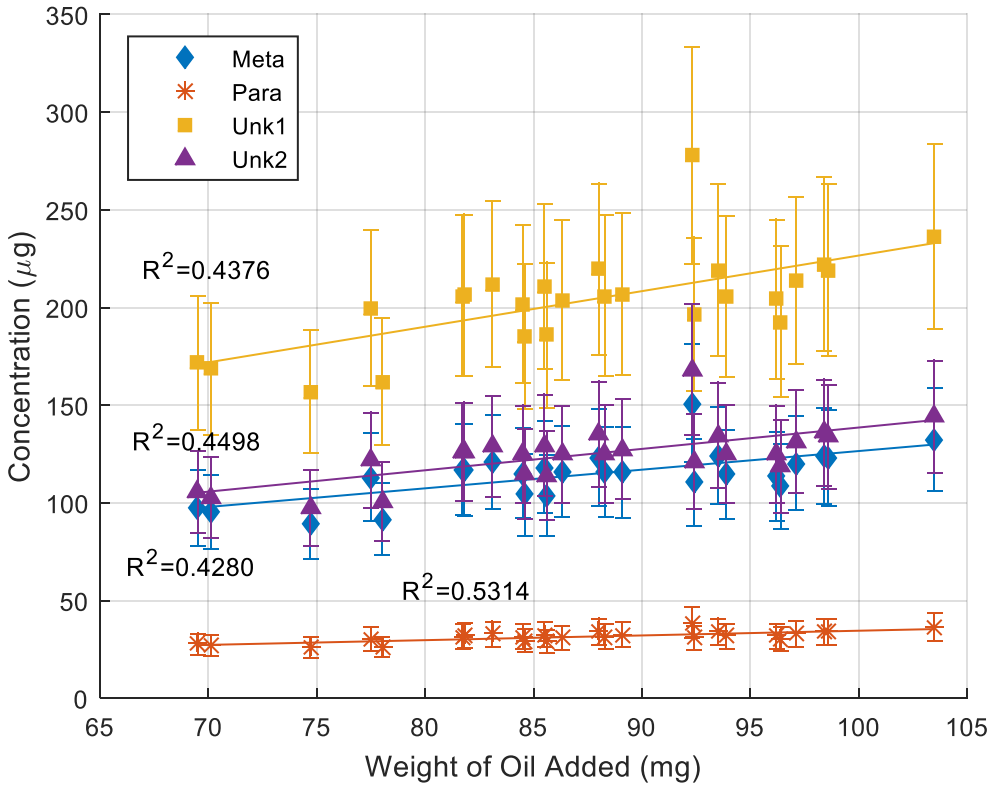

Figure 4: Weight of TCP present after experiment compared to initial amount of oil added

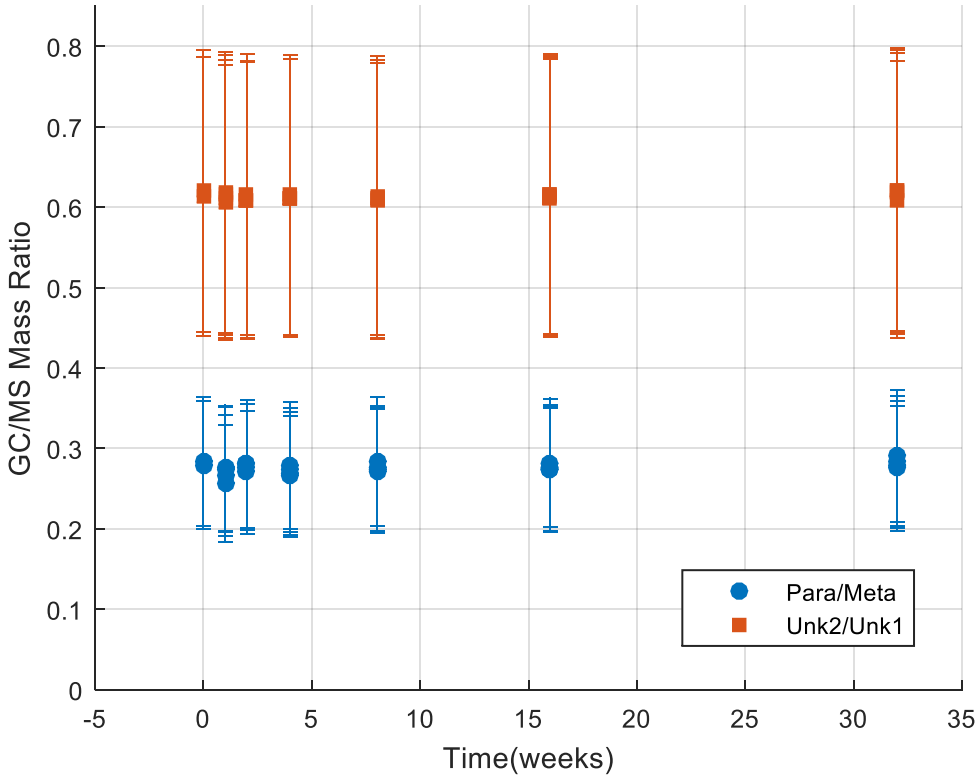

Figure 5: Composition of TCP versus exposure time.

TCPs are semi-volatile organic compounds and would be expected to be slow to evaporate at room conditions but would not be expected to persist indefinitely. The GC/MS data show that these compounds do, in fact, have long-term persistence on filter media just as the oil as a whole is shown to have long-term persistence as shown by the gravimetric data.

IV. Conclusions

Persistence and composition of jet engine oil on HEPA filter media under simulated flow conditions were studied with gravimetric and GC/MS analysis. The gravimetric results indicate that jet engine oil collected on aircraft cabin HEPA recirculation filters will remain present on the filter for the service life of the filter. In addition, it was concluded that there was virtually no loss of oil when a contaminated specimen was left open to the environment without flowing air. GC/MS analysis confirmed the persistence of TCP over the service life as well. Only small changes in TCP concentration were observed regardless of exposure time. The analysis also showed that the relative concentration between TCP isomers remained constant with exposure time. These results have important

implications for application of aircraft recirculation filter analysis for identifying oil contamination of aircraft cabin air. In particular, oil markers found on these filters are stable and represent an accumulated contamination over the life of the filter. On the positive side, substantial contamination that occurs at any time during the life of the filter will be reflected in the analysis. Contamination will not be missed if the filters are not removed and analyzed immediately after a contamination event. On the negative side, there is no time resolution for any contamination found. It could have occurred at any time during the life of the filter and the analysis does not distinguish between chronic, low-level contamination and one, or a few, more extreme contamination episodes. These shortcomings can be mitigated to some extent by installing clean filters on suspect aircraft to establish an earliest time of contamination for subsequent filter analysis.

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