

# **Investigation of Pipeline Drag Reducers in Aviation Turbine Fuels**

**(CRC Project No. CA-68-97)**

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Prepared by

Stanford P. Seto

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**CRC Aviation Fuel, Lubricant & Equipment Research Committee  
of the  
Coordinating Research Council, Inc.**

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The contributors to this report, mailing list, and Committee members are listed below and on the following page.

### Program Contributors

Gretchen Wendtland	Buckeye Pipeline Company
Dr. John Motier	Baker Petrolite
Dr. Yung Lee	Conoco
Rena J. Armstrong	Conoco, CSPI
Dr. Edward Matulevicius	Fuels Technology Associates, LLC
Tedd Biddle	Pratt & Whitney Aircraft
Robert W. Morris	US AFRL, WPAFB
Rick Kamin	Naval Air Systems Command
Greg Sprenger	Velcon Filters Inc.
Lt. Kirsten Wohlwend	USAF AFRL
Edward Binns	USAF AFRL
Dr. Andrew Waynick	Southwest Research Laboratories
Stanford Seto	GE Aircraft Engines

### Mailing List – CRC Project CA–68–97 (Disbanded May 2004)

Kevin Bower	Air BP Limited
Buster Brown	Colonial Pipeline
Chris Buhr	Lockheed Martin Aircraft
Eric Buschfort	Interav
Steve E. Casper	Consultant
Edwin Corporan	US AFRL
Francis Davidson	Phase Technology
Dennis Hoskin	ExxonMobil Research & Engineering
Joe Joseph	BP
Pedro Martinez	CEPSA – Spain
Jonathan O'neil	US Air Force
Mitch Oliver	ConocoPhillips Specialty Products
John Rhode	Facet USA
Phil Rugen	Shell Global Solutions (UK)
Ellen Strobel	US AFRL
William Taylor	W. F. Taylor Associates

**CRC Group on Additives in Jet Fuel, April 30, 2004 (Disbanded May 2004): CRC Project CA-68-97**

Glenn Harper, Ldr.	Boeing-Phantom Works
Ubaidallah S. Al-Ghamdi	Arabian Fuels Technology Ctr.
Steve Anderson	Air BP
Joanna M. Bauldreay	Shell Global Solutions, UK
Tedd Biddle	Pratt & Whitney
Peter Brook	QinetiQ
Gus Burmeister	Buckeye Pipeline Co.
Haydee Carlton	American Airlines
Clarence Chang	NASA-Glenn Research Center
Chuck Delaney	C4e, Inc.
Jim Evans	Shell Global Solutions, US
Howard Gammon	Gammon Technical Products
Roger Gaughan	ExxonMobil Research & Engrg.
Oren Hadaller	Boeing-Seattle
Greg Hemighaus	ChevronTexaco Global Aviation
Cy Henry	Associated Octel
Vic Hughes	Vic Hughes Associates Ltd.
Tuula Hujanen	Fortum Oil and Gas, Finland
Ron Jones	Consultant
Yung N. Lee	ConocoPhillips
Chris Lewis	Rolls-Royce Ltd.
Nick Makris	Consultant
John Motier	Baker Petrolite
Thomas J. Nelson	UOP LLC
Brad Oberg	Texas Eastern Products
Frank P. O'Neill	United Airlines
Roger Organ	Caltex AMEA
Chris Papastrat	Emcee Electronics
Didier Pigeon	Petroleum Analyzer Co.
C. David Roberts	Lubrizol
Wally Schrepfer	Consultant
Pam Serino	DESC
Stan Seto	Belcan Corp. (GE Aircraft Engines)
Kurt Strauss	Consultant
Ron Tharby	Tharby & Associates
Dale Wiseman	Colonial Pipeline Co.

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# 1.0 Summary

## 1.1 Conclusions

Engine, auxiliary power unit (APU)\* and airframe original equipment manufacturers (OEM's), and industry representatives reviewed the results from the GE Transportation (GE Aircraft Engines) pipeline drag reducer (PDR) in aviation turbine fuels (jet or jet fuel) testing for cold weather and altitude combustor ignition. The review concluded that the PDR in jet fuel, in concentrations of 8.8 ppm up to 32.0 ppm (active ingredient) is not acceptable for use.

Combustor sector-test data indicate a significant loss in both cold ignition on the ground from sea level pressure to 15,000 feet (4572 m) and in altitude ignition capability from 5000 feet (1524 m) to above 25,000 feet (7620 m). Loss in capability could be from 15% up to 55%. The presence of fully sheared PDR in the jet fuel did have the effect of diminishing the fuel-spray angle and atomization capability of several engine-type fuel nozzles and injectors at cold conditions but did not seriously compromise thermal stability, filterability, or other tested qualities. The presence of unsheared PDR did impair filterability.

Testing of the jet fuel did not progress beyond the sector ignition work. Consequently, there is no finding with regard to the effects of PDR on engine hot-section carboning or exhaust emissions.

## 1.2 History and Previous Experimental Work

Research into the formulation and use of PDR additives by Conoco petroleum scientists dates from the 1960's. PDR patenting for hydrocarbon systems began in 1972. The first full-scale testing in a crude pipeline system was done by Trans-Alaska Pipeline Systems in 1977, and they are still using PDR's today. From that time until now, the actual PDR has gone through many cycles of development and is a substantially more effective product. A measure of this improvement can be obtained from the Trans-Alaskan experience: in 1977 the pipeline flow rate was 1.3 million barrels per day, and the use of PDR increased it to 1.65 million barrels per day although the mechanical capacity of the system was only 1.4 million barrels. In 1982, and on a test basis, 1.85 million barrels was demonstrated. Today, PDR's are used in major pipeline systems all over the world in diesel fuel, crude oil, and gasoline. It has yet to be used in aviation turbine fuel.

## 1.3 Current Program

In 1997 the U.S. pipeline industry in the form of Buckeye Pipeline Company approached the aviation fuel community at Coordinating Research Council (CRC) to reconsider the use of PDR's. The request was the result of a survey done by the American Petroleum Institute (API) that showed the expected growth in demand for jet fuel and other refined products would result in the capacity of many pipelines being exceeded in the next few years. The request for reconsideration was based on several things, such as:

- The total of local dosages required would decrease from approximately 50 ppm active ingredient to 5 – 8 ppm
- The current PDR is a less complex (fewer side chains) material, although the molecular weight is still in the 20 to 30 million range, unsheared, and about 1.5 million fully sheared
- PDR's are already in use in many pipeline products.

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\* See page 128 for list of acronyms and nomenclature.

The involved manufacturer was Baker–Petrolite, and the PDR is called FLO XS<sup>®</sup>. The airlines supported these requests with letters to the OEM’s as replicated in Addendum 1.

In 1998 – 2003, research contracts were set-up with the U.S. Air Force (USAF) Fuels Branch, partnered with Pratt & Whitney (P&W), to investigate thermal stability; with DESC (Defense Energy Support Center) and with Velcon Filters Inc. to investigate filter clogging and water-separation characteristics; and with GE Aircraft Engines to investigate the cold-weather effects on fuel nozzle spray characteristics and combustion ignition. Conoco entered the program with two candidate PDR’s. In addition, several research efforts were donated to the investigations.

**Thermal Stability** – Alcor tested one fuel with several concentrations of PDR and monomers. Sixteen JFTOT tests were done. It was found that 8 ppm of the PDR reduced fuel breakpoint temperature by 10° C. Nineteen fuels were tested in the *Hot Liquid Process Simulator* (HLPS) test rig by P&W. All 19 fuels were tested neat and with 8.8 ppm each of Baker Petrolite FLO–XS<sup>®</sup>, a gel-based additive; CDR 203<sup>®</sup>, a gel-based PDR from Conoco; and RefinedPower<sup>®</sup> II Flow Improver, a suspension-based PDR from Conoco. Five fuels were retested with all three PDR’s at 35.2 ppm. Within the error of the test, fuel thermal stability was not affected by the PDR’s.

**Filter Cartridge Testing** – Velcon Filters, Inc. tested both coalescers and water-absorbing monitors using partially sheared (molecular weight 6 million) and fully sheared (molecular weight 1.5 million) Baker Product 1020 (FLO–XS<sup>®</sup>, kerosene diluted) and at 20 ppm active ingredient. The presence of the PDR had no adverse effect on effluent quality of the fuel. Both solids removal and water removal were unaffected. The PDR did cause an increase in differential pressure. The partially sheared material caused a significant increase, and the fully sheared material caused only a slight increase in the differential pressure.

NAVAIR Labs, Patuxent River Facility tested filter elements, investigating long-term effects of water slugs and soaking tests. There was no effect on particle or water-removal ability, but the presence of the PDR did reduce cartridge life.

**Low-Temperature Effects on Fuel Nozzle Spray Characteristics** – GE Aircraft Engines tested four commercial engine fuel nozzles — three duplex fuel-pressure-atomizing designs and one low-pressure fuel injector — at ambient fuel and air temperatures and at air and fuel temperatures cooled to 12 cSt fuel viscosity levels, to determine PDR effects on injector spray angle and fuel atomization. Results indicated some reduction in spray angle on all four nozzles and increasing of nozzle discharge droplet size as fuel was cooled to lowest temperatures and as PDR was added and concentration in the fuel was increased. In the limit, the most sensitive nozzle produced a solid stream of fuel at the lowest temperatures and highest concentrations of PDR. Testing was generally done at the nozzle minimum fuel flow (pounds per hour, pph) value for the engine. Testing was done with neat fuel, 8.8 ppm, and 32 ppm of the Baker Petrolite drag reducer.

**Low-Temperature Effects on Altitude and Cold-Day Ground Ignition** – GE Aircraft Engines tested one duplex fuel nozzle design in a five-cup sector combustor test rig to determine the effect on combustor ignition of cold conditions and the presence of the drag reducer. For the test points selected, the presence of the PDR either precluded ignition or reduced capability by requiring increased fuel flows to obtain ignition.

**PDR Detection in Jet Fuel** – Conoco did an investigation to determine under what conditions of sheared material the suspension PDR would be detectable based on measured filtration time. They used a 5-µm filter and determined that there was a relationship between filtration time and average molecular weight. Data presented for fully sheared samples indicated there were time differences

dependent on PDR concentration in the fuel; 8.8 ppm had the lowest time followed by 16 ppm, and the 32-ppm concentration had the longest time. There was also a time dilatation associated with degree of shearing, the unsheared taking the longest and the fully sheared the shortest.

**PDR Extraction from Jet Fuels** – Southwest Research Institute investigated the extraction of PDR from Jet A–1 fuel using carbonaceous material. Efficiency of the carbon material was a function of contact method used, fuel, the polymer being tested, the carbon materials being used, and the agitation level of the fuel and carbon mixture. Results ranged from no extraction to the carbon extracting up to half the polymer in solution.

**Position of the OEM's** – Pipeline drag reducers will not be permitted for use in aviation turbine fuels.

## 2.0 Introduction

Aviation turbine fuels with pipeline drag reducers were tested to determine the suitability of PDR for use in the fungible pipeline systems of America. This report documents the history of testing, summarizes the data and findings of the testing, and describes the decisions taken by the major OEM's. For clarity, the report is organized by topic rather than chronologically, except for an overview of precursor events in the following subsection.

### 2.1 History

**1972** – Pipeline drag reducers patented by the Petroleum Industry.

**1977 – 79** – First full-scale use of Conoco CDR<sup>®</sup> PDR by Trans-Alaska Pipeline System in a crude oil pipeline (Reference 1). Crude throughput increased 42% by 1982.

**1986** – CRC Fuel System Safety Group report reviewing use of PDR in jet fuel, treatment rate to be 30 to 70 ppm active ingredient, and expressing concerns for fuel-filter clogging, thermal stability, and long-term effects in aircraft and aircraft systems.

**1986 – 87** – Series of North Atlantic Treaty Organization (NATO) meetings. Working Group 4 of NATO AC/112 reviewed past and present uses of PDR (crude oil, diesel fuel, and auto gasoline) in pipeline operations, reviewed the properties of current PDR formulations (Conoco CDR<sup>®</sup> 102M as an example), and discussed a testing program that would result in the approval of PDR for use in aviation turbine fuels. The PDR was a polyalphaolefin with an unsheared molecular weight 10 to 20 million for the Conoco product and 20 to 30 million for the ARCO product. The molecular weight fully sheared was 300,000 to 500,000. There were concerns for the manufacturing residue of the Ziegler–Natta catalyst used to make the PDR, which might contain titanium, aluminum chlorides, and sodium — all of which could harm turbine engine hot sections. The meetings generated a list of questions to be answered by the PDR manufacturers, and four groups of tests that started with chemical compatibility of the PDR with fuel systems and led through compatibility with specification requirements, fuel-handing requirements, and combustion-performance demonstrations. The fuel to be used would be NATO F–34/F–35, JP–8.

**Late 1987** – NATO AC/112, WG 4 meeting resulted in decisions to test PDR in a German pipeline, 40 miles long, flowing diesel fuel product. Shell Oil (Thornton) would run some combustor and thermal stability testing, Rolls–Royce would do some fuel system simulator (FSS) testing for filtration and pumping, and the USAF Fuels Branch at Wright Patterson AFB would do some FSS testing to research PDR carboning characteristics in a simulated fuel nozzle flowpath labeled a “burner feed arm” and two other similar test rigs.

**December 1988** – German pipeline testing was completed and demonstrated 30% increase in throughput. Rolls–Royce FSS testing was completed and demonstrated no filter or pump problems up to 50 ppm of the PDR. Shell tests demonstrated no problems with fuel thermal stability or combustion. USAF tests were not started.

**1990** – Requirement for the use of PDR's in NATO pipelines disappears as relations with Soviet Bloc countries alters drastically. USAF FSS testing gets started.

**1992** – USAF FSS testing completed. In three different test rigs — the FSS, the extended duration thermal stability test (EDTST) and the Augmentor vaporization fouling rig (AVFR) — the presence of 15 ppm of the Conoco PDR demonstrated significant increases in fuel fouling rates at wetted wall

temperatures of 450° F (232° C) and higher. At 420° F (216° C), the PDR did not increase fuel fouling rates. The USAF recommendation was to not use PDR's in aviation fuels (Reference 2).

## 2.2 Technology

When fluids travel through a pipe, a velocity profile is developed in the flow that varies from zero velocity at the wall of the pipe to a maximum velocity at the centerline of the pipe. This profile is caused by the viscous flow properties in the fluid that create shear layers. At very low bulk flow velocities these shear layers are well-ordered laminae, and there is no transverse flow between the layers; this is described as laminar flow. Pressure drop per unit length of pipe is also low. As bulk flow velocities increase, the laminar nature of the flow begins to break down due to the viscous properties of the fluid. At the interface between laminae, the local flow begins to tumble due to shearing, creating transverse flow in which faster moving particles are transported into regions of lower velocity and vice-versa. This turbulent flow causes greater pressure drop per unit length of pipe and demands higher pumping energy into the flow to maintain the bulk velocity of the flow, Figure 1.

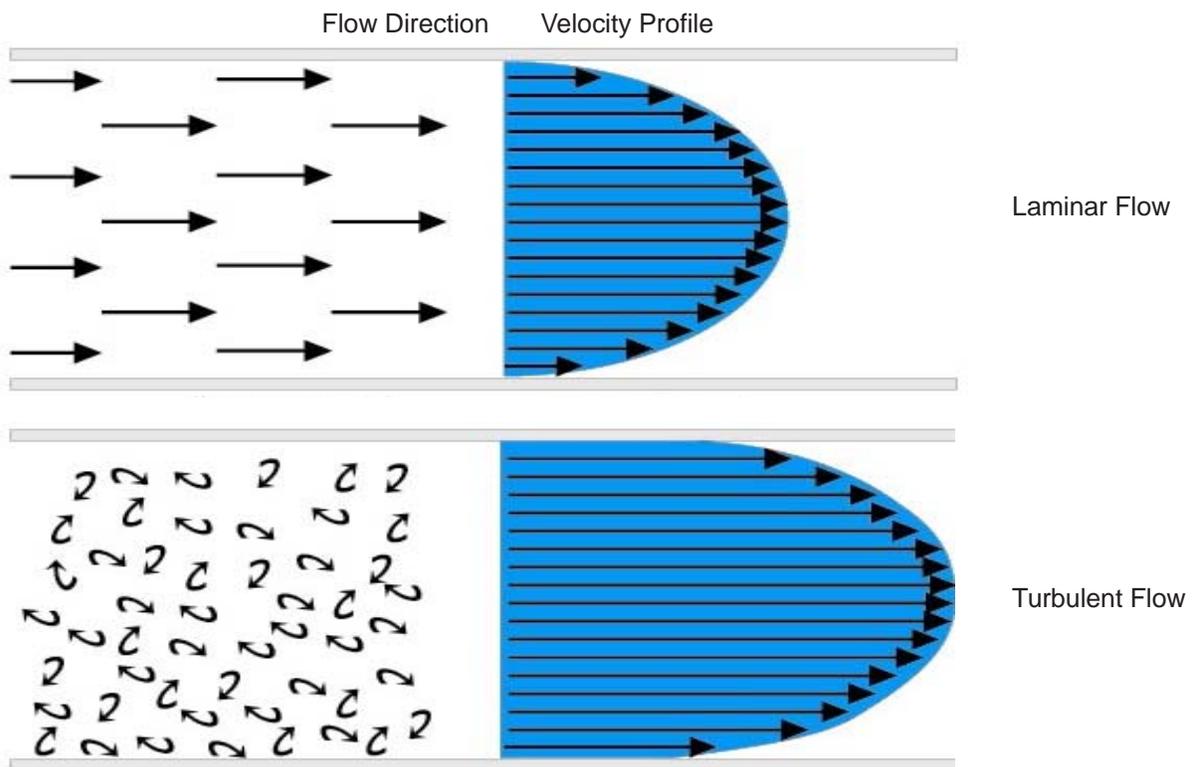


Figure 1. Laminar and Turbulent Flow Velocity Profiles

These two flow regimes are defined by Reynold's number ( $Re$ , Reference 3), the ratio of the fluid body forces to viscous forces ( $Re = VL\rho/\mu$ ). Values of  $Re$  of less than 2000 define the laminar flow regime for pipes. As  $Re$  increases, pipe flow transitions from laminar to turbulent over a range of values from 2,000 to 10,500 and is fully turbulent above 10,500.

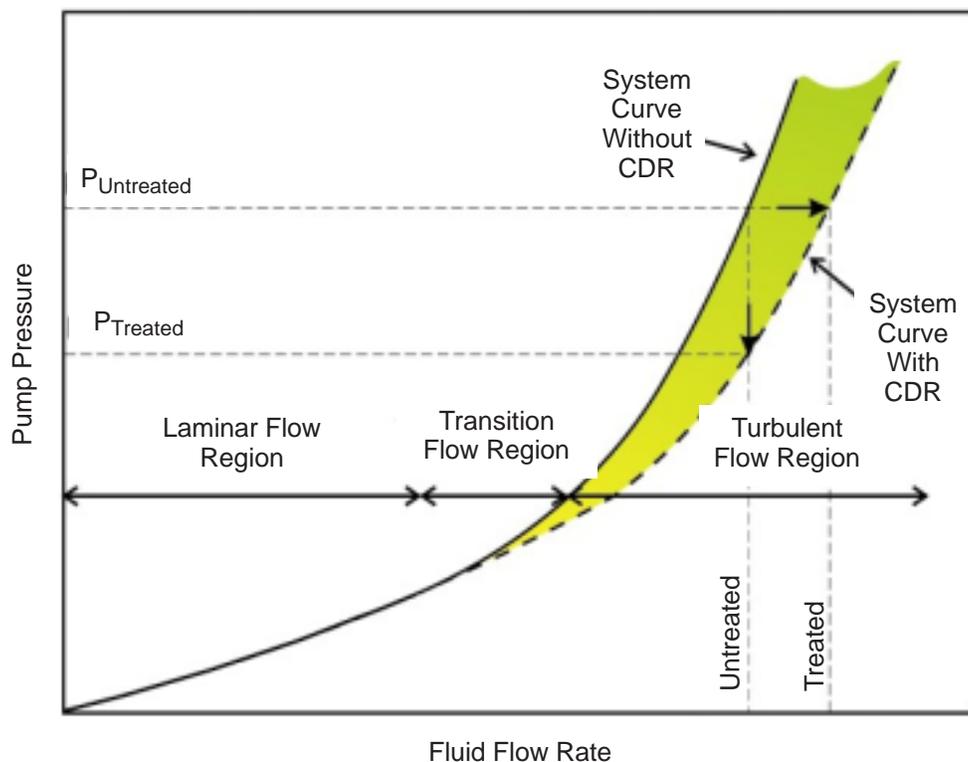
Due to the differences in density of the crudes being transported and the density of the refinery products in the pipeline systems, operators generally avoid the throughput velocities associated with laminar flow as being economically unattractive. In the finished-product pipelines, products are

batched by ascending or descending density and allowed to mix during transit, being cut at terminals in ways determined by product use and performance to minimize product contamination.

The use of PDR products reduces fluid turbulence, especially right next to the wall of the pipe, downstream of valves in the pipelines, and at branching points. By decreasing flow turbulence, pipeline drag (pressure loss) is reduced and higher product throughput can be achieved at the same or lower pumping pressures.

### 2.3 Drag Reducers

Typically, drag reducers are very high molecular weight hydrocarbon polymers suspended in a dihydrocarbon solvent. When added to crudes or refined products in a pipeline, these polymers reduce transverse flow gradients, effectively creating a laminar flow in the pipe. This is especially true close to the pipe walls where the axial flow velocity profile has a very steep gradient in which significant pressure losses occur. Lowering these internal fluid losses increases the bulk throughput of the pipeline for a given pumping energy, hence operating costs are reduced, Figure 2.



**Figure 2. Effect of Chemical Drag Reducers on Pipeline Pump Pressure of Flow Rate**

The amounts of drag reducer injected into the flow are very small, on the order of one part per million. The drag reducer molecular chain is very fragile, however. The chain can be sheared or broken by bends in the pipeline, valves, piping branches, and when the flow goes through a pumping station. Once the molecular chain is broken, the effectiveness of the drag reducer is immediately degraded, so the flow improver must be reinjected downstream of pumps, valves, and sharp turns in the pipeline to maintain the benefit.

It should be noted that drag reducer goes into solution with the fluid in the pipeline. The drag reducer does not coat pipe walls, nor does it plate out on valve components. Unsheared, it can clog filter devices, but sheared it passes through filters without agglomerating.

Drag reducers are widely used in pipeline systems to facilitate the flow of crudes, diesel fuels, and automotive gasolines. Drag reducers are not permitted in aviation fuels.

### **2.3.1 Baker–Petrolite FLO XS<sup>®</sup>**

FLO XS<sup>®</sup> is a very high molecular copolymer of 1-hexene and 1-dodecene made by a modified and proprietary Ziegler–Natta catalyst system. Addendum 2 presents Material Safety Data Sheet details. Molecular weight as supplied is estimated at 25–35 million. It is supplied as a viscous solution in isopentane at a nominal polymer concentration of 11% by weight. For quality assurance testing, a maximum concentration of 12.5% can be assumed. There are trace amounts of titania, alumina, and inorganic chlorides in FLO XS<sup>®</sup> as catalyst residues. The concentration of these compounds in FLO XS<sup>®</sup> and the proposed pipeline use concentration of FLO XS<sup>®</sup> itself have made their presence inconsequential.

When FLO XS<sup>®</sup> (or any polymeric drag reducer) flows through pipeline networks, it is degraded to about 1.5 million molecular weight. Thus multiple injections are required for multipump-station applications. The molecular weight and concentration of the degraded drag reducer are determined by established analytical procedures using size exclusion (also known as gel permeation) chromatography (commonly referred to as GPC). The methods may undergo some modifications as they travel through the American Society for Testing and Materials (ASTM) approval process.

### **2.3.2 ConocoPhillips CDR 203<sup>®</sup> and RefinePower<sup>®</sup> II Flow Improver**

CDR 203<sup>®</sup> is a gel-based hydrocarbon drag reducer. It is a copolymer of dodecene and hexene. Conoco CDR 203<sup>®</sup> is a 5% solution in a molex raffinate kerosene solvent.

RefinePower<sup>®</sup> II Flow Improver is the same polymer that Conoco uses in their gel-based PDR except it is suspended in a nonsolvent mixture of isooctyl alcohol and propylene glycol.

## **2.4 Pipeline Utilization and Dosing**

Pipelines dose the fuel with drag-reducing additives (PDR) on a volumetric basis, in gallons per hour. The ppm concentration is calculated on the pipeline volumetric throughput, in barrels per hour. When Buckeye Pipeline, in its leadership position, requested a jet fuel approval program for 8 ppm of polymeric PDR, the request was in reality for 8 ppm on a volume basis. However, all testing and analyses in the subsequent program were performed on a weight ppm basis: 8, 8.8, or 32.

Testing on a weight basis provided a cushion for accuracy/precision, and the subtlety of this was not mentioned until well into the program. With the density of FLO XS<sup>®</sup> at 5.32 lb/gal and an average jet fuel at 6.50 lb/gal, the 8 ppm (v/v) requested is only 6.54 ppm on a weight basis. The testing was being done at 8 ppm (w/w) or higher.

The choice of the 8-ppm level by the pipeline industry was based on a projected maximum cumulative dosage for pipelines requiring multiple dosages of PDR. The choice, unfortunately, was ambitious; indeed, a 1-ppm dosage of FLO XS<sup>®</sup> at that time would have been able to solve the anticipated shortages of jet fuel supplies. The limitation on supply to the cited airports (Kennedy, Newark, LaGuardia, Miami, Las Vegas, Vancouver, and Heathrow) would be the shunt line from the main

pipeline into the airport. Only one injection would be required for a 25% improvement in flow rate. With continuing advancement in PDR technology, today only 0.5 ppm (v/v) of the FLO XS<sup>®</sup> polymer would be required for this level flow improvement. The degraded polymer is unchanged.

## **2.5 PDR Injection Technology**

The technology of PDR injection has improved dramatically in reliability and precision over the past five years. Most applications now are under computer control as the injection module is tied directly into the pipeline SCADA systems (supervisory control and data acquisition). Dosing is automatically controlled to the desired batches, and the amount of PDR injected is proportionalized to the desired ppm level with the pipeline throughput.

## **2.6 Selection of Dosage**

In December 1997, Buckeye Pipeline presented the case for reconsideration of pipeline drag reducers in an ASTM Task Force Meeting; this was later named the *Additive Effectiveness Task Force*. The dosage rate requested was 8.0 ppm maximum based on a pipeline requirement of four injections of 2 ppm each, for a local improvement of up to 40 to 50% in product throughput. Buckeye indicated that in actual use, one or two injection sites and 1 or 2 ppm for a total of 4 ppm in the aviation turbine fuel was expected to be the norm. The 8 ppm referred to the active ingredient in the additive, not the total additive concentration including the carrier fluid. In addition, Buckeye noted that variables for the additive injection were manufacturing of the additive (5%), injection uncertainty (3%), and knowing the stream flow rate (2%), giving a total variability of 10%. This translates into minimum dosage of 8.8 ppm. The final dosage values set for the CRC task force to investigate then became 8.8 ppm, 16 ppm, and 32 ppm as the maximum.

## 3.0 Experimental Work

### 3.1 Thermal Oxidative Stability

Several thermal oxidative stability programs were run starting in mid-1998. In one of the first of these, Baker Chemical Company asked Alcor to perform JFTOT, ASTM D 3241, breakpoint testing on the Baker Petrolite PDR at several concentrations to determine the range of concentrations that would subsequently be tested in the Air Force Research Laboratories (AFRL)–Buckeye Cooperative Research and Development Agreement (CRADA). The JFTOT testing was performed using neat Jet A; Jet A doped with 8, 16, and 32 ppm of the polymer; and Jet A doped with 8 ppm of the C<sub>6</sub> – C<sub>12</sub> monomers. The monomers are the olefins that remain with the active polymer when the manufacturing process is completed; 8 ppm of the polymer would contain 3.5 ppm of the monomer. If the presence of the monomers was found to be deleterious, a method for removing them from the final product would be devised.

Seven tests on the neat fuel established the breakpoint to be 270° C. Addition of 8.0 ppm of the PDR reduced the fuel breakpoint to 265° C. With a concentration of 16 ppm, the fuel failed breakpoint at 270° C but passed at 260° C. At a concentration of 32 ppm, the fuel passed at 265° C and failed breakpoint at 270° C.

The Jet A fuel with 8 ppm C<sub>6</sub> – C<sub>12</sub> monomers recorded a 3 tube rating at 270° C and a 1 tube rating at 256° C.

The first two runs on the neat fuel were made without a filter pad in the prefilter holder. In the following 14 tests the highest filter delta pressure recorded was 6 mm of Hg at 150 minutes.

The individual test results are summarized in Table 1.

**Table 1. Alcor Test Results – ASTM D 3241 Break Point – Jet A Fuel**

Test No.	PDR Level	Fuel Temperature	Tube Code	Filter Pressure Drop
6411	Neat Fuel	280° C	4A	No Prefilter, Open B/P @ 250mm, (53 min.)
6412	Neat Fuel	260° C	1	No Prefilter, Open B/P @ 250mm, (121 min.)
6413	Neat Fuel	260° C	1	Prefilter, ΔP 1 mm Hg, 150m.
6414	Neat Fuel	260° C	1	As above
6415	Neat fuel	280° C	>4	As above
6416	Neat Fuel	270° C	1	As above, ΔP 0 mm Hg
6417	Neat Fuel	275° C	4A	As above, ΔP 1 mm Hg
6418	16 ppm PDR	270° C	4	As above, ΔP 3 mm Hg
6420	16 ppm	260° C	1	As above, ΔP 1 mm Hg
6422	8 ppm	270° C	4	As above
6423	8 ppm	260° C	<1	As above, ΔP 0 mm Hg
6424	8 ppm	265° C	<1	As above, ΔP 1 mm Hg
6425	32 ppm	265° C	1	As above, ΔP 6 mm Hg
6426	32 ppm	270° C	3	As above, ΔP 1 mm Hg
6427	8 ppm monomers	270° C	3	As above
6428	8 ppm monomers	256° C	1	As above, ΔP 0 mm Hg

On July 1, 1998, further testing with Alcor was discussed. It was agreed to retest the neat fuel, fuel with 2 ppm PDR, plus the monomers and 8 ppm of the polymer only. Tubes from all this testing were to be forwarded to the USAF Fuels Branch for ellipsometric testing of the tube deposits. No record exists that this additional testing was done.

From July 23, 1998 until March 31, 2003, an extensive program was run by United Technologies Corporation, P&W, Fuels and Lubricants Group, in East Hartford, CT, under the auspices of the USAF Fuels Branch, Turbine Engine Division, Propulsion Directorate (Reference 4). The purpose of the program was to evaluate the candidate PDR's for thermal oxidative stability characteristics, the area in which failure occurred in the earlier evaluation programs.

P&W conducted HLPS tests as a means of determining the effect of PDR's on fuel thermal oxidative stability. PDR's evaluated included a gel-based formulation manufactured by Baker Petrolite, a gel-based formulation manufactured by Conoco, and a suspension-based PDR in an alcohol carrier manufactured by Conoco. The additives were evaluated in a suite of 19 fuels at 8.8 ppm and in 5 fuels at 35.2 ppm. The dosage level requested for approval was 8.8 ppm active ingredient.

The HLPS is an accelerated, bench-scale, flowing-type test that subjects the fuel to conditions that can be related to those in gas turbine engine fuel systems. A test procedure developed by P&W has proven useful as a screening tool for comparing the propensity of different additives for forming deposits. When used in conjunction with carbon burn-off, this method has the ability to quantitatively rank additive performance based on  $\mu\text{g}/\text{cm}^2$  of carbon formed on a stainless steel tube.

The HLPS is similar in operation to the jet fuel thermal oxidation tester (JFTOT) employed in ASTM D 3241-01. The HLPS differs from the JFTOT in its modular design, extended temperature range, flow rate capabilities, and accommodation of greater fuel volumes. The test conditions selected to evaluate additive performance are much more severe than those specified in the standard JFTOT procedure. Tests are performed at 335° C (635° F) for 5 hours. Series 316 stainless steel tubes are substituted for conventional aluminum tubes to permit quantification of the deposit by carbon burn-off. Carbon burn-off is accomplished using a LECO RC-412 carbon analyzer.

### **3.1.1 Testing**

All HLPS tests were performed on fully sheared PDR as received from the additive manufacturers. The baseline reference fuels used for evaluating the drag reducers were from the Air Force's high-temperature fuel programs as well as the "Red Dye Program." The suite of fuels represented a wide spectrum of processing techniques and crude types. Included were straight run, hydrotreated, hydrocracked, hydrotreated/hydrocracked, and Merox-treated kerosenes. Crudes were light crude sweet, light crude sour, mixed crude, heavy crude sweet, and heavy crude sour.

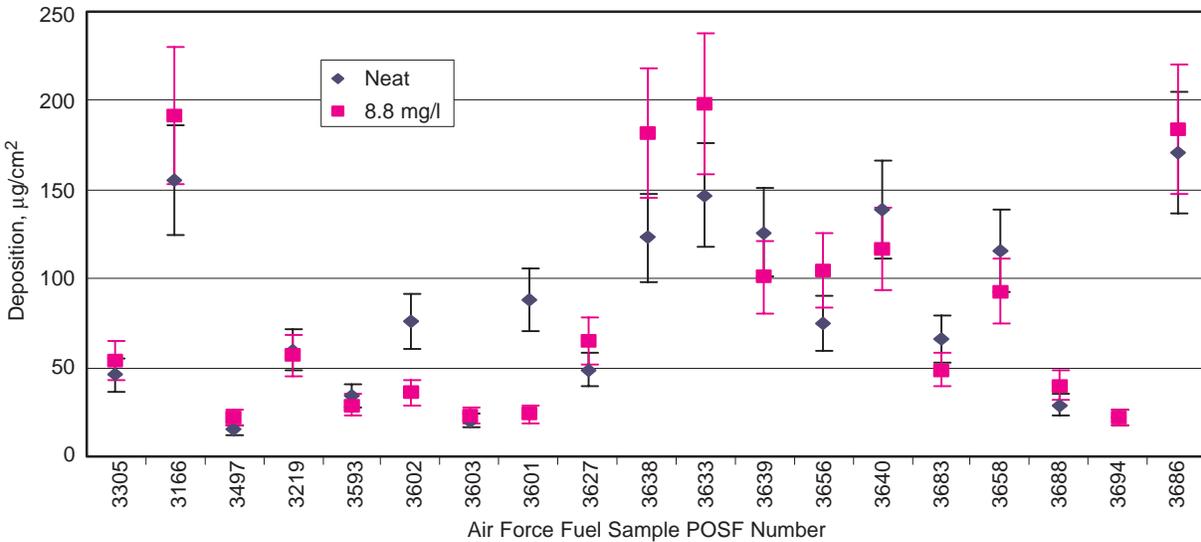
#### **3.1.1.1 Baker FLO XS®**

The Air Force sample designation for Baker FLO XS® is POSF-3597. HLPS tests were performed on 19 baseline fuels and 19 fuels additized at 8.8 ppm FLO XS®. Repeatability of the HLPS test is  $\pm 20\%$ . Within the uncertainty of these tests, the addition of 8.8 ppm PDR resulted in deposits and bulk fuel insolubles that were the same as, or lower than, the baseline fuels.

Table 2 is a tabulation of the test results. Figure 3 is a graphical representation of the effect of PDR on fuel thermal oxidative stability based on HLPS.

**Table 2. HLPS: Effect of Baker FLO XS® Pipeline Drag Reducer on Thermal Stability at 8.8 mg/l**

Source	Fuel Sample	Break Point, °C	Type	Deposit, µg/cm <sup>2</sup>	ΔP, mm Hg
U.S. Air Force	96-POSF-3305		Jet A		
	96-POSF-3305 + 8.8 ppm Baker PDR			54	>300/60
	95-POSF-3166	274	Jet A	155	>300/55
	95-POSF-3166+ 8.8 ppm Baker PDR			192 (213)	>300/108 (300/60)
	98-POSF-3497		JP-8	15	0/300
	98-POSF-3497 + 8.8 ppm Baker PDR			22	3/300
	96-POSF-3219	285	Jet A	60 (41)	>300/28 (31/300)
	96-POSF-3219 + 8.8 Baker PDR			57	1/300
SWRI	99-POSF-3602 (RDTF-1)	270	Jet A	76	>300/120
	99-POSF-3602 + 8.8 ppm Baker PDR			36	>300/240
	97-POSF-3603 (RDTF-2)	280	Jet A	11 (15) 20	2/300 (2/300) 2/300
	97-POSF-3603+ 8.8 ppm Baker PDR			50 (39) 23	7/300 (0/300) 0/300
	99-POSF-3601 (RDTF-3)	290	Jet A	88	11/300
	99-POSF-3601 + 8.8 ppm Baker PDR			24	0/300
	99-POSF-3627 (RDTF-4)	305	Jet A	49	>300/100
	99-POSF-3627 + 8.8 ppm Baker PDR			65	>300/155
	99-POSF-3638 (RDTF-5)	280	Jet A	123	>300/135
	99-POSF-3638+ 8.8 ppm Baker PDR			182	>300/75
	99-POSF-3633 (RDTF-6)	280	Jet A	147	>300/248
	99-POSF-3633+ 8.8 ppm Baker PDR			198	>300/265
	99-POSF-3639 (RDTF-7)	280	Jet A	126	>300/166
	99-POSF-3639+ 8.8 ppm Baker PDR			101	>300/208
	99-POSF-3656 (RDTF-8)	295	Jet A	75 (50)	>300/42 (>300/38)
	99-POSF-3656 + 8.8 ppm Baker PDR			105	>300/41
	99-POSF-3640 (RDTF-9)	295	Jet A	139 (140)	>300/57 (>300/228)
	99-POSF-3640+ 8.8 ppm Baker PDR			117	>300/58
	99-POSF-3658 (RDTF-10)	280	Jet A	116	>300/40
	99-POSF-3658 + 8.8 ppm Baker PDR			93	>300/20
	99-POSF-3683 (RDTF-11)	285	Jet A	66	6/300
	99-POSF-3683 + 8 ppm Baker PDR			49	3/300
	99-POSF-3686 (RDTF-12)	255	Jet A	171	>300/45
	99-POSF-3686 + 8.8 ppm Baker PDR			184	>300/72
	99-POSF-3688 (RDTF-13)	315	Jet A	29	>300/268
	99-POSF-3688 + 8.8 ppm Baker PDR			40	>300/220
	99-POSF-3694 (RDTF-14)	340	Jet A	22	>300/120
	99-POSF-3694 + 8.8 ppm Baker PDR			22	>300/120
99-POSF-3593 (RDTF-15/0)	340	Jet A	34	>300/145	
99-POSF-3593 + 8.8 ppm Baker PDR			29	>300/240	

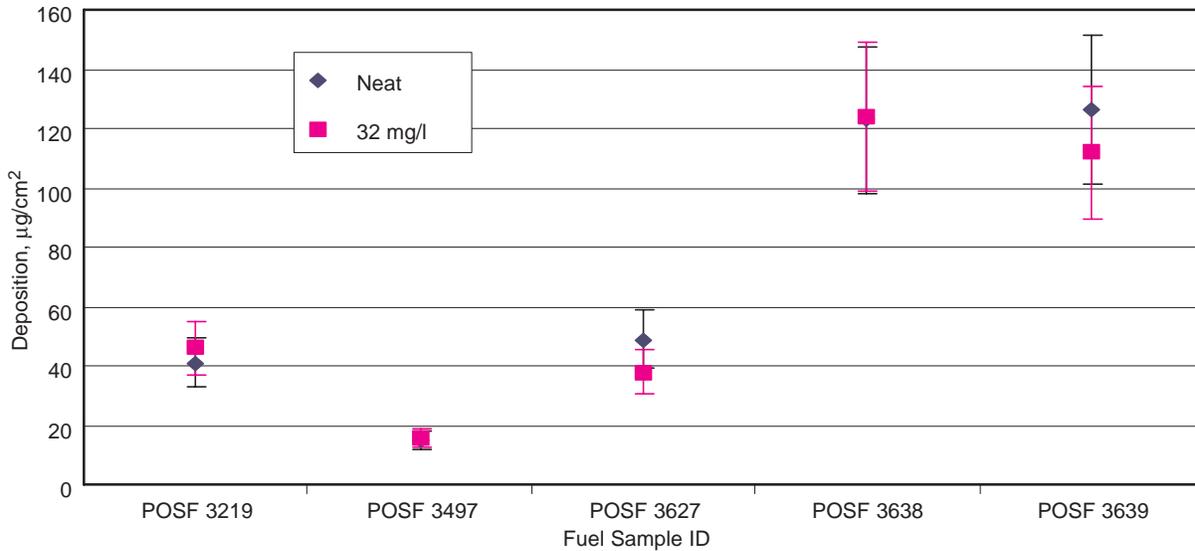


**Figure 3. HLPS: Effect of Baker FLO XS® Pipeline Drag Reducer on Fuel Thermal Stability at 8.8 mg/l**

Five fuels were selected to be tested at four times the concentration that Buckeye Pipeline was asking the CRC Pipeline Drag Reducer Task Force to investigate for approval. The baseline reference fuels were agreed upon by the CRC, engine manufacturers, and the military because they represented a good cross section of the refinery processes used to produce jet fuel. The test fuels included two Air Force reference fuels [96–POSF–3219 and 98–POSF–3497], a hydrotreated fuel [99–POSF–3627 (RDTF–4)], a straight-run fuel [99–POSF–3638 (RDTF–5)], and a Merox-processed fuel [99–POSF–3639 (RDTF–7)]. Within the uncertainty of the tests performed, the addition of 32 ppm PDR resulted in deposits and bulk fuel insolubles that were the same as, or lower than, the baseline fuels. Table 3 tabulates the HLPS test results. Graphical representation of the effect of PDR on fuel thermal oxidative stability based on HLPS is shown in Figure 4.

**Table 3. HLPS: Effect of Baker Pipeline Drag Reducer on Fuel Thermal Stability at 4X the Concentration of Intended Use**

Source	Fuel Sample	Type	Break Point, °C	Deposit, µg/cm <sup>2</sup>	ΔP, mm Hg
U.S. Air Force Ref. Fuel	96–POSF–3219	Jet A	285	60 (41)	>300/28 (31/300)
	96–POSF–3219 + 8.8 Baker PDR			57	1/300
	96–POSF–3219 + 32 ppm Baker PDR		P&W 288	46	>300/90
	98–POSF–3497	JP–8		15	0/300
	98–POSF–3497 + 8.8 ppm Baker PDR			22	3/300
	98–POSF–3497 + 32 ppm Baker PDR			16 (28)	1/300 (0/300)
Hydro-treated	99–POSF–3627 (RDTF–4)	Jet A	265	49	>300/100
	99–POSF–3627 + 8.8 ppm Baker PDR			65	>300/155
	99–POSF–3627 + 32 ppm Baker PDR		P&W 304	38	0/300
Straight Run	99–POSF–3638 (RDTF–5)	Jet A	275	123	>300/135
	99–POSF–3638 + 8.8 ppm Baker PDR			182	>300/75
	99–POSF–3638 + 32 ppm Baker PDR		P&W 274	112 (124)	>300/120 (>300/150)
Merox Treated	99–POSF–3639 (RDTF–7)	Jet A	270	126	>300/166
	99–POSF–3639 + 8.8 ppm Baker PDR			101	>300/208
	99–POSF–3639 + 32 ppm Baker PDR		P&W 268	112	>309/300



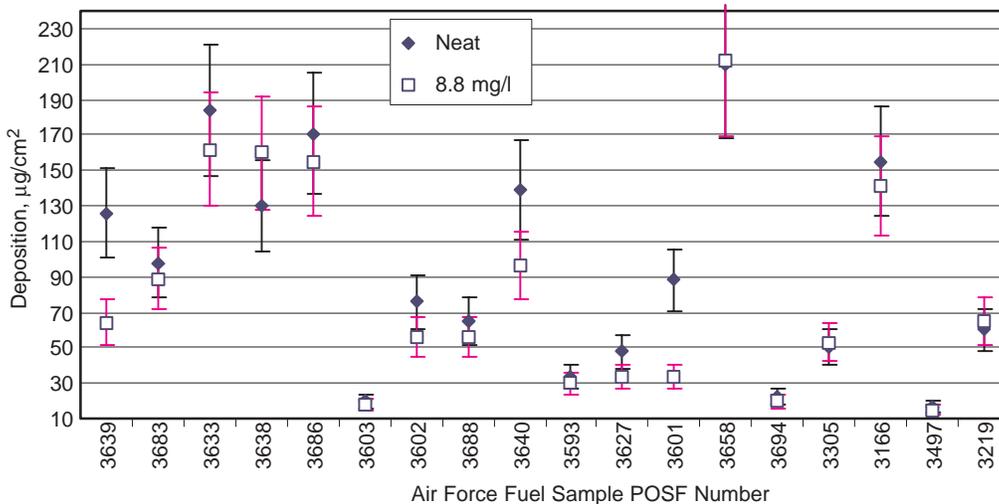
**Figure 4. Effect of Baker Flo XS® Pipeline Drag Reducer on Fuel Thermal Stability at 4X the Concentration of Intended Use**

### 3.1.1.2 Conoco CDR 203® Gel and Refined Power® II

The Air Force sample designation for Conoco CDR 203 is 00-POSF-3784. HLPS tests were performed on CDR 203 blended at 8.8 ppm in a suite of 18 fuels. Table 4 and Figure 5 show the results of those tests: there was no negative impact on the thermal stability of any of the reference fuels.

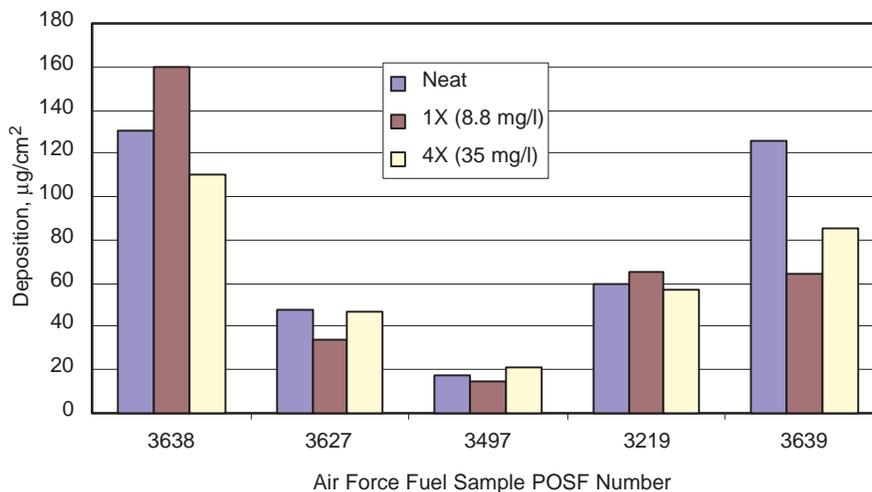
**Table 4. Effect of Conoco CDR 203 on Fuel Thermal Stability Based on HLPS Tests**

Baseline Reference Fuels	Neat-Fuel Deposits (µg/cm²)	Conoco Gel PDR at 8.8 mg/l			Conoco Gel PDR at 35.2 mg/l (4X)		
		Date	Deposits (µg/cm²)	ΔP, mm Hg (@ minute)	Date	Deposits (µg/cm²)	ΔP, mm Hg (@ minute)
99-POSF 3639	126	7/25/01	64	180 @ 300	11/01	85	unknown
99-POSF 3683	98	7/26/01	89	>300@30			
99-POSF 3633	184	10/24/01	162	>300@60			
99-POSF 3638	130	10/23/01	160	>300@120	11/1/01	110	>300@150
99-POSF 3686	171	8/2/01	155	>300@40			
99-POSF 3603	20	8/1/01	18	1 @ 300			
99-POSF 3602	76	7/5/01	56	>300@90			
99-POSF 3640	139	8/12/01	96	>300@165			
99-POSF 3688	65	8/7/01	56	>300@110			
99-POSF 3593	34	7/24/01	30	40 @ 300			
99-POSF 3627	48	10/22/01	34	>300@250	11/8/01	47	>300@265
99-POSF 3601	88	8/6/01	34	1 @ 300			
99-POSF 3658	210	10/29/01	212	>300@30			
99-POSF 3694	22	7/23/01	20	>300@129			
00-POSF 3305	50	10/25/01	53	>300@60			
95-POSF 3166	155	8/30/01	141	>300@120			
98-POSF 3497	17	10/26/01	15	3 @ 300	10/31/01	21	2
96-POSF 3219	60	9/4/01	65	>300@280	11/01	57	>300@240



**Figure 5. Effect of Conoco CR203 on Fuel Thermal Stability at 8.8 mg/l**

Five fuels were tested at 32 ppm concentration. These were the same five fuels used in the Baker PDR tests at the 32 ppm concentration. The fuels included a straight-run Merox-sweetened (POSF 3639), a straight-run no treatment (POSF 3638), a straight-run hydrotreated (POSF 3627), and two Jet A fuels used in the Air Force *High-Temperature Fuels* development program. Table 4 and Figure 6 show that thermal stability of the five reference fuels was not negatively impacted when doped at four times the concentration being sought for approval.

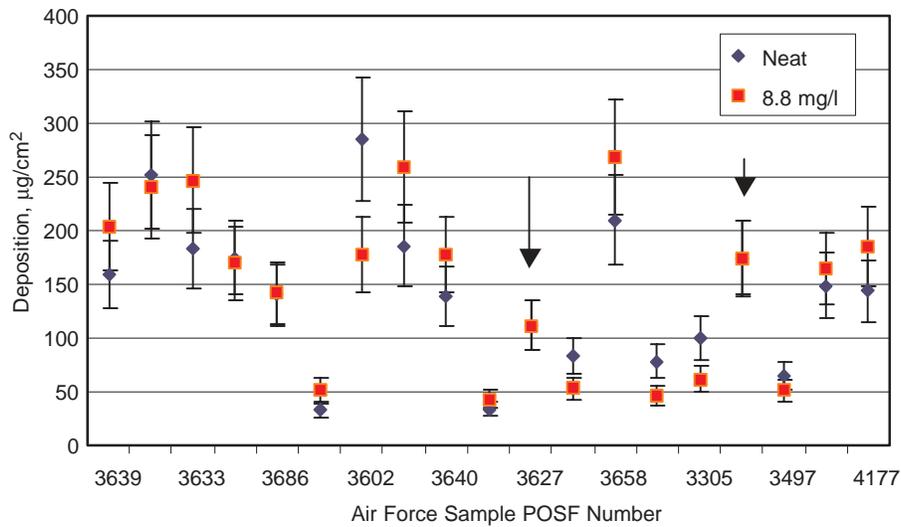


**Figure 6. Effect of Conoco CR203 on Fuel Thermal Stability at 35 mg/l**

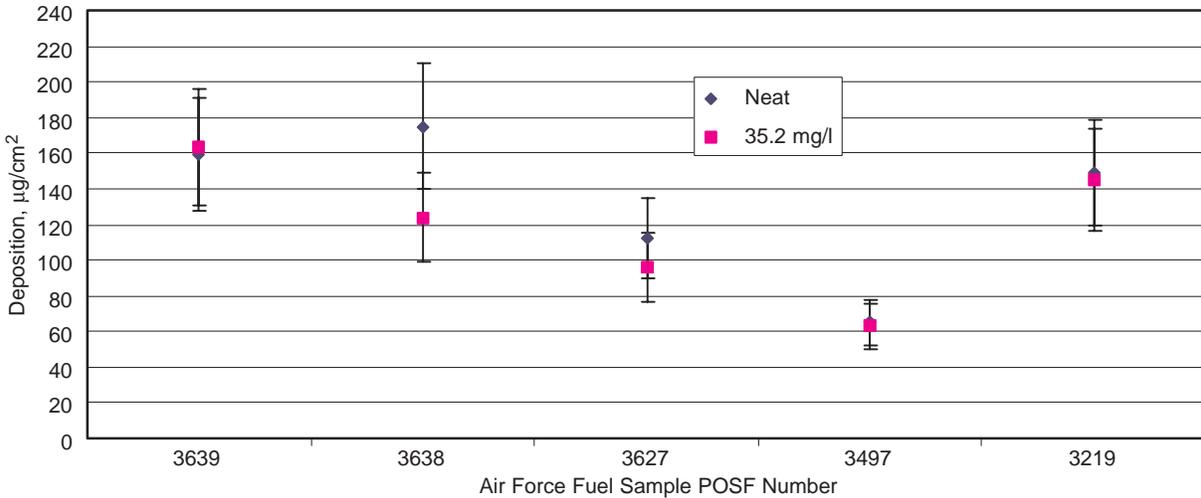
Refined Power<sup>®</sup> was evaluated in the same suite of 19 reference fuels used in the previous Baker FLO XS<sup>®</sup> and Conoco CDR 203 gel-type drag reducer tests. Five tests were performed at 4 times the approval concentration. The test results at 8.8 and 35.2 mg/l are shown in Table 5. Figure 7 is a graphical representation of the effect of the Conoco pipeline drag reducer on the thermal stability of the 19 test fuels at 8.8 mg/l. Figure 8 is a graphical representation of the effect of Refine Power on the five test fuels at 32 ppm concentration. Based on the test results shown in Table 5, Figure 7, and Figure 8, and considering a test error of  $\pm 20\%$ , the Conoco Refined Power<sup>®</sup> II flow improver drag reducer had no effect on the thermal stability of the test fuels.

**Table 5. Effect of Conoco Refine Power at 8.8 mg/l and 4x Concentration on HLPS**

Air Force POSF No.	Deposits ( $\mu\text{g}/\text{cm}^2$ )		
	Baseline	8.8 mg/l	4X Concentration, 35.2 mg/l
3639	159	204	163
3683	252	240	
3633	184	247	
3638	175	170	124
3686	140	142	
3603	33	52	
3602	285	178	
3688	186	259	
3640	139	178	
3593	34	43	
3627	112	112	96
3601	83	53	
3658	210	268	
3694	78	46	
3305	100	62	
3166	174	175	
3497	65	51	63
3219	149	165	145
4177	144	185	



**Figure 7. Effect of Conoco Refined Power at 8.8 mg/l**



**Figure 8. Effect of Conoco Refined Power II Flow Improver on Thermal Stability at 4X Concentration**

In parallel with the P&W–AFRL work, the AFRL had separate CRADA’s with Buckeye Pipeline Company for the Baker product and, eventually, Conoco Specialty Products to conduct series of thermal stability testing using other techniques, such as isothermal corrosion/oxidation test (ICOT) and quartz crystal microbalance (QCM), to screen candidate fuels and then HLPS (conducted by P&W as reported above), EDTST, near-isothermal flow test rig (NIFTR), augmentor simulator, and advanced reduced-scale fuel system simulator (ARSFSS) to do further evaluation. In review, the data obtained from these tests essentially duplicated the HLPS thermal stability results. The information from these tests is presented in Addendum 3.

### 3.1.2 Thermal Oxidative Stability Conclusions

The PDR’s evaluated included a gel-based formulation manufactured by Baker Petrolite, a gel-based formulation manufactured by Conoco, and a suspension-based PDR in an alcohol carrier manufactured by Conoco. The additives were evaluated in a suite of 19 fuels at 8.8 ppm and in 5 fuels at 35.2 ppm.

Testing done by ALCOR, using JFTOT, D 3241, indicates that 8.0 ppm and higher concentrations can degrade fuel break point by 10° C.

P&W HLPS tests for the Air Force and separate tests conducted by AFRL as a means of determining the effect of PDR’s on fuel thermal oxidative stability showed that, within the error of the test, PDR’s demonstrated no negative impact on fuel thermal stability.

### 3.2 Filterability

Testing of PDR’s for filterability was done by Velcon Filters, Inc. to assess the effects of the Baker Petrolite product on coalescers and monitors from December 1997 and into January 1998. A second series of tests in was conducted in April, at higher concentrations.

Navy Air Systems Research and Engineering ran two 80-hour coalescer tests to assess PDR effects on water separation.

### 3.2.1 Coalescer and Water Absorbing Monitor Testing – Initial Testing

As reported in Reference 5, Velcon Filters, Inc. did the test work at their facility in Colorado Springs. The PDR used was Baker Petrolite PDR 1020, which is FLO XS<sup>®</sup> diluted with kerosene and degraded to make it more appropriate for shipping.

The testing was initiated to determine the effects of the PDR on coalescence degradation, filter solids removal degradation, filter differential pressure increase, the effects of molecular weight on filter performance, and degradation of water-absorptive filter performance.

A bench-scale test loop was assembled. The test loop was composed of a 200-gallon fuel tank, main fuel pump, means to inject water into the pump, means to inject a solids slurry, means to inject the PDR additive, test filter vessels, and appropriate instrumentation to measure and monitor performance. Test time was limited by tank size and fuel volume.

The test cartridges were shortened filters, 2-inches long. The models used were the I-44085 coalescer cartridge and the CDF-230K water-absorbing monitor. Appropriate-sized filter vessels were provided.

The test plan was to run single-pass fuel only (45 minutes duration), fuel with solids injection (25 minutes), and fuel with water injection (20 minutes). Test runs were made to determine the amounts of contamination necessary to get an adequate result in the test time. The contamination levels chosen were:

- Coalescer solids injection: 35 mg/l
- Coalescer water injection: 2000 ppm
- Monitor solids injection: 2.0 mg/l
- Monitor water injection: 20 ppm
- Baker Product 1020, partially sheared: 20 ppm (Mol. Wt. 6 M)
- Baker Product 1020, fully sheared: 20 ppm (Mol. Wt. 1.5 M)

The Baker product was added at 2.5 requested dosage to increase test severity. Other additives used in the testing were Stadis 450, static dissipater, and DCI-4A corrosion inhibitor and standard dosages.

The solids were a mix of ultrafine silica dust (90% by weight) and R9998 red iron oxide (10%), and fuel sample checks were done using ASTM D 2276.

The water was filtered city water; fuel-sample checks were done using ASTM D 3240.

The test fuel was Diamond Shammrock Oil supplied Jet A. Fuel was clay treated after receipt.

The test runs were determined by design of experiments (DOE) concepts using three test factors: drag reducer, filter cartridge, and additional additives. The DOE resulted in a 10-run matrix, shown in Table 6. Runs 2 and 5 were repetitions to check repeatability. The test data are shown in Table 7. Details of the testing are provided in Addendum 4.

Note in Table 7 that the pressure drop increased rapidly in all tests using the partially sheared PDR additive, so rapidly that the addition of partially sheared PDR was stopped in the “fuel only” part of the test when the delta pressure reached 10 psid. To keep the pressure drop low enough to allow the water addition portion to be run, PDR was not added during the solids injection part of this test.

**Table 6. Test Plan for Coalescers and Monitors**

Test Run	Drag Reducer	Cartridge	Additives
1	20 ppm, Fully Sheared	Coalescer	Stadis / DCI
2	20 ppm, Partially Sheared	Coalescer	Stadis / DCI
3	20 ppm, Fully Sheared	Coalescer	None
4	None	Coalescer	Stadis / DCI
5	20 ppm, Partially Sheared	Coalescer	Stadis / DCI
6	None	Coalescer	None
7	None	Monitor	None
8	20 ppm, Fully Sheared	Monitor	Stadis / DCI
9	None	Monitor	Stadis / DCI
10	20 ppm, Partially Sheared	Monitor	None

**Table 7. PDR Test Plan for Coalescer and Monitor**

Run	ΔP, psid				Max. Eff Millipore, mg/l***		Max. Eff. Water, ppm
	Initial	End of Fuel Only	End of Solid Inj.	End of Water Inj.	Solids Inj.	Water Inj.	
1	4.7	5.7	8.1	18.2	0	0	1
2	3.7	10.0*	11.8**	18.0	0	0	1
3	4.2	4.2	4.6	14.1	0	0	<1
4	3.7	3.7	7.5	15.2	0	3.2	1
5	3.8	10.0*	10.3**	21.5	0	0.4	1
6	3.6	3.6	4.7	16.2	0.4	0	<1
7	4.0	4.1	7.8	10.5	0	0.4	<1
8	4.3	5.3	7.2	7.6	0	0.4	<1
9	4.0	4.2	7.8	11.8	5.6	0	<1
10	3.9	10.8*	25**	40	0	0.4	<1

\* Stopped PDR Injection at approximately 10 psid.  
 \*\* No injection of PDR during "Solids Injection."  
 \*\*\* Only 1/4 gallon sampled.

### 3.2.1.1 Analysis of Test Data

Filter/monitor pressure drop increased sharply when the partially sheared PDR was added to the fuel. Pressure drop increased more quickly in the monitor, possibly due to the more efficient media and less surface area. That result was also seen in the water injection portion of the test.

Fully sheared PDR caused only a slight increase in two of the three tests of "fuel only."

Effluent solids resulted in some scattering of the millipore test data. Two of the three runs exhibited high effluent solids but had no PDR injection. Data scatter is not unusual considering the shortened cartridges and small volume (1/4 gallon) of fuel sampled. The data suggest PDR's had no effect on the solids removal efficiency of the cartridges.

Effluent water in all tests remained very low. Coalescence was visibly unchanged, and coalesced water droplets were large. The monitor cartridge had no AquaGlo-detectable water downstream. Effluent water turbidity data were scattered, and are not presented in this report, but remained low throughout water injection.

The data were further analyzed by performing DOE on the pressure drop for the fuel-only and water-injection phases of the test. No results could be obtained from the solids-injection phase because there was no partial-sheared PDR injection and because the fully sheared injection did not result in significant pressure drop increase.

For the “fuel only” portion of the test, the DOE predicted that relative pressure drop would increase as follows:

- Partially Sheared injection: 5× higher than no PDR
- Fully Sheared: 1× higher than no PDR
- Monitor: 1× higher than Coalescer (tighter filter media?)

Stadis and DCI-4A had no significant effect on pressure drop.

For the “water injection” phase of the test, the DOE predicted that relative pressure drop would increase as follows:

- Partially Sheared injection: 4× higher than without PDR
- Fully Sheared: 1× higher than without PDR
- Monitor: 4× lower than Coalescer  
(A function, perhaps, of the difference in protocol for coalescers and monitors; better dispersion of the water may create better usage of the water absorbent materials.)
- Stadis and DCI-4A: 4× lower than without these additional additives  
(Additives may have provided better dispersion of the sheared PDR materials.)

The conclusion that presence of PDR’s lowered pressure loss is suspect, and may be an artifact of the data scatter, particularly between the repetition runs Nos. 2 and 5.

### **3.2.1.2 Conclusions (Test Report 597–98)**

The summary conclusions from these abbreviated, bench scale tests were that the Baker Product 1020 PDR had no detrimental effect on the particulate- and water-removing ability of the coalescer and monitor cartridges, but it did reduce cartridge life as a direct function of molecular weight.

## **3.2.2 Coalescer and Water Absorbing Monitor Testing – Second Series**

Velcon Filters Inc. did a follow-up series of tests to those reported above, on April 28, 1998, reported in Reference 6 and summarized here.

### **3.2.2.1 Test Description**

The focus of this testing was to better characterize the pressure drop increase of filters when PDR’s are present in the fuel. Various combinations of PDR type and concentration were tested with coalescers. Tests were fuel only with no other additives.

Testing was done in the lab at Colorado Springs and in a reassembled 2-gpm test loop. A shortened version of a Velcon model I-44085 coalescer cartridge (“85”) was used for one test to determine PDR effects on tighter coalescers. A shortened “87” series coalescer was used to simulate into-plane fueling.

Single-pass testing was used once again and the PDR material was Baker Product 1020, fully sheared (1.5 million molecular weight, mw) and partially sheared (6.0 million mw). The additive

contained 0.59% active polymer. Influent and effluent fuel samples were taken and Baker Petrolite determined the actual change in active polymer in the samples.

The Jet A fuel was obtained from Diamond Shamrock Oil Company and met ASTM D 1655 requirements. The Test Plan is shown in Table 8; individual test data are shown in Addendum 4.

**Table 8. Test Plan for “Fuel Only” PDR Injection, Series I-44085 and I-44087 Filters**

Test	PDR Condition	Concentration (ppm)	Main Pump	Coalescer
1	Fully Sheared	2.0	Centrifugal	New “85” Series
2	Fully Sheared	8.0	Centrifugal	New “85”
3	Fully Sheared	20.0	Centrifugal	Same “85”
4a	Partially Sheared	2.0	Prog. Cavity	New “85”
4b	None	–	Prog. Cavity	Same “85”
5a	Partially Sheared	2.0	Prog. Cavity	New “85”
5b	Partially Sheared	8.0	Prog. Cavity	Same “85”
6	Fully Sheared	8.0	Prog. Cavity	New “87”

### 3.2.2.2 Conclusions (Test Report 602 – 98)

The partially sheared PDR caused larger increases in filter pressure drop than did the fully sheared PDR, confirming results of earlier tests.

The pressure drop increases were substantially less than in the earlier testing. Probable cause was that the PDR was added into the fuel tank rather than being directly injected into the fuel ahead of the filter. Thus the PDR was more dispersed (more realistic) in this testing.

Pressure loss reached equilibrium values after some time.

Increases in PDR concentration caused only slight increases in filter cartridge pressure drop. Increases from 2 ppm to 20 ppm only doubled the pressure drop level.

There were some flow interruptions, causing a reduction in filter pressure drop in some cases. Probable cause: polymer reorientation in the filter as shear forces of flow were stopped.

### 3.2.3 Navy Long-Term Coalescence Tests

Two long-term coalescence tests were run by the Naval Air Systems Research and Engineering group, June through December 2002, and reported by Fuel Technology Associates, LLC at ASTM, in December 2002 (Reference 7). These 80-hour tests were run on single-element Facet coalescers. The commercial unit used was a Facet CA14-3, API/IP Third Edition, and the military unit used was a Facet CM100 14SB, qualified to API/IP 1581 Fourth Edition. The fuel used was Jet A additized with 3.5 ppm Stadis 450 (conductivity) and 2.9 ppm HiTec E-580 (corrosion inhibitor). The first test was without PDR, and the second test was with 20 ppm fully sheared Baker FLO XS<sup>®</sup> PDR added. Each test ran for 79.5 hours.

The purpose of the tests was to determine if long-term coalescence was affected by the presence of the PDR. The flow was set at 10% rated for 79 hours and raised to design flow and 0.1% water for the last 30 minutes of the test.

The commercial coalescer demonstrated little change in delta pressure measurement or in AquaGlo water measurement during this 30-minute time period.

The military coalescer demonstrated little change in the delta pressure measurement; the AquaGlo measurement increased from 2 to about 9 ppm/psi/gpm for the base fuel and from 2 to about 3 ppm/psi/gpm for the fuel with the sheared PDR.

Figures 9 and 10 show the data for the commercial element over the whole test period. Figures 11 and 12 show the data for the commercial element during the last hours of the test.

Figures 13 through 16 provide the same information for the Facet military element and in the same order.

It was concluded that the results were favorable. There was no deactivation by the presence of the PDR, but there may have been some slight delta pressure increase with the PDR that would bear further scrutiny if PDR's were approved for use. There was no monitor testing.

The collaboration of Fuel Technology Associates and NavAir resulted in the fabrication of a comprehensive test plan for filter/separators and monitors, "Effect of Pipeline Drag Reducer additive on Coalescence and Filtration in Aviation Fuels," and a potential ASTM Standard Test Method for determining the concentration of pipeline drag reducer additive in aviation turbine fuels, both to be saved for another day. An overview of the fuel-handling aspects with PDR's was presented by Fuel Technology Associates at the CRC Aviation Fuels meetings held in Alexandria, VA on April 29, 2003. The overview, replicated herein as Addendum 5, included work remaining and necessary elements to be considered if PDR's were to be removed from the fuels at the airport.

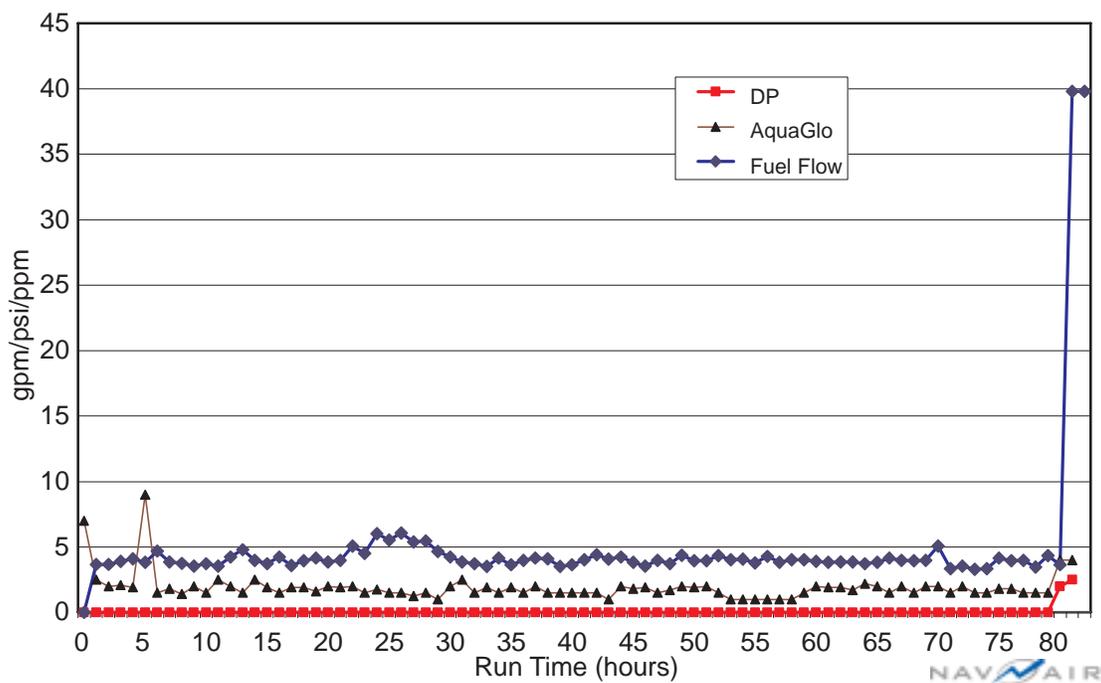


Figure 9. Facet Commercial Element, Fuel Without PDR

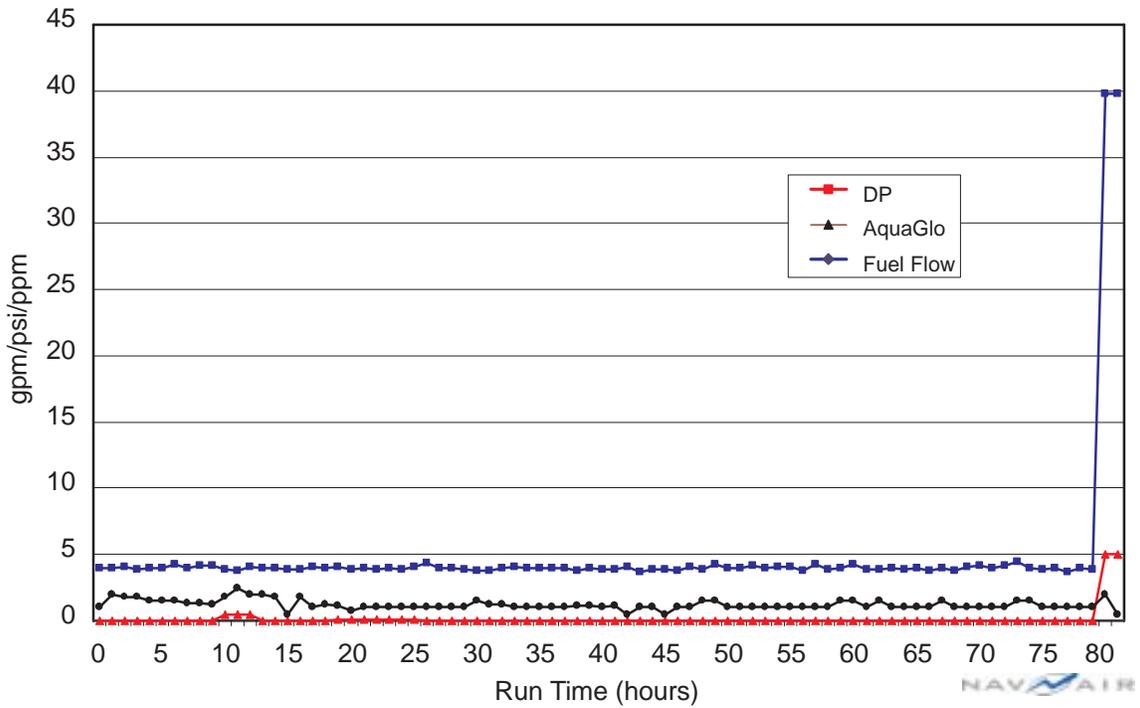


Figure 10. Facet Commercial Element, Fuel With PDR

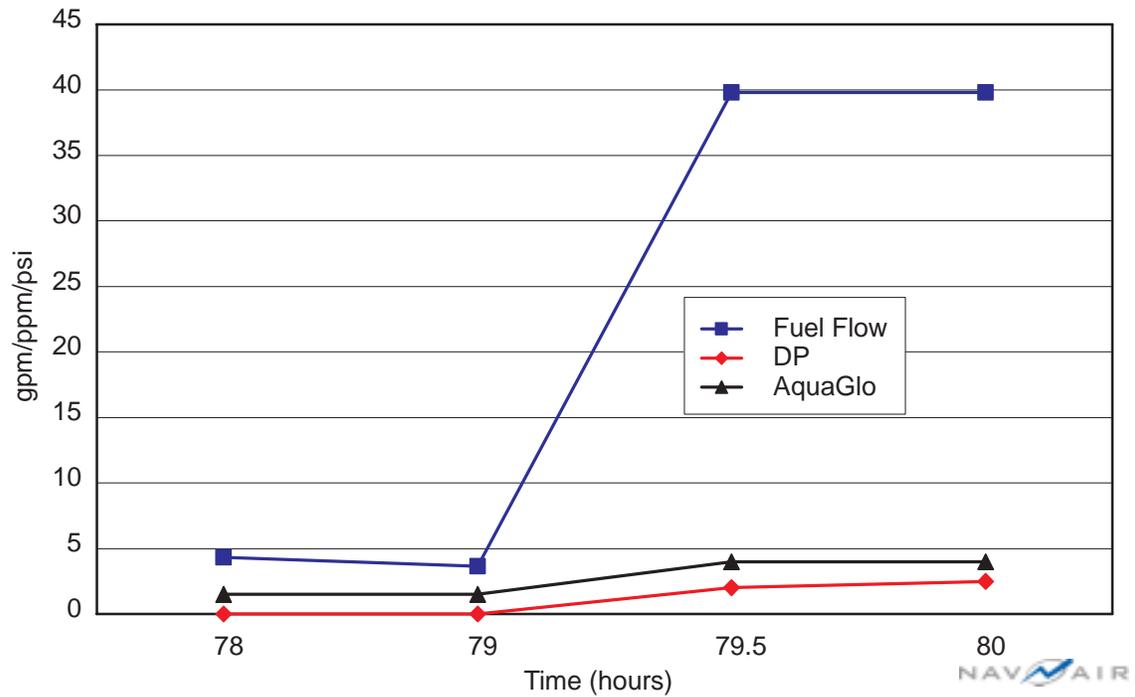


Figure 11. Last Two Hours of Test Using Fuel Without PDR, Commercial Element

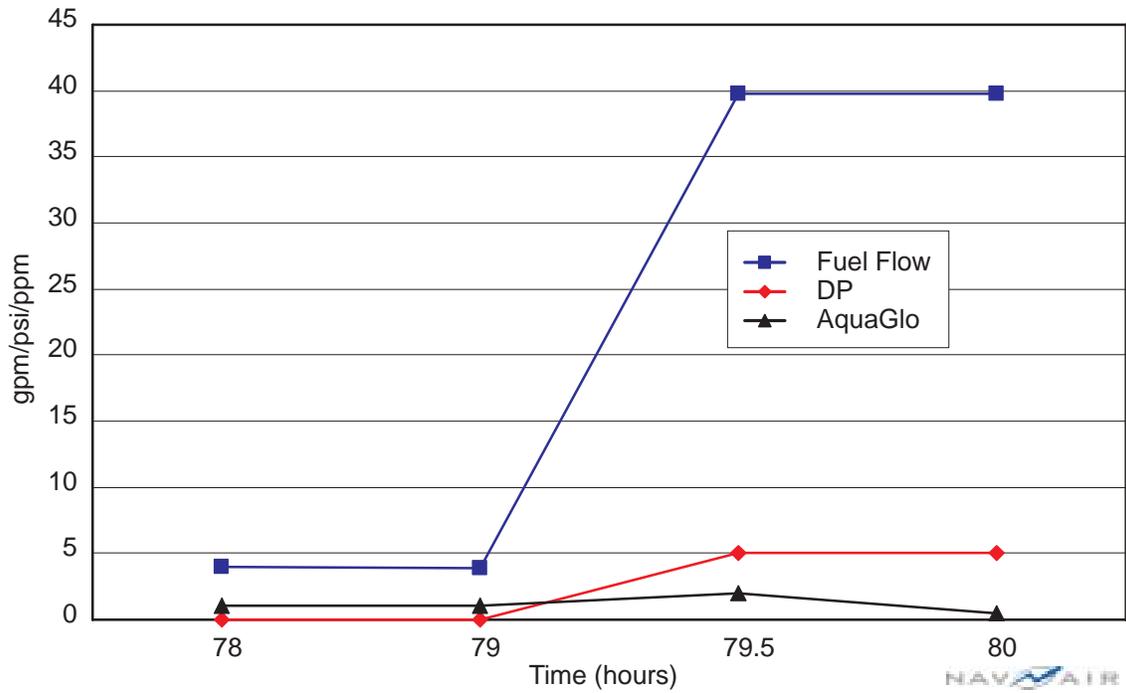


Figure 12. Last Two Hours of Test Using Fuel With PDR, Commercial Element

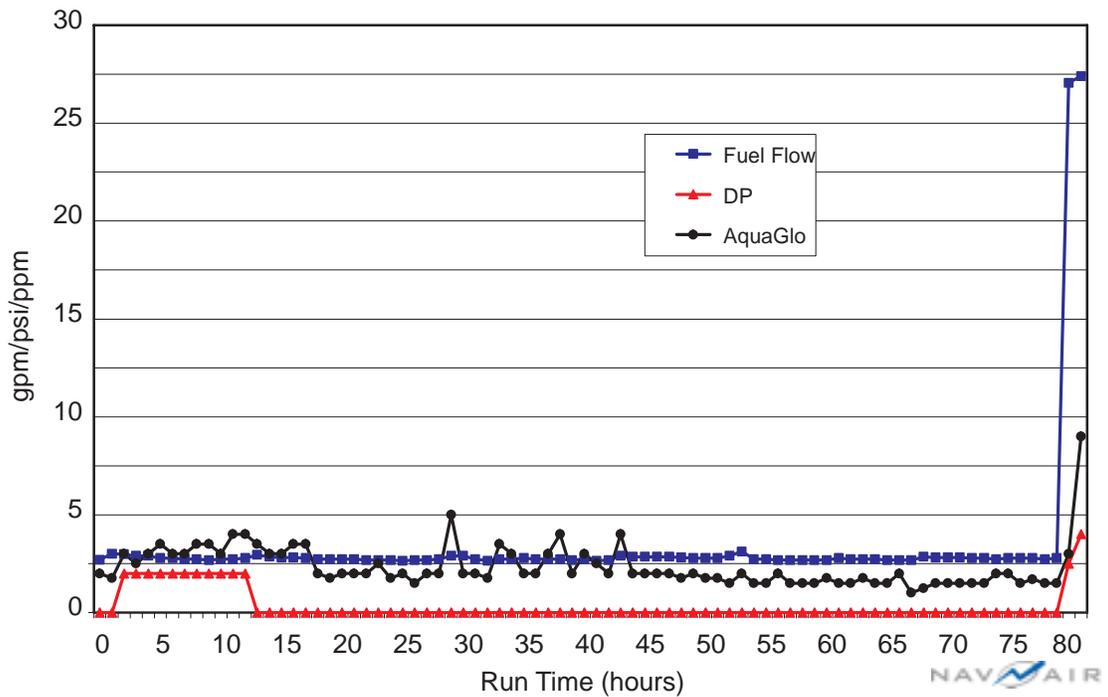


Figure 13. Facet Military Element, Fuel Without PDR

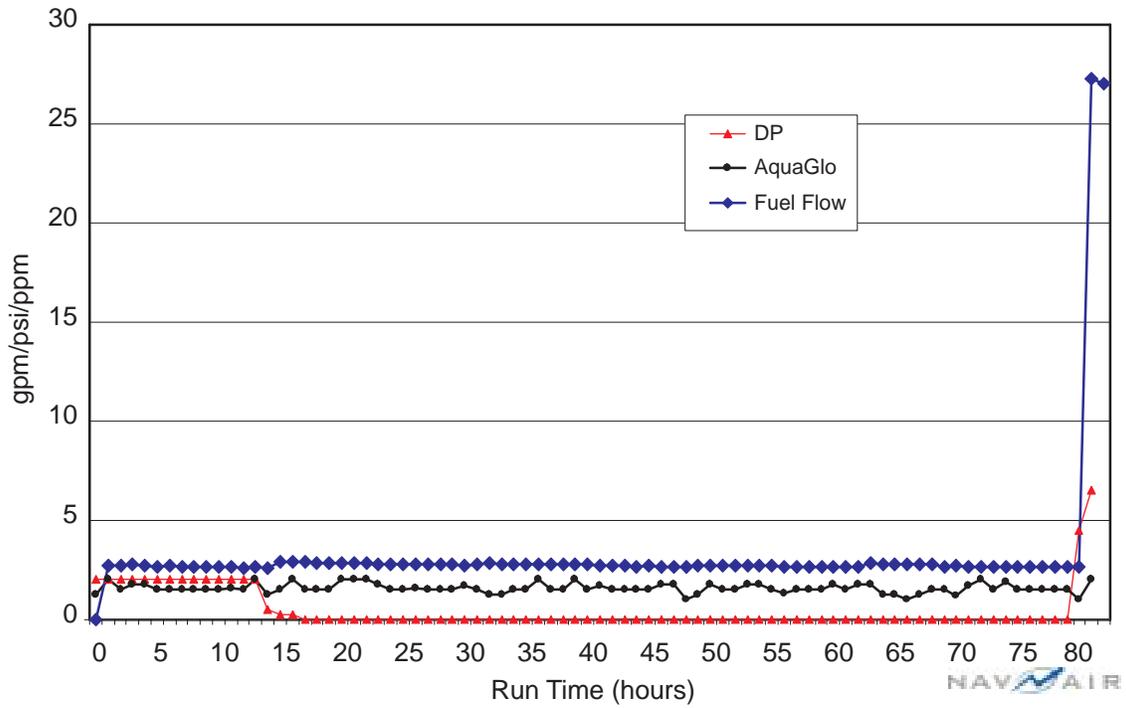


Figure 14. Facet Military Element, Fuel With PDR

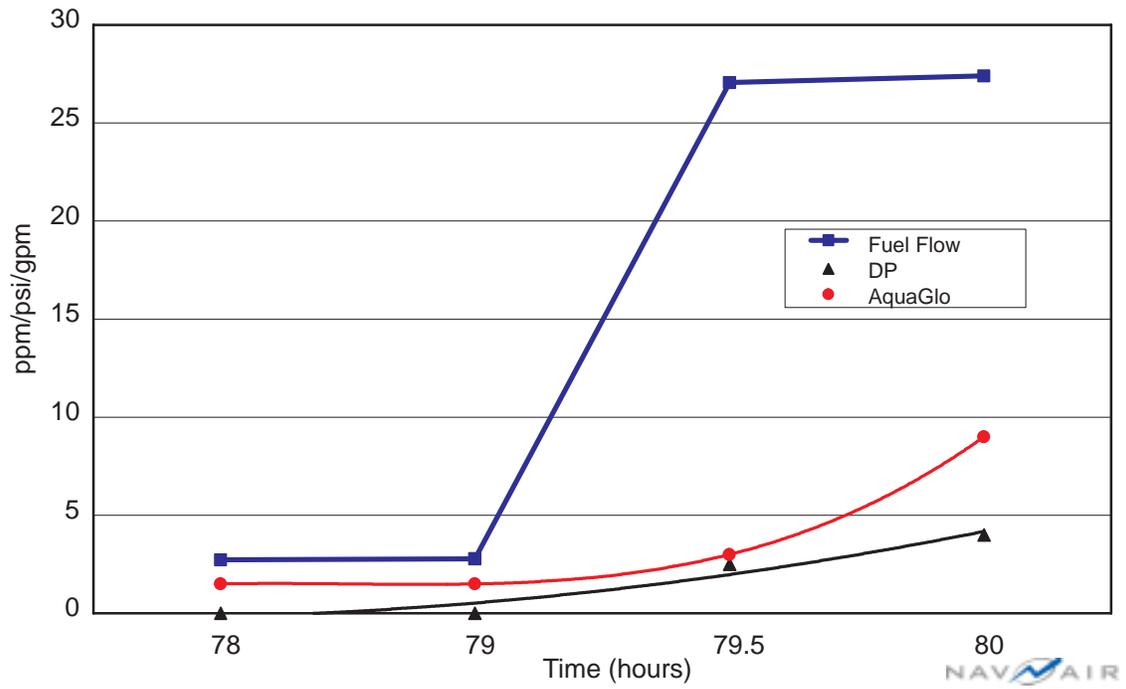


Figure 15. Last Two Hours of Test Using Fuel Without PDR, Military Element

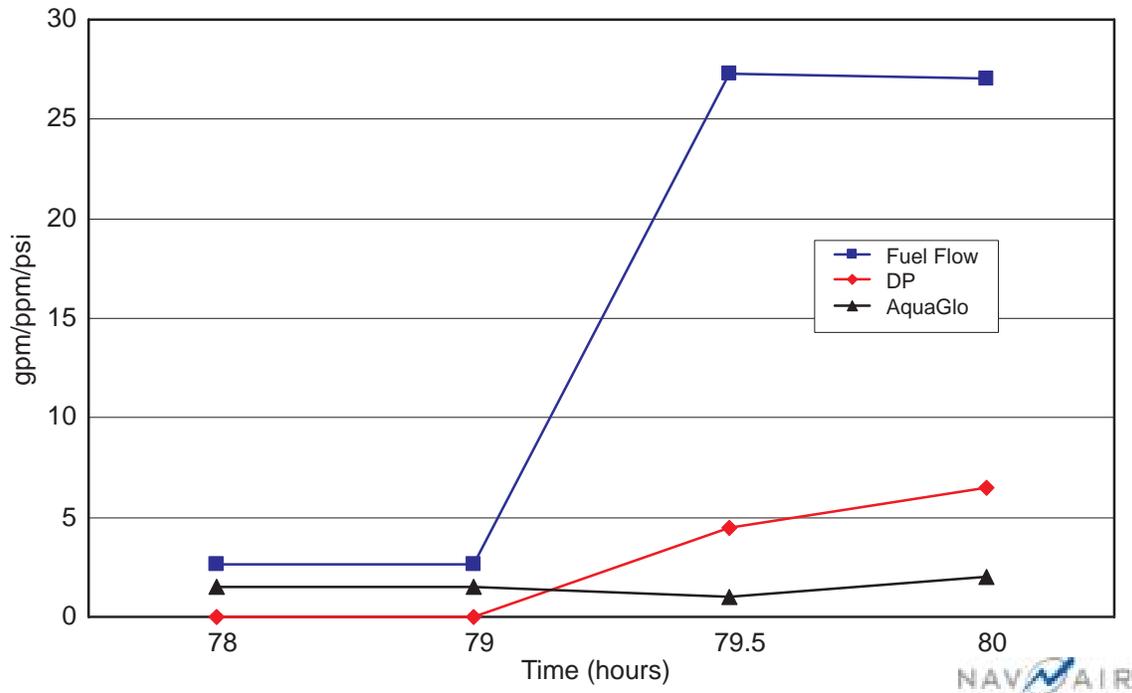


Figure 16. Last Two Hours of Test Using Fuel With PDR, Military Element

### 3.3 Combustion Performance Testing

#### 3.3.1 Summary of Fuel Nozzle Performance Evaluation and Ignition Testing

In the first part of this test program (Reference 8), four commercial engine fuel nozzles were chosen for testing to determine the effects of the pipeline drag reducer on the fuel nozzle spray characteristics, spray-cone quality, and droplet size. Testing was done in October and November 2001. JP-8 fuel was used. The fuel was provided to the fuel nozzle candidates in three versions: neat (without any PDR in it), with 8.8 ppm PDR, and with 32 ppm PDR. Each type of fuel was run at local ambient temperature and at successively colder temperatures down to about  $-30^{\circ}\text{F}$  ( $-34.4^{\circ}\text{C}$ ). Each fuel nozzle was encased in a metal box. Air, cooled to the fuel temperature or lower, was flowed into the box to maintain the fuel nozzle structure temperature at the fuel temperature. The nozzle spray characteristics were recorded with a digital camera. The fuel flows used for these tests were in the engine minimum fuel flow range expected at starting. The fuel nozzles selected were CF6, CFM56, GE90 (all fuel pressure atomizing nozzles), and T700, a low-pressure fuel injector design also used in some models of the CF34.

The observed results indicated that, compared to the neat fuel, fuel with 8.8 ppm PDR did not appear to cause any visual effect on the nozzle spray cone angle or droplet size. Fuel with 32 ppm PDR did appear to cause larger fuel droplets in the fuel spray cones of nozzles which spray cones had not collapsed, and 32 ppm PDR also appeared to tighten the fuel stream from those nozzles in which the spray cone had collapsed. Where the spray had collapsed to a stream, and with the PDR in the fuel, the fuel nozzle had to be flowed to a much higher level before the spray cone reestablished itself.

The ignition part of this investigation was started in August 2002 and completed in early December. The CFM56 fuel nozzle was selected for start testing. A  $90^{\circ}$  sector of an annular combustor was assembled into a test rig, which accurately modeled the combustor system flowpath from the compressor discharge to the turbine nozzle inlet. The sector was supplied with air at the proper

pressure and temperature to simulate operating conditions from sea level on the ground to 10,000 ft on the ground and from sea level to normal engine operating altitudes for both windmilling and starter-assist starting. Air and fuel temperatures were set to local ambient, 32°, 0°, -20°, and -30° F (0°, -18°, -29°, and -34° C) for the altitude testing and down to -60° F (-51° C) for the ground starting. The fuel used for this testing was JP-8, neat, with 8.8 ppm PDR and with 32 ppm PDR. The fuel was set initially to normal engine-starting fuel flows, as dictated by minimum fuel flow requirements, and the control  $W_f/P$  schedule. If ignition did not occur, fuel was slowly increased to the maximum that could be obtained at the engine core speed being simulated. Each start condition was demonstrated three times to ensure repeatability. The recorded results of this investigation were then evaluated using the neat fuel performance as a baseline.

When 8.8 ppm PDR was put into the fuel, there were a small number of operating conditions in which a higher fuel flow was required to obtain successful ignition. There were three operating points for which no ignition could be obtained.

When fuel with 32 ppm PDR was used, there was an increase in the number of test points for which higher fuel flow was required to obtain ignition. There were three points for which no ignition was obtained, the same points as with 8.8 ppm PDR.

### 3.3.2 Comments on the Fuel Used

The fuel used for this test was standard delivery JP-8. The fuel that was mixed with fully sheared PDR additive was delivered in March 2000 and put into each of two 1000-gallon fuel trailers. Trailer Number 25 received 500 gallons of fuel and was subsequently doped with 8.8 ppm of the PDR. Trailer Number 22 received 500 gallons of fuel and was doped to 32 PPM PDR. These fuels were quality checked by Baker Petrolite in August 2000, and it was determined that the PDR concentrations were correct. The spray tests were conducted in fourth quarter of 2001. Samples of the fuel in the tanks were pulled in June 2002 and checked to see if they met specification. They did, and these data are compared to data from the March 2000 refinery quality sheets in Table 9. The ignition testing was run in the third and fourth quarters of 2002.

**Table 9. Comparison of JP-8 Fuel Properties, Year 2000 and Year 2002**

Fuel Property		08 March 200 Intertek Testing	10 June 2002, GE Fuel/Lube Lab	
			Trailer 22	Trailer 25
Flash Point, °F		114	117	115
Distillation, °F/°C	Initial Boiling Point	315/157	298/148	296/147
	10% Point	342/172	344/173	342/172
	20% Point	353/176	356/180	356/180
	50% Point	386/196	388/198	386/196
Freeze Point, °C		-49	-48	-48
Specific Gravity		0.796	0.797	0.796
Viscosity, cSt at 100 °F		Not measured	1.32	1.30
Net Heat, Btu/lbm		Not measured	18,610	18,610
% Hydrogen		Not measured	13.96	14.04

### 3.4 Fuel Nozzle Spray Tests

#### 3.4.1 Equipment and Hardware

To do the fuel spray investigation, an Air Products liquid nitrogen trailer of 4000-gallon capacity was rented and parked near the test cell, Figure 17. The trailer had condensing coils to maintain pressure in the tank section. The nitrogen/air heat exchanger is shown in Figure 18. To the left of the rectangular unit is the nitrogen/fuel heat exchanger, wrapped in an insulating blanket and seated on a low dolly. Nitrogen from the trailer is supplied through the heavily insulated line in the upper left side of the figure. The nitrogen cools the air and is exhausted on the right side of the box. A portion of the nitrogen is fed to the fuel heat exchanger where it cools an alcohol bath that is used to cool the fuel. This system provides a means of controlling the fuel temperature, a little more carefully than the air system, to prevent fuel freeze-up.

The fuel nozzles are assembled into a small metal box and suspended in a Plexiglas spray chamber as shown in Figure 19. The side of the chamber opens up to permit close observation and photography of the spray. Cold fuel and cold air are piped to the metal box to cool the fuel nozzle and to keep the fuel cold all the way to the spray tip. Thermocouples on the fuel nozzle tip are used to set and maintain the proper test conditions. Figure 20 shows a fuel nozzle box opened up. Air is introduced by the 3/4-inch tube in the foreground. Cold fuel comes to the nozzle inlet fitting shown in the upper right of the figure, and the fuel nozzle tip protrudes from the box in the lower right of the figure. The nozzle shown is a CF6. A CFM56 nozzle is shown mounted in its box in Figure 21. Note that the offset configuration of the nozzle requires that the tip discharge be mounted through an attached housing on the bottom of the box. Similar boxes were made for the T700 fuel injector and the GE90 dual-annular fuel nozzle.

The fuel nozzles used in this testing were:

- CFM56, Part Number 1317M33 (37° primary spray angle)
- CF6–80, P/N 9331M72
- GE90 DAC II, P/N 1878M40, and a
- T700, P/N 4045T30

#### 3.4.2 Test Preparations

The fuel nozzles for the spray testing were checked for flow versus nozzle pressure drop in the fuel laboratory prior to testing. The pressure drops used covered the starting range and the lowest specification test point. The flows were then compared to requirements to ensure that the nozzles operated properly. During these checks, the spray characteristics of each type nozzle were observed to ensure that each produced the proper angle and that the spray was free of streaks.

The nozzles were then instrumented with Type K thermocouples (chromel-alumel), at the tip. These thermocouples monitored the tip temperatures to ensure that the fuel and surrounding environment were at the test temperatures selected. Similar thermocouples were located at the manifold discharge into the fuel nozzle fitting, to ensure the fuel temperature was controlled, and in the air inlet piping to monitor air temperature. The temperatures, fuel flow rates, and airflow rates were read out on a display screen that had the system piping diagram on it; the sensor locations and current values were indicated in local tables shown on the diagram.

Data were hand-recorded at each operating point set. Digital photographs were taken of the fuel nozzles to record the spray characteristics at the test points set.



Figure 17. Cryogenic Nitrogen Storage Trailer

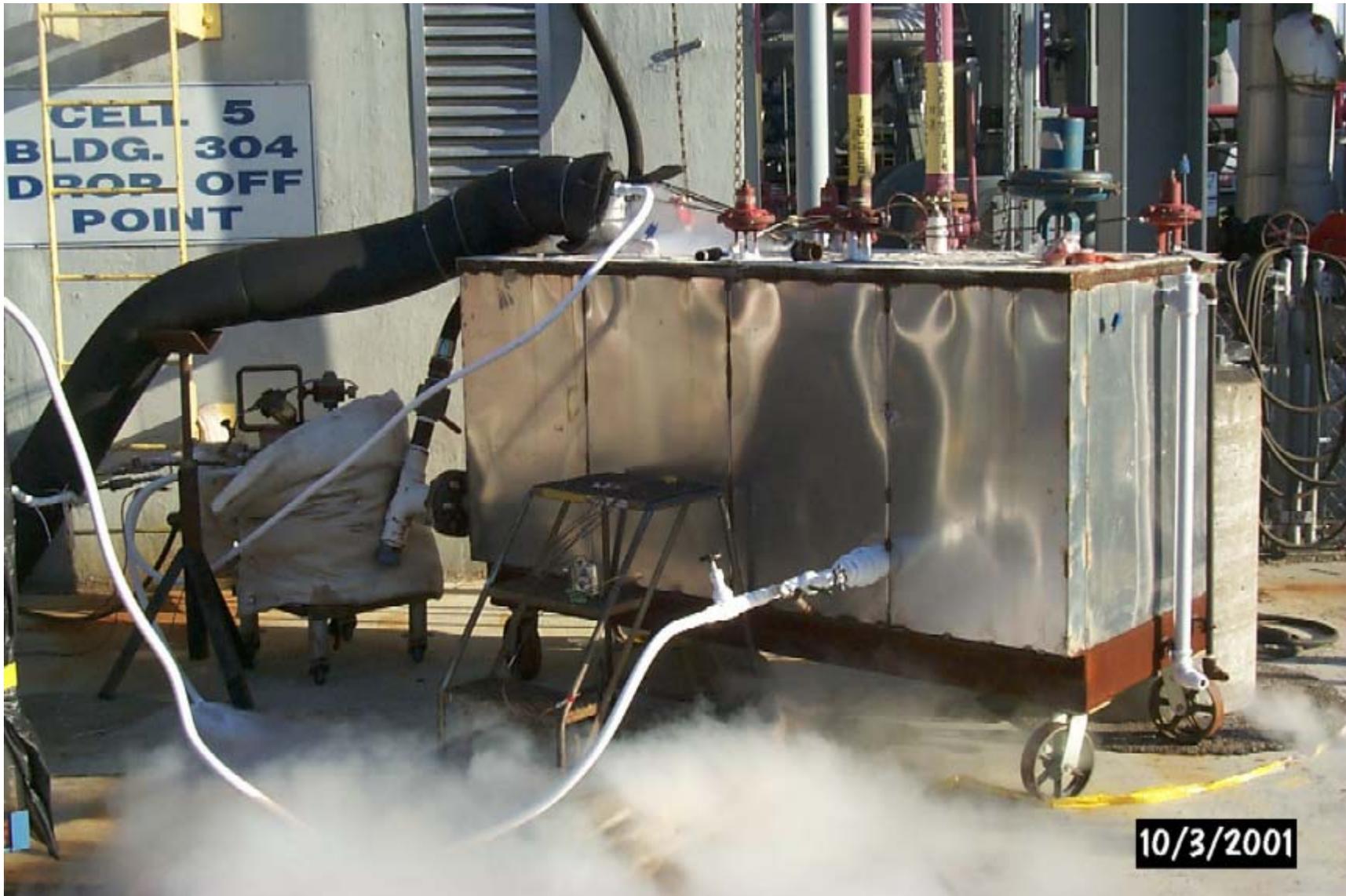


Figure 18. Nitrogen/Air Heat Exchanger Cabinet, Nitrogen/Fuel Heat Exchanger to Right of Cabinet



**Figure 19. Spray Chamber** *Door open, fuel nozzle spray box mounted and being cooled down.*



**Figure 20. CF6 Fuel Nozzle in Enclosure** *Air feed tube in foreground. Nozzle fuel inlet is upper horizontal line.*



**Figure 21. CFM56 Fuel Nozzle** *Note small housing to account for offset of fuel nozzle tip.*

The test plan was to run each of the four nozzles at ambient air and fuel temperatures, cold air and ambient fuel temperatures, and cold air and cold fuel temperatures. At each condition, a minimum starting fuel flow was set, and the spray patterns from each nozzle were photographed and observed. If the nozzle spray pattern exhibited any abnormalities at minimum fuel flow, the procedure was to then slowly increase fuel flow until the abnormality ceased or a flow level consistent with maximum fuel flow for the starting operation was reached. Maximum fuel flow for any of the nozzles was a function of the starting condition being simulated and the known control fuel schedule limitations. The plan was to start testing with neat JP-8, proceed to JP-8 with 8.8 ppm PDR, and then to 32 ppm PDR fuel.

### **3.4.3 Fuel Nozzle Test Results**

Figures 22 through 25 show the nozzle spray patterns from the four candidate nozzles using neat JP-8 at normal ambient temperatures.

The CFM56 nozzle was used in the altitude and ground ignition testing. Figures 26 through 28 show the effects of cooling the air and fuel, and then adding the PDR.

Cooling the air and fuel without the PDR resulted in some loss in fuel spray angle and two streaks within the spray. Adding 8.8 ppm PDR increased the two-streak tendency and the sheeting of the fuel just at the nozzle discharge face. Increasing PDR to 32 ppm caused the spray to collapse into

34° F (1.1° C) Air; 64° F (18° C) Fuel  
Normal Spray Pattern



Figure 22. CF6 Fuel Nozzle at Starting Flow

10° F (-12° C) Air; 16° F (-9° C) Fuel  
Normal Spray Pattern



Figure 23. CFM56 Nozzle, Starting Flow



65° F (18° C) Air; 65° F Fuel  
Both Tips Flowing Normally

**Figure 24. GE90 Nozzle at Starting Flow**



65° F (18° C) Air  
and Fuel

**Figure 25. T700 Fuel Injector** *Tip discharge is faced up, causing drool. Fuel is atomized by air from swirler nozzle is normally inserted into.*

-34° F (-37° C) Air; -32° F (-36° C) Fuel



**Figure 26. CFM56 Nozzle, Neat Fuel** *Spray narrows, becomes streaky, sheets near apex.*

-13° F (-25° C) Air; -25° F (-32° C) Fuel



35

**Figure 27. CFM56 Nozzle, 8.8-ppm PDR** *Fuel spray is more narrow, and becomes two streaks connected by a sheet of fuel near the apex. Downstream streaks are parallel.*

-41° F (-41° C) Air; -45° F (-43° C) Fuel



**Figure 28. CFM56 Nozzle, 32-ppm PDR** *Spray cone collapsed to a Stream. Spray reestablished at over 3X starting flow.*

a stream of fuel. At this condition, it took a fuel flow increase of over three times starting flow to reestablish a conical spray.

To a large degree, the GE90 nozzle flow characteristics were similar to the CFM56 under similar flow conditions.

The CF6 nozzle was better able to resist spray collapse with increasing cold temperatures and the addition of the PDR, but it evidenced spray instability at some conditions, earmarked by collapse and recovery of the spray at a slow cyclic rate.

The T700 nozzle evidenced little effect of the cold conditions or the PDR due to its operating mode, orientation, and the need for swirler air for atomization capability.

### 3.5 Cold-Start Testing

#### 3.5.1 Equipment and Hardware

The starting performance tests were conducted in late 2002. The testing was performed using a five-cup CFM56 combustor sector housed in a test rig made from a cut-up engine casing and otherwise adapted for this purpose. The rig was attached between an inlet plenum and an exhaust spool that had internal quench-water manifolds. The fuel nozzles were CFM56 and the hydraulic equivalent of the nozzle used in the fuel nozzle spray studies, above. The ignitor was a standard CFM engine plug attached to a high-energy engine exciter. A picture of the test rig is shown in Figure 29. The test sector combustor and a typical fuel nozzle are shown in Figure 30.



**Figure 29. Test Rig**

*Showing fuel line connection to nozzles, hard-piped ignitor lead, and flexible instrumentation lines.*



**Figure 30. Test Sector Combustor and Fuel Nozzle** *Combustor is an annular sector of a combustor; fuel nozzle is a standard commercial part.*

The air and fuel cooling system comprised the same elements used to cool the air and fuel for the nozzle spray tests. The fuel used was current on-hand (neat) JP-8 and fuel from trailers previously doped with 8.8 and 32 ppm Baker Petrolite PDR, fully sheared.

### **3.5.2 Test Preparation**

The combustor sector was test fitted into the rig. After assuring that the sector fit, the fuel nozzles were inserted into the rig and inspected. The nozzles were correctly located in the swirl cups; that is, centered and with about a 10 to 20-mil protrusion through the discharge plane of the swirler. The ignitor was fitted, and the tip immersion was shimmed to be about 60 mils through the liner inside surface, which placed the sparking surface near the inner surface of the combustor liner. Then the combustor sector was removed from the test rig and instrumented with 40-mil Type K (chromel-alumel) thermocouples (capped, ungrounded), one through each outer liner first-panel primary hole, in line with each swirl cup. These thermocouples were placed to give indication of swirl cup ignition during the test. The existent thermocouples on the test rig, which are used to measure inlet conditions (pressure and temperature), were checked for operation and replaced if necessary. The exhaust system instrumentation was similarly treated.

The test rig and combustor were reassembled; the instrumentation was terminated, and the rig was placed in the test cell. The fuel system was hooked up and checked out. The cold air and cold fuel systems were also checked out. As noted above, samples of the fuel in the trailers had been taken in June and tested in the Fuel Lab.

### **3.5.3 Test Plan and Testing**

The tests to be conducted were structured around typical engine ground-start and air-start conditions. The ground-start conditions were based on simulating engine motoring at the core speed at which the ignition system was in regulation and sufficient fuel pump pressure was available to provide minimum fuel flows. The air temperatures selected were ambient, 0° F (−18° C), −30° F (−34° C), and −60° F (−51° C). The ground-start altitudes selected were sea level and 10,000 feet (Mexico City). The air-start altitude test points were selected to be a mixture of windmilling and starter-assist points, military and civil applications, all at standard-day conditions. The objective of the particular testing was to establish a baseline of performance with neat (unadditized) fuel and compare the performance of the PDR enhanced fuel to this standard.

Test procedure was to set test-point pressure, temperature, and air flow. Fuel flow was started through the system but bypassed back to the supply to permit setting of preselected fuel flows. The next steps were to stop fuel flow, take a data reading, turn on ignitor, turn on fuel flow, and wait up to 30 seconds to obtain ignition indication. If no ignition was obtained at the end of 30 seconds, fuel flow was increased from the preset value slowly and continuously to a maximum value. If that did not induce ignition, fuel flow was held for an additional 15 seconds, then stopped. After a wait of two or three minutes for excess fuel to blow out of the exhaust system, the procedure was repeated — twice if necessary. If ignition occurred anywhere on ramp-up, the next steps were to check propagation of flame from ignited cup to the four other cups, close-off fuel flow, wait for system to cool, and repeat procedure until three consecutive starts were demonstrated, or five total attempts completed. Three successes out of five is considered “marginal success.” Three consecutive lights with propagation is considered “total success.”

To conserve test time, air temperature for the altitude air starting, the longest time-set parameter, was generalized to one of three values below ambient conditions. These values were 32° F (0° C), 0° F (−18° C), and −20° F (−29° C). The air start temperatures for the ground starting were left unchanged.

To establish the baseline, the neat fuel was run first with ambient temperature air and fuel. This allowed a check of the test procedure and gave a rough idea of time consumed to run the schedule. As this was the easiest of conditions, it allowed assessment of the test points and gave some idea of how to shorten the test-point list or how to modify the failed points in the schedule.

The plan was then to run with cold air and ambient fuel and finally cold air and cold fuel.

Following that was the switch to 8.8 ppm PDR fuel and cold air and cold fuel testing, followed using fuel with 32 ppm PDR and cold air and cold fuel.

A last air period was scheduled to reassess any data from the first three tests that seemed unusual.

At each test point there was a specified pressure, temperature, airflow, and initial fuel flow. If there was no ignition at this level of fuel flow, and after 15 to 30 seconds of sparking, fuel flow was ramped slowly to a maximum level. The highest fuel flow was the most that could be expected to be delivered for the engine operating point. Ignitor spark rate was 2 per second, and energy level was about 1.7 joules, delivered.

**19 August 2002** – Testing was started at ambient pressure, 14.5 psia (145 kPa). Eleven pressure levels were set with 5.0 psia (34.5 kPa) being the lowest. At each pressure level the lowest and highest airflow levels, and the rated fuel flow for each, were set. If ignition and propagation were successful three times at each airflow, then there would be a move to the next test point. If there was a problem getting ignition, or if the rig would not repeat ignition performance three times in a row, then all the airflows for that pressure were tested. Air temperature was 95° to 100° F (35° – 37.8° C) for these tests. Progress was successful down to 7.0 psia (48.3 kPa) P<sub>3</sub>. At this pressure, there was a problem with excess fuel in the exhaust lighting before the combustor lit. The exhaust had to be quenched, which delayed progress and shifted the test point parameters, which then had to be reset. Ignition could not be obtained at the highest airflow at 6.0 (41.3), 5.5 (37.9), and 5.0 (34.5) psia (kPa) but was obtained at the lower airflows. For example, at 6.0 psia (41.3 kPa) ignition was obtained at 0.40 pps (0.181 kg/s), but not at 0.6 pps (0.272 kg/s). Testing continued until a set of conditions was defined that covered the range test points needed to do a reasonable evaluation of the fuels which had the PDR added. Testing with PDR enhanced fuel continued into December.

**02 December** – A special test of 10 points was not successful with any of the three fuels. These were retested with lower air flows to determine if an ignition boundary could be defined. All three fuels were tested. One test point worked with neat JP–8 but did not work with 8.8 or 32 ppm PDR. One point continued to be a failure with all three fuels. Eight points were successful with all three fuels, but five of them required increased fuel flow for ignition. This test completed the ignition start testing with these fuels.

### 3.5.4 Data Analysis

Presentation of the data is on the basis of operating-point severity parameter. To help the designer, a severity parameter has been developed. The smaller the value of severity parameter, the more difficult the starting conditions. Combustor fuel/air ratios for ignition and for lean and rich extinction, plotted versus the severity parameter normally create a distinctively shaped curve (resembling the letter C with a long tail to the right). Each combustor design and fuel injection system has its own curve, and they are surprisingly similar even when comparing cannular systems to annular systems. The definition of severity parameter is:

$$\text{Severity Parameter} = (P_3 \times T_3 / V_3)$$

Where  $P_3$  is compressor discharge pressure, (psia),  $T_3$  is compressor discharge temperature, ( $^{\circ}\text{R}$ ), and  $V_3$  is a characteristic velocity based on the airflow through the test section and a selected cross-sectional area, (ft/s). Severity parameter is normally plotted as a function of combustor fuel/air ratio. Breaking the Severity Parameter down to test parameter constituents yields:

$$\text{Severity Parameter (SV P, SP)} = [\text{Exp}(T_3/540)] \times P_3^{1.75}/W_{36} \times 4,$$

Where temperature is normalized by a typical ambient value, and sector airflow is increased to equate to a full-annular value.

Not all the data from a given period of testing were used in plotting the figures that follow because, the way the data acquisition was grouped, a “same severity parameter value” is calculated for a number of test points — which may all have the same testing result, ignition or nonignition. Thus plotting repetition is avoided. The data are reported in the following sequence:

- Neat (or unadditized) JP–8, tested with ambient air and ambient fuel temperatures, retested with cold air and ambient fuel temperatures, and then tested with cold air and cold fuel temperatures.
- JP–8 fuel with 8.8 ppm PDR and tested at cold air and cold fuel temperatures.
- JP–8 fuel with 32 ppm PDR and tested with cold air and cold fuel temperatures.

### 3.5.5 Altitude Ignition Test Results

Figure 31 shows the ambient air/fuel results. For this portion of the testing, the variables are pressure and airflow, so the number of points tested is fewer than for the following tests. The ignition limit appears to be well defined. At higher SP values, the lower limit of ignition fuel/air ratio is about 0.020. On this figure, where ignition was encountered during the fuel flow ramp-up, only the “ignition” fuel/air ratio is plotted. Careful inspection of the “no ignition” points indicates that, in some cases, the same severity parameter value has a lower fuel/air ratio value and a higher value. These points were plotted to point out that the no-ignition result exists over a range of fuel flow.

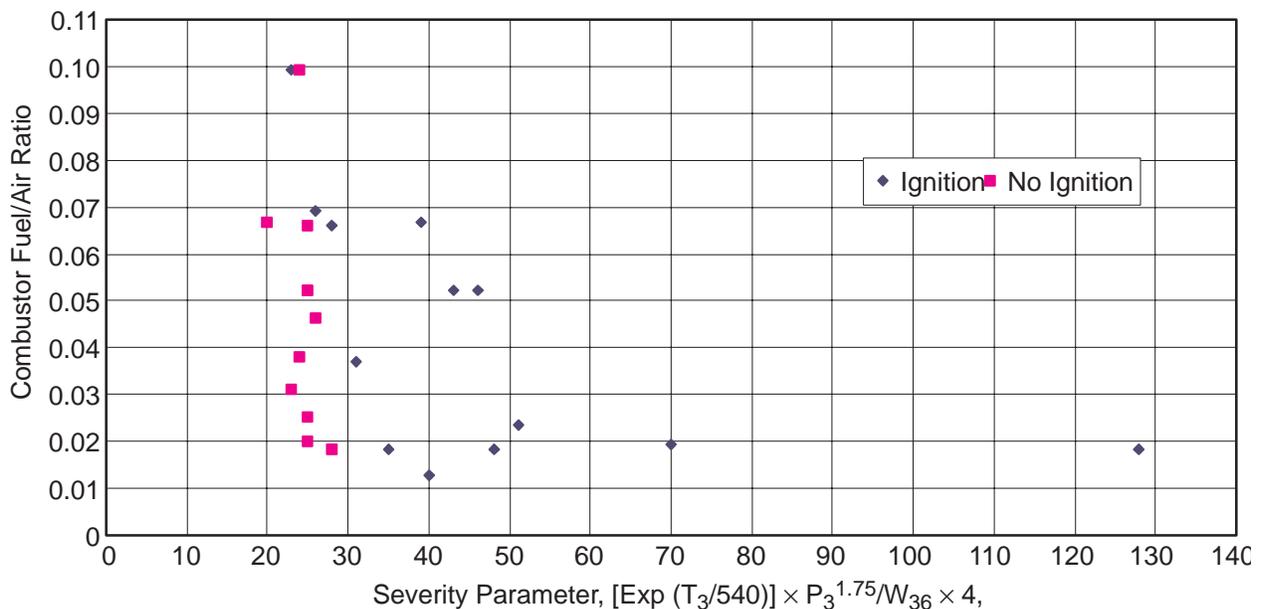


Figure 31. Ambient Air / Ambient Fuel, Neat JP–8

Figure 32 shows the results from the cold air, ambient fuel testing. The data show that the no-ignition points have migrated right to slightly higher severity values, approximately 29 to 30, and that the ignition limit line is harder to define because there is more overlap among the ignition and no-ignition points, in the limit. This overlapping can be a common result near the ignition boundary and creates a band of performance uncertainty. Further, at higher values of SP ( $> 50$ ), the minimum ignition fuel/air ratio has increased to about 0.030 to 0.035, a change of about 50% relative to ambient air.

Figure 33 shows the further result of cooling the fuel to the same temperature as the air and down to a limit of  $-30^{\circ}\text{F}$  ( $-34.4^{\circ}\text{C}$ ). The big difference was several points that lit with cold air became “no lights” with the cooled fuel. These points had SP values of 31, 29, and 28, respectively. Contrarily, two points that were no-ignition with ambient fuel lit with cold fuel. These points had SP values of 29.8 and 28.4, respectively. Additionally, five test points required higher fuel flows with the cold fuel. The increase required was 12% to 63%; the average was 42%, not small. The ignition limit is best described by a vertical line positioned at  $\text{SP} = 29.4$ .

Figure 34 shows the test result of cold air, cold fuel, and with 8.8 ppm PDR in the fuel. Relative to the data in Figure 35 (cold air, cold fuel, neat fuel), three points became “no lights.” The fuel flow for ignition was increased for seven test points by an average of 13.7%, highest value was 26% and the lowest was 4%. The ignition limit is best described by a vertical line through a  $\text{SP} = 31$ .

Figure 35 shows the test result for cold air, cold fuel, and with 32 ppm PDR in the fuel. The same three points that were no lights with 8.8 ppm PDR are still “no lights.” Fourteen test points required higher fuel flows for ignition relative to the neat fuel. The fuel flow increases required with 32 ppm PDR averaged 14.71%; the high value was 36%, and the low was 3%. The ignition limit is best described as a slanted line through  $\text{SP} = 36$  on the X-axis, and the limiting value defined by the intercept at a fuel/air ratio of 0.040,  $\text{SP} = 32$ .

Figure 36 is a replot of the above data in the more familiar framework of pressure altitude and flight Mach number. The lower left corner of this chart is sea level static. The loss in direct start capability is the “no starting” in an area defined by the solid square symbols. There is a region of high probability for “no starting” due to higher fueling requirements for the 32 ppm PDR and to a lesser extent the 8.8 ppm PDR, which extends from the lower left edge of the “no-starting zone” to lower Mach numbers and altitude.

The typical engine control has some tolerance adjustment, but changes to increase fuel scheduling which exceed 5% to 10% of the nominal flow schedule are generally not permitted because they would require a complete design change to the fuel schedule in the control — a new cam or a new electronic definition. There would be concern for hot-section life at the higher gas temperatures. Further, these design changes would require a complete recertification of the control. Consequently, any data point for which the ignition fuel flow increase was greater than 10% would become a no-start on an actual engine.

When using 8.8 ppm PDR, 4 of the 13 points that had ignition, or 33%, would not work even if the control were adjusted full rich.

When using 32 ppm PDR, six points, or roughly half, would be disallowed. Both levels of the PDR result in a significant reduction in air start capability.

At cold ground starting points, the greatest effect would be found with the 32 ppm PDR fuel.

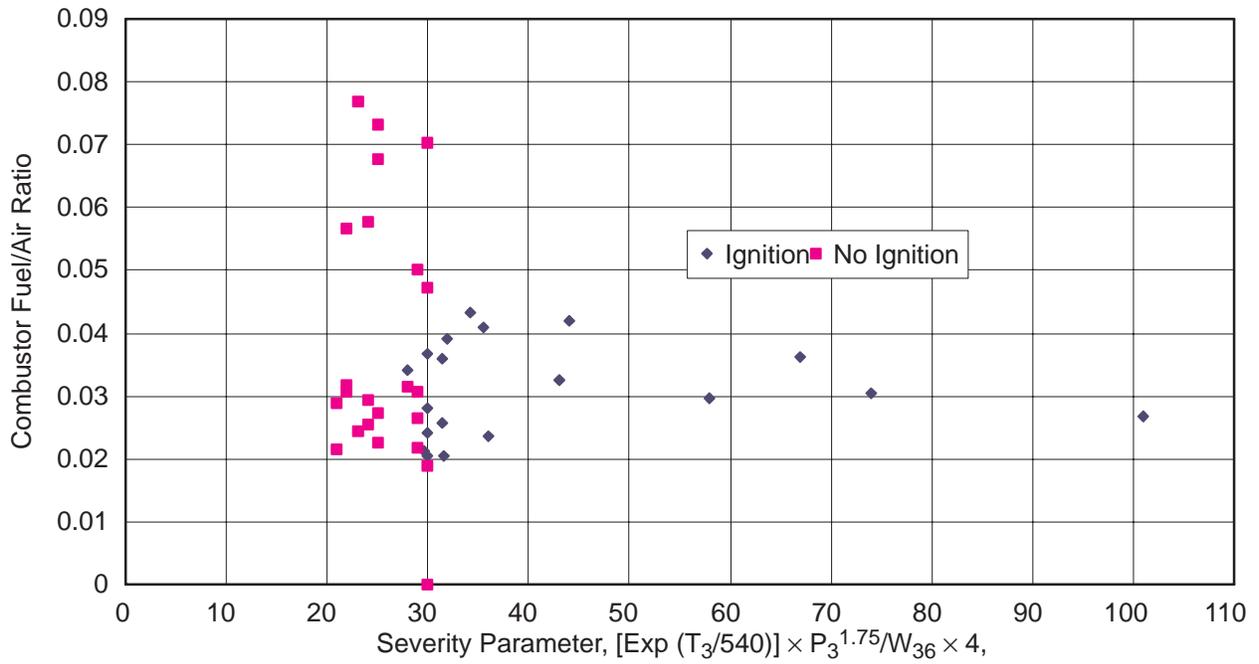


Figure 32. Cold Air / Ambient Fuel, Neat JP-8

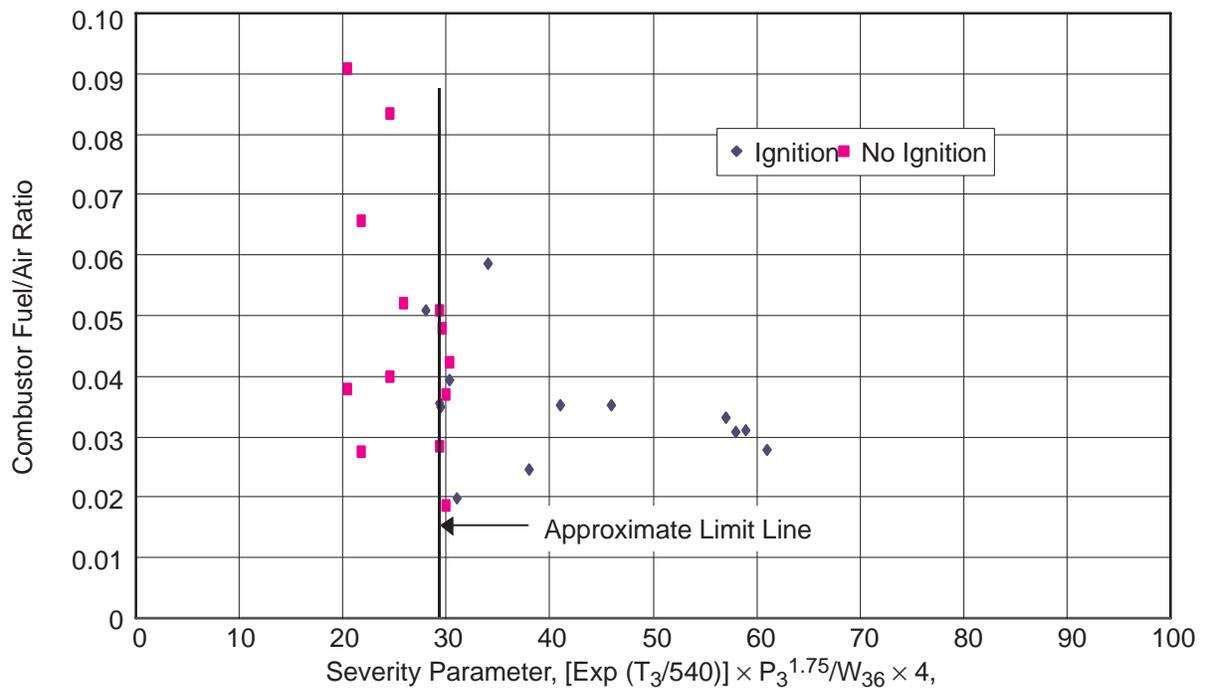


Figure 33. Cold Air / Cold Fuel, Neat JP-8

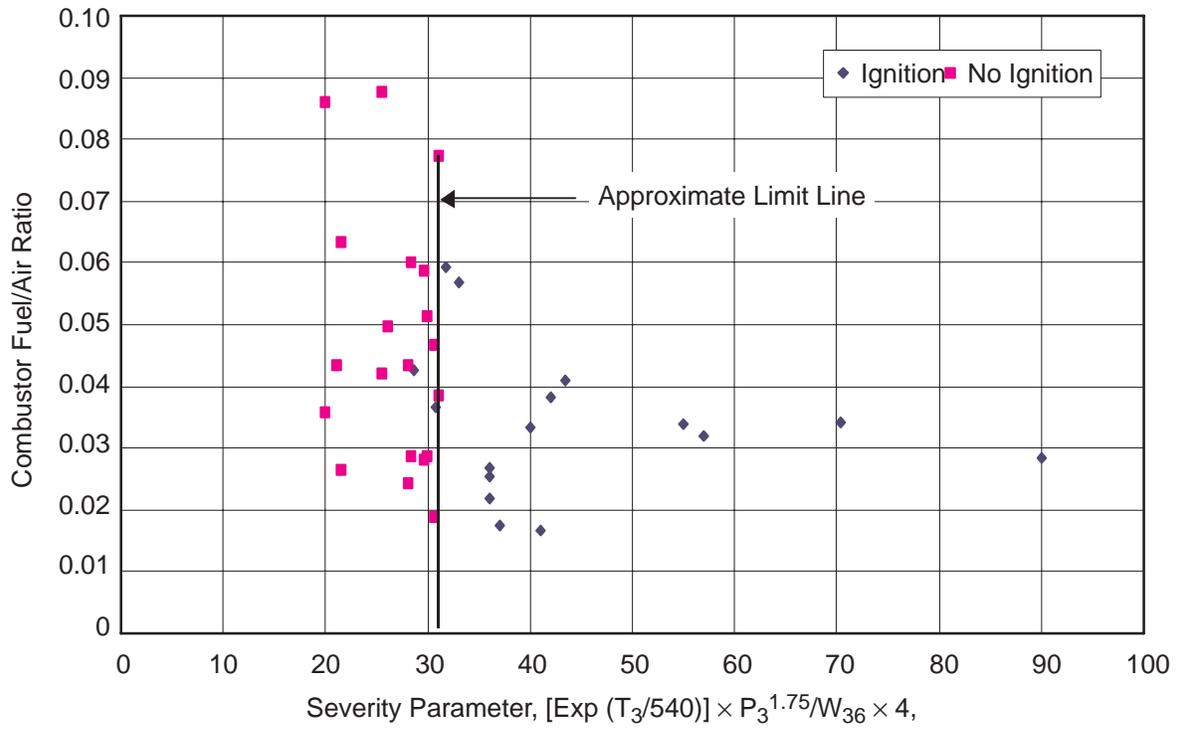


Figure 34. Cold Air / Cold Fuel, 8.8-ppm PDR JP-8

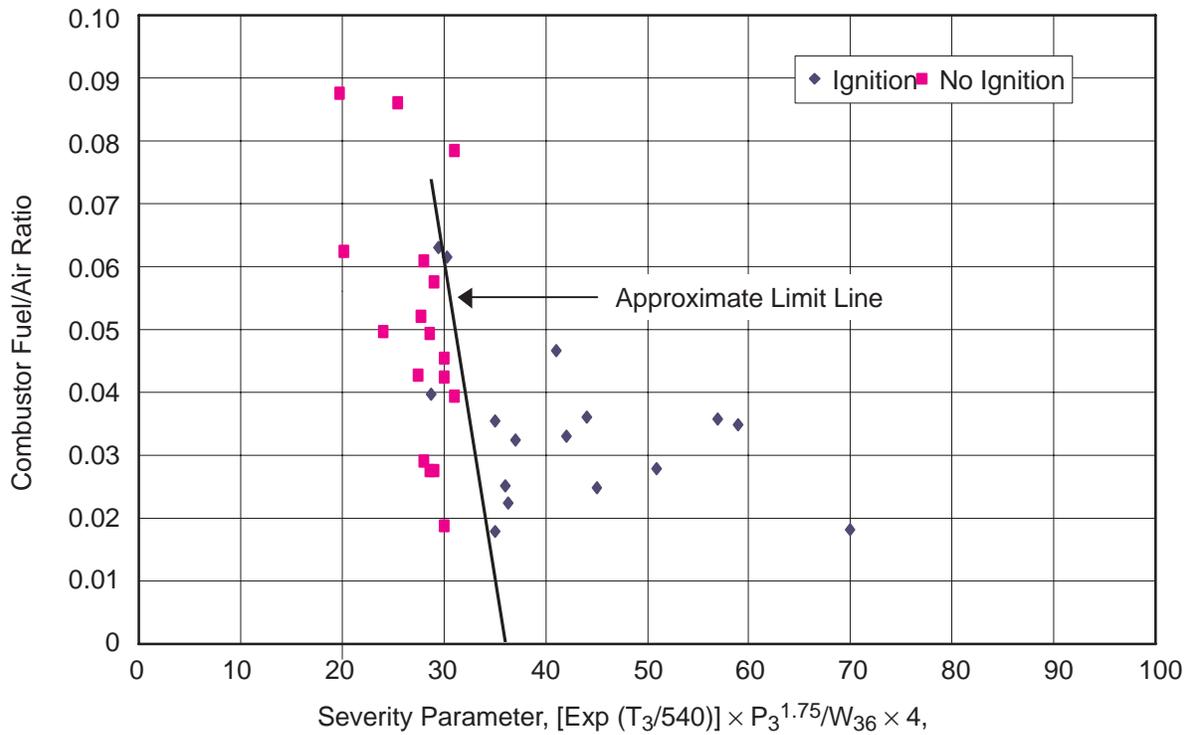


Figure 35. Cold Air / Cold Fuel, 32-ppm PDR JP-8

**Conclusion:** Overall loss in capability would be 15 up to approximately 50%, depending on engine start requirements.

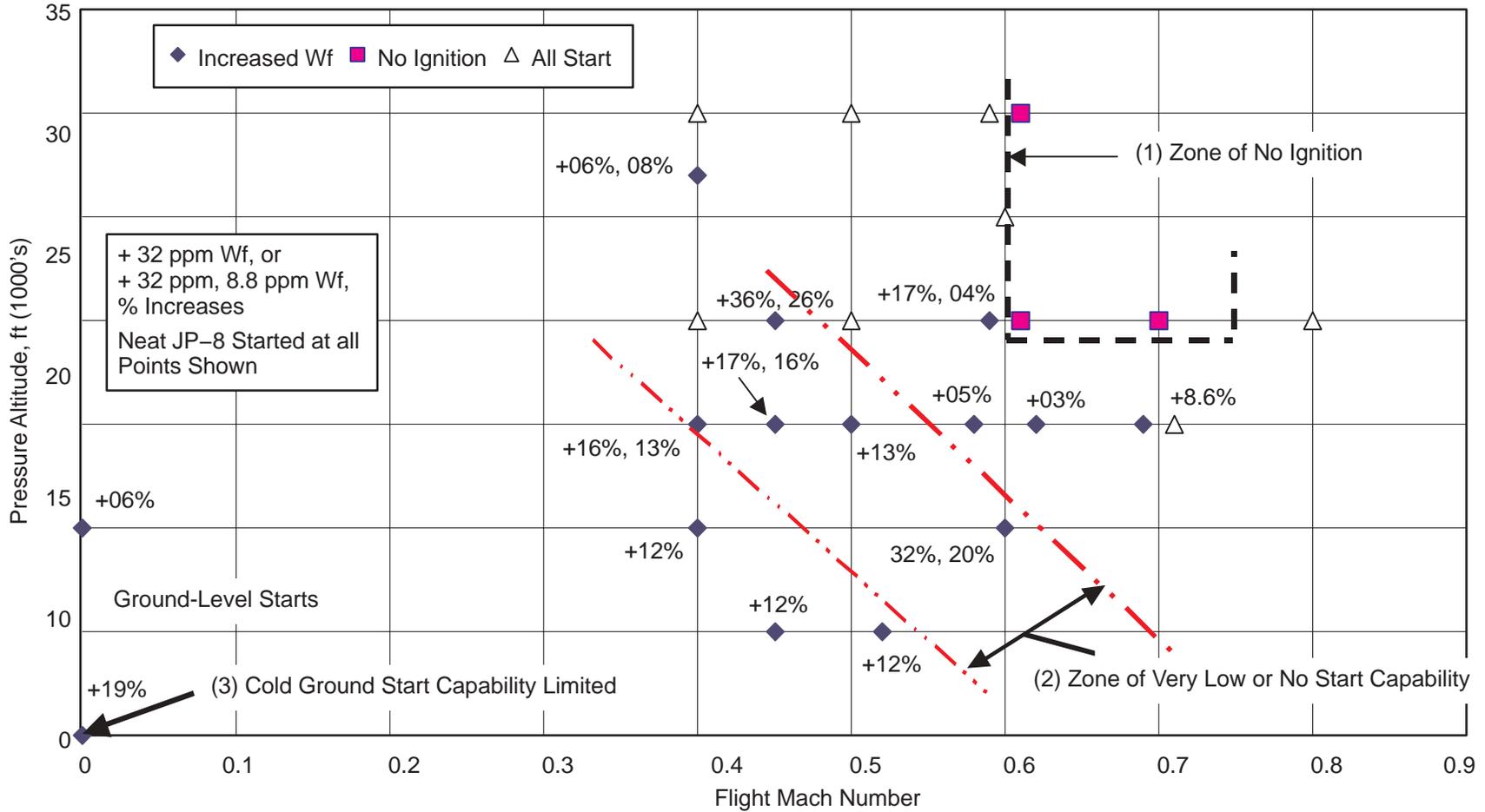


Figure 36. Pressure Altitude Vs Flight Mach Number, Starting Results With 8.8 and 32 ppm PDR

### **3.5.6 Conclusions – Spray Testing of the Nozzles and Injector**

At ambient fuel temperatures, the cooling of the air appeared to have little effect on the spray pattern and atomization of the fuel nozzles.

At ambient air and fuel conditions, the presence of 8.8 and/or 32 ppm PDR appeared to have little effect on the nozzle spray characteristics.

Cooling the fuel in a cold-air environment had the effect of coarsening the spray and reducing the effective droplet trajectory in all three nozzles, but it appeared to have little effect on the injector performance. The change in fuel viscosity from 1.4 cSt (ambient temperature) to 7 to 8 cSt (−30.5° F or −34.4° C) is the causative parameter. For the CFM56 and GE90 nozzles, the presence of cold fuel appeared to change the spray cone in the direction of a narrower stream of fuel that exited the nozzle in fuel sheet, round or flat, with several major fuel streaks embedded. The sheets broke down into defined streaks several nozzle diameters from the point of ejection.

The presence of PDR in the cold fuel and in a cold-air bath appeared to tighten the streaking characteristics of the CFM56 and GE90 nozzles and further coarsened the spray characteristics of the CF6 but, by comparison, had a smaller effect relative to just cooling the fuel. The presence of PDR did increase the initial sheeting of the fuel observed at the nozzle discharge. These sheets generally broke into definite streaks but much further away from the nozzle face.

The CF6 nozzle demonstrated a spray angle instability (chugging) at its starting flow with cold fuel. The instability was more noticeable with the presence of the PDR. The cycle of chugging was slower at 32 ppm PDR, than with neat fuel or 8.8 ppm PDR.

The GE90 nozzle demonstrated a one-time spray cone flip from wide to narrow on one nozzle and from narrow to wide on the other nozzle with 8.8 ppm PDR, but sprays were stable thereafter. It is not known if this is something of consequence or not.

In the current engine combustor designs, initial fuel atomization created by the fuel injector (pressure atomizing or not) is augmented by intensely swirling air at and around the injector discharge. The changes observed by cooling the air and the fuel have been tested for effect on ignition and are generally well known by the engine manufacturer. The effect of the PDR superposed on these conditions mandated ignition testing.

### **3.5.7 Conclusions, Altitude Ignition Testing**

The conclusions drawn from the data are that the presence of PDR in the cooled fuel limits the ground and altitude restart capability of the engines. Also, where ignition is achievable, the PDR could severely limit the ability of the engine to successfully accelerate to idle.

On the basis of Severity Parameter, the minimum average losses would be:

- 2000 ft (1829 m) reduction in relight with 8.8 ppm PDR
- 3000 ft (2743 m) reduction in relight capability with 32 ppm PDR, plus loss of cold ground start capability

On the basis of applying the data to a specific starting requirement, loss in capability from all factors could be 15% to 50% depending on the engine application. This would be unacceptable.

## 4.0 Methods of Detection and Methods of Removal

### 4.1 Methods of Detection

One requirement from the OEM's is that if PDR's are approved for use in aviation turbine fuels, there must be a field method to determine if PDR is in the fuel. The method must be sensitive enough to detect the presence of PDR to below the approved range of PDR permitted, probably to below 1.0 ppm by mass.

The laboratory method for detecting the presence of PDR in a fuel sample is gel-permeation chromatography (GPC), also known also as size-exclusion chromatography (SEC), and is used by both Baker Petrolite and Conoco.

Fuel Technology Associates, LLC worked up a draft ASTM Test Method based on GPC: *Standard Test Method for determining The Concentration of Pipeline Drag Reducer Additive in Aviation Turbine Fuels*. It is currently held in abeyance.

#### 4.1.1 Filtering as a Method of PDR Detection

One of the barriers to the approval of use of PDR in jet fuel is the lack of quick, field-test, detection method. RefinedPower<sup>®</sup> II Flow Improver by ConocoPhillips Specialty Products, Inc. (CSPI) was one of the PDR's being tested. In support of the additive approval program CSPI agreed to pursue the development of a PDR field detection method (Reference 9).

#### 4.1.2 Experimental Approach

Previous work done by others has shown that filtration time of PDR treated fuel through a filter correlates to the level of shear of the PDR in the solution. The filtration index (FI) test has been used in the field to detect a change in the level of shear of PDR in diesel fuel at given points in a pipeline and product terminal system. The test involves comparing the filtration time of two 200-ml samples of fuel through a 5- $\mu$ m filter. One of the samples is filtered as is; the other is sheared for 10 seconds and then filtered. The FI is the unsheared time divided by the sheared time. The FI should be near the baseline (1.0) if any PDR in the original diesel sample is acceptably sheared. A typical rack sample FI is 1.1 to 1.3, but this value may vary even higher during acceptable operation of a given system. Likewise, experience indicates acceptable diesel filtration times will typically range from 20 to 45 seconds, so a FI above 1.3 along with diesel filtration times > 45 seconds indicate that the PDR in the sample is not fully sheared. If the FI from a test is less than 1.0, the test should be repeated. Water or dirt may have influenced the test.

This work was to expand the existing FI test to develop it into a field method that could distinguish the concentration and shear level of PDR in jet fuel. The three objectives of the experimental plan were to first correlate shear level of PDR to the filtration time through a vacuum filter, then characterize the shear level with molecular weight analysis. The final objective was to correlate concentration of PDR to filtration time.

The first step in the method development was to determine how to obtain different levels of shearing using a blender available in the lab. The blender was a Waring Commercial, a laboratory blender. The Waring blender was plugged into a Powerstat variable transformer so the power could be varied. The initial results indicated that varying the power of the Waring blender with the Powerstat setting was effective at yielding partial shearing. At Powerstat settings of less than 50, very little shearing

of the DRA occurred. At a Powerstat setting of 60, the DRA was close to fully sheared. Therefore, it was decided to vary the shear time at a Powerstat setting of 50 to achieve different levels of shear.

Solutions of jet fuel containing varying amounts of PDR polymer were prepared. All the samples for this study were prepared by adding the desired amount of RP™ II Flow Improver to the jet fuel and then rolling the sample overnight to dissolve the DRA without shearing it. These samples were then used to study the filtration times of Jet A treated with different levels of polymer and sheared to different extents. The general procedures used to perform this work are described below.

1. Prepare filtration samples from the solutions of jet fuel that contain different amounts of DRA and shear according to the matrix below. Filter each sample by vacuum filtration and record filtration times in seconds.

Sample Type (165 grams, 200 ml)	8 ppm	16 ppm	32 ppm
A, Unsheared	2 Samples	2 Samples	2 Samples
B, Shear for 15 seconds with Waring set at 50	3 Samples	3 Samples	3 Samples
C, Shear for 30 seconds with Waring set at 50	3 Samples	3 Samples	3 Samples
D, Shear for 60 seconds with Waring set at 50	3 Samples	3 Samples	3 Samples
E, Shear for 60 seconds with Moulinex (Completely sheared)	3 Samples	3 Samples	3 Samples

2. Prepare one 25-gram GPC sample for each box of the matrix. Make samples by adding an extra 25 grams to one of the filtration samples before shearing. Shear the sample and then pour the extra 25 grams into the corresponding GPC sample bottle. These samples are to be submitted to the GPC lab for determination of the molecular weight distribution of the polymer.

#### 4.1.2.1 Equipment Setup

A vacuum pump is set up to evacuate the vacuum flask. The filter funnel apparatus is placed with a stopper into the top of the vacuum flask. The 5- $\mu$ m filters are placed into the filter funnel apparatus, using one for each filter timing run. The stopwatch is used to time the filtrations.

#### 4.1.2.2 General Procedure

1. With the stopwatch in hand, quickly pour the 200-ml sample into the funnel and record from the time the diesel first hits the filter until the diesel fully passes through the filter. Record this time to the nearest 0.1 seconds.
2. Turn off the vacuum pump. Remove the filter funnel and used filter. Wipe out the filter funnel for the next run.
3. Repeats steps 1 through 3 until all samples have been filtered.
4. Remove the filter funnel apparatus and pour out the filtered jet fuel from the vacuum flask into the appropriate fuel sump. Remove the used filter and wipe out the filter funnel.

Jet A fuel produced at the Ponca City Refinery was used for these tests. A five-gallon sample was secured. Test results are shown in Figures 37 and 38.

The data suggest that, when the PDR is unsheared and when the PDR is fully sheared, the filtration time is controlled by the concentration of PDR. In both cases, the filtration time of the 32-ppm

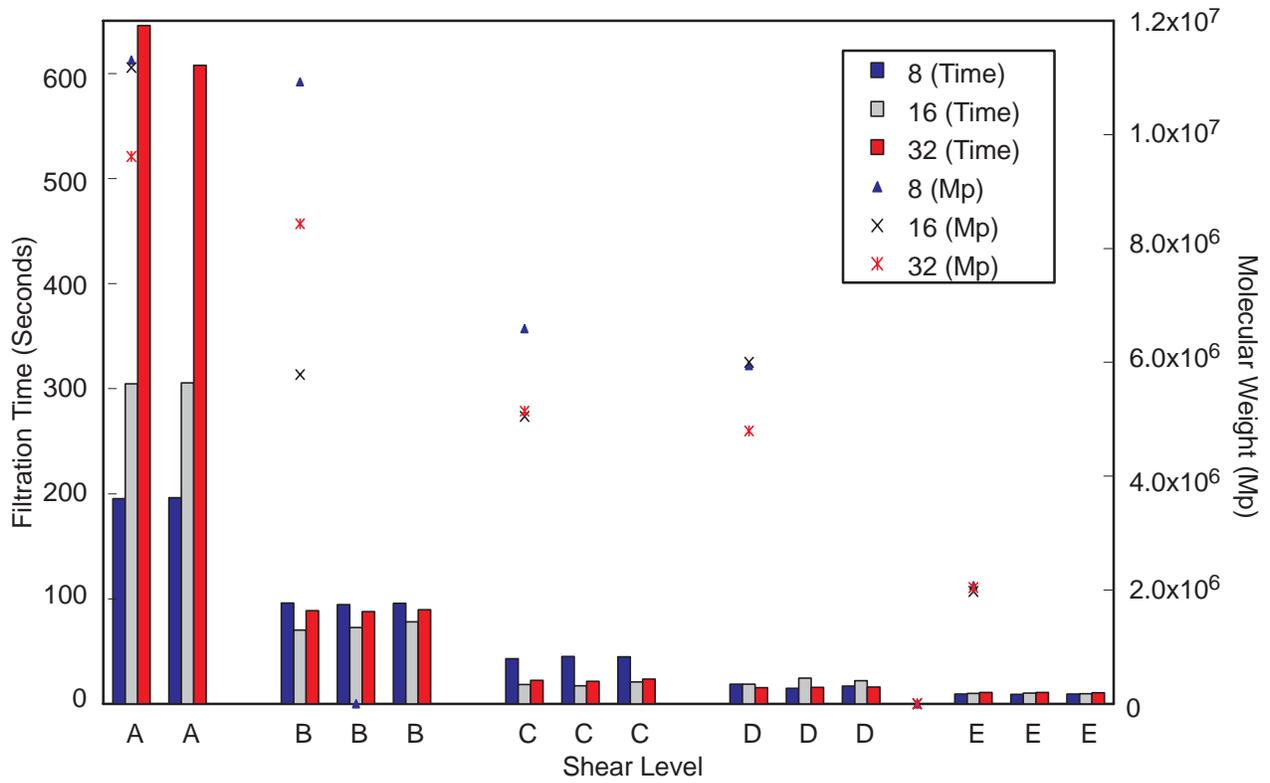


Figure 37. Filtration Study of Jet A Treated With 8, 16, and 32 ppm DRA Polymer

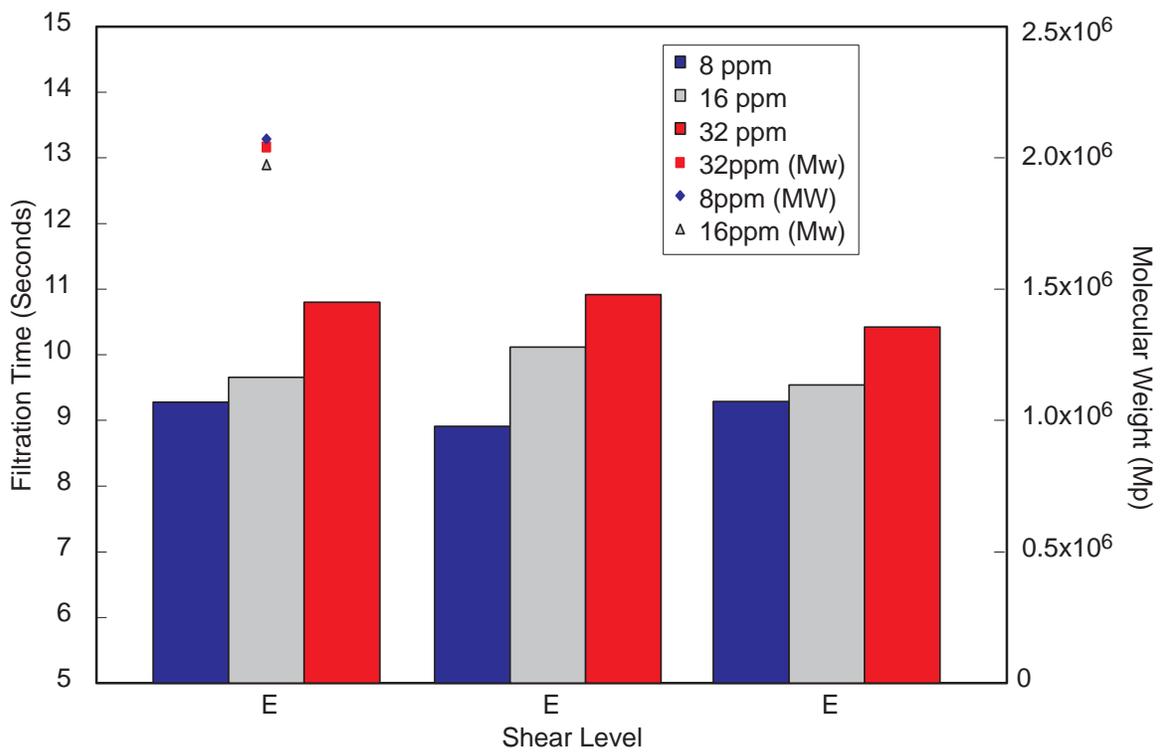


Figure 38. Filtration Data for Fully Sheared Samples Only

samples had the longest filtration time, followed by the 16-ppm samples, with the 8-ppm samples always having the quickest filtration time. The effect was magnified when the samples contained unsheared PDR because the filtration times were much longer than when the PDR was fully sheared. At the intermediate shear levels, the filtration time appears to be controlled by the average molecular weight of the PDR in the sample. The sample with the highest average molecular weight consistently had the longest filtration time. However, there was no correlation between the concentration of the sample and the degradation achieved.

#### 4.1.3 Conclusions

- The presence of unsheared PDR in jet fuel can be detected by measuring the vacuum filtration time of the fuel through a 5- $\mu\text{m}$  filter.
- There is a relationship between the average molecular weight of the PDR and vacuum filtration time through a 5- $\mu\text{m}$  filter.
- Filtration data of fully active and fully sheared samples suggest that this method can detect PDR concentration difference in samples of jet fuel.
- More work needs to be done to validate this method.

**Future Work Scope:** In order to validate this method, the following experimental work is suggested. Take filtration time of fully sheared 8ppm sample as baseline. Then prepare samples of jet fuel with various DRA concentrations and shear levels. Perform the vacuum filtration test and then compare the filtration time of these samples to 8-ppm baseline data.

#### 4.2 Methods of Removal

It might well occur that ultimately the use of PDR's could be approved for use if a method can be devised to remove the PDR from the fuel prior to uplift into the aircraft.

One method of removal is being investigated at Southwest Research Institute (Reference 10). The method is based on the absorption of the PDR molecules into carbonaceous solids. The method has been tested on gasolines and one Jet A-1 fuel. The results, summarized, are as follows.

Forty-three carbonaceous solids were evaluated for ability to remove, via adsorption, two different drag reducer additives from two unleaded base gasolines and a Jet A-1 base fuel. Two different contact methods of differing efficiencies were used for mixing carbon with DRA-containing fuel. The effect of preheating some of the carbons prior to evaluation was determined. Carbon performance was compared between sheared and unsheared polymer, between different polymer chemistries, between the two different gasolines, and between the two gasolines and the jet fuel.

“Results indicated that carbon adsorption efficacy varied widely, with some carbons removing no DRA polymer from the fuels and with others removing more than half the polymer, depending on the fuel, polymer, and carbon used. Carbon performance was also dependent on the contact method used, with adsorption typically improving as carbon/fuel mixing severity increased. However, this effect appeared more important in gasoline than in jet fuel. Carbon performance was strongly dependent on the polymer chemistry. One DRA polymer was much more effectively removed from gasoline and jet fuel than the other DRA polymer. Typically, unsheared DRA polymer was somewhat more effectively adsorbed than sheared DRA polymer, regardless of the fuel used. Overall, the results of this study suggest that carbon and DRA polymer chemistries necessary for optimum polymer removal performance have not yet been achieved, but are possible with sufficient cooperative development.”

## 5.0 Current Status and Future Work

Pipeline Drag Reducer additives are not permitted in aviation turbine fuels.

The Baker additive tested and reported herein demonstrated a reduction in JFTOT measured thermal oxidative stability but was tested and had acceptable results in other oxidative stability test methods. The Conoco additive was not tested by the JFTOT method but also had acceptable results with other oxidative stability methods.

Fully sheared additives demonstrated acceptability in filtration tests, water separation, and monitor testing. Unsheared additive blocked filters.

The presence of the additive in aviation turbine fuel at below ambient temperatures of air and fuel compromised fuel nozzle performance and reduced combustor ignition capability.

Development of the additives continues for the purpose of improving performance at lower concentrations. It is expected that the use of PDR will be revisited by the aviation fuel community. It is also anticipated that, at that time, the maximum concentration requested for use will be 3.0 ppm or less.

Future work considerations should continue to encompass thermal oxidative stability improvement, demonstration of cold-weather combustion ignition suitability, and testing in areas of combustion not yet addressed — such as gaseous emissions and fuel-system and hot-section carboning.

A field method must be developed to detect PDR in aviation fuels, a method that measures presence and concentration.

A method by which PDR may be removed from aviation turbine fuels must also be developed.

The need for these two methods is based on the fact that PDR is approved for use in practically all other products in the pipeline. In consequence, it is conceivable that aviation turbine fuels are being delivered that contain PDR. If PDR is ever approved for jet fuel, and limited in concentration, the concentration of PDR in delivered fuels will have to be known and reported, and if more than the maximum is present PDR will have to be removed.

## 6.0 References

1. *Oil and Gas Journal*, 19 October 1981.
2. R.W. Morris (USAF) and K.E. Binns (UDRI), APPD, Wright–Patterson Air force Base, Ohio, “Evaluation of the Effects of a Pipeline Flow Improver on Aircraft Fuel Systems,” Technical Report WL–TR–2085, January 1993.
3. V.L. Streeter, *Fluid Mechanics*, Second Edition, McGraw–Hill Books, 1958.
4. T. Biddle, P&W Aircraft, “HLPS Tests Performed on Baker and Conoco Pipeline Drag Reducers Performed under Air Force Contract,” F33615–97–D–2783, Delivery Order No. 2 in response to CDRL No. 0002, Period of Performance 23 July 1998 to 31 March 2003.
5. G.S. Sprenger, Velcon Filters, Inc., “Effect of Pipeline Drag Reducer on Coalescer and Monitor Cartridges,” Test Report No. 597 – 98, 2 December to 27 January 1998.
6. G.S. Sprenger, Velcon Filters, Inc., “Effect of Pipeline Drag Reducer on Coalescer Pressure Drop,” Test Report 602–98, 29 April, 1998
7. E. Matulevicius, Fuel Technology Associates, LLC, “CRC Additive Effectiveness in Jet Fuel Group,” Presentation at ASTM Subcommittee (CRC Panel on the Effect of PDR on Handling Jet Fuel) J Meeting, Anaheim, CA, 10 December 2002.
8. S.P. Seto, GE Aircraft Engines, “Buckeye Pipeline Drag Reducer Investigation, 2001 – 2002,” TM 2003–56, 8 January 2003. (Distribution limited due to information contained therein Proprietary to GE.)
9. R.J. Armstrong, ConocoPhillips Specialty Products, “Filtration Testing of Jet Fuel as a Method for Detecting the Presence of Drag Reducing Additives,” Technical Service Report No. 987, 3 August 2004.
10. J.A. Waynick, Southwest Research Institute Abstract, “Removal of Drag Reducer Additive from Petroleum Fuels, Part 2: Effect of Fuel and Polymer Structure,” publication date unknown

# Addendum 1 – Requests for Reconsideration of PDR

This addendum replicates some letters from aircraft operating companies to the OEM's requesting reconsideration of the use of PDR.



Maintenance Operations

Bob Brooks  
Customer Service Representative  
General Electric / CFMI

January 13, 2000

## Approval Request - Pipeline Drag Reducer Additives

We at United Airlines are becoming very concerned in having acceptable jet fuel supplies at major airports in the United States in the near future. We have been advised by representatives of the pipeline and petroleum industry that future aviation turbine fuel supplies may be significantly impacted unless they can improve the capacity of their distribution systems. Constructing new or expanding present older pipeline systems at many of the large metropolitan areas are becoming cost prohibitive and our industry needs an acceptable alternative. As a major user of aviation turbine fuels, we solicit your support and approval for the future use of pipeline drag reducing (PDR) additives as an alternative cost effective means in accomplishing this task.

As your aviation fuel technical representatives are aware, cooperative studies and discussions by industry participants has been an ongoing effort by Coordinating Research Council (CRC) and American Society of Testing Materials (ASTM) work groups for the past few years. The time has come that we need OEM approval in using PDR additives in our aircraft fuel in order for this effort to be finalized. It is our opinion that acceptance criteria shall include a maximum total concentration of PDR not to exceed 8 PPM of active polymer at any time in the distribution system and/or upon receipt at airports. For specification reasons, we expect guidance from OEM's in establishing acceptable QA testing procedures and equipment to ensure compliance.

Your early attention to this request will be greatly appreciated. I will appreciate a confirmation outlining your proposed time schedule and evaluation program in accomplishing the above request by February 15, 2000. Please do not hesitate to contact me at 650-634-7540 in San Francisco if you have any questions or comments. A list of technical work group members, U. S. Air Force approval data, API survey results and other information for supporting a business case is available for reference if desired. Thank you...

Cc:  
Jay Gray  
D.K. Loo  
Lou Mancini  
Bob Sturtz  
Jim Uhl

Sincerely,

A handwritten signature in black ink, appearing to read "Steve Casper".

Steve Casper  
Manager  
Fuel Technical Service

PDR User.doc  
San Francisco International Airport, San Francisco, California 94128



United Parcel Service 33 Grenville Parkway, NE  
Atlanta, GA 30329  
(404) 226-6000

February 14, 2000

Boeing Commercial Airplane Group  
Andy Andrus  
%UPS Hangar, Room 231  
Louisville, KY 40213

Dear Mr. Andrus:

We request Boeing Commercial Airplane Group concurrence to support the efforts of the CRC Group on Additive Effectiveness in Jet Fuels to pursue approval of Pipeline Drag Reducing (PDR) Agent, Baker FLO® XS PDR additive at a maximum use concentration of 8 parts per million (ppm) for use in commercial aviation turbine fuels.

As demand for aviation fuel grows, especially at some of the World's oldest airports, we need to consider cost effective means of maintaining adequate aviation fuel supplies for our fleets. We understand that PDR is being used in essentially all other petroleum products to provide low cost pipeline capacity expansion. The work being done by the CRC group could lead to low cost capacity for aviation turbine fuel pipelines, as well. This request is supported by the enclosure of the results of an API (American Petroleum Institute) survey of US member pipelines on the financial benefits of PDR to meet future pipeline capacity needs. The substantial cost savings of using PDR in aviation fuel over other alternatives will help keep fuel prices from rising further.

The US Air Force Research Lab at Wright - Patterson AFB has completed an initial study of thermal stability impacts of Baker FLO® XS PDR in aviation fuel. In their study the Air Force concludes "the Baker Flow-XS drag reducing additive has no negative impact on thermal stability of jet fuel up to 162 deg C (325 deg F) bulk and 232 deg C (450 deg F) wetted wall temperature." Based on these results and other work presented by the CRC group, we feel that PDR appears to be a viable alternative to more expensive options to increase pipeline capacity to airports.

We request that Boeing Commercial Airplane Group evaluate the work of the CRC group to determine any additional test that may be required to pursue approval of the Baker PDR additive in aviation turbine fuel for use in your engines. Given the potential value of this project an early response would be greatly appreciated to enable it to move along as quickly as feasible, while assuring that the necessary work is done to properly demonstrate this additive is acceptable to be used in aviation fuel.

A request for the unrestricted use of the additive at a maximum concentration of 8 ppm in commercial jet fuel will be forwarded once any required test program has been carried out to your satisfaction. Please be advised that other member airlines of the IATA AFWG will be submitting similar requests.

Sincerely,

Dan Walden  
United Parcel Service  
Procurement Services

Enclosure

cc: Glenn Harper, CRC Additive Effectiveness in Jet Fuel Chairman, Boeing  
OEM member of CRC Group on Additive Effectiveness in Aviation Fuel



# American Airlines'

January 6, 2000

Airbus – I. Bullamore  
Boeing – R. Lehnher  
Fokker – P. Koeter  
Garrett – J. Cybulski  
General Electric – D. Dobbins  
Pratt & Whitney – J. Martin  
Rolls Royce – E. Reilly

Subject: Approval for use of Pipeline Drag Reducing (PDR) Agent

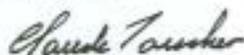
I am writing on behalf of American Airlines, a member of the IATA and ATA Aviation Fuels Technical Working Group, to support the efforts of the CRC Group on Additive Effectiveness in Jet Fuels to pursue the approval of a Pipeline Drag Reducing (PDR) Agent for use in aviation fuels.

As demand for aviation fuel continues to grow, especially at some of our nation's oldest airports, we need to consider a cost-effective means of maintaining adequate aviation fuel supplies for our fleets and airports. We understand that a PDR is being used in essentially all other petroleum products to provide low cost pipeline capacity expansion. The study presently being done by the CRC group could lead to low a cost capacity increase for aviation turbine fuel pipeline stubs as well. Enclosed are the results of an API (American Petroleum Institute) survey of member pipelines on the financial benefits of PDR to meet future pipeline capacity needs. The substantial cost savings of using an approved PDR in aviation fuel over other alternatives will help keep our fuel costs under control.

The Air Force Research Laboratory at Wright- Patterson AFB has completed an initial study on the thermal stability impacts of Baker Flo-XS PDR in aviation fuel. In their study, the Air Force concludes "the Baker Flow-XS drag reducing additive has no negative impact on thermal stability of jet fuel up to 162.8°C (325° F) bulk and 232.2°C (450° F) wetted wall temperatures." Based on these results and other work presented by the CRC group, we feel that an approved PDR appears to be a viable alternative to the more expensive options to increase pipeline capacity to airports.

Accordingly, we request that you begin evaluating the work of the CRC group to determine what additional tests are or may be required to pursue approval of a PDR for use in aviation fuel. Given the potential value of this project, we ask that you move it along as expeditiously as feasible, while assuring that all necessary work is done to properly determine the viability of this product in aviation fuel.

Sincerely,



Claude Taucher  
Sr. Specialist Engineering  
Fuel Engineering/TULE

MO 117, P.O. BOX 562809, TULSA, OKLAHOMA 74156-2809, CABLE ADDRESS AMAIR

# Addendum 2 – Baker–Petrolite FLO XS<sup>®</sup> Particulars



## Material Safety Data Sheet

Section 1. Chemical Product and Company Identification			
<b>Product Name</b>	<b>FLO XS<sup>®</sup></b>	<b>Code</b>	<b>FLOXS</b>
<b>Supplier</b>	Baker Petrolite A Baker Hughes Company 12645 W. Airport Blvd. (77478) P.O. Box 5050 Sugar Land, TX 77487-5050 For Product Information/MSDSs Call: 800-231-3606 (8:00 a.m. - 5:00 p.m. cst. Monday - Friday) 281-276-5400	<b>Version</b>	<b>2.0</b>
<b>Material Uses</b>	Pipeline Booster.	<b>Effective Date</b>	<b>4/1/2003</b>
<b>24 Hour Emergency Numbers</b>	CHEMTREC 800-424-9300 (U.S. 24 hour) Baker Petrolite 800-231-3606 (North America 24 hour) CANUTEC 613-996-6666 (Canada 24 hours) CHEMTREC Intl 01-703-527-3887 (International 24 hour)	<b>Print Date</b>	<b>4/1/2003</b>
<b>National Fire Protection Association (U.S.A.)</b>			

Section 2. Composition and Information on Ingredients			
Name	CAS #	% by Weight	Exposure Limits
1) Isoparaffinic Solvent	78-78-4	60-100	TWA: 1770 (mg/m <sup>3</sup> ) from ACGIH (TLV) TWA: 600 (ppm) from ACGIH (TLV)
2) 2-Butoxyethanol	111-76-2	1-5	TWA: 97 (mg/m <sup>3</sup> ) from ACGIH (TLV) TWA: 20 (ppm) from ACGIH (TLV) TWA: 50 (ppm) from OSHA (PEL) SKIN TWA: 240 (mg/m <sup>3</sup> ) from OSHA (PEL) SKIN

Section 3. Hazards Identification	
<b>Physical State and Appearance</b>	State: Gel, Liquid., Color: Light Colorless., Odor: Slight Hydrocarbon.
<b>CERCLA Reportable Quantity</b>	Not applicable.
<b>Hazard Summary</b>	WARNING. May cause chronic effects. Flammable liquid. Vapors can form an ignitable or explosive mixture with air. Can form explosive mixtures at temperatures at or above the flash point. Vapors can flow along surfaces to a distant ignition source and flash back. Static discharges can cause ignition or explosion when container is not bonded. May be irritating to eyes, skin and respiratory tract. May be toxic by skin absorption. May cause central nervous system (CNS) effects if inhaled.
<b>Routes of Exposure</b>	Skin (Permeator), Skin (Contact), Eyes, Inhalation.
<b>Potential Acute Health Effects</b>	<p><b>Eyes</b> May be severely irritating to the eyes.</p> <p><b>Skin</b> May be irritating to skin. May be toxic if absorbed through the skin.</p> <p><b>Inhalation</b> May cause central nervous system (CNS) effects if inhaled. May be irritating to lungs.</p> <p><b>Ingestion</b> Not considered a likely route of exposure, however, may be aspirated into the lungs if swallowed. Can result in chemical pneumonitis (irritation) and pulmonary edema (accumulation of fluids) and hemorrhaging (bleeding).</p>
<b>Continued on Next Page</b>	

**Medical Conditions aggravated by Exposure** Exposure to this product may aggravate medical conditions involving the following: blood system, kidneys, nervous system, liver, respiratory tract, immune system, skin/epithelium, eyes.

See Toxicological Information (section 11)

**Additional Hazard Identification Remarks** May be harmful if ingested. This product may be aspirated into the lungs during swallowing or vomiting of swallowed material. Aspiration into the lungs may produce chemical pneumonitis, pulmonary edema, and hemorrhaging. Repeated or prolonged contact may cause dermatitis (inflammation) and defatting of the skin (dryness).

#### Section 4. First Aid Measures

**Eye Contact** Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention if irritation occurs.

**Skin Contact** Remove and launder or clean contaminated clothing and shoes. Wash with soap and water until no evidence of material remains. Get medical attention if irritation occurs.

**Inhalation** Remove to fresh air. Oxygen may be administered if breathing is difficult. If not breathing, administer artificial respiration and seek medical attention. Get medical attention if symptoms appear.

**Ingestion** Get medical attention immediately. If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never induce vomiting or give anything by mouth to a victim who is unconscious or having convulsions.

**Notes to Physician** Not available.

**Additional First Aid Remarks** Not available.

#### Section 5. Fire Fighting Measures

**Flammability of the Product** Flammable liquid. Vapors can form an ignitable or explosive mixture with air. Can form explosive mixtures at temperatures at or above the flash point. Vapors can flow along surfaces to a distant ignition source and flash back. Static discharges can cause ignition or explosion when container is not bonded.

**OSHA Flammability Class** IA

**Autoignition temperature** Not available.

**Flash Points** CLOSED CUP: -68.9°C (-74°F) (PMCC SFCC)

**Flammable Limits** L.E.L. Not available, U.E.L. Not available.

**Products of Combustion** These products are carbon oxides (CO, CO2).

**Fire Hazards in Presence of Various Substances** Open Flames/Sparks/Static. Heat.

**Fire Fighting Media and Instructions** In case of fire, use foam, dry chemicals, or CO2 fire extinguishers. Evacuate area and fight fire from a safe distance. Water spray may be used to keep fire-exposed containers cool. Keep water run off out of sewers and public water ways. Note that flammable vapors may form an ignitable mixture with air. Vapors may travel considerable distances and flash back if ignited.

**Protective Clothing (Fire)** Do not enter fire area without proper personal protective equipment, including NIOSH approved self-contained breathing apparatus.

**Special Remarks on Fire Hazards** Not available.

#### Section 6. Accidental Release Measures

**Spill** Put on appropriate personal protective equipment. Keep personnel removed and upwind of spill. Shut off all ignition sources; no flares, smoking, or flames in hazard area. Approach release from upwind. Shut off leak if it can be done safely. Contain spilled material. Keep out of waterways. Dike large spills and use a non-sparking or explosion proof means to transfer material to an appropriate container for disposal. For small spills add absorbent (soil may be used in the absence of other suitable materials) scoop up material and place in a sealed, liquid-proof container. Note that flammable vapors may form an ignitable mixture with air. Vapors may travel considerable distances from spill and flash back, if ignited. Waste must be disposed of in accordance with federal, state and local environmental control regulations.

**Other Statements** Not applicable.

Continued on Next Page

Additional Accidental Release Measures Remarks Not available.

### Section 7. Handling and Storage

**Handling and Storage** Put on appropriate personal protective equipment. Avoid contact with eyes, skin, and clothing. Avoid breathing vapors or spray mists. Use only with adequate ventilation. Store in a dry, cool and well ventilated area. Keep away from heat, sparks and flame. Keep away from incompatibles. Keep container tightly closed and dry. To avoid fire or explosion, ground container equipment and personnel before handling product.

**Additional Handling and Storage Remarks** Store under nitrogen.

### Section 8. Exposure Controls/Personal Protection

**Engineering Controls** Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors or particles below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

#### Personal Protection

Personal Protective Equipment recommendations are based on anticipated known manufacturing and use conditions. These conditions are expected to result in only incidental exposure. A thorough review of the job tasks and conditions by a safety professional is recommended to determine the level of personal protective equipment appropriate for these job tasks and conditions.

**Eyes** Chemical safety goggles.

**Body** Wear long sleeves to prevent repeated or prolonged skin contact.

**Respiratory** Respirator use is not expected to be necessary under normal conditions of use. In poorly ventilated areas, emergency situations or if exposure levels are exceeded, use NIOSH approved full face respirator.

**Hands** Chemical resistant gloves.

**Feet** Chemical resistant boots or overshoes.

**Other information** Nitrile or neoprene gloves.

**Protective Clothing (Pictograms)**



**Additional Exposure Contr Remarks** Not available.

### Section 9. Typical Physical and Chemical Properties

<b>Physical State and Appearance</b>	Gel. Liquid.	<b>Odor</b>	Slight Hydrocarbon.
<b>pH</b>	6 - 8 (5% in IPA/water)	<b>Color</b>	Light Colorless.
<b>Specific gravity</b>	0.634 - 0.646 @ 16°C (60°F)		
<b>Density</b>	5.28 - 5.38 lbs/gal @ 16°C (60°F)		
<b>Vapor Density</b>	>1 (Air = 1)		
<b>Vapor Pressure</b>	356.8 - mm of Hg @ 20°C (68°F)		
<b>Evaporation Rate</b>	Not Available or Not Applicable for Solids.		
<b>VOC</b>	Not available.		
<b>Viscosity</b>	95000 - 105000 cps @ 16°C (60°F)		
<b>Pour Point</b>	Not available.		
<b>Solubility (Water)</b>	Insoluble		
<b>Boiling Point</b>	27°C (81°F)		

Continued on Next Page

Physical Chemical Comments	Not available.
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**Section 10. Stability and Reactivity**

Stability and Reactivity	The product is stable.
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Conditions of Instability	Not available.
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Incompatibility with Various Substances	Oxidizing material.
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Hazardous Decomposition Products	Not applicable.
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Hazardous Polymerization	Hazardous polymerization is not expected to occur.
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Special Stability & Reactivity Remarks	Not available.
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**Section 11. Toxicological Information****Component Toxicological Information****Acute Animal Toxicity**

1) Isoparaffinic Solvent	Not available.
2) 2-Butoxyethanol	ORAL (LD50): Acute: 1230 mg/kg [Mouse], 470 mg/kg [Rat]. DERMAL (LD50): Acute: 400 mg/kg [Rabbit], 200 mg/kg [Rabbit].

**Chronic Toxicity Data**

## 1) Isoparaffinic Solvent

Isopentane is a component of this product. Chronic exposure may effect the liver and heart muscle. Similar hydrocarbons have produced liver, kidney, or CNS damage with chronic exposure.

## 2) 2-Butoxyethanol

2-Butoxyethanol [synonym: ethylene glycol monobutyl ether (EGBE)] is a component of this product. EGBE has no tendency to accumulate in humans or animals (Clayton & Clayton, 1994). Little is known about the potential long-term or delayed effects of low-level chronic EGBE exposure.

In mice, treatment with doses of 500 or 1,000 mg/kg/day for 4 days induced atrophy of the thymus and lymphocytopenia, indicative of potential depression of the immune system. Hemolytic anemia was also produced (Grant et al, 1985). Anemia was also produced in rats.

In laboratory animals they have gotten mixed results regarding the reproductive studies.

**Product Toxicological Information**

Acute Animal Toxicity	Not available.
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Target Organs	blood system, kidneys, nervous system, liver, respiratory tract, immune system, skin/epithelium, eyes.
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Other Adverse Effects	Not available.
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**Section 12. Ecological Information**

Ecotoxicity	Not available.
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BOD5 and COD	Not available.
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Biodegradable/OECD	Not available.
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Toxicity of the Products of Biodegradation	Not available.
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Special Remarks	Not available.
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**Section 13. Disposal Considerations**

Responsibility for proper waste disposal rests with the generator of the waste. Dispose of any waste material in accordance with all applicable federal, state and local regulations. Note that these regulations may also apply to empty containers, liners and rinsate. Processing, use, dilution or contamination of this product may cause its physical and chemical properties to change.

Additional Waste Remarks Not available.

**Section 14. Transport Information**

DOT Classification FLAMMABLE LIQUID, N.O.S., (contains Isoparaffinic Solvent), 3,  
UN1993, 1



DOT Reportable Quantity Not applicable.

Marine Pollutant Not applicable.

Additional DOT information Not available.

Emergency Response Guid 128  
Page Number

**Section 15. Regulatory Information**

HCS Classification Target Organ Effects. Flammable liquid. Vapors can form an ignitable or explosive mixture with air. Can form explosive mixtures at temperatures at or above the flash point. Vapors can flow along surfaces to a distant ignition source and flash back. Static discharges can cause ignition or explosion when container is not bonded. Irritant.

**U.S. Federal Regulations**

Environmental Regulations Extremely Hazardous Substances: Not applicable to any components in this product.  
SARA 313 Toxic Chemical Notification and Release Reporting: 2-Butoxyethanol;  
SARA 302/304 Emergency Planning and Notification substances: Not applicable to any components in this product.  
Hazardous Substances (CERCLA 302): Not applicable to any components in this product.  
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: fire; immediate health hazard; delayed health hazard;  
Clean Water Act (CWA) 307 Priority Pollutants: Not applicable to any components in this product.  
Clean Water Act (CWA) 311 Hazardous Substances: Not applicable to any components in this product.  
Clean Air Act (CAA) 112(r) Accidental Release Prevention Substances: Isoparaffinic Solvent;

Threshold Planning Quantity (TPQ) Not applicable.

TSCA Inventory Status All components are included or are exempted from listing on the US Toxic Substances Control Act Inventory.

This product does not contain any components that are subject to the reporting requirements of TSCA Section 12(b) if exported from the United States.

State Regulations State specific information is available upon request from Baker Petrolite.

**International Regulations**

Canada Not all components are included on the Canadian Domestic Substances List.

WHMIS (Canada) B-2, D-1B, D-2B

European Union All components are included or are exempted from listing on the European Inventory of Existing Commercial Chemical Substances or the European List of Notified Chemical Substances.

International inventory status information is available upon request from Baker Petrolite for the following countries: Australia, and Australia (NICNAS), China, Korea (TCCL), Philippines (RA6969), or Japan.

Harmonized Tariff Code Not available.

*Continued on Next Page*

Other Regulatory Information	No further regulatory information is available.
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**Section 16. Other Information**

Other Special Considerations	File 1668 3/31/03 - Changes to Sections 2, 3, 5, and 11
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**Baker Petrolite Disclaimer**

*NOTE: The information on this MSDS is based on data which is considered to be accurate. Baker Petrolite, however, makes no guarantees or warranty, either expressed or implied of the accuracy or completeness of this information.*

*The conditions or methods of handling, storage, use and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of this product.*

*This MSDS was prepared and is to be used for this product. If the product is used as a component in another product, this MSDS information may not be applicable.*

# Addendum 3 – Thermal Stability Testing

## Testing of Baker FLO–XS

The following pages replicate: AFRL–PR–WP–TR2001–2060 “Testing of Baker FLO–XS Pipeline Drag Reducer Additive.” Pagination, page layout, figure and table numbers, etc. have been revised and text, heading, and table styles have been modified slightly to help integrate this addendum with the rest of the report. The material is otherwise unedited and unchanged from the original report.

### Summary

Pipeline drag-reducing additives have been used for many years in crude oil and some products to increase throughput in the pipeline. In recent years, interest in using drag-reducing additives in jet fuel has increased because of greater demand on the petroleum product pipelines for jet fuel. Thus, testing was completed on the Baker Flo–XS pipeline drag-reducing additive to determine if the additive had any negative impact on the fuel. The proposed use of the additive was to add 2 ppm at up to 4 points along the pipeline(s). Thus, the majority of testing was completed using 8.8 ppm (8 ppm total plus 0.8 ppm for errors in injection). Through a CRADA with Buckeye Pipeline Company, thermal stability testing of the additive was completed. Additionally, low temperature testing, additive/additive compatibility testing and specification testing of additized fuel was also completed. Material compatibility testing was also taken into consideration.

Since jet fuel is used as a coolant in aircraft, one concern with any new additive is the impact of the additive on the thermal stability properties of the fuel. Thus, thermal stability testing was the main concern for this set of tests. To capture the variety of jet fuel available, nineteen fuels were used. Testing techniques included the ICOT, QCM, HLPs, EDTST, NIFTR, Augmentor Simulator and ARSFSS. Based on the results of testing at a polymer concentration of 8.8 ppm, the Baker FLO XS drag-reducing additive had no deleterious impact on thermal stability of jet fuel up to 325°F bulk and 450°F wetted wall temperature. When added to the +100 additive package at the same concentration, it had no deleterious impact on thermal stability up to 375°F bulk and 500°F wetted wall conditions. Based on the results of the screening tests using a wide variety of fuels, Baker FLO XS is not sensitive to fuel types or treatments.

The additional tests also showed no deleterious impact on the jet fuel. Material compatibility was considered, but was determined to not be necessary.

### Introduction

The American Petroleum Institute (API) conducted a survey in 1997 that showed over 40% of the pipelines dedicated to jet fuel use in the US will be at maximum capacity in the next 10 years [1]. This is due to the forecasted increased demand for jet fuel by the commercial airlines. Many of the pipelines that deliver commercial jet fuel also deliver jet fuel to Air Force bases. In addition, the operators of over 80% of the existing multi-product pipelines need to increase throughput in order to move sufficient product to meet demand during the same time period. The delivery of the additional volume of jet fuel can be achieved in a number of ways. Additional pipelines could be built or alternative transportation modes such as tank trucks could be used. Both of these options are costly and will ultimately increase the price of jet fuel. The API survey results indicate that to construct additional pipelines to meet demand will cost in excess of \$500M. Fulfilling the increased

demand by truck transportation is even more costly. A third alternative is the use of a pipeline drag-reducing additive (DRA) in the jet fuel in the existing lines to achieve the desired throughput. This alternative has generated interest because drag reducing additives have already been used in crude oil and some of its other products. The third alternative is the driving force of this testing.

Thermal stability testing was performed on the Baker Flo XS pipeline drag-reducing additive (AFRL/PRSF identification number POSF-3597) to determine any negative impact of the additive on fuel properties. The test matrix used was developed through discussions at American Society of Testing and Materials (ASTM) Committee D-2 meetings. A cooperative research and development agreement was created between Buckeye Pipeline and the Air Force Research Laboratory, Propulsion Directorate, Propulsion Sciences and Advanced Concepts Division, Fuels Branch. In this agreement, thermal stability tests developed during the JP-8+100 program in order to screen potential +100 additives were used to study POSF-3597.

The test hardware, protocols and conditions used were developed by the Air Force over many years as the +100 program developed in order to evaluate the acceptability of fuel additives for use in aircraft. Equipment manufacturers input was also considered during development of the testing. This series of tests was very successful in screening the potential additives for the JP-8+100 and reducing the risk of full-scale engine and aircraft testing [2].

Additional testing beyond that described in the CRADA was also completed. Specification testing of a variety of the test fuels was completed at various concentrations of the Baker Flo-XS additive to determine if the additive has any impact. Also, low temperature testing was completed to determine any low temperature impact of the additive. The low temperature was a concern because of the additive's high weight.

### **Baker FLO-XS**

Baker Flo-XS is a 12.5% solution of a 70/30 (w/w) copolymer of 1-dodecene/1-hexene in isopentane. The testing was completed using a polymer dosage of 8.8 ppm into jet fuel. At this dosage, residual catalyst hetero atoms in the jet fuel are Ti (0.8-1.1 ppb), Al (9.6-15.9 ppb) and Cl (12.0-19.1 ppb) [3]. Because the polymer is difficult to get into solution, Baker Chemical diluted the 12.5% polymer solution to a 1% polymer level using a high-grade kerosene for the laboratory testing. To achieve the 8.8 ppm needed for testing, 0.80 was assumed to be the density of the fuel. Assuming that density, 704 mg/L of the 1% polymer additive was used.

### **Tasks**

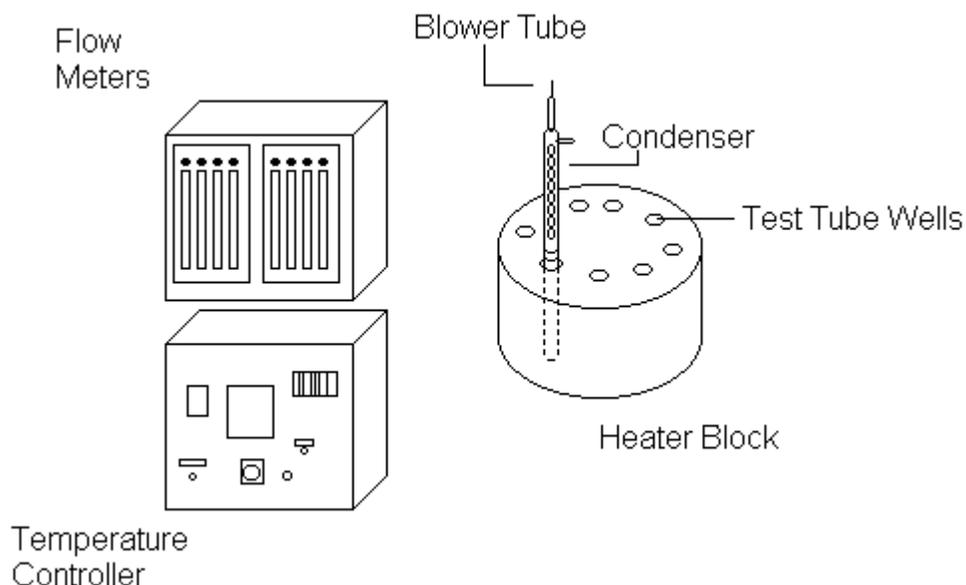
The screening tests were the Isothermal Corrosion/Oxidation Test, the Quartz Crystal Microbalance and the Hot Liquid Process Simulator. After the screening tests, the larger Extended Duration Thermal Stability Test was completed on two test fuels with POSF-3597 as well as one test with POSF-3597 + Betz 8Q462 (+100) additive at the more rigorous +100 conditions. The Advanced Reduced Scale Fuel System Simulator (ARSFSS) was completed on one test fuel with POSF-3597. Other tests included the Augmentor Fouling Simulator, the Near-Isothermal Flowing Test Rig, Low Temperature testing, specification testing, additive/additive compatibility and material compatibility. The standard additization rate was 8.8 ppm polymer. This rate assumed a maximum additization of 8 ppm total over the length of the pipeline with the 0.8 ppm added to cover injection inaccuracy. The 8.8 ppm rate was chosen because the pipelines determined that the most useful rate would be adding 2 ppm at 4 different points throughout the pipeline.

## Methods, Assumptions and Procedures & Results and Discussions

### Section I. Screening Tests

#### 1. Isothermal Corrosion/Oxidation Test

The Isothermal Corrosion/Oxidation Test (ICOT) is a static thermal stability experiment. Figure 39 shows a basic schematic of the test apparatus.



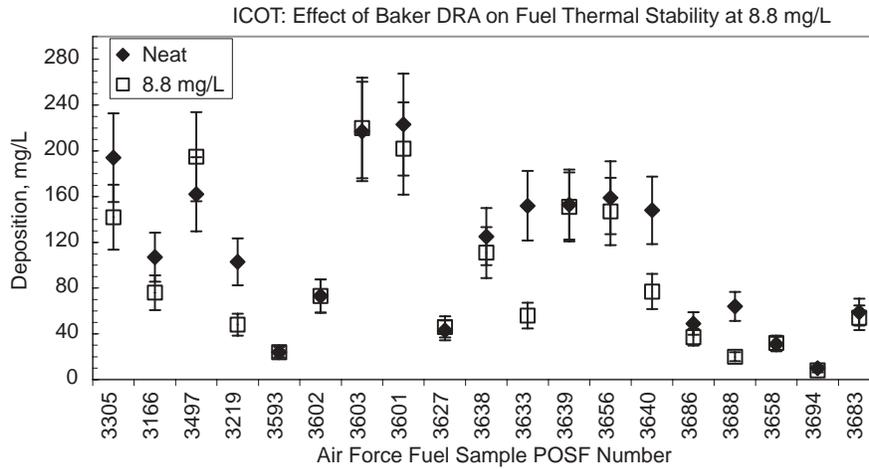
**Figure 39. Isothermal Corrosion/Oxidation Test Apparatus**

In a typical experiment, the heater block temperature is set at 180° C. Once 180° C is maintained, a test tube with 100 mL of fuel is placed into a tube well in the heating block. A condenser is attached to the test tube and a glass blower tube is inserted down the middle of the condenser. A continuous supply of dry air is sparged into the fuel at a rate of 1.3 L/hr via tygon tubing connecting the glass blower tube with the flow meter. The sample is thermally and oxidatively stressed for 5 hours. At the end of 5 hours, the air is turned off, the condenser detached, and the test tube removed from the heating block. The sample is allowed to cool overnight. The next day, the sample is vacuum filtered through a pre-weighed 0.7  $\mu\text{m}$  glass fiber filter. The bulk particulates collected on the filter are rinsed with heptane to remove any remaining fuel. The filter is placed in an oven at 100°C for several hours to completely dry the filtered material. It is then removed from the oven and placed in a dessicator to cool before weighing. The effect of an additive is based on the difference between the bulk insolubles formed from the neat fuel and the bulk insolubles formed from the additized fuel. Repeatability of the ICOT test is  $\pm 20\%$  [4].

Figure 40 shows the results from all the fuels tested, additized at 8.8 ppm polymer, including the 20% error bars. Table 10 shows the numerical results of the same tests.

Within the uncertainty of the test, the addition of 8.8 ppm POSF-3597 results in ICOT insolubles that are the same as, or lower than, the baseline fuels. Thus, all the fuels tested at 8.8 ppm had acceptable results for this screening test.

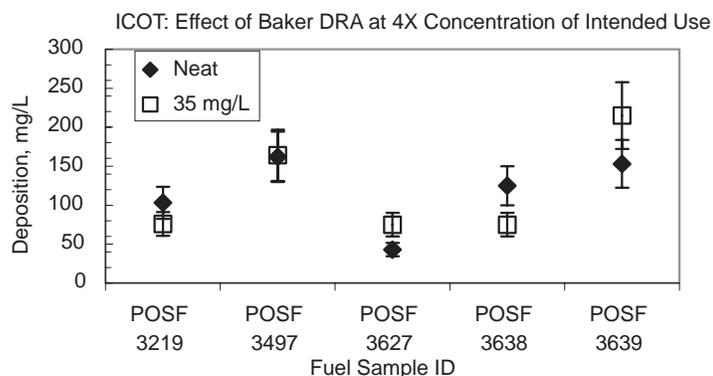
Other tests were completed using 35.2 ppm (4 times the 8.8 concentration) and the results are shown in Figure 41. The numerical data is shown in Table 11.



**Figure 40. ICOT Results – 8.8 ppm Polymer**

**Table 10. ICOT Results – 8.8 ppm Polymer**

Fuel Sample Identification	ICOT (mg/L) Neat Fuel	ICOT (mg/L) Fuel + 8.8 ppm DRA
96-POSF-3305	194	142
95-POSF-3166	107	76
98-POSF-3497	162	195
96-POSF-3219	103	48
99-POSF-3593	24	24
99-POSF-3602	73	73
99-POSF-3603	217	220
99-POSF-3601	223	202
99-POSF-3627	43	46
99-POSF-3638	125	111
99-POSF-3633	152	56
99-POSF-3639	153	151
99-POSF-3656	159	147
99-POSF-3640	148	77
99-POSF-3686	49	37
99-POSF-3688	64	20
99-POSF-3658	31	32
99-POSF-3694	10	8
99-POSF-3683	59	54



**Figure 41. ICOT Results – 4x Original Concentration**

**Table 11. ICOT Results – 4x Original Concentration**

Fuel Sample Identification	ICOT (mg/L) Neat Fuel	ICOT (mg/L) Fuel + 35 ppm DRA
96-POSF-3219	103	76
98-POSF-3497	162	164
99-POSF-3627	43	75
99-POSF-3638	125	75
99-POSF-3639	153	215

Within the uncertainty of the test, the addition of 35.2 ppm POSF-3597 results in ICOT insolubles that are the same as, or lower than, the baseline fuels in all but one fuel. This fuel, POSF-3627, is a hydrotreated fuel which yields relatively low deposition in both tests. The presence of the additive increases the deposition only slightly outside the 20% error bars at this 4x concentration. The bulk insolubles formed from the 4x concentration of the additive are still quite low relative to other unadditized fuels. Thus, these data show that addition of the additive at either the 1x or 4x concentration is unlikely to produce significant changes in fuel thermal stability.

## 2. Quartz Crystal Microbalance

The Quartz Crystal Microbalance is a static test that monitors both deposition and oxidation during the thermal stressing of a jet fuel. Figure 42 shows a cross-section schematic of the test apparatus.

A quartz crystal microbalance is used to measure the deposition while a polarographic oxygen sensor is used to monitor oxidation. The Parr bomb is a 100 mL stainless steel reactor. It is heated with a clamp-on band heater and its temperature is controlled by a PID controller through a thermocouple immersed in the fuel. The reactor contains an rf feedthrough, through which the connection for the quartz crystal resonator is attached. The crystals are 2.54 cm in diameter, 0.33 mm thick and have a nominal resonant frequency of 5 MHz. Mass deposition is monitored as a decrease in the resonant frequency of the crystal. The QCM measures deposition (i.e., an increase in mass) which occurs on overlapping sections of the two-sided electrodes. Thus, the device responds to deposition that occurs on the metal surface and does not respond to deposition on the exposed quartz.

The device is also equipped with a pressure transducer (Sensotec) to measure the absolute headspace pressure and a polarographic oxygen sensor (Ingold) to measure the headspace oxygen concentration. A personal computer is used to acquire data at one-minute intervals during the experimental run. The following data are recorded during a run: temperature, crystal frequency, headspace pressure, headspace oxygen concentration, and crystal damping voltage.

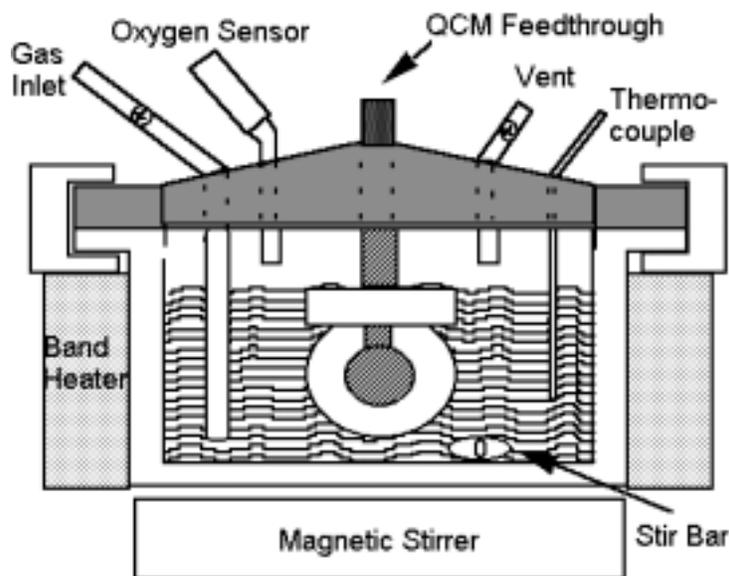


Figure 42. Quartz Crystal Microbalance Schematic

The reactor is charged with 60 mL of fuel, which is sparged with the appropriate gas for one hour before each test. The reactor is then sealed and the heater is started. All runs in this study were performed at 140°C; heat-up time to this temperature is 40±5 minutes. Most runs are conducted for 15 hours, after which the heater is turned off and the reactor allowed to cool. Surface mass measurements can only be determined during the constant temperature (±0.2°C) portion of an experimental run [5]. Figure 43 shows the results from all the fuels tested, additized at 8.8 ppm polymer, including the 20% error bars. Table 12 shows the numerical results.

Within the uncertainty of the test, the addition of 8.8 ppm POSF-3597 results in QCM deposits that are the same as, or lower than, the baseline fuels. Thus, all the fuels tested at 8.8 ppm had acceptable results for this screening test.

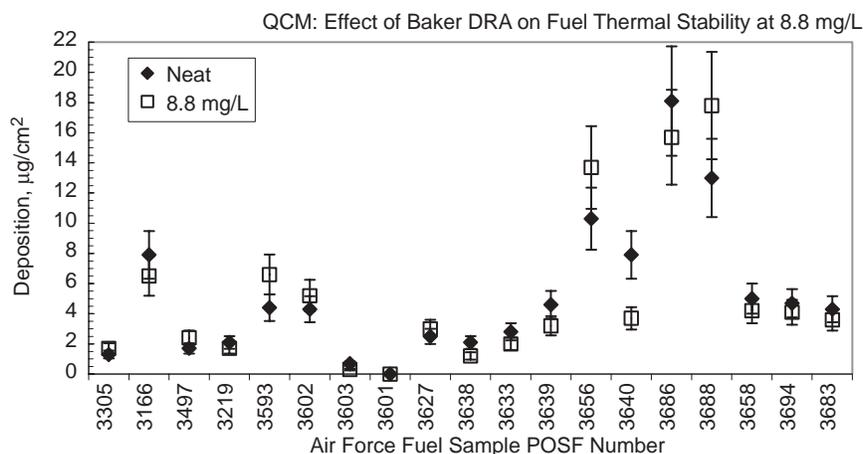


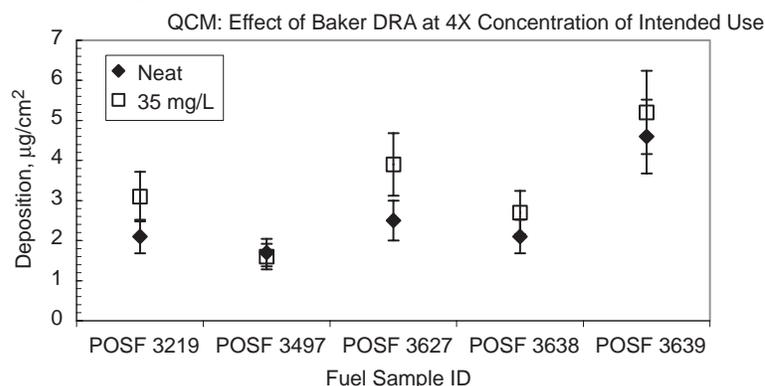
Figure 43. QCM Results – 8.8 ppm Polymer

**Table 12. QCM Results – 8.8 ppm Polymer**

Fuel Sample Identification	QCM ( $\mu\text{g}/\text{cm}^2$ ) Neat Fuel	QCM ( $\mu\text{g}/\text{cm}^2$ ) Fuel + 8.8 ppm DRA
96-POSF-3305	1.3	1.7
95-POSF-3166	7.9	6.5
98-POSF-3497	1.7	2.4
96-POSF-3219	2.1	1.7
99-POSF-3593	4.4	6.6
99-POSF-3602	4.3	5.2
99-POSF-3603	0.7	0.3
99-POSF-3601	0	0
99-POSF-3627	2.5	3
99-POSF-3638	2.1	1.2
99-POSF-3633	2.8	2
99-POSF-3639	4.6	3.2
99-POSF-3656	10.3	13.7
99-POSF-3640	7.9	3.7
99-POSF-3686	18.1	15.7
99-POSF-3688	13	17.8
99-POSF-3658	5	4.2
99-POSF-3694	4.7	4.1
99-POSF-3683	4.3	3.6

Other tests were completed using 35.2 ppm (4 times the 8.8 concentration) and the results are shown in Figure 44 with the numerical results in Table 13.

In the 4x concentration, POSF 3627 yields a higher deposition with the additive present in the QCM as well. Again, this fuel is a hydrotreated fuel that yields relatively low deposition in both tests. The presence of the additive increases the deposition only slightly outside the 20% error bars for both tests at the 4x concentration. Most importantly, the fuel deposition with the 4x concentration of the additive is still quite low relative to other unadditized fuels. For example, some fuels used by the Air Force in aircraft have had QCM deposition levels of  $10 \mu\text{g}/\text{cm}^2$  and above. Thus, these data show that addition of the additive at either the 1x or 4x concentration is unlikely to produce significant changes in fuel thermal stability.



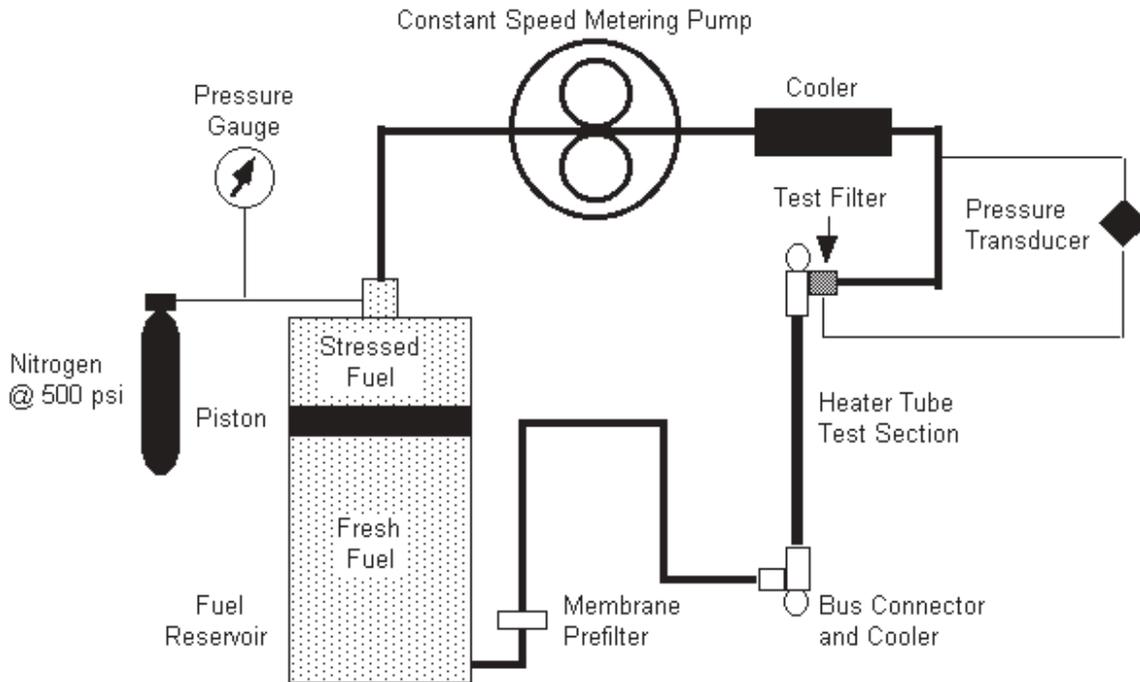
**Figure 44. QCM Results – 4x Original Concentration**

**Table 13. QCM Results – 4x Original Concentration**

Fuel Sample Identification	QCM ( $\mu\text{g}/\text{cm}^2$ ) Neat Fuel	QCM ( $\mu\text{g}/\text{cm}^2$ ) Fuel + 35 ppm DRA
96-POSF-3219	2.1	3.1
98-POSF-3497	1.7	1.6
99-POSF-3627	2.5	3.9
99-POSF-3638	2.1	2.7
99-POSF-3639	4.6	5.2

### 3. Hot Liquid Process Simulator

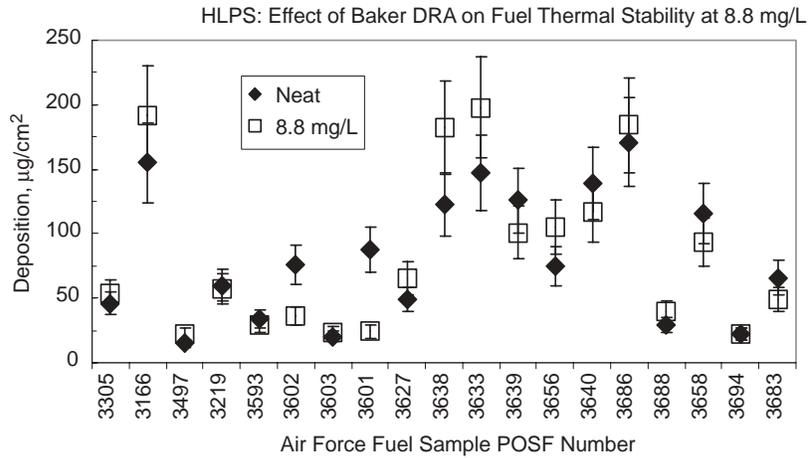
The Hot Liquid Process Simulator (HLPS) is a derivative of the Jet Fuel Thermal Oxidation Tester (JFTOT) employed in ASTM D 3241 to rate the tendencies of aviation turbine fuels to form deposits under thermal-oxidative stress. A schematic of the HLPS is shown in Figure 45.



**Figure 45. Hot Liquid Process Simulator Schematic**

The test conditions selected to evaluate additive performance are much more severe than those specified in the standard JFTOT procedure. Tests are performed at 335°C for 5 hours at a flow rate of 3 mL/min. Series 316 stainless steel tubes are substituted for the conventional aluminum tubes to permit quantitation of the deposit by carbon burnoff using a LECO RC-412 Carbon Analyzer [6]. Differences in deposition show additive effects. Figure 46 shows the results for all the fuels tested. Table 14 shows the numerical results for those tests.

Within the uncertainty of the test, the addition of 8.8 ppm POSF-3597 results in HLPS deposits that are the same as, or lower than, the baseline fuels. Thus all the fuels tested at 8.8 ppm had acceptable results for this screening test.

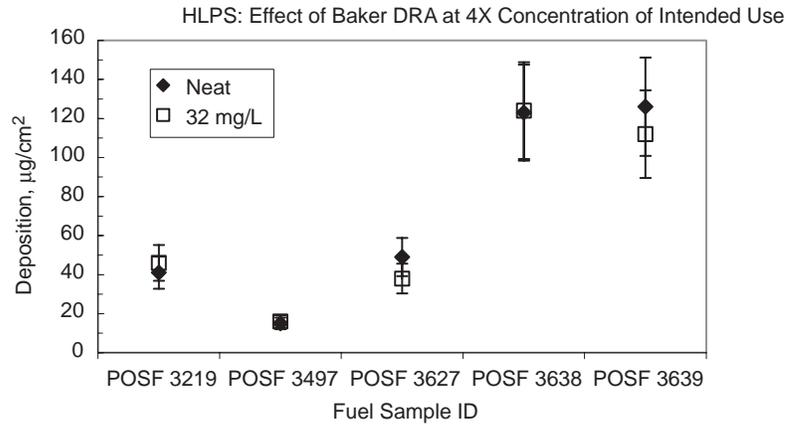


**Figure 46. HLPS Results – 8.8 ppm Polymer**

**Table 14. HLPS Results – 8.8 ppm Polymer**

Fuel Sample Identification	HLPS (µg/cm <sup>2</sup> ) Neat Fuel	HLPS (µg/cm <sup>2</sup> ) Fuel + 8.8 ppm DRA
96-POSF-3305	46	54
95-POSF-3166	155	192
98-POSF-3497	15	22
96-POSF-3219	60	57
99-POSF-3593	34	29
99-POSF-3602	76	36
99-POSF-3603	20	23
99-POSF-3601	88	24
99-POSF-3627	49	65
99-POSF-3638	123	182
99-POSF-3633	147	198
99-POSF-3639	126	101
99-POSF-3656	75	105
99-POSF-3640	139	117
99-POSF-3686	171	184
99-POSF-3688	29	40
99-POSF-3658	116	93
99-POSF-3694	22	22
99-POSF-3683	66	49

Other tests were completed using 32 ppm (4 times the 8 concentration). This rate was the actual intention for the 4x tests. The 0.8 was added to the initial screening tests to cover additive injection error. When the 4x tests were developed, it was decided that additization error would be covered in the much greater amount of polymer added to the fuel. However, AFRL/PRSF did not receive that word in time. The QCM and ICOT tests were already completed. Thus, there is a slight difference between the additization rates for the HLPS and the other screening tests. The results of the 4x concentration tests are shown in Figure 47 and the numerical data is shown in Table 15.



**Figure 47. HLPS Results – 4x Original Concentration**

**Table 15. HLPS Results – 4x Original Concentration**

Fuel Sample Identification	HLPS (µg/cm <sup>2</sup> ) Neat Fuel	HLPS (µg/cm <sup>2</sup> ) Fuel + 32 ppm DRA
96-POSF-3219	41	46
98-POSF-3497	15	16
99-POSF-3627	49	38
99-POSF-3638	123	124
99-POSF-3639	126	112

Within the uncertainty of the test, the addition of 32 ppm POSF-3597 results in HLPS deposits that are the same as the deposits for the baseline fuels. An interesting point is that the low depositing POSF-3627 that was showing a slight increase in the ICOT and QCM tests, did not show the same increase in the HLPS test. These data show that addition of the additive at either the 1x or 4x concentration is unlikely to produce significant changes in fuel thermal stability.

#### 4. Fuels Used During Testing

A wide variety of jet fuels were used in this testing program. Because a matrix of jet fuels had already been determined for red dye contamination of jet fuel testing, the same set of fuels was used for this program. Table 16 shows the red dye fuels used (reported as four digit POSF numbers) and how they were processed.

Thus, a wide variety of fuels were tested in the screening tests. Comparing the screening test results, especially for the samples that were processed similarly, does not indicate a pattern suggesting that any given type of fuel is sensitive to Baker DRA.

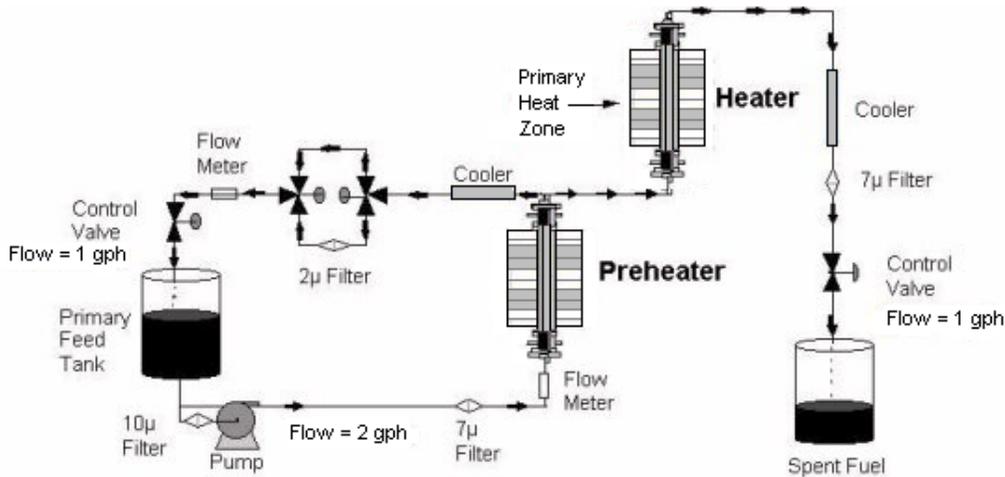
**Table 16. Processing of Red Dye Test Fuels Used**

Processing	Light Crude		Mixed Crude	Heavy Crude	
	Sweet	Sour		Sweet	Sour
Str-Run No Treatment	3638				
Str-Run Clay Treated	3633				
Srt-Run Sweetened Merox	3639 3694				
Srt-Run Sweetened Blender Treated	3593				
Srt-Run Doctor Sweetened	3656				
Srt-Run Hydrotreated	3640	3603	3601	3602	3627
Hydrocracked			3658 3688		3686
Thermal Cracked, HT			3683		

## Section II. Simulation Tests

### 1. Extended Duration Thermal Stability Test

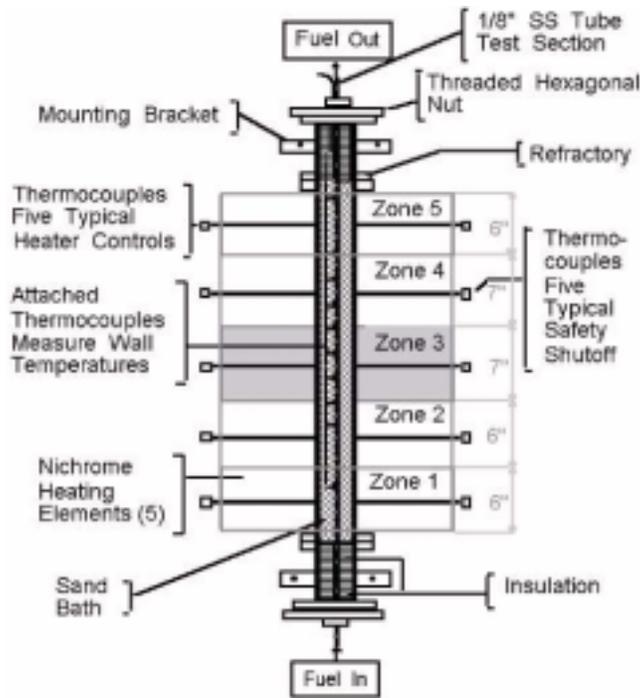
The EDTST was established to provide fuel thermal stability information for designers in addition to evaluating fuels. Figure 48 shows a schematic of the EDTST.



**Figure 48. EDTST Schematic**

The system consists of a 60 gallon feed tank, an electrical motor driven gear pump, two clamshell furnace heaters, and a scrap tank. The first furnace heater (preheater) in the system is used to establish the desired fuel bulk temperature into the second heater and to establish the desired fuel bypass temperature. The fuel bulk temperature represents the temperature that results from aircraft and engine heat loads. The second furnace heater (main heater) establishes the wetted wall temperatures associated with engine injection nozzles.

Both furnace heaters are 0.81 meters long and resistance heated. A typical main heater assembly is shown in Figure 49. Both heaters have 5 heating element zones that are independently controlled. The fuel flows upward through a single stainless steel tube in each heater. The tube in the preheater



**Figure 49. EDTST Heater**

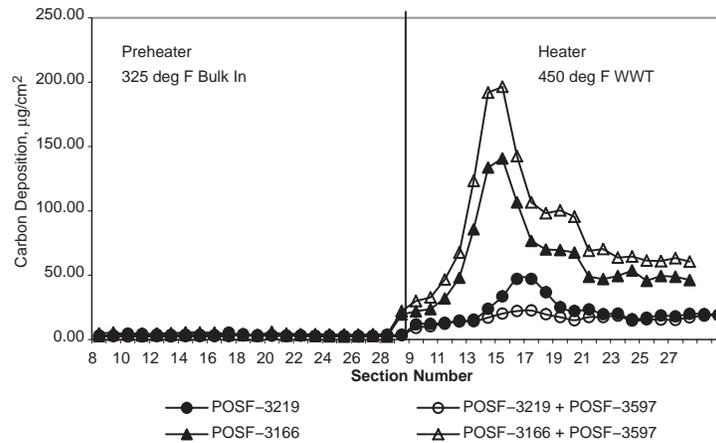
has an O.D. of 1.27 cm and a wall thickness of 0.0889 cm. The tube in the main heater has an O.D. of 0.32 cm and a wall thickness of 0.0889 cm. Each tube is assembled inside a thick walled furnace tube that has an I.D. of 2.54 cm and an O.D. of 5.08 cm. The tubes have thermocouples attached to the outer wall for measuring wetted wall temperatures. The annular space between the furnace tube and heater tubes is filled with sand.

A fuel bypass line is installed downstream of the preheater to represent the aircraft recirculation line from the engine to the airframe tanks. A water/fuel cooler is installed in this line to represent the aircraft ram air heat exchanger. A  $2\mu$  filter is also installed in the line for 4 hours to measure particles in the recirculated bulk fuel. Since studying the effects of recirculation is one of the purposes of this test, the filter is installed only for a short duration. Aircraft fuel systems will probably not have a filter in the recirculation line. A  $7\mu$  filter is also installed downstream of the heater. This filter provides an indication of particles that the fuel nozzles will experience in future engines where a heat exchanger is downstream of the engine fuel controls.

The flow rate into the preheater is 2 gallons per hour (gph). The flow is split at the exit of the preheater such that 1 gph is delivered to the main heater and 1 gph to the bypass flow line. The residence time from the inlet of the preheater to the outlet of the main heater is approximately 50 seconds. The residence time from the inlet to the outlet of the main heater is 1.1 seconds with a Reynolds number of  $\sim 2,400$ . This residence time is representative of those in aircraft and engine fuel systems. The typical test period for an EDTST run is 96 hours [7].

The series of tests for POSF-3597 included testing in two different fuels as well as testing with the +100 additive package at +100 conditions. The two fuels used were POSF-3219 and POSF-3166, both Jet-A fuels. Tests were conducted with and without POSF-3597 in both fuels at 325°F bulk and 450°F wetted wall temperature conditions. An additization rate of 8.8 ppm polymer was used

for these tests. All tests were conducted for a 96-hour duration. The carbon deposits in the preheater and heater tubes for these tests are shown in Figure 50.

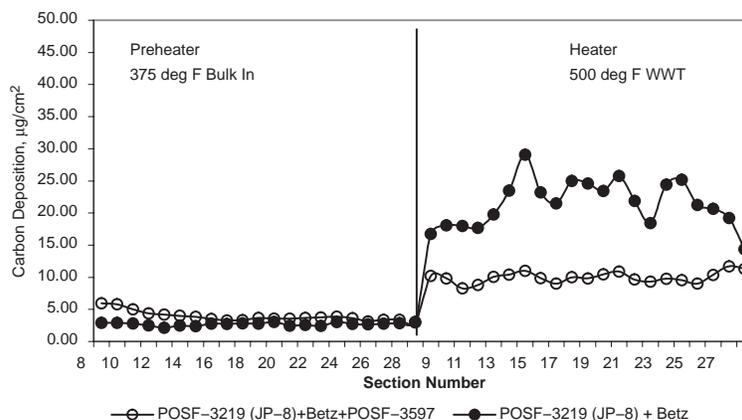


**Figure 50. EDTST using POSF-3219 and POSF-3166: Preheater and Heater Sections**

The additive had slightly lower deposits in POSF-3219 and slightly higher deposits in POSF-3166 fuel. However, these differences are within the uncertainty of the test.

Another test was conducted with POSF-3597 in POSF-3219 fuel that had both the JP-8 additives and the Betz 8Q462 additive. This test was to determine if POSF-3597 would effect the thermal stability of JP-8+100 fuel. Again, 8.8 ppm polymer additization rate was used. This test was conducted at 375°F bulk and 500°F wetted wall temperature conditions. The carbon deposits in the preheater and heater tubes for this test are shown in Figure 51. Results of a previous run of the same fuel at the same conditions only without POSF-3597 are shown in this figure for comparison purposes.

The differences between the two are within the uncertainty of the test. Based on these results, POSF-3597 is unlikely to degrade the thermal stability of Jet A or JP-8+100 fuels.



**Figure 51. EDTST using POSF-3219 + Betz 8Q462 + POSF-3597: Preheater and Heater**

## 2. Augmentor Fouling Simulator

The augmentor simulates the leaking or residual fuel in the augmentor injection system of a military aircraft. Figure 52 shows a schematic of the augmentor simulator.

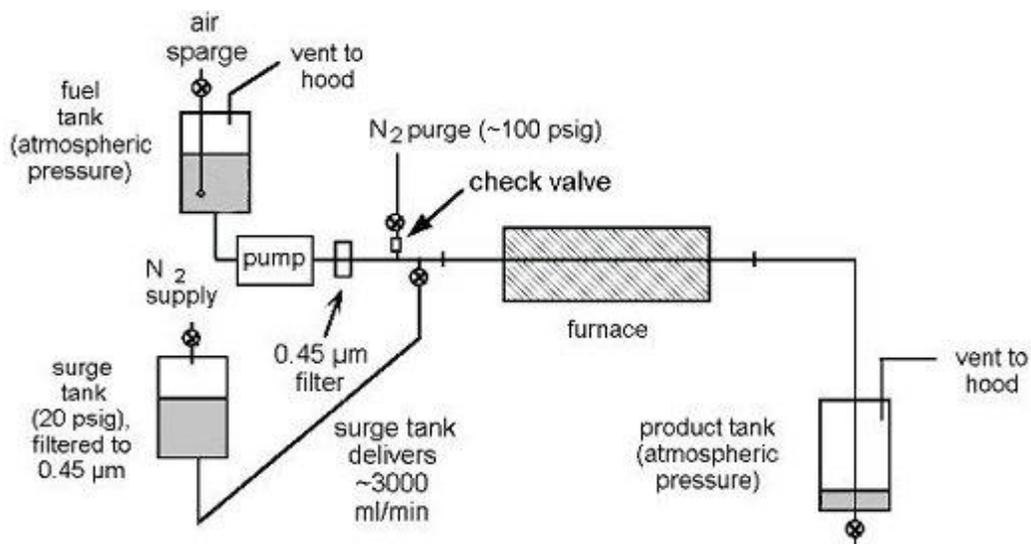


Figure 52. Augmentor Simulator Schematic

The fuel is fed by a SSI 222C HPLC pump to a ¼ in. outer diameter 316-type stainless steel tubing (0.035 in. wall thickness) which passes through a T-intersection containing a Parker 5 µm filter. From there, the tubing enters a Lindberg 55035 heater that heated the fuel to 550°C. Thermocouples are placed along the stainless steel tubing approximately every 2 inches inside the heater to ensure temperature requirements are met to vaporize the fuel. The tube drops ¼ in. from the inlet of the heater to the outlet. Before beginning each test run, the system is purged with nitrogen for approximately 2 minutes to rid it of any oxygen. The fuel flow is established at 1.5 mL/min and is constant for the duration of the run. After the test period of 15 hrs, the tube is sectioned and the deposition determined by carbon burnoff in a LECO RC-412 Multiphase carbon determinator [8].

Two fuels were tested, POSF-3219 and POSF-3497. The standard test value of 8.8 ppm polymer of POSF-3597 was used.

The largest deposit always occurs at the point where the fuel vaporizes. In this test, that point is at 15.24 cm down the tube length. This deposit is created by all of the insoluble and high-boiling material formed by thermal-oxidative reactions.

As shown in Figure 53, addition of POSF-3597 to POSF-3219 fuel slightly lowered the deposition at 15.24 cm while addition to POSF-3497 fuel caused a slight increase in the deposition. The increase was within the uncertainty of the test (20 %). Thus, this test agrees with the earlier tests that the additive is unlikely to damage thermal stability when 8.8 ppm polymer additization is used.

## 3. Near-Isothermal Flowing Test Rig

The NIFTR uses dynamic isothermal techniques to evaluate additives. Using this technique, the dependence of both dissolved oxygen and surface deposition can be monitored as a function of stress or reaction time under isothermal conditions of 185°C. In addition, the bulk insolubles are evaluated over the complete reaction time. A diagram of the NIFTR is shown in Figure 54.

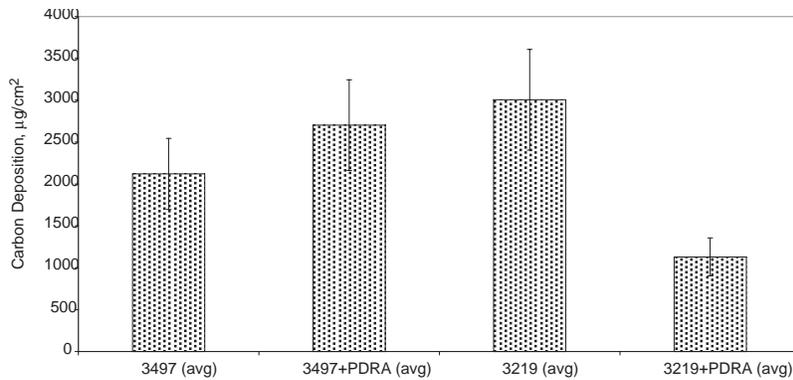


Figure 53. Augmentor Deposition at 15.24 cm

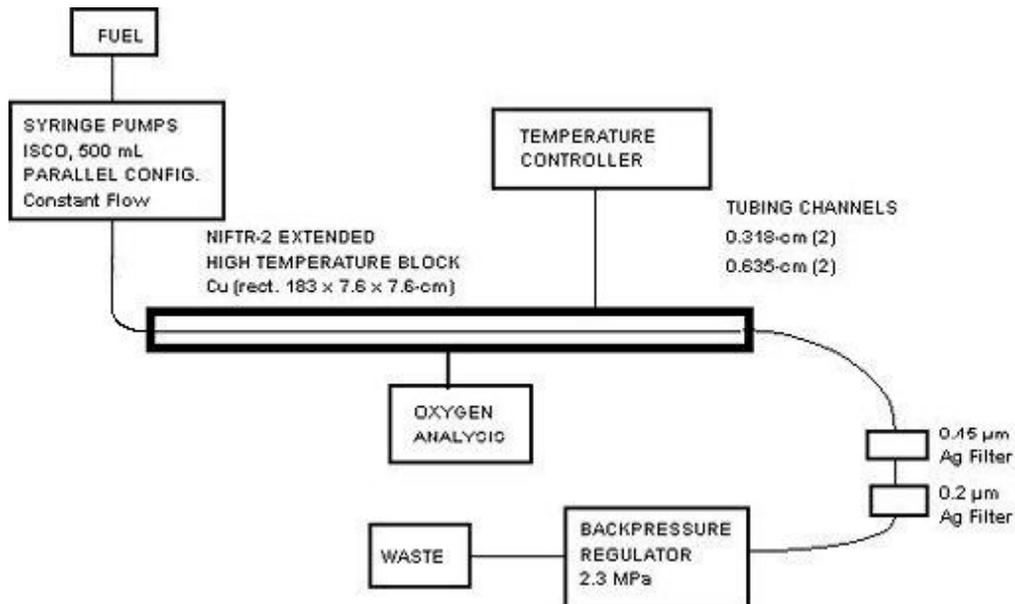


Figure 54. NIFTR Schematic

The fuel flows through heated tubing at pressures above 2.3 MPa ensuring a single reaction phase and simulating fouling that occurs in aircraft. Typically, experiments are conducted to allow depletion of all dissolved oxygen and completion of the corresponding deposition processes. This is usually accomplished in 23 min of stressing at 185°C.

Oxidation and deposition experiments are performed in different experiments, briefly summarized in the following:

**Oxidation:** Fuel is passed through 32 in. of passivated tubing maintained at constant wall temperature by a heat exchanger. Fuel residence time is changed by varying fuel flow rate. Concentration of O<sub>2</sub> is determined by GC. 100 % corresponds to air-saturated fuel.

**Deposition:** Fuel flows at 0.25 mL/min through 72 in. of 0.125-in outer diameter, 0.085-in inner diameter stainless steel tubing. Tubing walls are maintained at 185°C by the Cu-block heat exchanger. The test lasts 72 hours and uses 1.08 L fuel. Surface and bulk carbon are determined by surface carbon burnoff of tube sections and in-line filters. Stress duration is proportional to distance along the tube and is calculated assuming plug flow. Quantity of insolubles is expressed in units of µg/mL [9].

The NIFTR results for deposition and oxidation are shown in Figures 55 and 56. From a deposition standpoint neat JP-8, Jet-A and additized Jet-A are approximately the same within experimental uncertainty yielding 1.53, 1.68, and 1.47  $\mu\text{g}/\text{mL}$ , respectively. The in-line bulk insolubles, however, are significantly reduced in the additized sample, compared to either the neat JP-8 or Jet-A (compare 0.11 with 0.64 and 0.84). These results suggest some detergent/dispersant properties of POSF-3597 in this fuel.

The JP-8 additive package tends to be slightly pro-oxidant as we have seen in other fuels. However, the oxidation changes from the POSF-3597 are more pronounced. The POSF-3597 has distinct antioxidant behavior at 185°C as evidenced by the factor of 2 delay in the oxidation time. Overall, POSF-3597 appears to enhance the fuel behavior.

#### **4. Advanced Reduced Scale Fuel System Simulator**

The ARSFSS simulates the thermal performance and flow profile of turbine engine fuel systems, including engine hardware. The simulator consists of three integrated subsystems: 1) the fuel conditioning system, 2) the airframe fuel system, and 3) the engine fuel system. A schematic of the simulator is shown in Figure 57.

The simulator was configured to simulate the F-22 aircraft with the F119 engine. The fuel flow established in the simulator is 1/72 scale of the F119 engine and the burn flow is 1/3 of the flow for a single F119 fuel nozzle. The total fuel required for each test is approximately 1,500 gallons.

Real-world engine components are incorporated into the engine portion of the simulator to help evaluate the impact of fuel deposits on component performance. The two real world components are both servo valves. The first servo valve bypasses flow back to the tank providing for recirculation. The second is the flow divider valve which controls flow to the burner feed arm. Both valves are actual F119 components that have been modified for reduced flow by changing the slot width. The performance of the valves is determined by hysteresis before and after the test.

Two other components of interest are the fuel-cooled oil cooler (FCOC) and the burner feed arm (BFA). These components are simulated on the ARSFSS and are incorporated to study thermal stability effects. The FCOC represents the engine lube system cooler. It consists of an induction heater and a steel manifold with three 3/8" tubes and associated thermocouples. The tubes are connected and provide for three passes through the heater. The tube that is used for the final pass is removed after each test. It is cut into 2 inch segments and subjected to carbon analysis. The burner feed arm is RF induction heated. It consists of a steel clamshell with a 1/8 inch stainless steel tube installed in middle of the clamshell. Thermocouples on the outside of the tube are positioned along the entire length to measure the temperature profile of the tube. At the end of the tests, this tube is cut up into 1 inch segments and subjected to carbon analysis as well [7].

A test of POSF-3597 was evaluated at conditions of 325°F bulk fuel out of the FCOC and a wetted wall temperature of 450°F. These conditions were selected to simulate worst case conditions that today's engine experience using Jet-A fuels. This test was conducted with POSF-3219 fuel with the POSF-3597 drag reducer additive at 8.8 ppm. The modified duty cycle was used and 65 missions (approximately 150 hours) were conducted for this test. The servo and flow divider valves were disassembled after this test and were in as-new condition. The hysteresis tests of these valves also indicated no change in valve performance. Plots of these tests are shown in Figures 58 and 59. The carbon deposits on the FCOC and burner feed arm tubes are shown in Figures 60 and 61. Data from a previous test of POSF-3219 fuel with the Betz 8Q462 additive is shown for reference purposes. The JP-8+100 test level demonstrates an acceptable amount of deposition. As seen in Figures 60

EFFECT OF PDR ON POSF-3219 (JET-A)  
 COMPARED TO NEAT JET-A and NEAT  
 JP-8

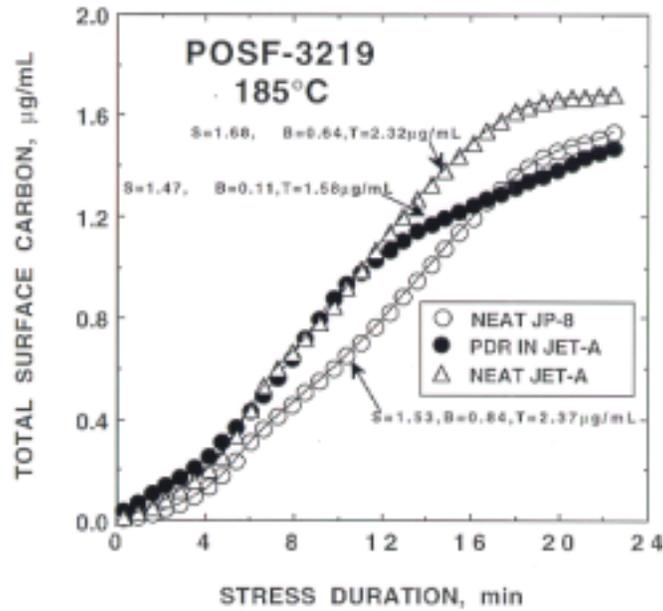


Figure 55. NIFTR Deposition Results

EFFECT OF PDR ON POSF-3219 (JET-A)  
 OXIDATION COMPARED TO NEAT JET-A  
 AND NEAT JP-8

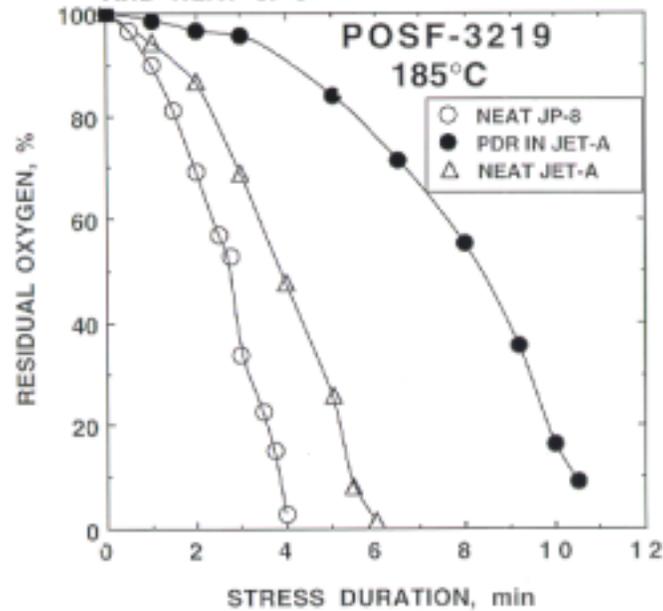


Figure 56. NIFTR Oxidation Results

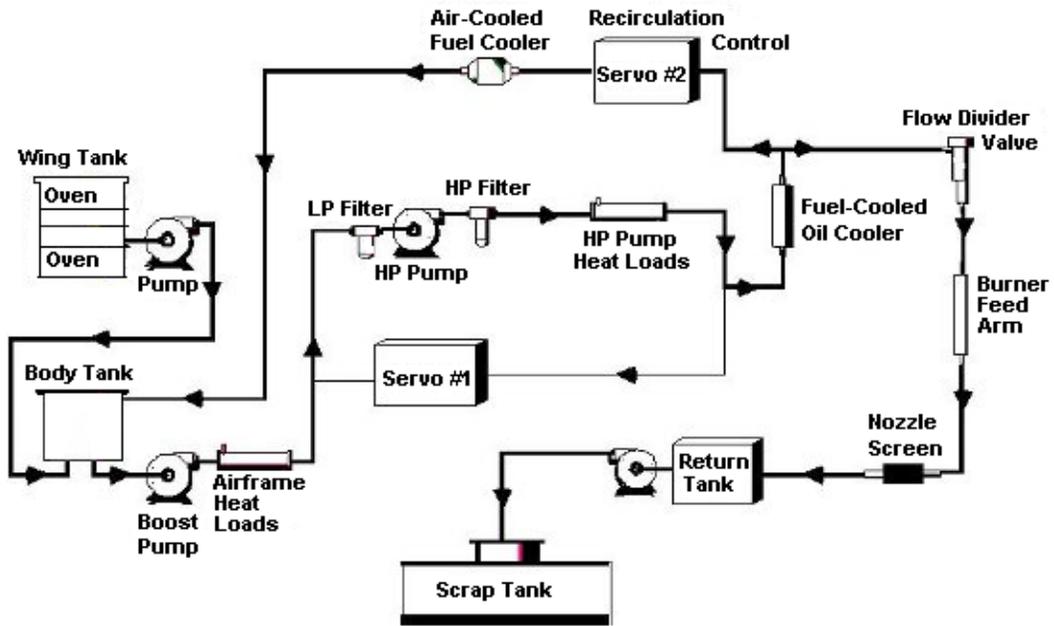


Figure 57. ARSFSS Schematic

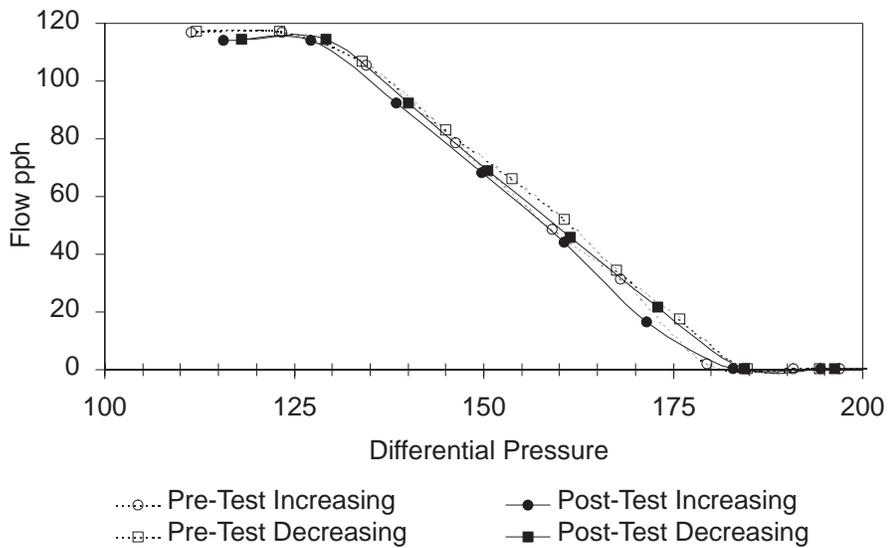


Figure 58. Hysteresis Results for Servo Valve

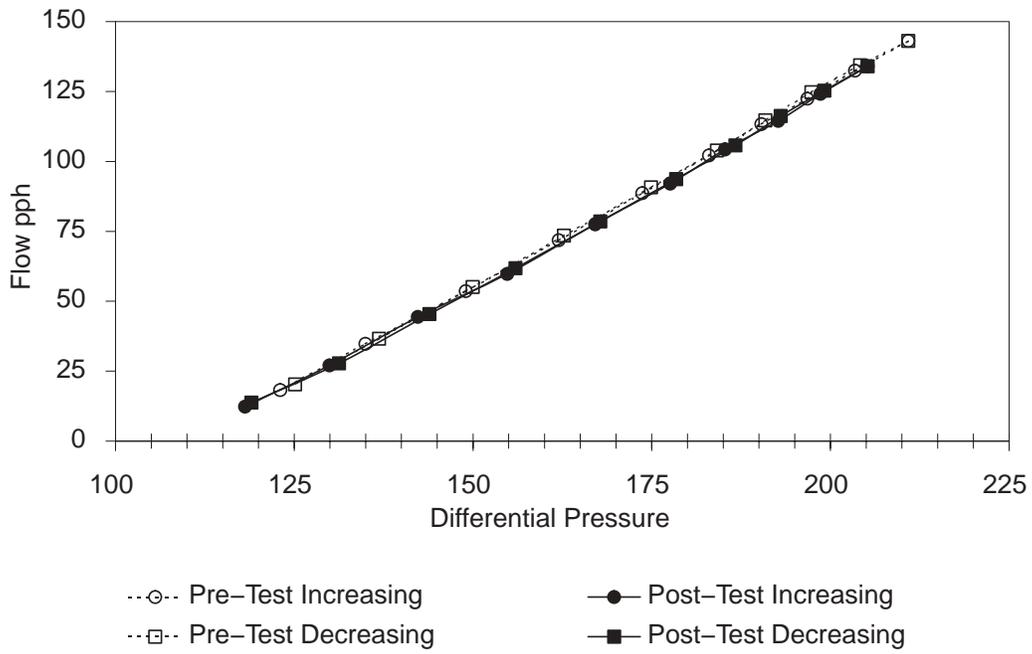


Figure 59. Hysteresis Results for the Flow Divider Valve

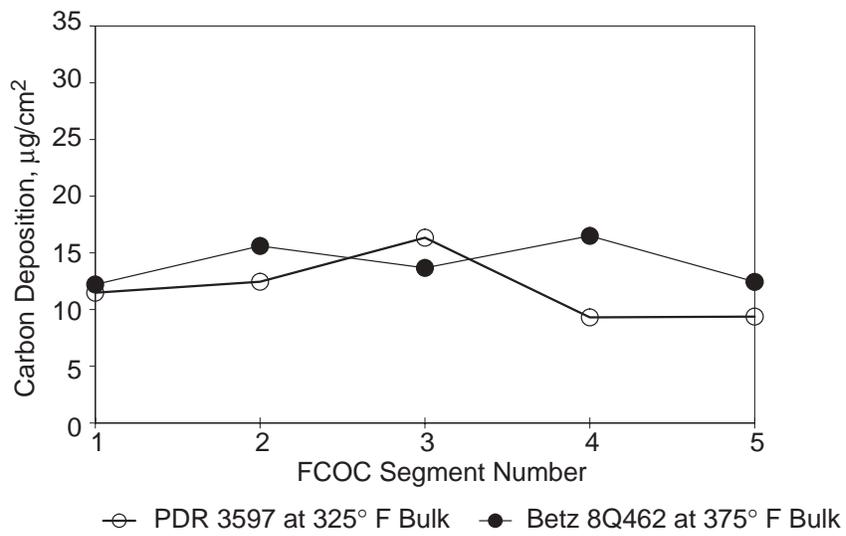
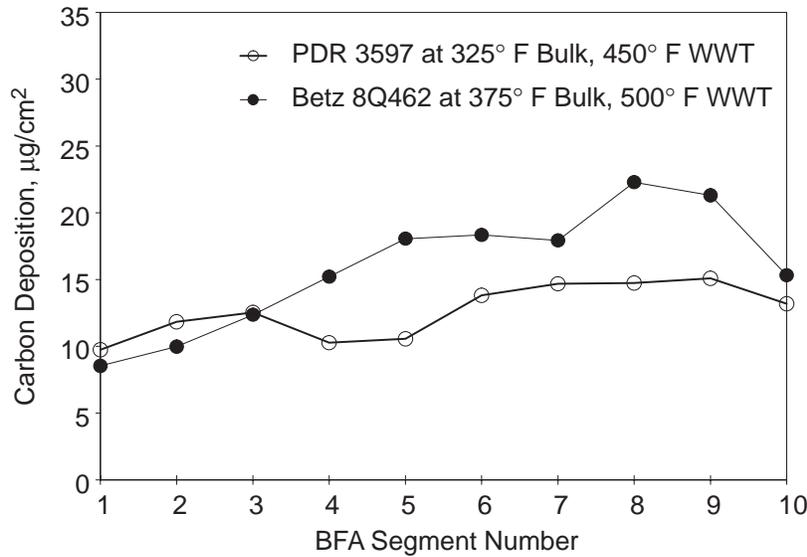


Figure 60. Carbon Burnoff of the Fuel Cooled Oil Cooler



**Figure 61. Carbon Burnoff of the Burner Feed Arm**

and 61, the carbon deposits from the POSF–3597 test were in the same acceptable range. Based on the results of this test, the drag reducer is considered to be thermally stable at bulk temperatures up to 325°F and 450°F wetted wall temperatures.

### Section III. Other Tests

#### 1. Material Compatibility

The composition of Baker DRA was studied by Alan Fletcher of the Materials Behavior and Evaluation Section of the Materials Directorate, Air Force Research Laboratory. He determined that the additive does not have material compatibility issues and thus, material compatibility testing was not necessary. Figure 62 is a letter from John Motier of Baker Petrolite / Pipeline Products describing the composition of Baker DRA (FLO XS). Figure 63 is a letter from Lt Kirsten Wohlwend, AFRL/PRSF, to Alan Fletcher, AFRL/MLSA, requesting a material compatibility review of Baker DRA. Figure 64 is Alan Fletcher’s response, determining that Baker DRA is compatible with all aircraft fuel system materials and will not require material compatibility testing.

#### 2. Additive/Additive Compatibility

A slightly modified ASTM Standard D 4054 procedure B was completed on POSF–3597 using POSF–3219 as the base fuel. First the base fuel was clay treated. The base fuel was separated into 100 mL portions. Baker FLO XS was added to one set of the portions at 35 ppm (4 times 8.8 ppm). Corrosion Inhibitor (DCI 4A), Fuel System Icing Inhibitor and a static dissipator (Stadis 450) were all added at four times their respective maximum allowable concentration to the other portions of base fuel. Each 100 mL portion of base fuel plus FLO XS was then blended with the corresponding 100 portion of base fuel plus approved additives. These resulting mixtures had 2 times the maximum recommended concentration of FLO XS and 2 times the maximum allowable concentration of the mil spec additives. The sample was then divided into two 100 mL portions. The samples were then placed in cold storage (–15.5°C / 4°F) for 24 hours. The samples were visually inspected after removal to look for indications of incompatibility (precipitation, cloudiness, darkening, separation etc). The samples were then warmed, shaken to make sure components were still mixed, and placed



**Baker Petrolite**

**John F. Meier**  
Technical Director  
Baker Petrolite / Product Products  
9500 W. 27<sup>th</sup> Street  
Sand Springs, OK 74063  
Tel: (918) 341-4997  
Fax: (918) 341-4966  
E-mail: john.meier@baker-petrolite.com

July 28, 2009

LT Kristen Wahlwood  
AFRL/PRSE  
1790 Loop Road North  
Wright Patterson AFB OH 45433

Dear LT Kristen Wahlwood:

This will serve to confirm the composition of FLO XS previously acknowledged to the CRC. Working Group. FLO XS is a 12.5% (w/w) solution of a 7000 (w/w) copolymer of 1-dodecene/1-hexene in toluene. A proprietary Ziegler-Natta catalyst is used for the polymerization and a very small amount of olefin is added to terminate the polymerization once the reaction has proceeded to a polymer content of 12.5%. This does leave a residual monomer content in FLO XS of 1.8% 1-dodecene and 0.8% 1-hexene.

The molecular weight of the copolymer produced is estimated to be ca. 30 million in its non-degraded state.

At a polymer dosage of 8.8 ppm into jet fuel, the resulting concentrations of the catalyst hetero atoms are: Ti, 0.8-1.1 ppb; Al, 9.6-12.9 ppb; Cl, 12.0-19.1 ppb. The variation is intentional and reflects adjustment in catalyst component amount depending on reactivity of FLO XS batches.

Please contact me if there are any questions. Kind regards,

Very truly yours,  
*John F. Meier*  
John F. Meier

Figure 62. Baker DRA (FLO XS) Composition Letter from Baker Petrolite



DEPARTMENT OF THE AIR FORCE  
AIR FORCE RESEARCH LABORATORY  
WRIGHT PATTENSON AIR FORCE BASE OHIO 45433

MEMORANDUM FOR AFRL/MLSA (ALAN FLETCHER)

FROM: AFRL/PRSF (ILT KRISTEN WOHLWEND)

SUBJECT: Request for Material Compatibility Review

1. As part of CRADA # 98-173-PR-01, AFRL/PRSF is studying the Baker FLO-XS pipeline drag reducing additive (POSF-3597) and if it has detrimental effects to jet fuel thermal stability. Another issue is that of material compatibility of POSF-3597 with materials it would come in contact with in an aircraft.
2. POSF-3597 is a 12.5% solution of a 70/30 (w/w) copolymer of 1-dodecene/1-hexene in isoparane. A proprietary Ziegler-Natta type catalyst is used for the polymerization and a small amount of alcohol is added once the reaction has proceeded to 12.5% polymer to kill the catalyst. The catalyst is comprised of titanium salt and aluminum alkyl activator. At the expected polymer dosage of 8.8 ppt, the resulting concentrations of residual catalyst heteroatoms in jet fuel are the following:

Ti	0.8-1.1 ppb
Al	9.6-15.9 ppb
Cl	12.0-19.1 ppb
3. Based on this information, does POSF-3597 require material compatibility testing? The POC for this project is Lt Kristen Wohlwend who can be reached via email at [Kristen.Wohlwend@wpafb.af.mil](mailto:Kristen.Wohlwend@wpafb.af.mil) and via telephone at 5-3190. Thank you for your help in this matter.

*Kristen Wohlwend*  
KRISTEN WOHLWEND, LT, USAF  
AEROSPACE FUELS CHEMIST

Figure 63. Request to AFRL/MLSA for Material Compatibility Review



DEPARTMENT OF THE AIR FORCE  
AIR FORCE RESEARCH LABORATORY  
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433

28 JUL 2000

MEMORANDUM FOR AFRL/PRSF (1LT KIRSTEN WOHLWEND)

FROM: AFRL/MLSA

SUBJECT: Request for Material Compatibility Review

1. This letter is in response to your letter requesting a material compatibility review for POSF 3597 pipeline drag reducing additive. Based upon the information that you have provided concerning the chemical composition of the additive, this additive is compatible with all aircraft fuel system materials and will not require material compatibility testing. The additive is composed primarily of organic compounds that are known to have no adverse effect on the materials used in an aircraft fuel system. There is a small amount of metallic catalyst, which also should have no detrimental effect to any fuel system material.

2. Should you need further assistance or information, I can be reached at x57481 or [alan.fletcher@wpafb.af.mil](mailto:alan.fletcher@wpafb.af.mil)

  
ALAN J. FLETCHER, Materials Engineer  
Adhesives, Composites and Elastomers Team  
Materials Integrity Branch  
Systems Support Division

Attachment  
AFRL/PRSF Letter(ad)

Figure 64. Response from AFRL/MLSA

in an oven (75°C / 164°F) for 24 hours. The samples were removed and inspected for visual indications of incompatibility. They were then allowed to cool to room temperature and again inspected. No indications of precipitation, cloudiness, darkening or other visual evidence of incompatibility ever appeared.

### 3. Specification Testing

Specification testing was completed on a variety of the fuels used in the screening tests. Screening tests were performed on eleven of the neat test fuels. Specification testing was completed on nine of those fuels additized with 8.8 ppm Baker FLO XS. Additional specification testing was completed on five of the fuels using a polymer concentration of 35.2 ppm. The results of those tests are shown in Table 17.

**Table 17. Specification Testing**

POSF Number	Total Acid Number, mg KOH/g	Aromatics, % vol	Sulfur, % Mass		Flash Point, °C
			Mercaptan	Total	
96-POSF-3219	0	18.3	0	0.04	54
96-POSF-3219 + 26 ppm DRA					
96-POSF-3219+ 35.2 ppm DRA	0.001	20.5	0	0.04	55
98-POSF-3497	0.002	8.4		0.0037	47
98-POSF-3497+ 35.2 ppm DRA	0	8	0	0	49
99-POSF-3593	0	19	0.002	0.2	48
99-POSF-3593+ 8.8 ppm DRA	0	18.49	0	0.21	48
99-POSF-3601	0	16	0	0	61
99-POSF-3601+ 8.8 ppm DRA	0	14.56	0	0.01	64
99-POSF-3602	0	24	0	0	50
99-POSF-3602+ 8.8 ppm DRA	0	23.54	0	0.02	53
99-POSF-3603	0	22	0	0	56
99-POSF-3603+ 8.8 ppm DRA	0	19.8	0	0.02	59
99-POSF-3627	0	20	0	0	49
99-POSF-3627+ 8.8 ppm DRA	0	20.4	0	0.02	50
99-POSF-3627+ 35.2 ppm DRA	0	22	0	0	51
99-POSF-3633	0.01	15	0	0	51
99-POSF-3633+ 8.8 ppm DRA	0	15.8	0	0.02	53
99-POSF-3638	0	12	0.001	0	47
99-POSF-3638+ 8.8 ppm DRA	0	12.2	0	0.02	50
99-POSF-3638+ 35.2 ppm DRA	0	14	0.001	0	49
99-POSF-3639	0.01	15	0	0.1	46
99-POSF-3639+ 8.8 ppm DRA	0	15	0	0.06	48
99-POSF-3639+ 26 ppm DRA					
99-POSF-3639+ 35.2 ppm DRA	0	16	0	0.1	48
99-POSF-3639+ 44 ppm DRA					
99-POSF-3640	0	17	0	0	54
99-POSF-3640+ 8.8 ppm DRA	0	15.6	0	0.01	56

**Table 17. Specification Testing (Continued)**

POSF Number	Freezing Point, °C (Automatic)	Viscosity @ -20° C	Smoke Point, mm	Copper Strip Corrosion	Existent Gum, mg/100mL	Water Reaction
96-POSF-3219	-46	5.2	21	1a	0.8 / 4.6 **	1
96-POSF-3219 + 26 ppm DRA					2.8	
96-POSF-3219+ 35.2 ppm DRA	-46	5.2	21	1a	3.6 / 4.8 **	1
98-POSF-3497	-64	4.1	25	1a	2.6	1
98-POSF-3497+ 35.2 ppm DRA	-61	4.2	26	1b	2.4	1
99-POSF-3593	-43	5.9	21	1a	0.3	1b
99-POSF-3593+ 8.8 ppm DRA	-43	5.5	27	1a	0.2	1b
99-POSF-3601	-48	5	24	1a	0.1	1b
99-POSF-3601+ 8.8 ppm DRA	-48	5	27	1a	0	1b
99-POSF-3602	-54	5.9	20	1a	0	1b
99-POSF-3602+ 8.8 ppm DRA	-54	5.4	25	1a	0	1b
99-POSF-3603	-47	5	19	1a	0	1b
99-POSF-3603+ 8.8 ppm DRA	-48	5	26	1a	0.2	1b
99-POSF-3627	-50	6	20	1a	0	1b
99-POSF-3627+ 8.8 ppm DRA	-50	5.6	20	1a	0.4	1b
99-POSF-3627+ 35.2 ppm DRA	-50	5.3	19	1b	2.2	1
99-POSF-3633	-56	4	23	1a	1	1b
99-POSF-3633+ 8.8 ppm DRA	-55		23	1a	0.2	1b
99-POSF-3638	-53	4	25	1a	0.3	1b
99-POSF-3638+ 8.8 ppm DRA	-53	4	24	1a	0	1b
99-POSF-3638+ 35.2 ppm DRA	-53	4	22	1a	2.4	1
99-POSF-3639	-43	6.8	22	1a	0.7	1b
99-POSF-3639+ 8.8 ppm DRA	-43	6.2	24	1a	0.4	1b
99-POSF-3639+ 26 ppm DRA					5.2	
99-POSF-3639+ 35.2 ppm DRA	-43	6.3	22	1b	5 / 5.2 **	1
99-POSF-3639+ 44 ppm DRA					5.4	
99-POSF-3640	-48	5.4	20	1a	0	1b
99-POSF-3640+ 8.8 ppm DRA	-46	5.9	24	1a	0.2	1b

\*\* Shows repeated tests

**Table 17. Specification Testing (Continued)**

POSF Number	Conductivity, pS/m	Distillation			
		10% Recovered	50% Recovered	90% Recovered	FBP, °C
96-POSF-3219	5	184	208	245	263
96-POSF-3219 + 26 ppm DRA					
96-POSF-3219+ 35.2 ppm DRA	5	183	208	245	262
98-POSF-3497	440	170	193	226	251
98-POSF-3497+ 35.2 ppm DRA	595	174	195	227	250
99-POSF-3593	0	177	206	253	270
99-POSF-3593+ 8.8 ppm DRA	0	174	205	253	270
99-POSF-3601	0	190	206	231	243
99-POSF-3601+ 8.8 ppm DRA	0	189	206	231	244
99-POSF-3602	0	180	208	238	258
99-POSF-3602+ 8.8 ppm DRA	0	180	208	239	259
99-POSF-3603	0	188	207	239	254
99-POSF-3603+ 8.8 ppm DRA	0	185	207	238	255
99-POSF-3627	0	179	206	249	264
99-POSF-3627+ 8.8 ppm DRA	0	178	206	248	265
99-POSF-3627+ 35.2 ppm DRA	0	179	206	249	267
99-POSF-3633	0	174	191	225	243
99-POSF-3633+ 8.8 ppm DRA	0	173	191	225	244
99-POSF-3638	0	176	195	221	235
99-POSF-3638+ 8.8 ppm DRA	0	174	195	221	237
99-POSF-3638+ 35.2 ppm DRA	0	176	195	222	238
99-POSF-3639	0	180	217	262	286
99-POSF-3639+ 8.8 ppm DRA	0	181	218	263	287
99-POSF-3639+ 26 ppm DRA					
99-POSF-3639+ 35.2 ppm DRA	0	179	218	263	290
99-POSF-3639+ 44 ppm DRA					
99-POSF-3640	0	183	209	246	262
99-POSF-3640+ 8.8 ppm DRA	0	184	210	247	263

**Table 17. Specification Testing (Concluded)**

POSF Number	Distillation, % vol		Lubricity Test (BOCLE) wear scar, mm	Thermal Stability @ 260° C	
	Residue	Loss		Tube Rating Visual	ΔP, mm Hg
96-POSF-3219	1.1	1	0.55	2	1
96-POSF-3219 + 26 ppm DRA					
96-POSF-3219+ 35.2 ppm DRA	1.2	1.1	0.57	1	5
98-POSF-3497	0.5	0.5	0.62	1	0
98-POSF-3497+ 35.2 ppm DRA	1.2	1.1	0.6	1	2
99-POSF-3593	1.5	1.1	0.73	2	3
99-POSF-3593+ 8.8 ppm DRA	1.5	1.4	0.74	2	2
99-POSF-3601	1.2	1.1	0.68	1	1
99-POSF-3601+ 8.8 ppm DRA	1.2	1.5	0.58	1	5
99-POSF-3602	1.2	1.2	0.69	2	3
99-POSF-3602+ 8.8 ppm DRA	1.3	0.7	0.65	1	1
99-POSF-3603	1.2	1.4	0.73	3	5
99-POSF-3603+ 8.8 ppm DRA	1.3	0.5	0.74	1	3
99-POSF-3627	1.3	1.4	0.64	1	1
99-POSF-3627+ 8.8 ppm DRA	1.4	0.8		1	4
99-POSF-3627+ 35.2 ppm DRA	0.9	1.1	0.69	2	4
99-POSF-3633	1	0.9	0.55	1	4
99-POSF-3633+ 8.8 ppm DRA	1.4	0.3	0.58	1	2
99-POSF-3638	1.3	1.1	0.58	1	5
99-POSF-3638+ 8.8 ppm DRA	1.2	0.8		1	0
99-POSF-3638+ 35.2 ppm DRA	1	0.9	0.58	1	3
99-POSF-3639	1.4	1.4	0.61	1	5
99-POSF-3639+ 8.8 ppm DRA	1.5	1.4	0.6	1	0
99-POSF-3639+ 26 ppm DRA					
99-POSF-3639+ 35.2 ppm DRA	1.2	1.1	0.65	2	3
99-POSF-3639+ 44 ppm DRA					
99-POSF-3640	1.2	1.4	0.58	1	0
99-POSF-3640+ 8.8 ppm DRA	1.2	1.6	0.6	1	2

The addition of Baker Flo XS did not cause any of the samples to become out of specification, even at the higher concentrations of the additive. One area of interest is existent gum. While the addition of Flo XS at 35.2 ppm did not cause the fuel to become out of specification, for four of the five fuels used for high concentration testing, there was an increase. Additional testing was completed on the two fuels with the largest difference. The increase hit a plateau at 26 ppm (3x concentration) and the plateau was confirmed at 44 ppm (5x concentration). The 2 x concentration level was not tested. Because the increase hit a plateau instead of continuing to increase as more additive was added, it is not a concern.

#### 4. Low Temperature Testing

A low temperature test system that was established for evaluating potential low temperature additives for U-2 aircraft fuel was used for these tests. In the system, shown as Figure 65, fuel passes from the tank (7.6 L) through stainless-steel tubing (1.9 cm OD x 1.7 cm ID) which is in series with a screen and valve. The screen (8 mesh) is typical of a boost pump inlet screen and is considered a likely location for flow blockage. The tank, fuel line, valve, and screen are contained within a chamber that is capable of operating down to  $-73\text{ }^{\circ}\text{C}$ . The fuel exits the cooled chamber and is collected in a tank that is on scale outside the chamber. The scale is used to measure the mass of fuel flowing from the fuel tank and screen. Thus, a timer used in combination with the mass measurement provides an average mass flow rate of the fuel exiting the chamber. In addition, the fuel tank is pressurized with nitrogen such that the internal pressure of the tank was 10.5 kPa above the ambient pressure. This pressure difference is similar to that used for pressurization of aircraft wing tanks.

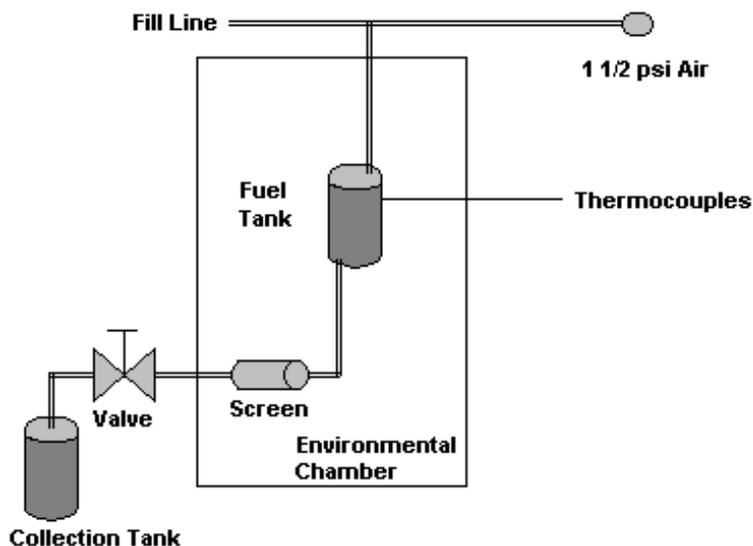


Figure 65. System for Low-Temperature Flow Reduction and Hold-Up Experiments

The bulk fuel temperatures within the fuel tank were measured by thermocouples (type T) at two locations within the tank and one location directly in the center of the screen. The chamber was set to the desired cooling temperature and the fuel allowed to cool for 16 hours. The fuel in the tank was maintained at the desired steady-state temperature for at least one hour before flow is permitted from the fuel tank. Differences in mass flow rate at a given temperature and source pressure provide an indication of the flow resistance through the tubes and the screen. Since the mass of fuel is known before initiating flow, the mass of fuel that solidifies within the tank (fuel hold-up) is determined from measurement of the mass of fuel collected in the tank outside of the cooling chamber [10].

The tests were conducted in POSF-3219 fuel at  $-60$  and  $-65\text{ }^{\circ}\text{F}$ , respectively. The results of these tests are shown in Table 18. The test results of the fuel without the additive are included for comparison purposes. The holdup was higher with the additive than with the baseline fuel. The additive did not significantly effect the flow rate at  $-60^{\circ}\text{F}$ . Since the actual freeze point was not effected; low temperature operation is not considered to be a problem with this additive.

**Table 18. Low Temperature Test Results**

Fuel		Holdup (%)	Flow (lb/min)
POSF 3219	@ -60°F	4	9.2
	@ -65°F	15	*not recorded
with DRA	@ -60°F	8	9
	@ -65°F	18	*not recorded

Note: \*Flow was not recorded because partially blocked strainer impeded flow.

## Conclusion

The Baker FLO XS Pipeline Drag Reducer was put through a series of tests developed over the course of the JP-8+100 program. These tests were found to be accurate in predicting the impact of an additive on the thermal stability of jet fuel.

Based on the results of testing at a polymer concentration of 8.8 ppm, the Baker FLO XS drag-reducing additive had no deleterious impact on thermal stability of jet fuel up to 325°F bulk and 450°F wetted wall temperature. When added to the +100 additive package at the same concentration, it had no deleterious impact on thermal stability up to 375°F bulk and 500°F wetted wall conditions. Based on the results of the screening tests using a wide variety of fuels, Baker FLO XS is not sensitive to fuel types or treatments.

## References

1. Matheson, M., American Petroleum Institute Survey of Member Pipelines (1997).
2. Heneghan, S.P., Zabarnick, S., Ballal, D.R., Harrison III, W.E., 1996, "JP-8+100: The Development of High-Thermal-Stability Jet Fuel," *Journal of Energy Resources Technology*, Vol. 118, pp.170-179.
3. Motier, J., letter in material compatibility section, 2000.
4. Grinstead, B., *Energ. Fuels.*, 13, 756-760 (1999).
5. Zabarnick, S., Whitacre, S.D., *J. Eng. Gas Turbines Power.*, 120, 519-525 (1998).
6. Pratt and Whitney Report # FR-24664, "JP-8+100 An Improved Thermally Stable JP-8 Fuel for Current and Future Aircraft," August 1999, page 1-13, "Hot Liquid Process Simulator Measurements of the Betz 8Q462 Thermal Stability Additive Package."
7. Dieterle, G.L., Binns, K.E., 1997, "System Evaluation of JP-8+100 Additives at High Bulk Temperatures," ASME 97-GT-71, June 1997.
8. Edwards, T., 1994, "Fuel Effects in an Augmentor Fouling Simulator," AIAA 94-2958, June 1994.
9. Jones, E.G., Balster, W.J., Post, M.E., 1995, "Degradation of a Jet A Fuel in a Single-Pass Heat Exchanger," *Journal of Engineering for Gas Turbines and Power*, Vol. 117, pp. 125-131.
10. J.S. Ervin, S. Zabarnick, E. Binns, G. Dieterle, D. Davis, and C. Obringer, "Effect of Jet Fuel Additives on Low-Temperature Fluidity and Tank Hold-Up," XIV International Society for Air Breathing Engines, Florence, Italy, September 1999.

# Conoco Tests

A formal report is not available for the Conoco testing. Table 19 is a matrix identifying the samples tested. A summary of the test plan and graphic displays of the results follow.

**Table 19. Conoco Test Matrix**

Processing	Light Crude		Mixed Crude	Heavy Crude	
	Sweet	Sour		Sweet	Sour
Str Run, No Treatment	POSF-3638				
Str Run, Treated	POSF-3633				
Srt Run, Sweetened Merox	POSF-3639				
Srt Run, Sweetened Blender Treated	POSF-3593				
Srt Run Doctor, Sweetened	POSF-3656				
Srt Run, Hydrotreated	POSF-3640	POSF-3603	POSF-3601	POSF-3602	POSF-3627
Hydrocracked			POSF-3658		POSF-3686
Thermal Cracked, Hydrotreated			POSF-3683		

## Conoco Suspension PDR Test Plan

The Conoco PDR additive will be tested in the QCM, ICOT, and HLPS at 4× the recommended concentration in five fuels:

POSF-3219	POSF-3497	POSF-3627
POSF-3638	POSF-3639	

Simultaneously, the additive will be run on the EDTST in two different fuels under the same conditions as the Baker additive and Conoco 203 PDR.

If results are “favorable,” the additive will be tested at 8.8-ppm polymer in the red-dye fuels received from SwRI. The fuels come from five different types of crude and a variety of refining processes. These fuels include:

POSF-3305	POSF-3166	POSF-3497
POSF-3219	POSF-3593	POSF-3602
POSF-3601	POSF-3627	POSF-3638
POSF-3633	POSF-3639	POSF-3656
POSF-3640	POSF-3686	POSF-3688
POSF-3658	POSF-3694	POSF-3683

A 48-hour additive/additive compatibility test will be performed at some time during the testing discussed above.

ICOT: 2 tests per fuel (*neat and additized*), 2 fuels per day (4 tests)  
= 5 days of testing for the 4× concentration

QCM: 2 tests per fuel (*neat and additized*), 4 tests per week  
= 3 weeks of testing for the 4× concentration

HLPS: 2 tests per fuel (*neat and additized*), 3 tests per week (*including carbon burn off*)  
= 3+ weeks of testing for the 4× concentration

The Conoco additive will be tested in the QCM, ICOT, and HLPS at 1× the recommended concentration in 18 fuels. The fuels come from five different types of crude and a variety of refining processes. These fuels include:

POSF-3305	POSF-3166	POSF-3497
POSF-3219	POSF-3593	POSF-3602
POSF-3601	POSF-3627	POSF-3638
POSF-3633	POSF-3639	POSF-3656
POSF-3640	POSF-3686	POSF-3688
POSF-3658	POSF-3694	POSF-3683

A 48-hour additive/additive compatibility test will be performed at some time during the testing discussed above.

ICOT: 2 tests per fuel (36 tests) (*neat and additized*), 3 fuels per day (6 tests)  
= 6 days of testing (2 weeks)

QCM: 2 (possible) tests per fuel (*neat\*and additized*), 1 test per day  
= 18 (or more) days of testing (4 weeks)

HLPS: 2 (possible) tests per fuel (*neat\*and additized*), 1 test per day,  
4 tests per week (*including carbon burn off*)  
= 4 to 5 weeks of testing

\* Neat fuels will be rerun on QCM and HLPS only if a discrepancy is noticed.

## Results

Figures 66 through 75 display the test results.

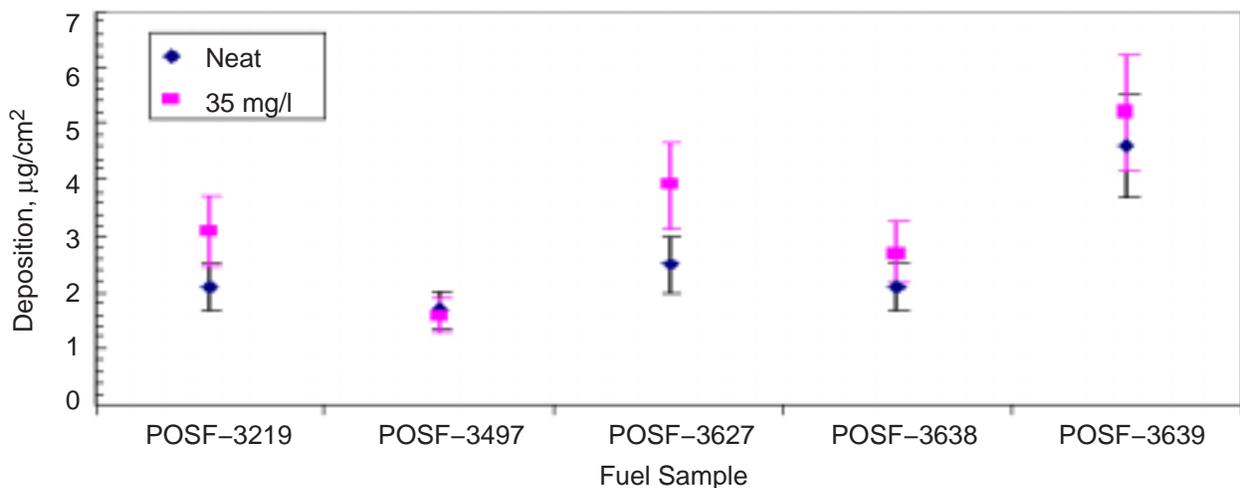


Figure 66. QCM: Effect on Fuel Thermal Stability of Conoco Gel PDR at 4x Concentration of Intended Use

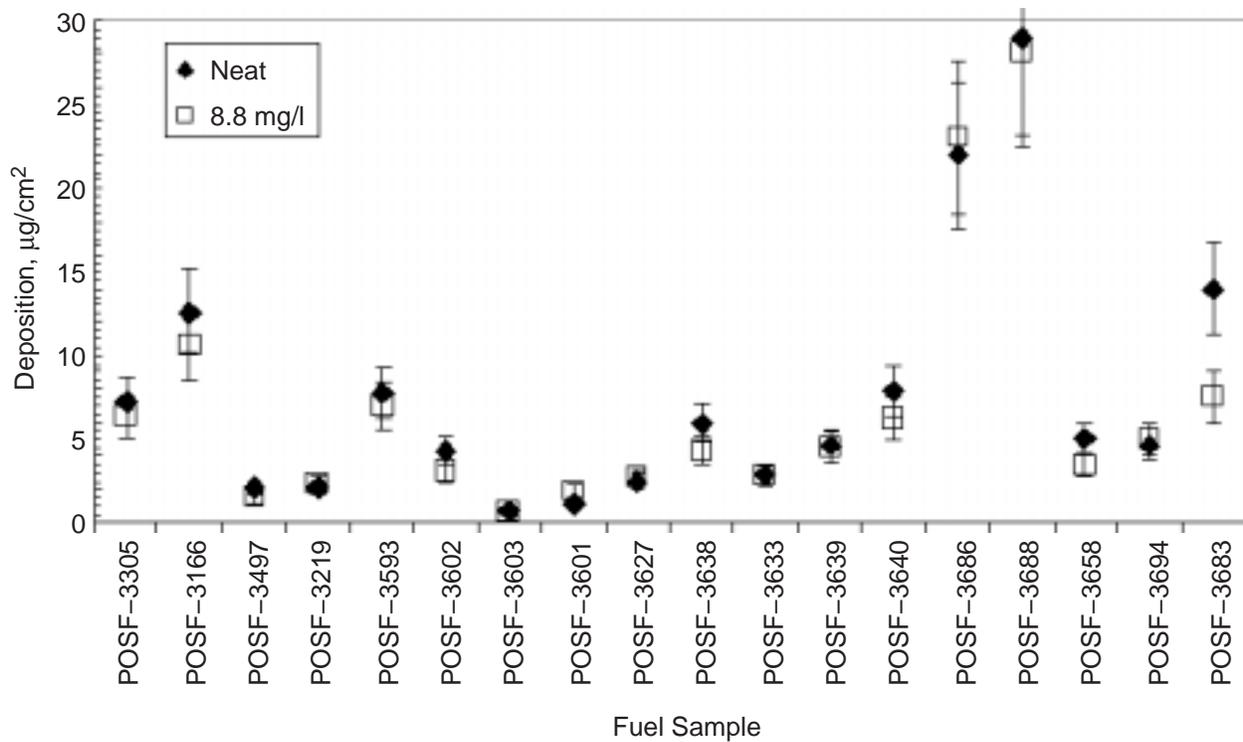


Figure 67. QCM: Effect on Fuel Thermal Stability of Conoco Gel PDR at 1x Concentration of Intended Use

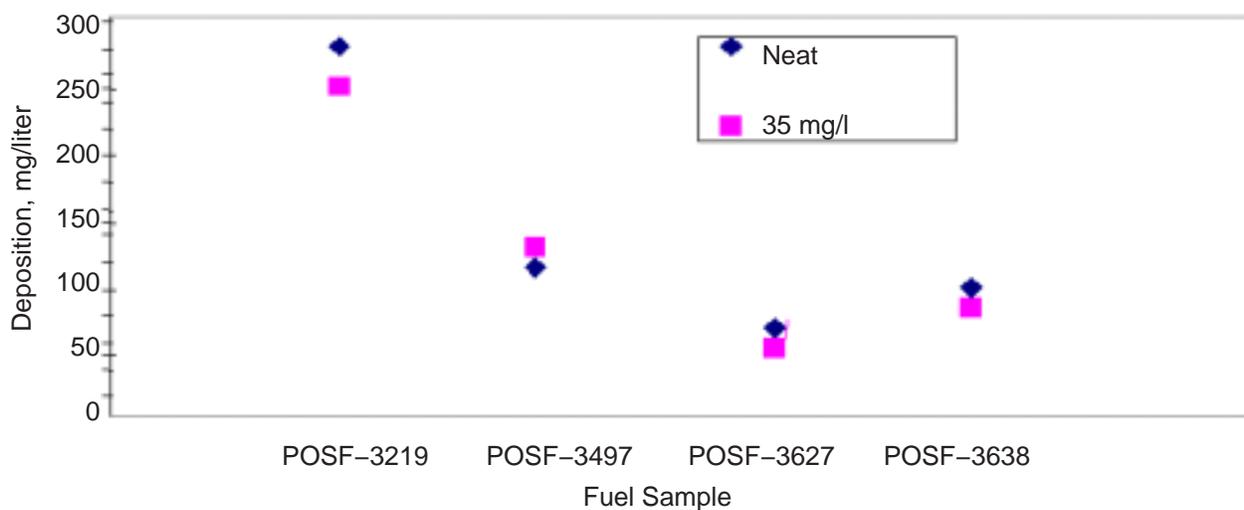
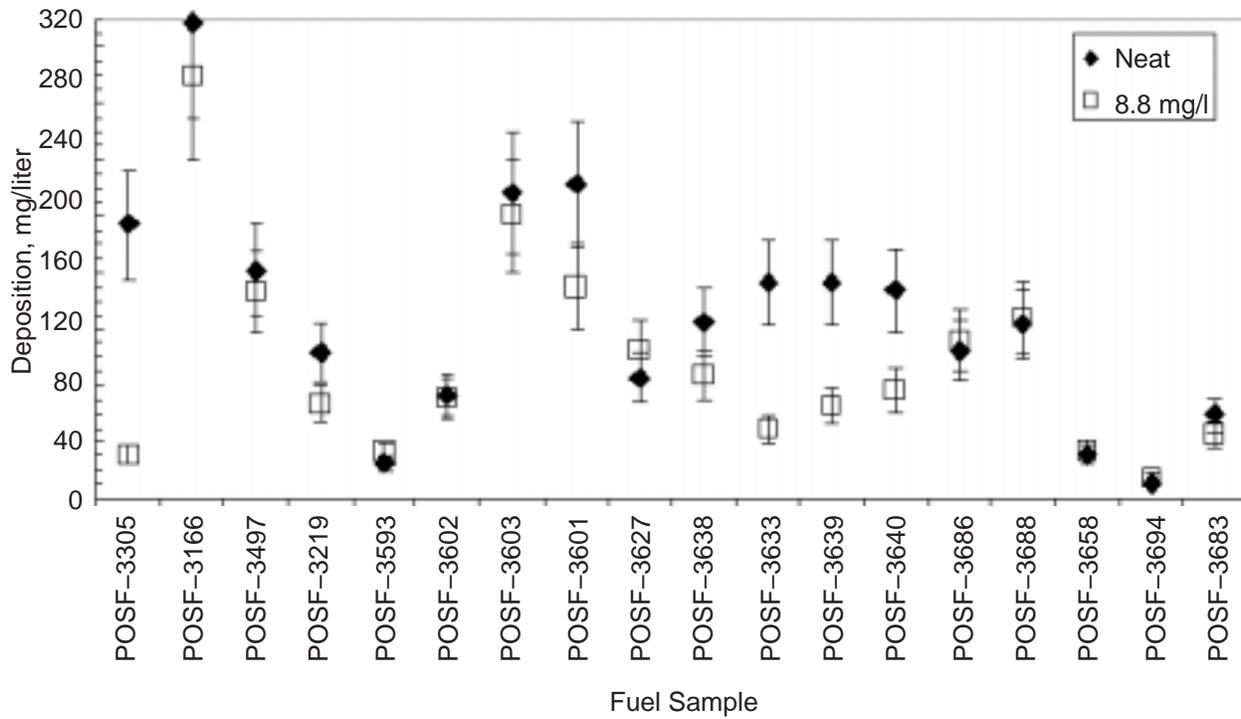
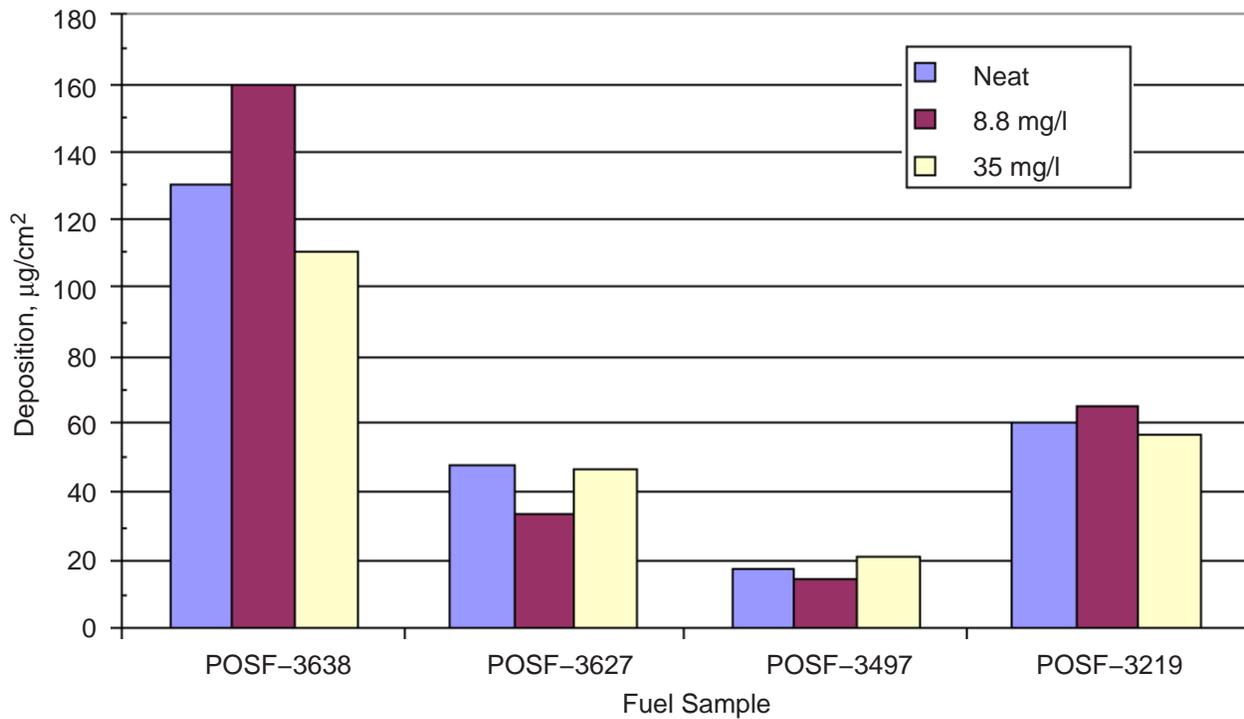


Figure 68. ICOT: Effect on Fuel Thermal Stability of Conoco Gel PDR at 4x Concentration of Intended Use



**Figure 69. ICOT: Effect on Fuel Thermal Stability of Conoco Gel PDR at 1x Concentration of Intended Use**



**Figure 70. HLPS: Effect on Fuel Thermal Stability of Conoco Gel PDR at 1x and 4x Concentration of Intended Use**

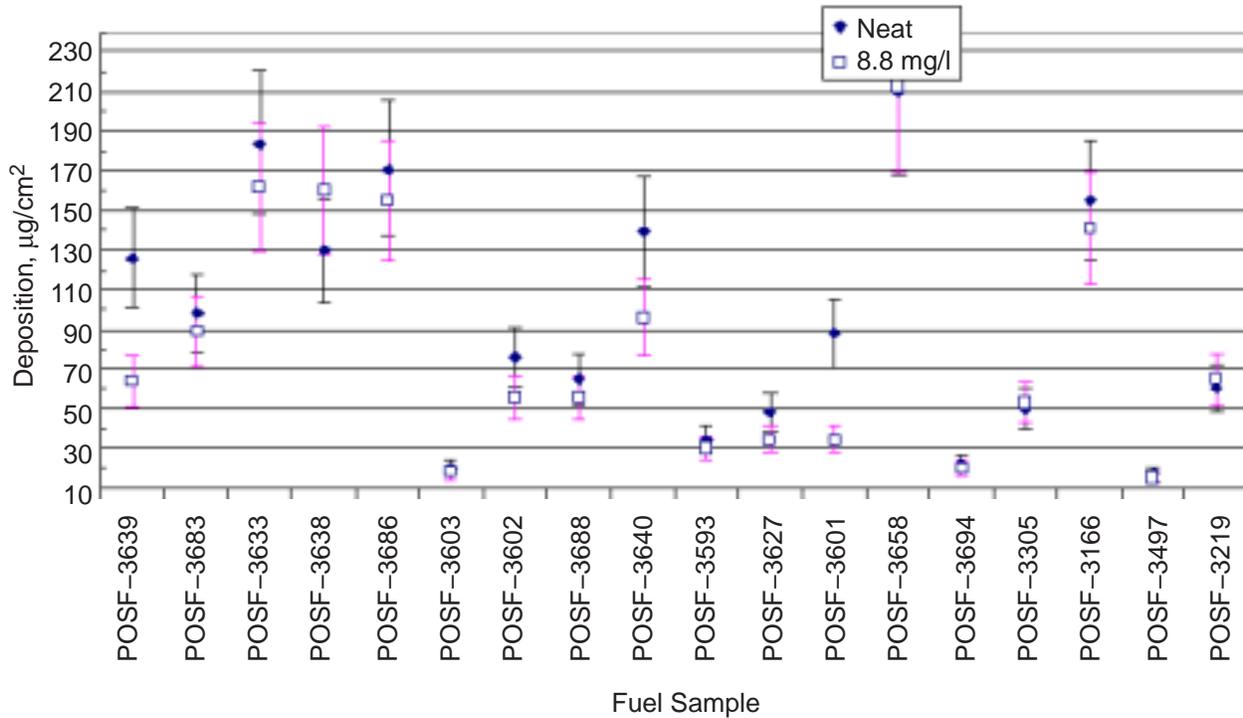


Figure 71. HLPS: Effect on Fuel Thermal Stability of Conoco Gel PDR at 1x Concentration of Intended Use

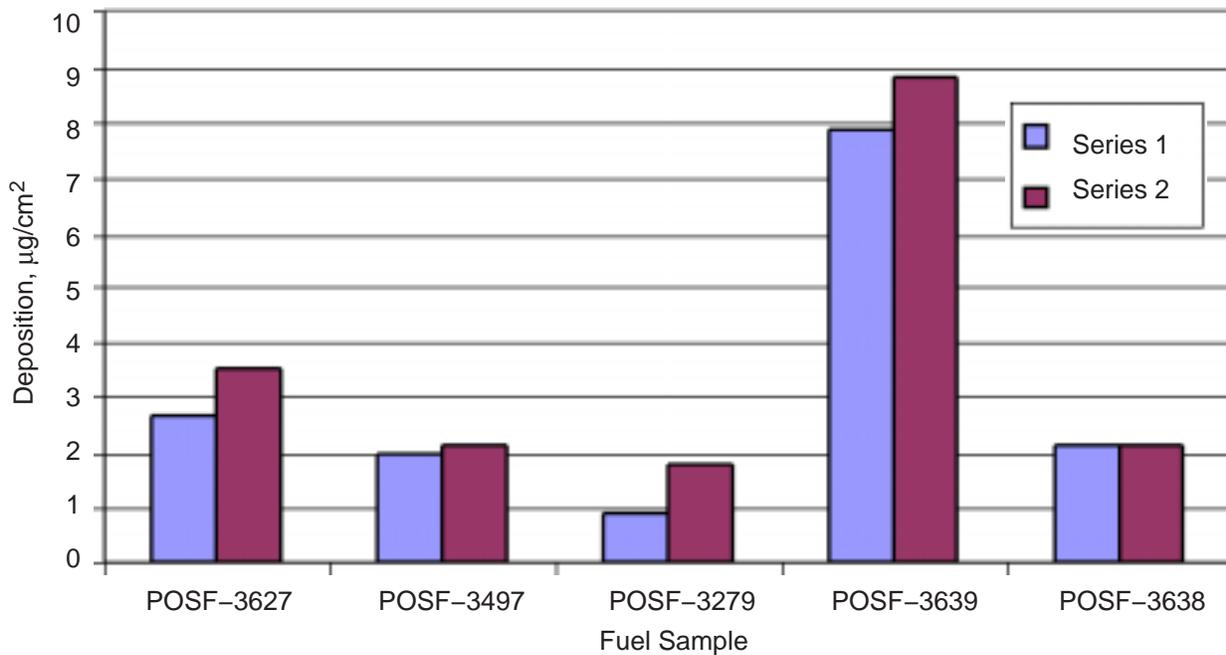


Figure 72. QCM: Effect on Fuel Thermal Stability of Conoco Suspension PDR at 4x Concentration of Intended Use

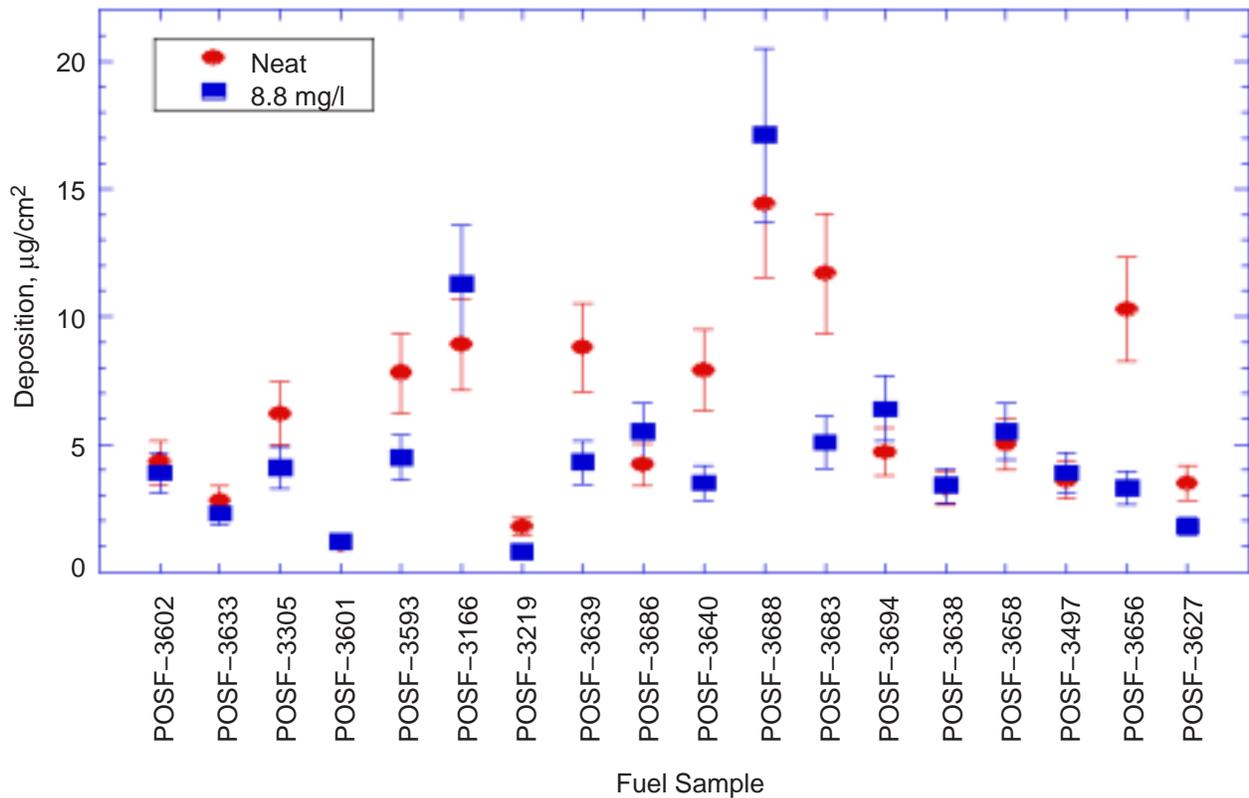


Figure 73. QCM: Effect on Fuel Thermal Stability of Conoco Suspension PDR at 1x Concentration of Intended Use

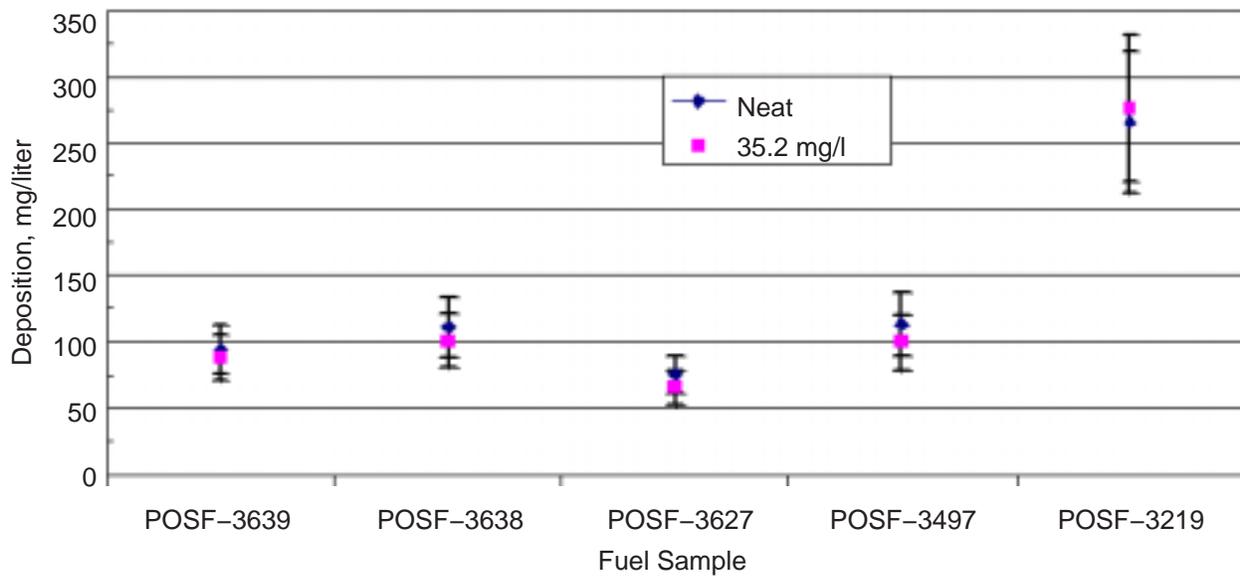
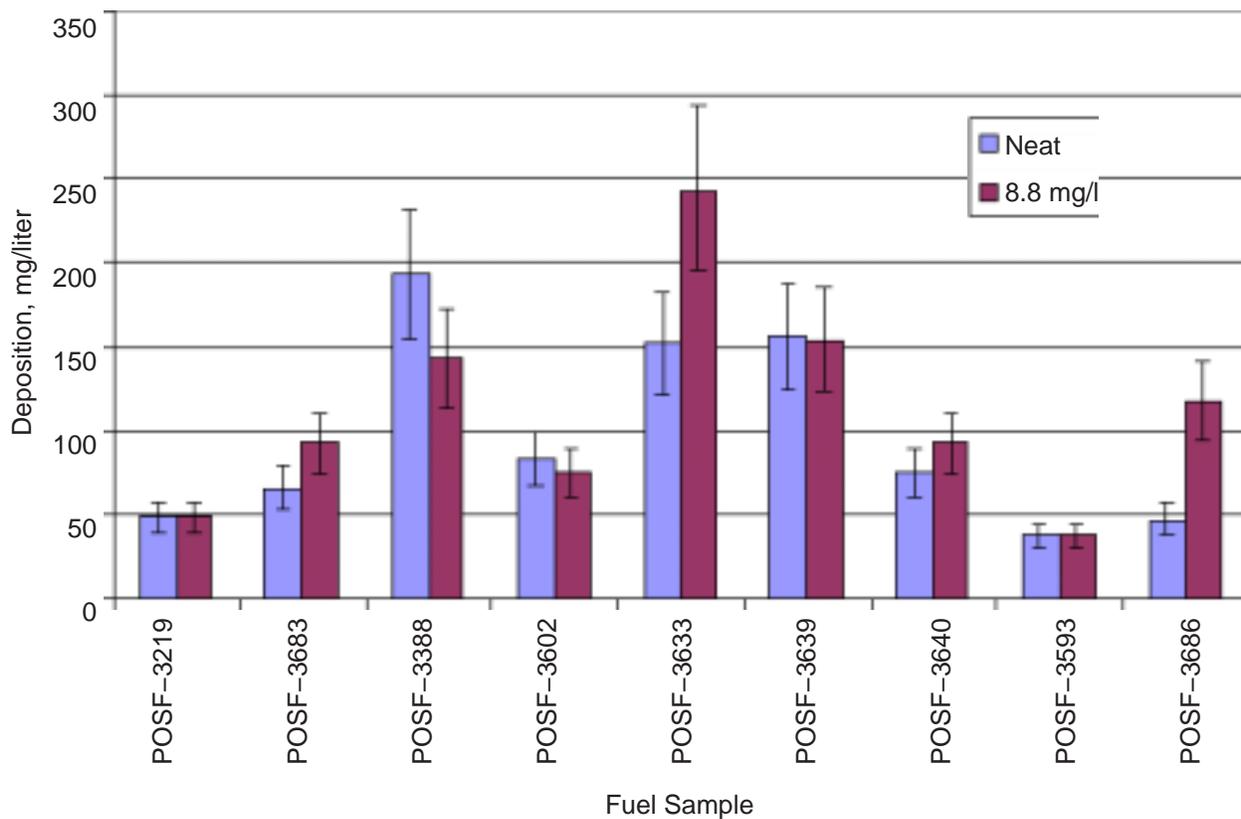


Figure 74. ICOT: Effect on Fuel Thermal Stability of Conoco Suspension PDR at 4x Concentration of Intended Use



**Figure 75. ICOT: Effect on Fuel Thermal Stability of Conoco Suspension PDR at 1x Concentration of Intended Use**

## **Addendum 4 – Baker 1020 PDR Testing (C6–C12 Copolymer Formulation)**

The testing was performed by:

Velcon Filters, Inc.  
4525 Centennial Blvd.  
Colorado Springs, CO 80919

This addendum is a replication of Velcon Test Reports No. 597–98 dated January 1998 and 602–98 dated April 1998. The Test Reports were prepared by: Gregory S. Sprenger, Manager – Technical Services and approved by: Richard Waite, Aviation Products Manager.

The following text has been replicated by scanning a hardcopy and processing with OCR (optical character reading) software. Fonts, paragraph and heading styles, table numbers, and pagination were then modified to help integrate the Test Reports with this document as an addendum. Barring OCR error, the text is otherwise unedited and unchanged. The graphics and test data sheets are images extracted from PDF files provided by Velcon.

### **Test Report Number 597–98: Report of Filter Testing Effect of Pipeline Drag Reducer on Coalescer and Monitor Cartridges**

#### **Introduction**

Pipeline drag reducer (PDR) has been added to motor gasoline to increase the flow in pipelines. Pipeline companies now have an interest in adding these additives to Jet A fuel, to also increase the flow capability in these pipelines. This testing was initiated to determine the effects of one of these additives on fuel filter cartridges. The Baker product 1020 was tested. Both coalescers and water-absorbing monitors were tested.

Tests were initiated on 2 December 1997 at the Velcon Filters, Inc. Test Facility in Colorado Springs, Colorado. The testing program was completed on 27 January 1998.

#### **Conclusions**

The Baker 1020 PDR showed no adverse effects on the effluent quality of the fuel. Both solids removal and water removal were unaffected. However, the PDR did cause an increase in differential pressure. The partially sheared 1020 caused a significant increase in differential pressure in both filter cartridges. The fully sheared PDR 1020 caused a slight increase in differential pressure.

#### **Scope**

This testing was initiated to determine the effect of the PDR additive on jet fuel filters. The testing was designed to answer these specific questions:

1. Does the additive degrade coalescence?
2. Does the additive degrade solids removal?
3. Does the additive cause significant differential pressure increase?
4. Is the molecular weight of the additive a key factor in filter performance?
5. Does the additive degrade water-absorptive filter performance?

To answer these questions, a bench-scale test loop was assembled. A test protocol and test plan were developed. Shortened filter cartridges were tested. Effluent fuel quality was monitored, along with other filter performance parameters.

### **Test Loop, Cartridges, and Protocol**

**Test Cartridges** – A shortened version of the Velcon Filters, Inc. model IA4085 coalescer cartridge was used for the coalescer testing. A shortened version of the Velcon Filters, Inc. model CDF-230K was used for the water-absorptive monitor testing. Both cartridges were cut down to 2". Appropriate housings were used.

**Test Loop** – A 2 gpm test loop was assembled. This included a 200 gallon fuel tank, main pump, means to inject water into the pump, means to inject a solids slurry, means to inject the PDR additive, test filter vessels, differential pressure gauge, downstream fuel analysis means, and a fuel flowmeter. A loop schematic can be found in the Appendix. The PDR additive was injected downstream of the main pump to prevent additional shear of the additive. However, to help disperse the PDR, a globe valve was added. This globe valve had a differential pressure of 7 psid at 2 gpm.

**Test Protocol** – The test was run single-pass. The test protocol was divided into 3 sections: Fuel only, solids injection, and water injection. During the "Fuel only" section, pressure drop increase due to the PDR additives could be easily evaluated. During contaminant injection, pressure drop changes could be evaluated, along with contaminant removal performance.

Due to the limitation of tank size and fuel volume, the test time was shortened. These were the test times used:

Fuel only	45 minutes
Solids injection	25 minutes
Water injection	20 minutes

Also, due to the nature of the filters, the contaminant injection had to be tailored to the filter used. Coalescers are designed to remove larger quantities of contaminants, so more solids and water were injected for the coalescer tests. Preliminary runs were done to determine the amount of contaminants to add for each test. For both the coalescer and the monitor, sufficient solids were injected with additive-free fuel to provide adequate increases in differential pressure. For the monitor, sufficient water was injected to raise the differential pressure within the test time. The contaminant levels injected were:

Coalescer solids injection	35 mg/l
Coalescer water injection	2000 ppm
Monitor solids injection	2 mg/l
Monitor water injection	20 ppm

**Pipeline Drag Reducer** – Baker Product 1020 was used for this testing. Baker supplied 2 versions of the additive:

Partially sheared	ave. molecular weight of 6 million
Fully sheared	ave. molecular weight of 1.5 million

Fuel was doped to 20 ppm. This is approximately 2.5x the normal usage in the field. This higher doping was used to exaggerate any effects.

### **Other Additives:**

**Stadis 460** – The Stadis 450 additive conforming to the latest product specification was obtained from Octel America.

DCI-4A – The DCI-4A additive conforming to the latest product specification was obtained from Octel America.

**Test Contaminants:**

Water – Filtered city water was used for all tests.

Solids – A mixture of Ultrafine silica dust and R9998 Harcross red iron oxide was used. The ratio was 90% wt Ultrafine / 10% wt R9998 oxide.

Sampling Equipment – All fuel samples were drawn through upstream facing probes installed in the system piping. Sampling equipment and techniques and the corresponding measuring techniques were in accordance with the following:

Solids           ASTM D-2276  
Free Water       ASTM D-3240

Test Fuel – Commercial grade Jet-A turbine fuel obtained from Diamond Shamrock Oil Company was used for all testing. The fuel meets all product specifications as determined by ASTM-1 655. Upon receipt, the fuel was clay treated prior to testing.

**Test Plan**

The test plan was developed using Design of Experiment (DOE) concepts. A software program aided in determining the minimum test runs, without sacrificing results. Three test factors were used: drag reducer, filter cartridge, and additional additives. In the case of the PDR, 3 levels were used: partially sheared PDR, fully sheared PDR, and no PDR. Two filter cartridges were used: coalescer and monitor. Two levels of additives were used: either no additional additives or 2 mg/l Stadis 450 + 20 mg/l DCI-4A. The test plan follows in Table 20.

**Table 20. Test Plan**

Test Run	Drag Reducer	Cartridge	Additives
1	20 ppm, Fully sheared	Coalescer	Stadis/ DCI
2	20 ppm, Partially sheared	Coalescer	Stadis/ DCI
3	20 ppm, Fully sheared	Coalescer	None
4	None	Coalescer	Stadis/ DCI
5	20 ppm, Partially sheared	Coalescer	Stadis/ DCI
6	None	Coalescer	None
7	None	Monitor	None
8	20 ppm, Fully sheared	Monitor	Stadis/ DCI
9	None	Monitor	Stadis/ DCI
10	20 ppm, Partially sheared	Monitor	None

Most combinations of these factors are included in the test plan. In addition, runs 2 and 5 are repetitions, to determine the repeatability of the test data.

**Test Data**

Table 21 lists the key data values obtained during the test runs. Detail of each test run follows in the Appendix.

**Table 21. PDR Test Data**

Run	$\Delta P$				Max Eff Millipore (mg/l)***		Max Eff Water (ppm)
	Initial	End of Fuel Only	End of Solids Inj	End of Water Inj	Solids Inj	Water Inj	
1	4.7	5.7	8.1	18.2	0	0	1
2	3.7	10*	11.8**	18	0	0	1
3	4.2	4.2	4.6	14.1	0	0	< 1
4	3.7	3.7	7.5	15.2	0	3.2	1
5	3.8	10*	10.3**	21.5	0	0.4	1
6	3.6	3.6	4.7	16.2	0.4	0	< 1
7	4	4.1	7.8	10.5	0	0.4	< 1
8	4.3	5.3	7.2	7.6	0	0.4	< 1
9	4	4.2	7.8	11.8	5.6	0	< 1
10	3.9	10.8*	25**	40	0	4.4	< 1

\* Stopped PDR injection at approximately 10 psid  
 \*\* No injection of PDR during solids injection  
 \*\*\* Only 1/4 gallon sampled

Note that the pressure drop increased quite rapidly in all tests with the partially sheared PDR additive. The addition of the partially sheared PDR was stopped during the “Fuel only” part of the test. The additive injection was stopped when the pressure drop reached 10 psid. During the solids injection portion of those tests, PDR was not added. This was to keep the pressure drop low enough so that the water addition portion could be run.

### Analysis of Test Data

**Pressure Drop Increase** – Data indicates that the partially sheared PDR caused a sharp increase in pressure drop in all tests. Injection of this PDR was stopped within the “Fuel only” portion of the test protocol. The partially sheared PDR caused the greatest increase in pressure drop during the monitor test. This may be due to the more efficient media, coupled with less surface area. This result was also seen during the water injection portion of the testing.

The fully sheared PDR caused a slight increase in 2 of 3 tests during the “Fuel only” portion of the test.

**Effluent Solids** – The effluent millipore test data appear to be a bit scattered. Two of the 3 runs exhibiting high effluent solids had no PDR injected. Considering the small nature of the cartridges, and the small volume sampled (114 gallon), scatter is not unusual. Based on the data here, the PDR appears to have no effect on the solids removal efficiency of the cartridges.

**Effluent Water** – In all tests, the effluent water remained very low. Coalescence was visibly unchanged; coalesced drops were large in all cases. In all cases, the monitor cartridges allowed no Aquagio-detectable water downstream. Effluent fuel turbidity, although a bit scattered due to the meter itself, remained low during water injection. (Those data are not presented here, due to the scatter.)

### Design of Experiment Analysis of Test Data

Because the largest consistent effect of the PDR was seen in the pressure drop data, those data were further analyzed using the DOE program. The DOE program determines relative effects, based on fitting the data to an equation.

**Fuel Only** – The pressure drop at the end of this portion of the test protocol was estimated, based on the rate of rise in pressure drop. (This was necessary because the PDR injection was stopped in the middle of this “Fuel only” portion of the test protocol.) These estimates were then compared to data when no PDR was present.

For fuel containing only the additives (“Fuel only” portion), the DOE program predicted the following relative pressure drop increase due to the PDR additives:

Partially sheared	5x higher than no PDR
Fully sheared	1x higher than no PDR
Monitor	1x higher than coalescer (This may be due to the tighter filter media in the monitor)

Stadis and DCI-4A had no significant effect on pressure drop

**Solids Injection** – Estimates of the effect of PDR on pressure drop increase during solids injection could not be made. During tests using the partially sheared PDR, no addition was made during solids injection. Fully sheared PDR was continuously added during this test portion, exhibiting only slight pressure drop increase.

**Water Injection** – The DOE program made the following predictions of pressure drop change due to the PDR additives:

Partially sheared	4x higher than without PDR
Fully sheared	1x higher than without PDR
Monitor	4x <u>lower</u> than coalescer (This may be a function of the difference in protocol for coalescers and monitors, better dispersion of water may create better usage of the water absorbent material.)
Stadis and DCI-4A	4x <u>lower</u> than without these additional additives, these additives may have provided better dispersion of the PDR additives, particularly the partially sheared PDR.

This conclusion that the PDR lowered the pressure drop is a bit suspect. There was quite a bit of scatter in the data during the water injection portion of the test. The repetition data, runs 2 and 5, had a large difference in pressure drop values.

## Conclusions

The PDR additives produced some visible effects on these test filters.

1. Although there was quite a bit of scatter in the data, solids removal efficiency appears to be unaffected by the PDR additives. Solids capacity effects could not be determined in this testing due to the large pressure drop effect by the partially sheared PDR.
2. Water removal was unaffected by the PDR additives. Even at 2.5x, the normal concentration, coalescence was good. Water removal by the water absorptive monitor was unaffected.
3. The PDR additives did cause a large increase in pressure drop in the filter cartridges. The partially sheared PDR caused the largest increase. Test data

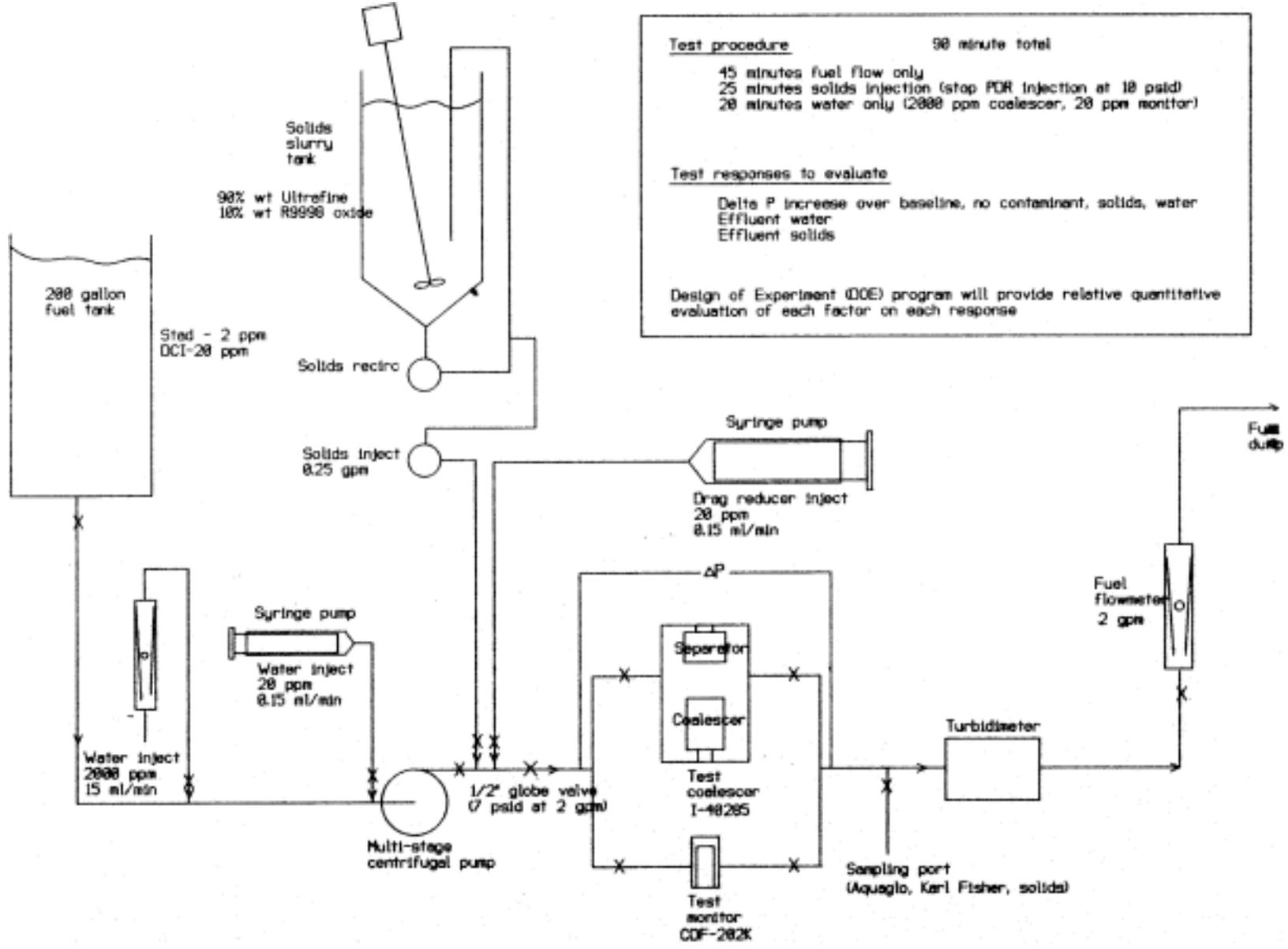
indicated that the pressure drop did fall slightly when the PDR addition was stopped. This may indicate that the PDR was dispersing further into the filter media, or back into the fuel. The presence of surfactant-containing additives appears to reduce the pressure drop increases. This may be due to the additional dispersing properties of these additives.

Largest pressure drop increases were found with the higher molecular weight PDR and the monitor. Larger molecules and tighter filter media (in the monitor) caused larger increases. This pressure drop increase was exaggerated here due to the increased concentration of PDR used.

The removal of the PDR additive by the filters is similar to removal of solid particles. In some ways, removal of the higher molecular PDR by the filters may elevate further complications downstream. This may reduce the amount reaching the aircraft, where its effects are not yet known.

Based on this bench-scale testing, although abbreviated, the Baker 1020 PDR additive has no detrimental effect on the particulate and water removing ability of coalescer and monitor cartridges. It will, however, cause reduced life of the filter cartridges. This reduced life appears to be a function of the molecular weight of the PDR.

# DRAG REDUCER TEST APPARATUS



# VELCON FILTERS INC.

## BAKER DRAG REDUCER TESTING

### DATA USED FOR DESIGN OF EXPERIMENT DATA ANALYSIS

RUN	DRAG REDUCER	CARTRIDGE	ADDITIVES	dP INCREASE FOR EACH TEST PORTION		
				FUEL ONLY	SOLIDS INJECTION	WATER INJECTION
1	FULLY SHEARED	COALESCER	STADIS 450 / DCI-4A	1	2.4	10.1
2	PARTIALLY SHEARED	COALESCER	STADIS 450 / DCI-4A	8**	1.8*	7
3	FULLY SHEARED	COALESCER	NONE	0	0.4	9.5
4	NONE	COALESCER	STADIS 450 / DCI-4A	0	4	7.7
5	PARTIALLY SHEARED	COALESCER	STADIS 450 / DCI-4A	9**	1.5*	11.2
6	NONE	COALESCER	NONE	0	1.3	11.4
7	NONE	MONITOR	NONE	0.1	3.3	2.7
8	FULLY SHEARED	MONITOR	STADIS 450 / DCI-4A	1	1.8	1.8
9	NONE	MONITOR	STADIS 450 / DCI-4A	0.2	3.3	3
10	PARTIALLY SHEARED	MONITOR	NONE	20**	15*	15

\*NO PDR ADDITION DURING SOLIDS INJECTION

\*\*dP AT END OF TEST PORTION ESTIMATED

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 5 DECEMBER 1997

VESSEL: 6 INCH PLEXI HOUSING

RUN NUMBER: 1

FIRST STAGE COALESCER: 1 EA I-40285

PDR TYPE: FULLY SHEARED, 20 PPM

SECOND STAGE SEPARATOR: 1 EA SO-302C

OTHER ADDITIVES: STADIS 450/ DCI-4A

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	4.7	66	0.15	-	-	-	-	-
5	2.0	5.2	67	0.15	-	-	-	-	-
10	2.0	5.2	68	0.15	-	-	-	-	-
15	2.0	5.3	68	0.15	-	-	-	-	-
20	2.0	5.4	69	0.15	-	-	-	-	-
30	2.0	5.6	69	0.15	-	-	-	-	-
40	2.0	5.7	69	0.15	-	-	-	-	-
45	2.0	5.7	69	0.15	-	-	-	-	-
0	2.0	5.7	69	0.15	0.265	-	-	-	-
5	2.0	5.9	69	0.15	0.265	-	-	-	-
10	2.0	6.3	69	0.15	0.265	-	-	-	-
15	2.0	6.9	70	0.15	0.265	-	-	-	-
20	2.0	7.4	70	0.15	0.265	-	0.0	-	-
25	2.0	8.1	70	0.15	0.265	-	-	-	-
0	2.0	8.1	70	0.15	-	15	-	-	-
2	2.0	12.8	69	0.15	-	15	-	<1	63.4
5	2.0	14.7	69	0.15	-	15	-	1	69.2
10	2.0	16.8	69	0.15	-	15	0.0	1	73.2
15	2.0	17.8	69	0.15	-	15	-	<1	72.1
20	2.0	18.2	69	0.15	-	15	-	<1	74.7

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 10 DECEMBER 1997

VESSEL: 6 INCH PLEXI HOUSING

RUN NUMBER: 2

FIRST STAGE COALESCER: 1 EA I-40285

PDR TYPE: PARTIALLY SHEARED, 20 PPM

SECOND STAGE SEPARATOR: 1 EA SO-302C

OTHER ADDITIVES: STADIS 450/ DCI-4A

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	3.7	66	0.15	-	-	-	-	-
10	2.0	8.1	70	0.15	-	-	-	-	-
17	2.0	8.6	72	0.15	-	-	-	-	-
20	2.0	8.8	73	0.15	-	-	-	-	-
25	2.0	9.3	73	0.15	-	-	-	-	-
40	2.0	10*	73	0.15	-	-	-	-	-
45	2.0	9.2	73	0	-	-	-	-	-
0	2.0	9.2**	73	0	0.265	-	-	-	-
10	2.0	9.4**	73	0	0.265	-	-	-	-
15	2.0	9.8**	74	0	0.265	-	-	-	-
20	2.0	10.5**	74	0	0.265	-	0.0	-	-
25	2.0	11**	75	0	0.265	-	-	-	-
0	2.0	11	75	0.15	-	15	-	-	-
2	2.0	14.6	74	0.15	-	15	-	<1	71.9
5	2.0	15.3	74	0.15	-	15	-	<1	72.9
10	2.0	17	74	0.15	-	15	-	1	-
15	2.0	17.5	74	0.15	-	15	0.0	1	83.2
20	2.0	18	74	0.15	-	15	-	1	82.8

\* PDR ADDITION STOPPED

\*\* NO PDR ADDITION

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 2 DECEMBER 1997

VESSEL: 6 INCH PLEXI HOUSING

RUN NUMBER: 3

FIRST STAGE COALESCER: 1 EA I-40285

PDR TYPE: FULLY SHEARED, 20 PPM

SECOND STAGE SEPARATOR: 1 EA SO-302C

OTHER ADDITIVES: NONE

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	4.2	72	0.15	-	-	-	-	-
5	2.0	4.3	73	0.15	-	-	-	-	-
10	2.0	4.3	74	0.15	-	-	-	-	-
15	2.0	4.3	75	0.15	-	-	-	-	-
20	2.0	4.3	75	0.15	-	-	-	-	-
25	2.0	4.3	76	0.15	-	-	-	-	-
30	2.0	4.3	76	0.15	-	-	-	-	-
40	2.0	4.3	76	0.15	-	-	-	-	-
45	2.0	4.3	76	0.15	-	-	-	-	-
0	2.0	4.3	77	0.15	0.265	-	-	-	-
10	2.0	4.4	77	0.15	0.265	-	-	-	-
15	2.0	4.5	77	0.15	0.265	-	-	-	-
20	2.0	4.7	77	0.15	0.265	-	-	-	-
25	2.0	4.8	77	0.15	0.265	-	-	-	-
0	2.0	4.8	77	0.15	-	15	-	-	-
2	2.0	10.6	77	0.15	-	15	-	<1	75.6
5	2.0	12.8	76	0.15	-	15	-	<1	83.3
10	2.0	13.5	76	0.15	-	15	-	<1	96.0
15	2.0	13.8	76	0.15	-	15	0.0	<1	93.7
20	RAN OUT OF FUEL								

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 15 DECEMBER 1997

VESSEL: 6 INCH PLEXI HOUSING

RUN NUMBER: 4

FIRST STAGE COALESCER: 1 EA I-40285

PDR TYPE: NONE

SECOND STAGE SEPARATOR: 1 EA SO-302C

OTHER ADDITIVES: STADIS 450 / DCI-4A

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	3.7	72	0	-	-	-	-	-
10	2.0	3.6	72	0	-	-	-	-	-
20	2.0	3.6	73	0	-	-	-	-	-
30	2.0	3.6	74	0	-	-	-	-	-
40	2.0	3.5	74	0	-	-	-	-	-
45	2.0	3.5	74	0	-	-	-	-	-
0	2.0	3.5	74	0	0.265	-	-	-	-
5	2.0	4.2	74	0	0.265	-	-	-	-
10	2.0	4.6	74	0	0.265	-	-	-	-
15	2.0	5.4	74	0	0.265	-	0.0	-	-
20	2.0	5.8	74	0	0.265	-	-	-	-
25	2.0	7.5	74	0	0.265	-	-	-	-
0	2.0	7.5	74	0	-	15	-	-	-
2	2.0	13.1	72	0	-	15	-	<1	106
5	2.0	13.8	71	0	-	15	3.2	1	117
10	2.0	14.7	71	0	-	15	-	1	78.7
15	2.0	15	71	0	-	15	-	1	78.7
20	2.0	15.2	71	0	-	15	-	<1	79.4

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 17 DECEMBER 1997

VESSEL: 6 INCH PLEXI HOUSING

RUN NUMBER: 5

FIRST STAGE COALESCER: 1 EA I-40285

PDR TYPE: PARTIALLY SHEARED, 20 PPM

SECOND STAGE SEPARATOR: 1 EA SO-302C

OTHER ADDITIVES: STADIS 450 / DCI-4A

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	3.8	68	0.15	-	-	-	-	-
10	2.0	9.2	69	0.15	-	-	-	-	-
20	2.0	9.8	70	0.15	-	-	-	-	-
23	2.0	10*	70	0.15	-	-	-	-	-
30	2.0	9.0	70	0	-	-	-	-	-
40	2.0	8.8	70	0	-	-	-	-	-
45	2.0	8.8	70	0	-	-	-	-	-
0	2.0	8.8**	70	0	0.265	-	-	-	-
5	2.0	9.0**	71	0	0.265	-	-	-	-
10	2.0	8.9**	71	0	0.265	-	-	-	-
15	2.0	9.3**	71	0	0.265	-	-	-	-
20	2.0	9.8**	71	0	0.265	-	0.0	-	-
25	2.0	10.3**	72	0	0.265	-	-	-	-
0	2.0	10.3	72	0.15	-	15	-	-	-
5	2.0	17.5	71	0.15	-	15	-	<1	55.3
10	2.0	19.8	71	0.15	-	15	-	<1	68.0
20	2.0	21.5	71	0.15	-	15	-	1	65.2
25	2.0	22.0	71	0.15	-	15	0.2	1	63.1

\*PDR ADDITION STOPPED

\*\* NO PDR ADDITION

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 19 DECEMBER 1997  
RUN NUMBER: 6  
PDR TYPE: NONE  
OTHER ADDITIVES: NONE

VESSEL: 6 INCH PLEXI HOUSING  
FIRST STAGE COALESCER: 1 EA I-40285  
SECOND STAGE SEPARATOR: 1 EA SO-302C

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	3.6	68	0	-	-	-	-	-
10	2.0	3.5	69	0	-	-	-	-	-
20	2.0	3.5	74	0	-	-	-	-	-
30	2.0	3.4	74	0	-	-	-	-	-
40	2.0	3.4	74	0	-	-	-	-	-
45	2.0	3.4	74	0	-	-	-	-	-
0	2.0	3.4	74	0	0.265	-	-	-	-
5	2.0	3.5	75	0	0.265	-	-	-	-
10	2.0	3.8	76	0	0.265	-	-	-	-
15	2.0	4.1	77	0	0.265	-	-	-	-
20	2.0	4.4	78	0	0.265	-	-	-	-
25	2.0	4.7	78	0	0.265	-	0.2	-	-
0	2.0	4.8	78	0	-	15	-	-	-
5	2.0	13.8	76	0	-	15	-	<1	89.8
10	2.0	15.1	75	0	-	15	-	<1	102.0
20	2.0	15.5	74	0	-	15	-	<1	80.9
25	2.0	16.2	74	0	-	15	0.0	-	81.1

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 31 DECEMBER 1997  
RUN NUMBER: 7  
PDR TYPE: NONE  
OTHER ADDITIVES: NONE

VESSEL: VF-21  
FIRST STAGE MONITOR: 1 EA CDF-202K

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	4.0	66	0	-	-	-	-	-
10	2.0	4.0	70	0	-	-	-	-	-
20	2.0	4.0	70	0	-	-	-	-	-
30	2.0	4.1	71	0	-	-	-	-	-
40	2.0	4.1	71	0	-	-	-	-	-
45	2.0	4.1	71	0	-	-	-	-	-
0	2.0	4.5	71	0	0.015	-	-	-	-
5	2.0	4.5	71	0	0.015	-	-	-	-
10	2.0	4.7	72	0	0.015	-	-	-	-
15	2.0	4.9	72	0	0.015	-	-	-	-
20	2.0	5.4	73	0	0.015	-	-	-	-
25	2.0	7.8	73	0	0.015	-	0.0	-	-
0	2.0	7.8	73	0	-	0.15	-	-	-
5	2.0	9	73	0	-	0.15	-	<1	56.1
10	2.0	10.2	73	0	-	0.15	-	<1	63.3
20	2.0	10.4	72	0	-	0.15	-	<1	66.4
25	2.0	10.5	72	0	-	0.15	0.4	<1	68.5

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 9 JANUARY 1998

VESSEL: VF-21

RUN NUMBER: 8

FIRST STAGE MONITOR: 1 EA CDF-202K

PDR TYPE: FULLY SHEARED, 20 PPM

OTHER ADDITIVES: STADIS 450 / DCI-4A

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	4.3	67	0.15	-	-	-	-	-
10	2.0	4.7	68	0.15	-	-	-	-	-
20	2.0	5.0	70	0.15	-	-	-	-	-
30	2.0	5.3	69	0.15	-	-	-	-	-
40	2.0	5.3	69	0.15	-	-	-	-	-
45	2.0	5.3	69	0.15	-	-	-	-	-
0	2.0	5.4	69	0.15	0.015	-	-	-	-
5	2.0	5.7	70	0.15	0.015	-	-	-	-
10	2.0	6.1	70	0.15	0.015	-	-	-	-
15	2.0	6.4	70	0.15	0.015	-	-	-	-
20	2.0	6.8	70	0.15	0.015	-	-	-	-
25	2.0	7.2	71	0.15	0.015	-	0.0	-	-
0	2.0	5.8*	70	0.15	-	0.15	-	-	-
10	2.0	6.8	70	0.15	-	0.15	-	<1	72.5
15	2.0	7.2	70	0.15	-	0.15	-	<1	78.6
20	2.0	7.6	70	0.15	-	0.15	0.2	<1	85.3

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 19 JANUARY 1998  
RUN NUMBER: 9  
PDR TYPE: NONE  
OTHER ADDITIVES: STADIS 450 / DCI-4A

VESSEL: VF-21  
FIRST STAGE MONITOR: 1 EA CDF-202K

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	4.0	68	0	-	-	-	-	-
10	2.0	4.1	70	0	-	-	-	-	-
20	2.0	4.1	69	0	-	-	-	-	-
30	2.0	4.2	66	0	-	-	-	-	-
40	2.0	4.2	66	0	-	-	-	-	-
45	2.0	4.2	66	0	-	-	-	-	-
0	2.0	4.5	66	0	0.015	-	-	-	-
5	2.0	4.9	68	0	0.015	-	-	-	-
10	2.0	5.2	69	0	0.015	-	-	-	-
15	2.0	5.7	70	0	0.015	-	5.6	-	-
20	2.0	6.3	71	0	0.015	-	-	-	-
25	2.0	7.8	71	0	0.015	-	-	-	-
0	2.0	7.8	71	0	-	0.15	-	-	-
5	2.0	9.5	70	0	-	0.15	-	<1	86.3
10	2.0	10.6	70	0	-	0.15	-	<1	86.9
15	2.0	11.1	70	0	-	0.15	0.0	<1	80.4
20	2.0	11.8	70	0	-	0.15	-	<1	82.6

# VELCON FILTERS INC.

# BAKER DRAG REDUCER TESTING

TEST DATE: 27 JANUARY 1998

VESSEL: VF-21

RUN NUMBER: 10

FIRST STAGE MONITOR: 1 EA CDF-202K

PDR TYPE: PARTIALLY SHEARED, 20 PPM

OTHER ADDITIVES: NONE

ELAPSED TIME (MINS)	FLOW RATE (GPM)	DELTA P (PSID)	FUEL TEMP (DEG F)	PDR ADD RATE (ML/MIN)	SOLIDS ADD RATE (GM/MIN)	WATER ADD RATE (ML/MIN)	EFFLUENT SOLIDS (MG/GAL)	AQUA GLO (PPM)	KARL FISHER (TOTAL PPM)
0	2.0	3.9	68	0.15	-	-	-	-	-
1.5	2.0	10*	68	0.15	-	-	-	-	-
10	2.0	11.4	68	0	-	-	-	-	-
20	2.0	11.3	69	0	-	-	-	-	-
30	2.0	11.0	69	0	-	-	-	-	-
40	2.0	10.9	69	0	-	-	-	-	-
45	2.0	10.8	69	0	-	-	-	-	-
0	2.0	10**	69	0	0.015	-	-	-	-
5	2.0	10.3**	69	0	0.015	-	-	-	-
10	2.0	10.9**	69	0	0.015	-	-	-	-
15	2.0	13.3**	70	0	0.015	-	-	-	-
20	2.0	15.4**	70	0	0.015	-	-	-	-
25	2.0	25**	70	0	0.015	-	0.0	-	-
0	2.0	25.0	70	0.15	-	0.15	-	-	-
5	2.0	42.0	70	0.15	-	0.15	-	<1	88.9
10	1.9	42.0	70	0.15	-	0.15	-	<1	80.6
15	1.9	42.0	70	0.15	-	0.15	-	<1	65.6
20	1.9	40.0	70	0.15	-	0.15	4.4	<1	76.1

\*PDR ADDITION STOPPED AT 1.5 MINUTES

\*\*NO PDR ADDITION

## **Test Report Number 602–98: Report of Filter Testing Effect on Coalescer Pressure Drop**

### **Introduction**

This report details follow-up tests to those performed in report 597–98, dated January 1998. The focus of this testing was to better characterize the pressure drop increase of filters when pipeline drag reducer (PDR) is present in the fuel. Various combinations of drag reducer type, PDR concentration, and coalescers were tested. No contaminants or other additives were added to the fuel.

Tests were conducted on 28 April 1998 at the Velcon Filters, Inc. Test Facility in Colorado Springs, Colorado.

### **Conclusions**

A number of conclusions can be drawn from this set of tests:

1. The partially sheared Baker PDR 1020 caused larger increases in pressure drop than the fully sheared material. This also occurred in the previous testing.
2. The pressure drop increases were substantially less than in the previous tests. This was most likely a result of the improved dispersion of the additive. The PDR was dispersed into the fuel tank for this set of tests. For the first set, the PDR was injected into the piping just upstream of the filters. This technique may have been inadequate to properly disperse the PDR, causing inaccurate filter effects.
3. Pressure drop increases generally reached an equilibrium after a period of time.
4. Increases in PDR concentration caused only slight increases in filter cartridge pressure drops. Concentration increases from 2 ppm active polymer to 20 ppm had only a doubling effect in pressure drop increase.
5. Flow interruptions caused a drop in filter pressure drops in some cases. This may be due to polymer reorientation in the filter as the shear forces of flow are stopped.

### **Test Loop, Cartridges, and Protocol**

**Test Cartridges** – A shortened version of the Velcon Filters, Inc. model 1–44085 coalescer cartridge was used for most of this testing. A shortened version of the Velcon Filters, Inc. model 1–44087F was used for one test, to determine the PDR effects on tighter coalescers. The “87” series coalescer is used for into-plane fueling. Appropriate housings were used.

**Test Loop** – A similar 2 gpm test loop was assembled. This included a 200 gallon fuel tank, main pumps, test filter vessel, differential pressure gauge, downstream fuel analysis means, and a fuel flowmeter. A loop schematic can be found in the Appendix. The PDR was added directly to the fuel tank. It was dispersed using a paddle wheel mixer in the tank.

Both a centrifugal pump and a progressing cavity pump were used as the main pump. The centrifugal pump was used for the fully sheared PDR, while the progressing cavity pump was used to reduce shear when the partially sheared PDR was present in the fuel.

**Test Protocol** – The test was run single-pass. Coalescer pressure drop was monitored continuously. Both fully sheared and partially sheared PDR were tested at various concentrations.

**Pipeline Drag Reducer** – Baker Product 1020 (C6 – C12 copolymer formulation) was used for this testing. Baker supplied 2 versions of the additive:

Partially sheared	avg. molecular weight of 6 million
Fully sheared	avg. molecular weight of 1.5 million

The PDR concentration was targeted to the level of active polymer. The actual liquid additive contained 0.59% active polymer.

Both influent and effluent fuel samples were taken during these tests. Baker/Petrolite will be checking the concentrations of the active polymer in the samples, and determining the change in concentration caused by the filters.

**Test Contaminants** – No contaminants were used for this testing

**Test Fuel** – Commercial grade Jet–A turbine fuel obtained from Diamond Shamrock Oil Company was used for all testing. The fuel meets all product specifications as determined by ASTM–1655. Upon receipt, the fuel was clay treated prior to testing.

### Test Plan

Testing consisted of the following parameters, in the order listed:

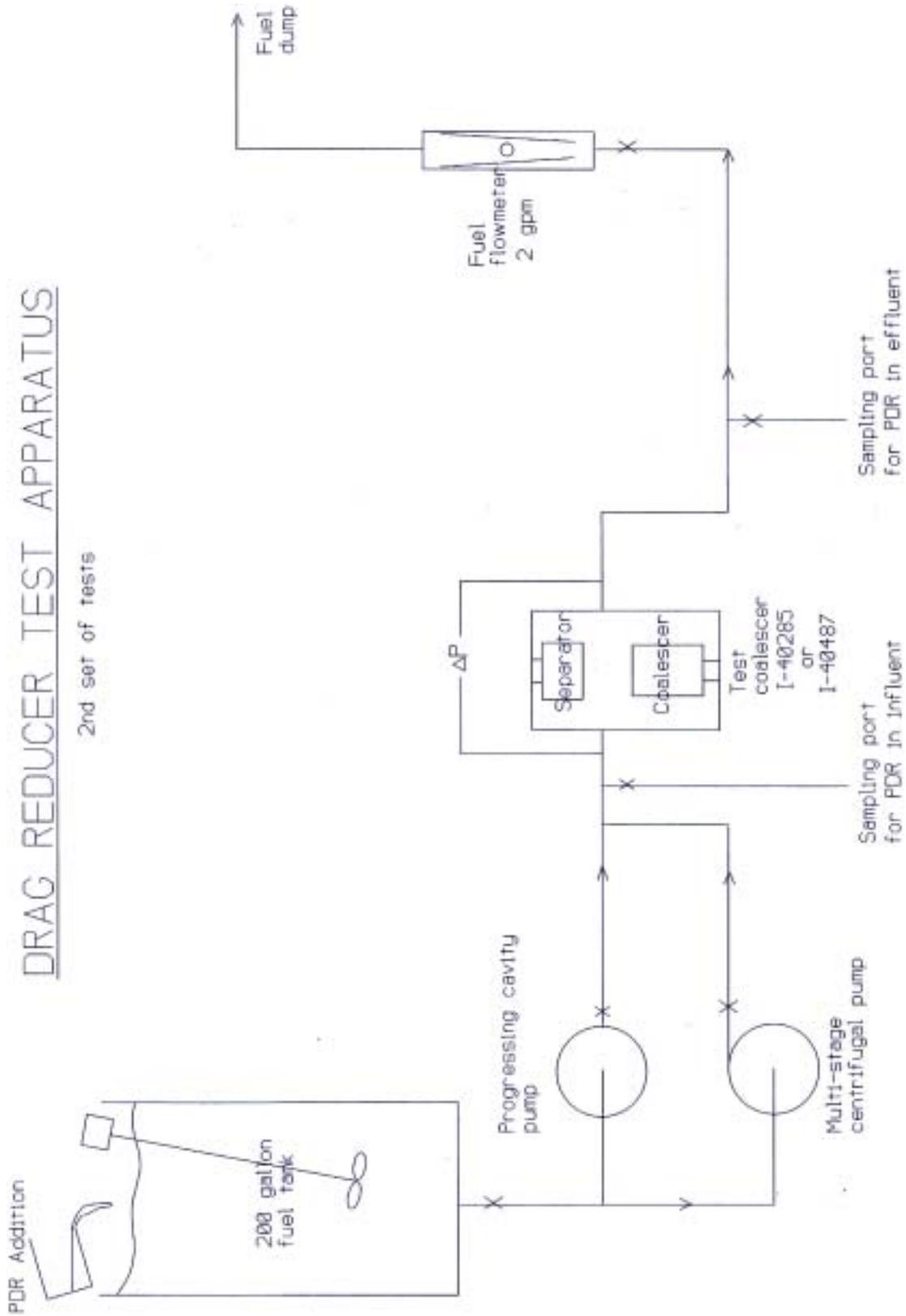
Test	PDR	Concentration (ppm)	Main Pump	Coalescer
1	Fully Sheared	2	Centrifugal	New “85” Series
2	Fully Sheared	8	Centrifugal	New “85”
3	Fully Sheared	20	Centrifugal	Same “85”
4a	Partially Sheared	2	Prog Cavity	New “85”
4b	None	–	Prog Cavity	Same “85”
5a	Partially Sheared	2	Prog Cavity	New “85”
5b	Partially Sheared	8	Prog Cavity	Same “85”
6	Fully Sheared	8	Prog Cavity	New “87”

Test data follow in the Appendix.

Appendix

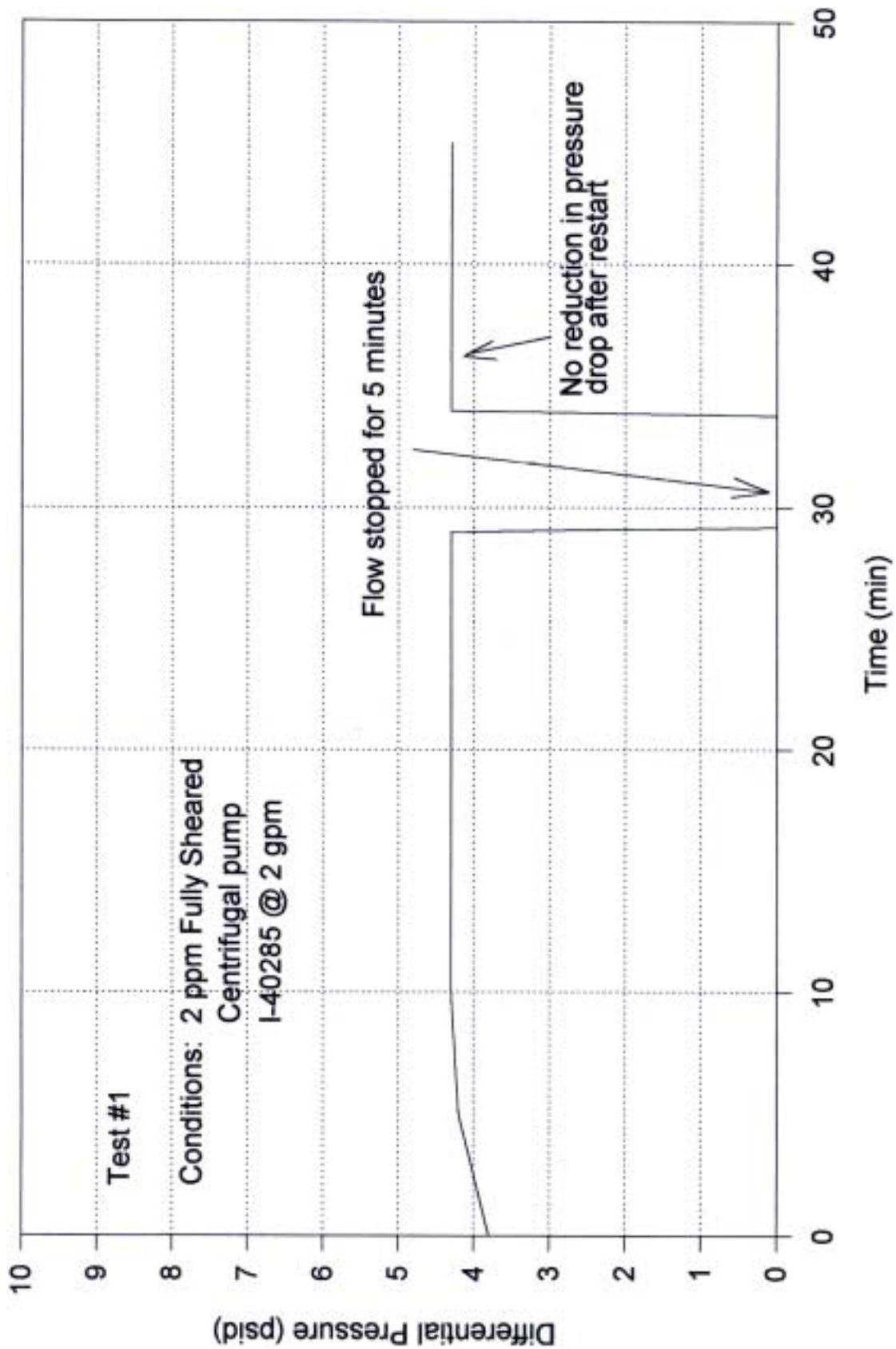
DRAG REDUCER TEST APPARATUS

2nd set of tests

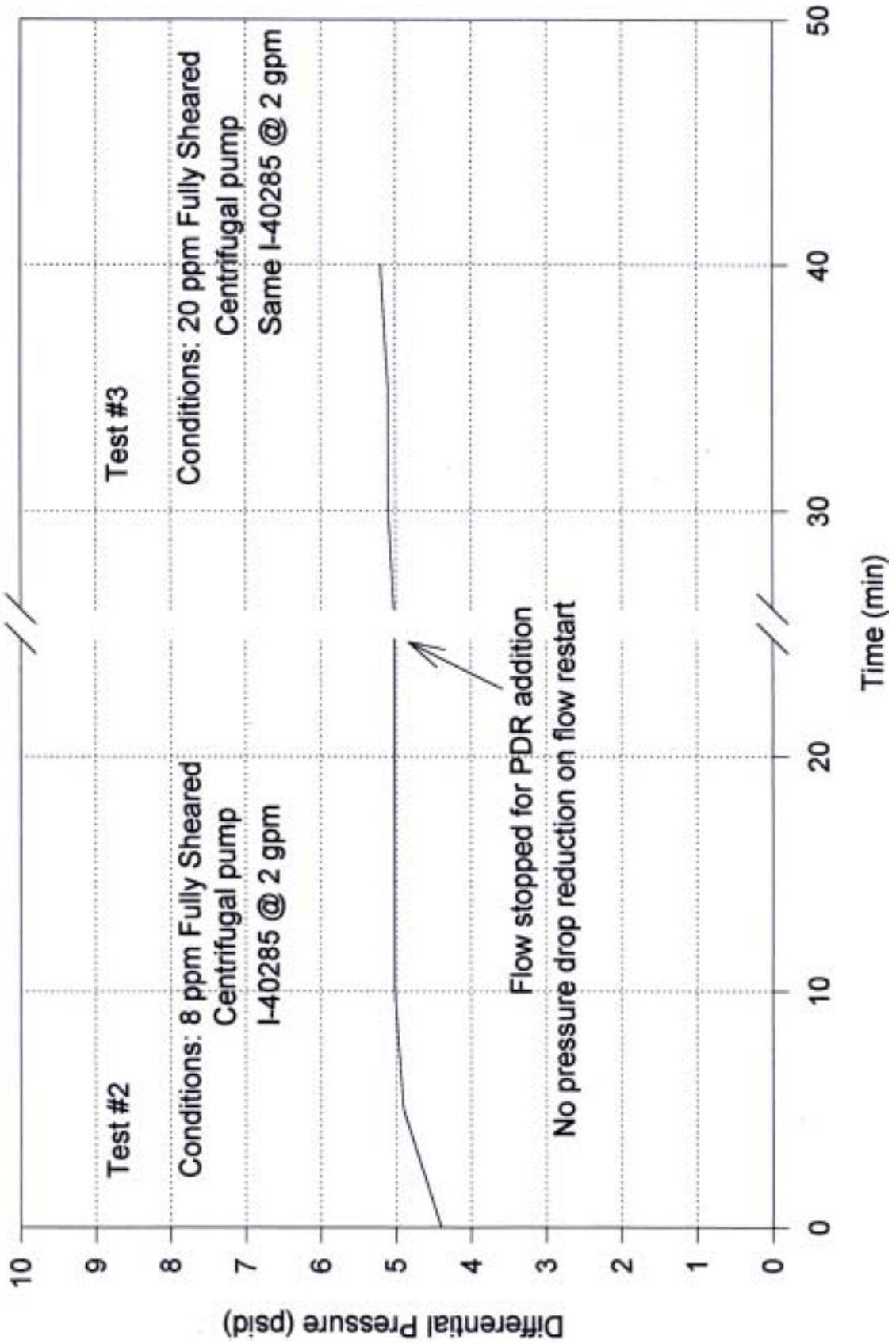


dragred3fcd

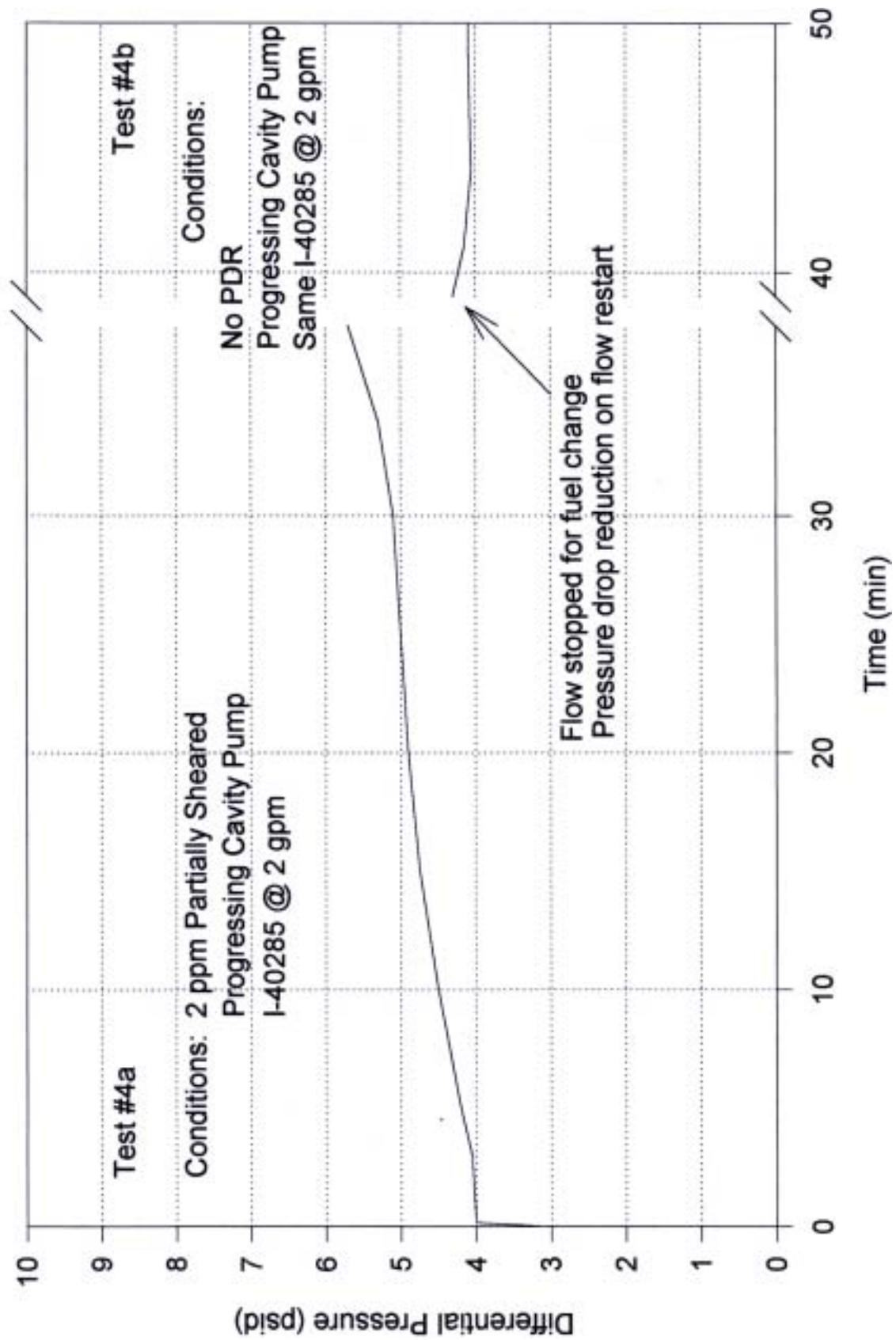
# PRESSURE DROP vs. TIME



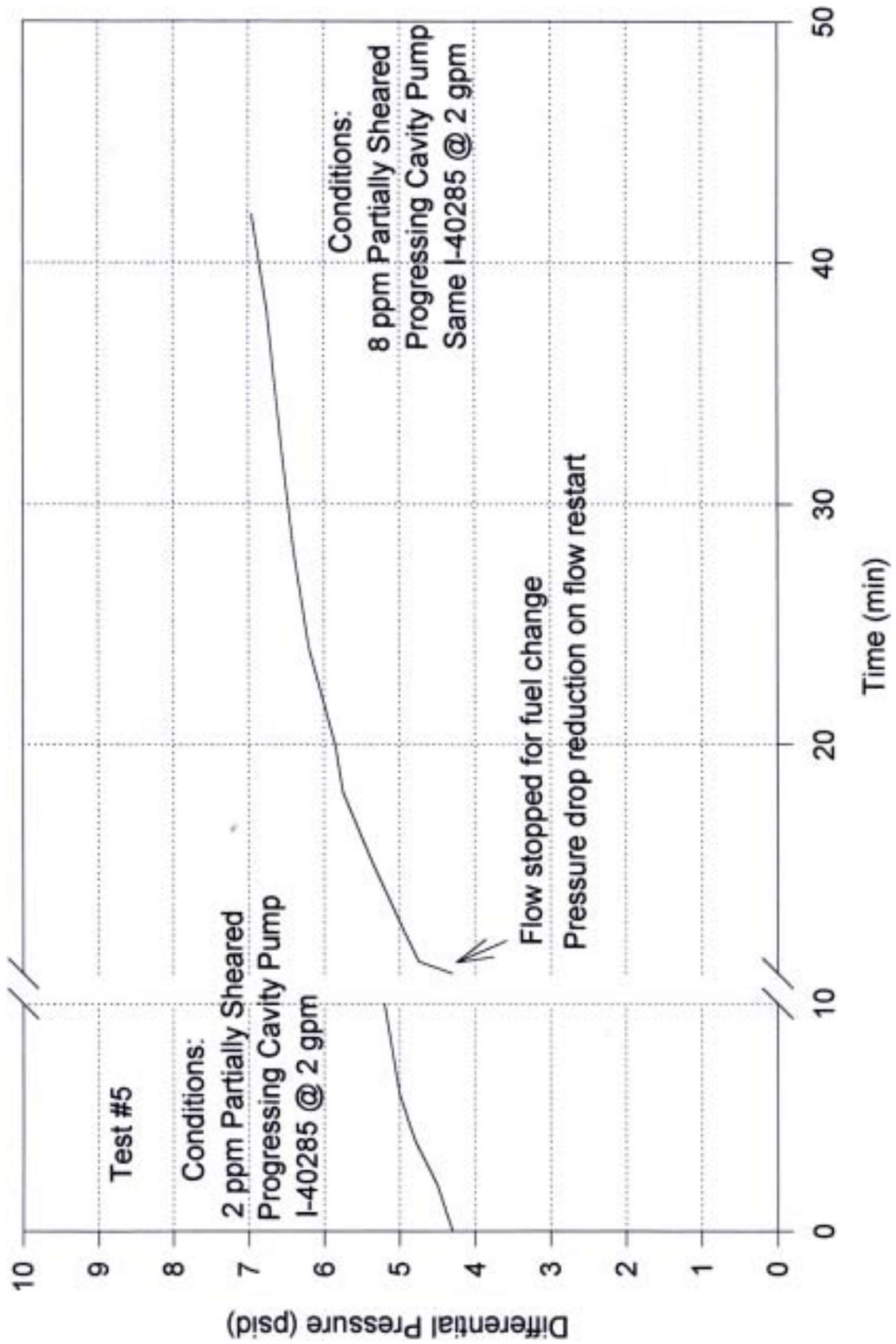
# PRESSURE DROP vs. TIME



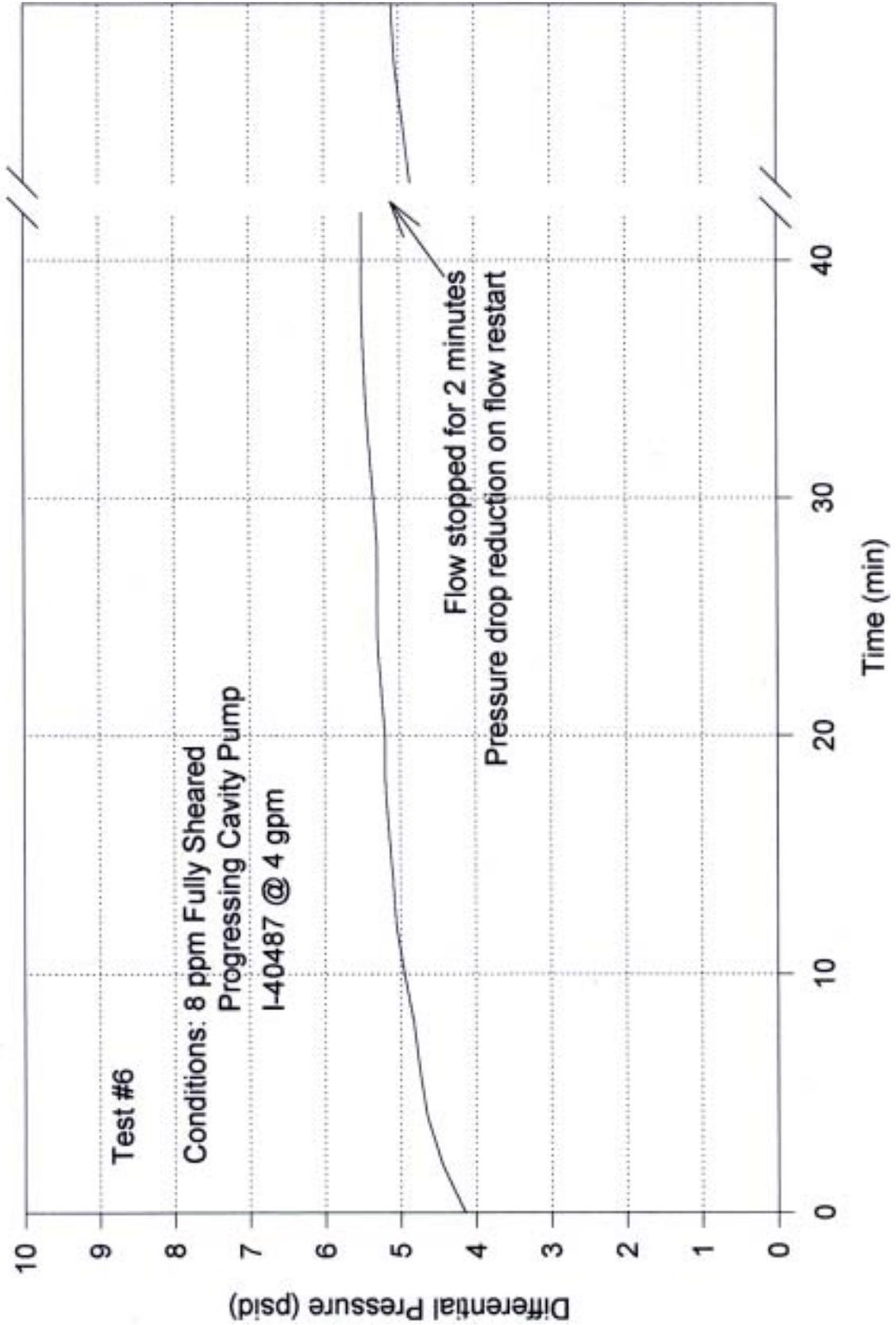
# PRESSURE DROP vs. TIME



# PRESSURE DROP vs. TIME



# PRESSURE DROP vs. TIME



## Addendum 5 – CRC Meeting Overview

### *CRC Panel Handling PDR in Aviation Fuels*



### CRC Aviation Meeting

Alexandria, Va

April 29, 2003

*Edward Matulevicius  
Fuel Technology Associates, LLC*



### *Progress & Status*

- **Program**

- PDR does not affect long term absorption or coalescence of water compared to non-additized Fuel

- **Program Direction**

- Program slowed to permit conservation of funds while waiting for assessment of data from Additives Group
  - Adverse spray and re-ignition effects possible
- Procedure for detecting fully sheared PDR in draft form



## *Further Work Necessary*

- **Work Remaining for PDR Effects**
  - Tests to determine performance of Filter/Separators
  - Tests to determine performance of monitors
  - Tests to assess effect of PDR on clay adsorption
  - Tests on **Baker** additive
    - Program needs to be repeated for **ConocoPhillips**
  - Tests and Round Robin for PDR Detection procedure
  - Assess program required for water-based additive
- **Other options**



## *Options- Available*

- **Additives to Improve Spray Pattern**
  - Long term R&D
    - Making droplets smaller could affect handling equipment
- **Remove Additives at Airport**
  - Possible solutions suggested
  - Requires R&D to assess feasibility
  - Need agreement for what constitutes removal



## Removal of PDR- Specification

- **What Constitutes Removal of PDR**
  - 1. Remove PDR at airport
    - Detection methods ~  $\pm$  1ppm for fully sheared material
      - <1 ppm
      - Non-detectible
  - 2. Degrade polymer to some MW
    - Present polymer ~ 1- 1.5 M MW
    - Ultrasonic to < 0.5M MW
    - Require ????



## Removal Options

Method	Benefits	Deficits
<b>Filtration</b> - Need < 0.1 $\mu$ pore	-Ease of fabrication -Existing equipment	- $\Delta$ P could be high - Other particulate
<b>Ultrafiltration</b>	- Technology for large surface area available	- High cost & maintenance -Availability of membranes of required flux for jet fuel -Removal of concentrates
<b>Renewable</b>	- Tailored filtration	- Removal of filter media - Complexity



## *Adsorption Options*

<b>Method</b>	<b>Benefits</b>	<b>Deficits</b>
<b>Moving Bed Adsorption</b>	<ul style="list-style-type: none"><li>- Existing Technology in Refineries &amp; Chem Plants</li><li>- Tailored adsorption material to selectively remove PDR</li></ul>	<ul style="list-style-type: none"><li>- <b>Chem plant at airport</b></li><li>- <b>Removal of concentrate from regeneration</b></li></ul>
<b>Shear Degradation</b>	<ul style="list-style-type: none"><li>- No concentrate</li></ul>	<ul style="list-style-type: none"><li>- <b>Energy requirements</b></li><li>- <b>Unique technology</b></li><li>- <b>Contaminant</b></li></ul>



## *Final Word*

- **Next Steps**
  - Advice from CRC Additive Group & Involved Parties
- **Program**
  - What to focus on if work continued
  - Documentation and work if program dissolved

## Acronyms and Nomenclature

AC	Action Committee
AFRL	Air Force Research Laboratories
Alcor	A corporate entity
API	American Petroleum Institute
APU	Auxiliary power unit, normally located in tail of aircraft
ARSFSS	Advanced reduced-scale fuel system simulator
ASTM	American Society for Testing and Materials
AVFR	Augmentor vaporizing fouling rig
BFA	Burner feed arm
C <sub>6</sub> , C <sub>12</sub>	Carbon with atom count
CDR	Conoco drag reducer
Conoco	A corporate entity: Continental Oil Company
CRADA	Cooperative Research and Development Agreements
CRC	Coordinating Research Council
CRT	Cathode ray tube
CSPI	ConocoPhillips Specialty Products, Inc.
DESC	Defense Energy Support Center
DOE	Design of experiments
ΔP, dP, DP	Delta pressure, a pressure drop or differential
DRA	Drag-reducing additive, same as PDR, below
EDTST	Extended-duration thermal stability test
FCOC	Fuel-cooled oil cooler
FI	Filtration index
FSS	Fuel system simulator
GPC	Gel permeation chromatography
JFTOT	Jet fuel thermal oxidation tester
HLPS	Hot-liquid process simulator
ICOT	Isothermal corrosion oxidation test
mil, mils	Milli-inch, milli-inches (0.001 inch)
MSDS	Material safety data sheets
mw	Molecular weight
NATO	North Atlantic Treaty Organization
NIFTR	Near-isothermal flow test rig
OCR	Optical character reading
OEM	Original equipment manufacturer, examples: Boeing and Pratt & Whitney
P&W	Pratt & Whitney
PDR	Pipeline-drag reducer
pph	Pounds (mass of fuel) per hour
QCM	Quartz crystal microbalance

Re	Reynold's number, ratio of fluid body forces to viscous forces ( $Re = VL\rho/\mu$ )
SCADA	Supervisory control and data acquisition
SEC	Size-exclusion chromatography
SP, SV P	Severity parameter
SWRI	Southwest Research Institute
USAF	United States Air Force
$W_f/P$	Engine fuel flow divided by compressor discharge pressure in atmospheres
WG	Working group