THE USE OF ANTIMISTING KEROSENE (AMK) IN TURBOJET ENGINES

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SUMMARY

Test conducted by the FAA have demonstrated the crash-fire resistance of antimisting kerosene (AMK), a jet fuel containing an antimisting additive. This additive, a high-molecular-weight polymer, causes the fuel to resist atomization and liquid shear forces, which also affect flow characteristics in the engine fuel system. The flow rate of AMK is not a constant function of the pressure differential as in the case of Newtonian liquids. However, this shear resistance and its resultant non-Newtonian flow characteristics can be negated by molecular shear degradation. The purpose of this program was to evaluate the effect of AMK flow characterisitcs on fan-jet engines and the impact of degradation requirements on the fuel system.

It has been determined from the present program that AMK fuel cannot be used without predegradation, although some degradation occurs throughout the fuel feed system, especially in the fuel pumps. Although the technical feasibility of a mechanical fuel degradation system has been demonstrated, the practicability and cost effectiveness must be established. Several potential problem areas have been identified.

There is a tendency toward FM-9 AMK additive agglomeration and gel formation when the liquid flows at a critical velocity through very small passages. The data indicate this phenomenon to be a function of the degree of degradation, the passage size, the differential pressure, the fluid temperature, and the accumulated flow time. Additionally, test results indicate that the long-term cumulative effects of this phenomenon may require more degradation than the theoretical requirement determined from short-term tests.

INTRODUCTION

Antimisiting kerosene is a kerosene-fraction jet fuel containing an additive which reduces the flammibility of the fuel in an aircraft crash. The most promising AMK additives are high-molecular-weight polymers that are dissolved in Jet A fuel in concentrations in the range of 0.3 percent. These additives have demonstrated their ability to inhibit ignition and flame propagation of the released fuel in simulated crash tests.

The AMK fuel resists misting and atomization from wind shear and impact forces and instead tends to form globules. This agglomeration significantly reduces ignitibility and flame propagation.

The antimisting additive (FM-9) selected for more comprehensive testing in this program was developed by the Imperial Chemical Industries and the Royal Aircraft Establishment (RAE) of the United Kingdom and is being evaluated for crash-fire resistance by the FAA and RAE.

The properties of AMK that make it fire resistant also give it undesirable flow characteristics in the engine fuel feed system. The main problems are its non-Newtonian flow characteristic, which results in lower friction losses at low flow rates; a variable onset of turbulent flow rates, which depend on the degree of degradation; and the tendency for the additive to agglomerate with gel formation when the liquid is throttled (accelerated) through small clearances or passages.

In cooperation with the FAA, NASA conducted a program to evaluate AMK for airline use through a contract the Pratt & Whitney Aircraft Group who tested and evaluated the effects of FM-9 AMK on the fuel feed system of the JT8D engine. The purpose of the tests was to identify operating problems, assess the adaptability of existing engines to AMK, and to determined the potential viability of this fuel in present and future fan-jet engines. The data presented herein were obtained in that program.

Critical fuel system components and subsystems were tested and evaluated for AMK compatibility. Components tested included the fuel pump, the fuel controller, system filters, nozzles, and combustors.

The program included laboratory tests for fuel characterization, chemical compability, thermal stability, heat transfer, and rheological properties. System tests included nozzle spray-pattern tests, filtration limits, controller function, pump performance, ignition start, and relight tests.

AMK CHARACTERISTICS

Antimisting kerosene fuel exhibits the greatest shear resistance and crash-fire resistance before exposure to shear, such as pumping flow through pipes and fittings, filters, or other components. Successive exposure to any of these shear forces tends to break the polymeric molecules, thereby reducing the average molecular weight and the subsequent shear resistance. Continuation of such shear degradation causes AMK to revert to the original properties of the base fuel.

This characteristic provides the possibility of using AMK in existing engines if the level of degradation required for acceptable performance for each critical component is assured.

The AMK additives have a molecular weight of over 5 000 000, and these molecules tend to resist the turbulent flow in liquid boundary layers and extend the viscous flow regime, thereby acting as a drag reducer. The resistance to shear and droplet breakup also affects nozzle performance. For example, figure 1(a) shows the typical atomization of Jet A fuel in a standard JT8D nozzle at ignition flow rates. Figure 1(b) shows the behavior of undegraded AMK in the same nozzle. Similarly, figure 2 shows fuel behavior for the standard nozzle, and figures 3 and 4 for nozzles with successively increased atomization capabilities built into their designs. As shown in figure 5, the calibration curve for turbine flowmeters with antimisting fuel does not exhibit constant K (cycle per cubic meter); therefore, the flowmeter must be recalibrated for any given conditions (degradation level and temperature) to be used.

With the use of a micromotion mass meter, the flow rate of AMK can be accurately measured at any level of degradation (fig. 6). It was determined that, at the level of degradation required by the propulsion system, the normal accuracy of turbine flowmeters is obtained.

Heat-transfer measurements show a marked reduction in the heat transfer with undegraded AMK in the turbulent flow range, because of the boundary-layer turbulence suppression of the undegraded FM-9 molecules (fig. 7). Note that increasing levels of degradation causes the heat-transfer coefficient to approach Jet A values. The thermal stability of AMK (table I) was better than Jet A, and further study is planned to determine the reason for this apparent improvement.

Two additional characteristics were tested: water solubility and materials compatibility. The results of the water solubility tests are shown in table II. Although the unsheared Jet A/FM-9 appears to absorb less water than the Jet A fuel, further investigation is required because some of the FM-9 additive separated from the solution during the tests. The standard test procedure used for this test may not be representative of the actual AMK/water compatibility, but this will have to be thoroughly explored.

Some incompatibilities of component materials were observed and measured with the FM-9 AMK tested. The hardness and tensile strength of Buna-N and fluoro-silicone elastomers were lowered after a 30-day exposure, and there was a tendency towards swelling. Also, chemical interaction was measured in alloys containing copper, although bronze materials in the test components were not adversely effected by the AMK during the test program.

FUEL SYSTEM COMPONENTS TESTS WITH FM-9 AMK

The non-Newtonian flow behavior, caused by these large FM-9 molecules, is more pronounced in flow through small passages or close clearances (such as through filters and fuel flow controllers). The flow velocity of AMK through a capillary or filter increases (in Newtonian fashion) as a function of pressure until a "critical" transition occurs, requiring a sharply increased rate of pressure increase to cause a continuing flow-rate increase (fig. 8). During this transition, the AMK molecules have an increased tendency to agglomerate, forming a gel precipitate. (This "critical region is also a function of the degree of degradation.)

These critical velocity effects can be controlled or accommodated in several ways:

(1) By increasing the level of degradation
(2) By increasing the flow area of filters
(3) By increasing the flow passage length to diameter ratio, thereby reducing the flow-rate increase for a given change in pressure
(4) By increasing the temperature, which increases the velocity at which critical flow occurs

As the pressure and flow rate is increased past the critical velocity, a second critical velocity is reached when the shear forces are sufficient for molecular fragmentation and AMK degradation. Two parameters effect the degradation process:

(1) Time of exposure to degradation process
(2) The amount of stress or energy at or above degradation stress levels

The use of AMK for crash-fire mitigation requires the fuel in the aircraft fuel tanks to be maintained in a relatively undegraded state, and, as the fuel is metered to the engine, a degradation level, as required to permit the AMK flow through all critical components, must be provided. This will require an energy efficient degrader that can provide the highest molecular shear stress with the lowest possible power requirement.

The major problem in the effort to evaluate the effects of AMK on the performance of fuel system components was the accurate measurement of the degree or percent of degradation of the test fuel. The filtration rate ratio of AMK versus Jet A provided the best discrimination of the viscosity change as a function of the degree of shear degradation of three viscosity measurement techniques used (fig. 9).

Seventeen-micrometer mesh metal filters were used as the measurement standard, which gave a good discrimination of degradation as a function of stress time to a filtration rate ratio (AMK/Jet A) of approximately 4; but below 4 the curve flattens out. However, by measuring the amount of flow as a function of shear exposure and using 8- and 10-micrometer filters, better viscosity discrimination was achieved at the higher degradation levels.

The JT8D fuel pump assembly was used to degrade the AMK test fuel to desired levels. Figure 10 shows the degradation achieved as a function of the number of passes through the pump.

The difference in the power input into the pump was not measurable, even though significant degradation was achieved in the process. Preliminary data tend to support the possibility that the drag reduction characteristic of the polymer additive in part compensates for the energy used in the degradation process. Follow-on experimental tests are expected to quantify the degradation energy requirement and to identify the best method of degrading the fuel.

Qualitative comparisons of the emissions characteristics of AMK versus Jet A using the standard nozzle and the later low-emissions nozzle are shown in figure 11. It should be pointed out that 3-pass AMK (i.e., AMK after 3 passes through the fuel pump) is only partially degraded, and it is expected that AMK degraded to full system requirements will meet Jet A emission values. Subsequent testing will determine the optimum level of degradation.

Tests were conducted to compare engine-ignition and altitude-relight characteristics of AMK and Jet A. Partially degraded AMK required approximately 25 percent higher fuel flows to achieve full ignition in the nine-can burner test rig (fig. 12). Further tests are expected to show fully degraded AMK to be equivalent to Jet A.

The altitude relight tests at an air flow of 2.27 kilograms were the same for AMK and Jet A; at all other flow rates, the AMK relights were poorer.

Performance testing of the fuel controller with 16-pass AMK was completed without detrimental effects in comparative performance between Jet A and 16-pass AMK. An 8-hour closed-loop cycle test was subsequently completed without measurable differences or effects from the AMK.

Pump testing and calibration with undegraded AMK showed no detrimental effects. An apparent improvement in the flow rate and differential pressure for a given speed was observed with partially degraded and undegraded fuel. This drag reduction influence became negligible with increasing degradation, and pump performance with 16-pass AMK was the same as for Jet A fuel.

RESULTS AND CONCLUSIONS

1. It is technically feasible to operate JT8D engines with 0.3 percent FM-9 AMK fuel.

2. The degree of degradation that is necessary for AMK fuel compatibility with existing fuel system designs has been determined to be in the filter ratio range of 1.2, or lower, using a 17-micrometer filter.

3. The primary modification requirements for turbofan jet engines to accommodate FM-9 AMK will be the addition of a fuel degrader before the fuel pump, which will provide the selected level of degradation.

4. Methods of predegrading AMK fuel in a flight certified system must be evaluated for practicability, cost, and energy effectiveness.

5. Data obtained with JT8D engine are applicable to other engines because the characteristic limiting parameters of AMK are the critical flow velocity and the degradation level, and these are a function of filter mesh sizes and clearance specification of component parts.

TABLE I. - THERMAL STABILITY OF UNSHEARED ANTIMIST FUEL AND FUEL CONTAINING NO ADDITIVE

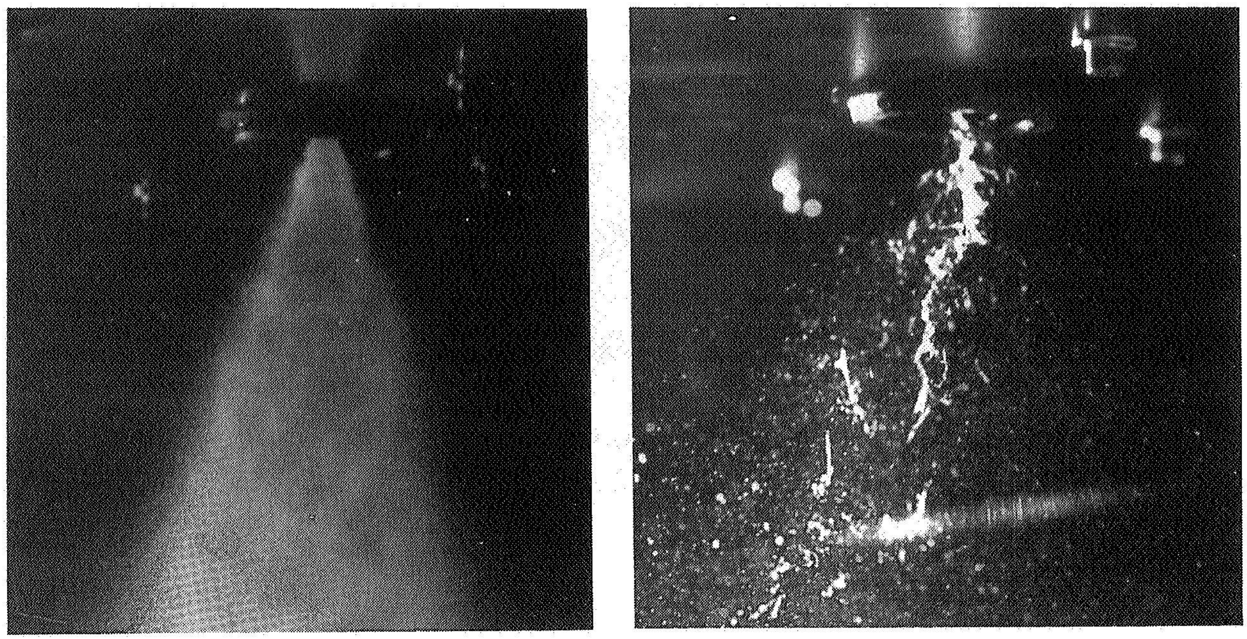
Temperature, °C	Parent fuel		Fuel containing additive	
	Deposit code	Differential pressure, mPa (mm Hg)	Deposit code	Differential pressure, mPa (mm Hg)
230	1	0.53 (4.0)	-	----------
245	1	7.3 (55)	-	----------
260	4	6.8 (51)	1	0.03 (0.2)
275	-	----------	4	.07 (.5)
290	-	----------	4	.13 (1.0)
320	-	----------	4	.20 (1.5)

Fuel	Breakpoint temperature, °C	Failure mode
Jet A	230 - 245	ΔP
3-Pass	275 - 290	Deposit code
1-Pass	260 - 275	Deposit code
Undegraded	260 - 275	Deposit code

TABLE II. - WATER SOLUBILITY TESTS

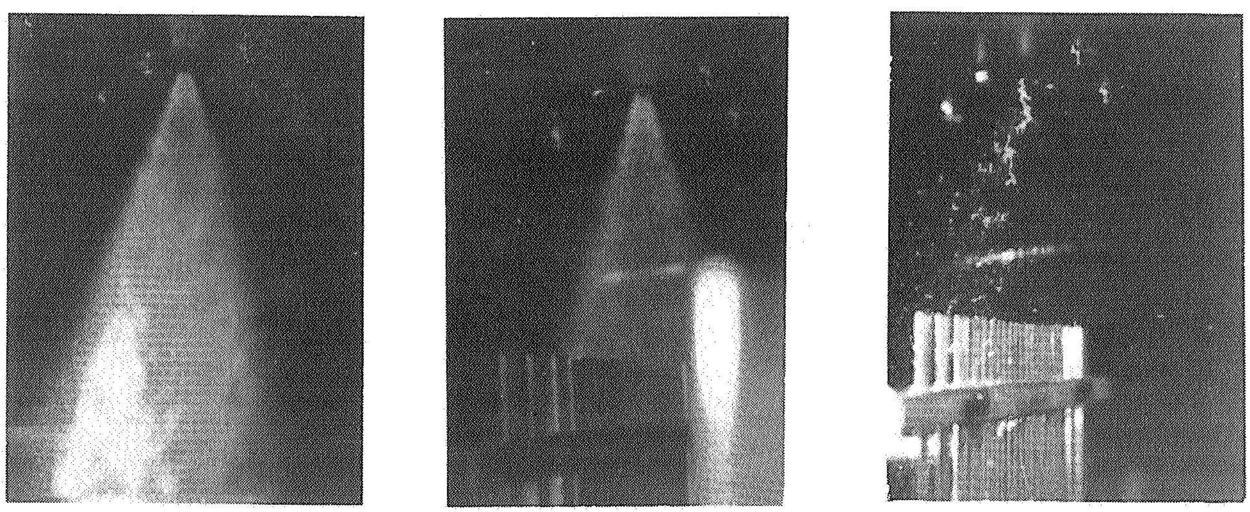
[Parts per million]

	Jet A	AMK unsheared
Before test	22	32
After test	60 - 64	40



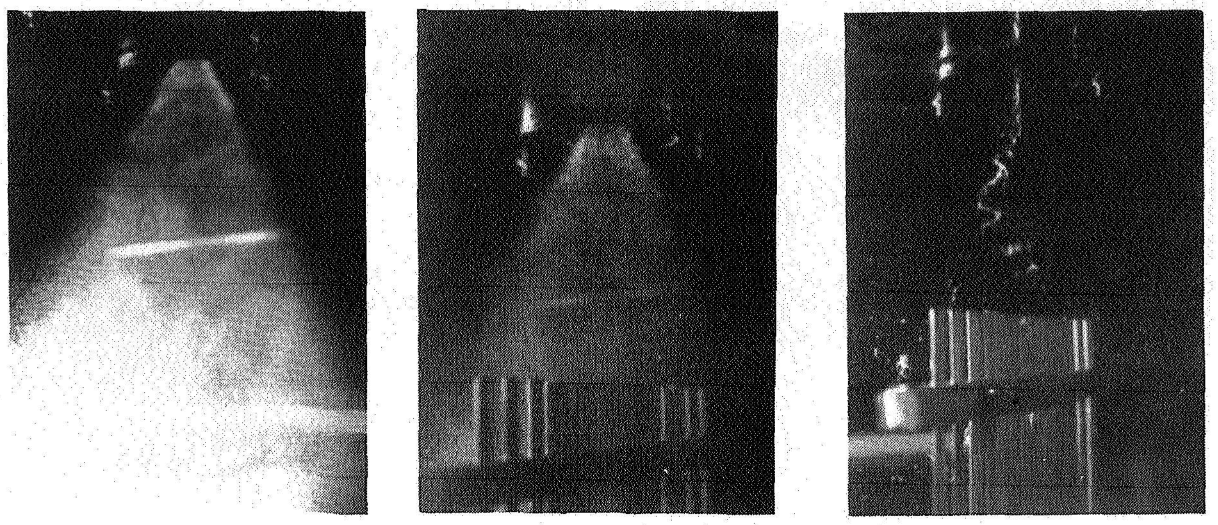
(a) Jet A. (b) Undegraded antimisting fuel.

Figure 1.- Comparison of spray patterns with JT8D production-pressure atomizing nozzle and Jet A undegraded antimisting fuel.



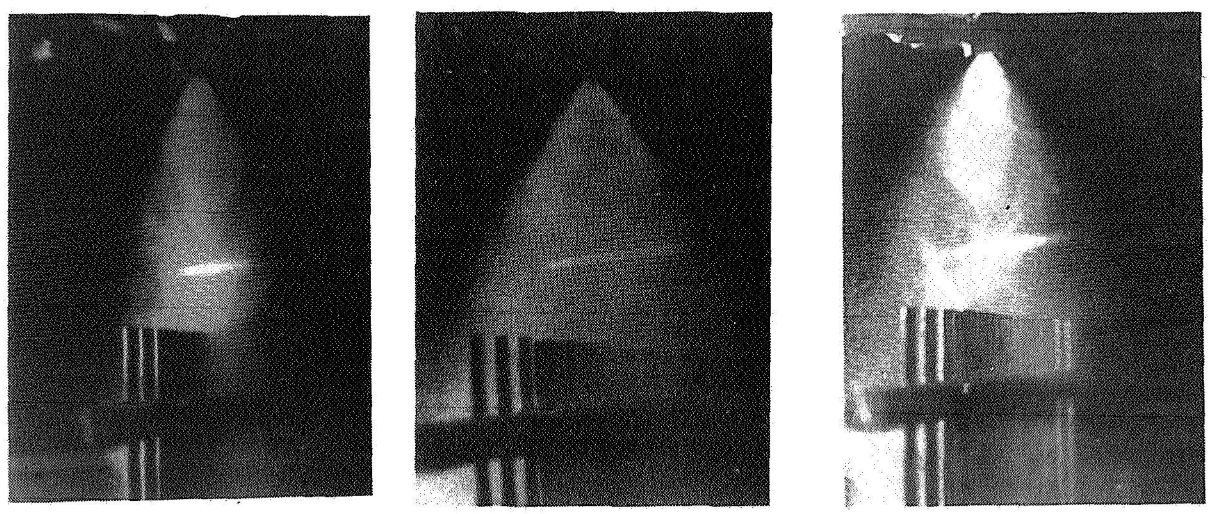
(a) Jet A. (b) Degraded FM-9. (c) Undegraded FM-9.

Figure 2.- Spray pattern with standard JT8D engine at ignition conditions.



(a) Jet A. (b) Degraded FM-9. (c) Undegraded FM-9.

Figure 3.- Spray pattern with JT8D low-emission engine at ignition conditions.



(a) Jet A. (b) Degraded FM-9. (c) Undegraded FM-9.

Figure 4.- Spray pattern with JT8D air-boost engine at ignition conditions.

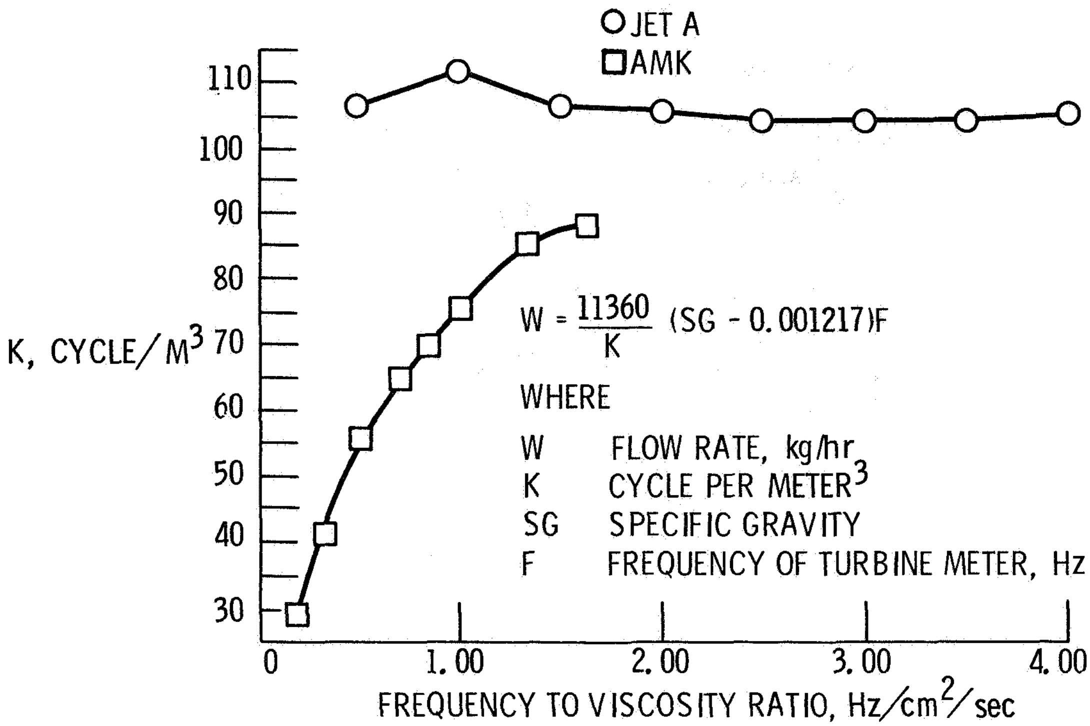


Figure 5.- Calibration curve for No. 8 turbine flowmeter.

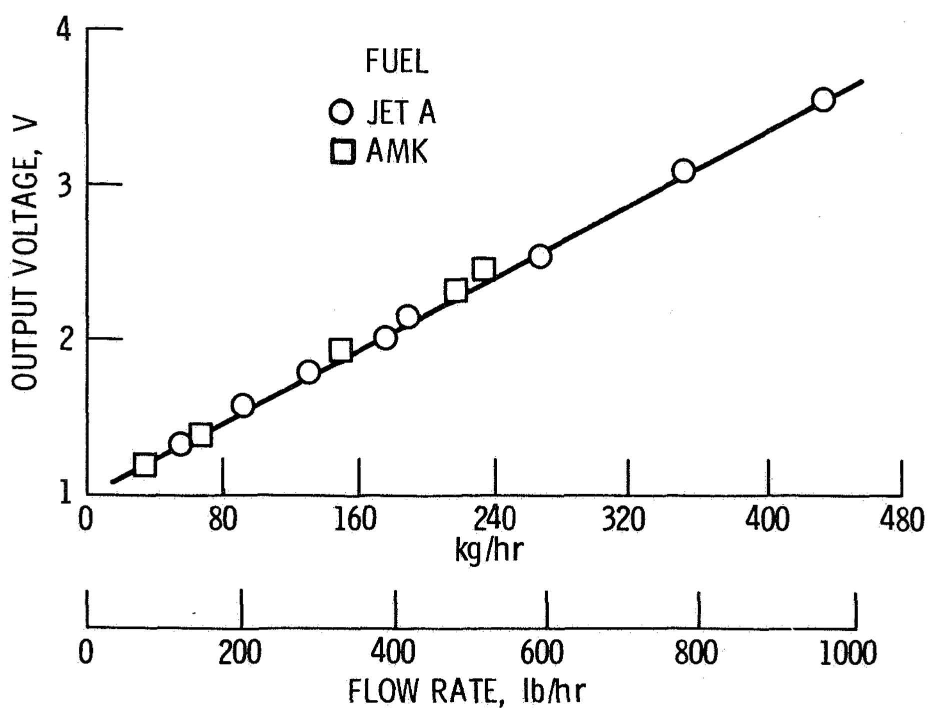


Figure 6.- Calibration data for a micrometer mass flowmeter.

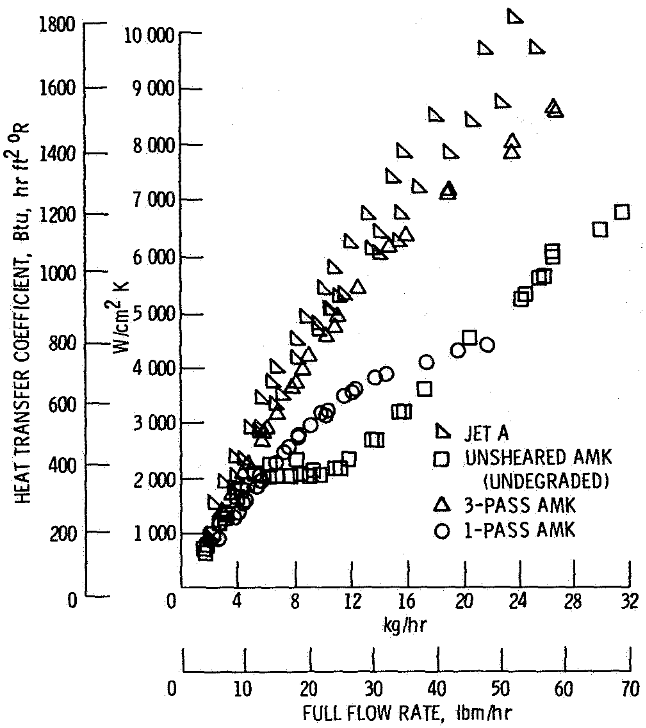


Figure 7.- Effect of anitmisting additives on heat transfer in fuel-oil cooler tubes.

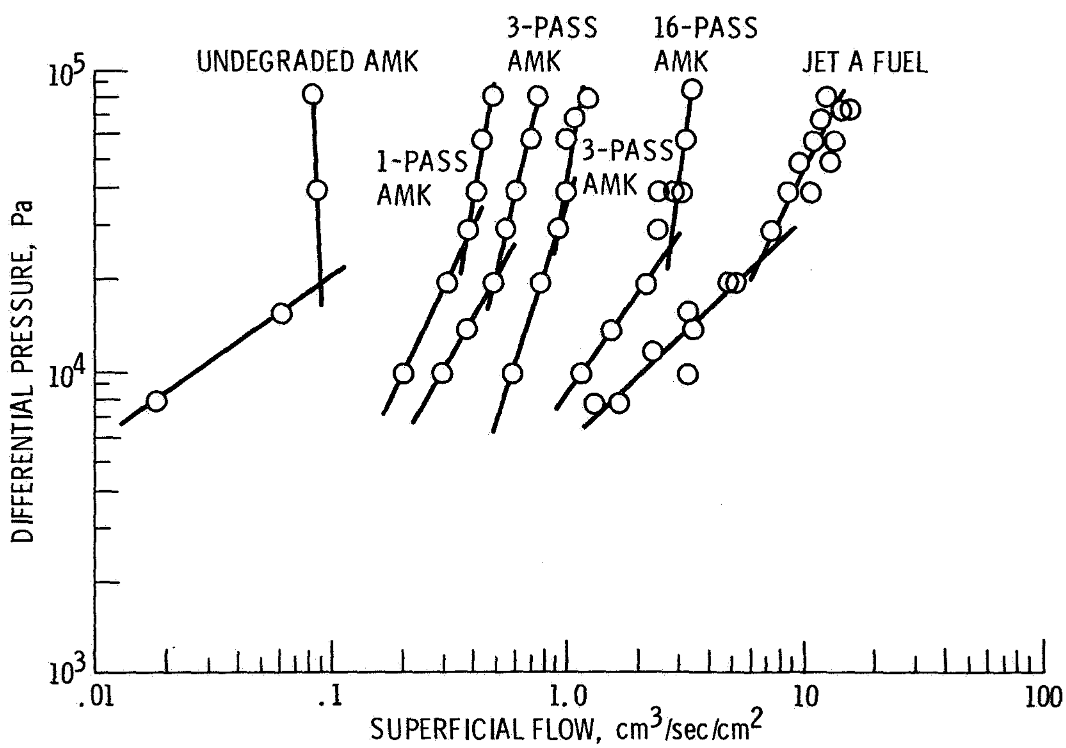


Figure 8.- Degree of AMK degradation as function of superficial flow velocity and differential pressure.

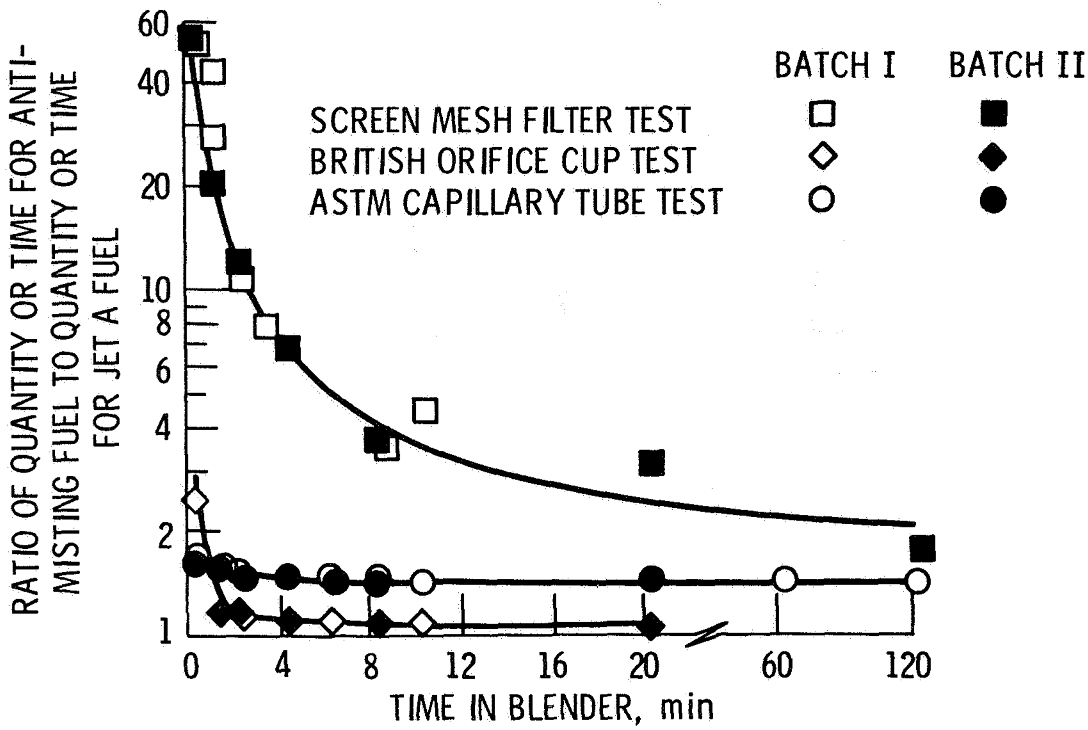


Figure 9.- Correlation of three viscosity measuring devices.

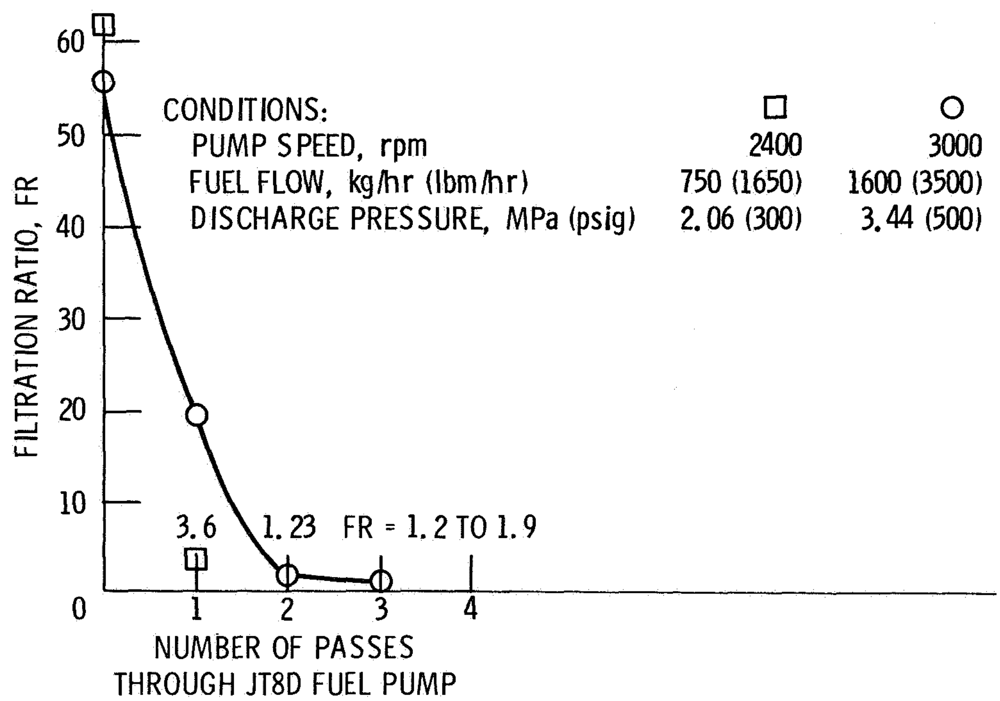


Figure 10.- Typical antimisting kerosene (AMK) shearing characteristics filter ratio (AMK time to Jet A time through 17-μm screen) sampled at collection tank.

EMISSION	STANDARD JT8D		LOW EMISSION JT8D	
	1-PASS AMK	3-PASS AMK	1-PASS AMK	3-PASS AMK
NO_x	SAME[a]	SAME	SAME	SAME
SMOKE	SAME	SAME	SAME	SAME

[a]AS JET A.

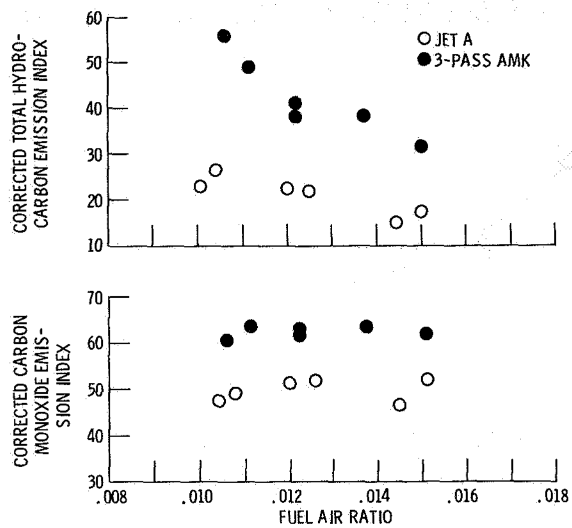


Figure 11.- Comparison of degraded antimisting kerosene (AMK) with Jet A fuel, tested in JT8D nozzles.

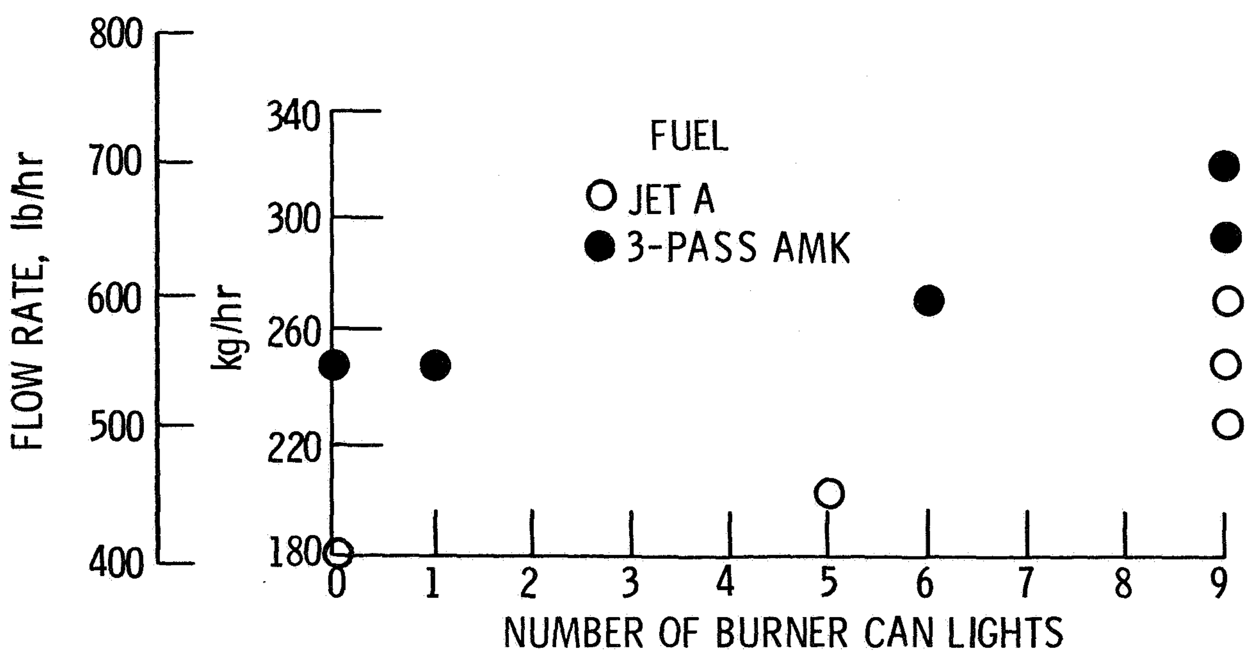


Figure 12.- Sea-level ignition behavior for antimisting kerosene (AMK) and Jet A fuels.