Feasibility of a Full-Scale Degrader for Antimisting Kerosene

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Experiments are described which demonstrate the feasibility of degrading antimisting kerosene (AMK) in a single pass with a system consisting of an axial piston pump from a TF30 engine and a needle valve The performance of the degraded AMK was evaluated with full scale aircraft filters (JT8D and CF6), a T63 combustor and laboratory scale tests for filtration and mist ignition At room temperature and higher it was found that AMK could be degraded to perform like Jet A in a single pass with modest power expenditure However, at low temperatures the power requirement increases substantially

Background

WHEN a high molecular weight polymer (FM 9)† is blended into aviation kerosene the resulting fuel is able to resist the formation of small droplets under impact survivable crash conditions and thus has been identified as antimisting kerosene (AMK) Simulated crash tests have demonstrated that AMK has improved fire safety; however, FM 9 creates significant filtration and atomization problems that preclude the direct use of AMK in aircraft turbine engines [1 2] Therefore, methods must be developed by which these undesirable characteristics can be eliminated just prior to the fuel entering the engine fuel delivery system Experiments in which AMK was forced to flow through metal screens or packed tubes have shown that the filtration and ignition properties of AMK can be made to approach those of Jet A at a specific degrader power (i e , ΔP) of 15kWs/l [3]‡ Since these experiments were intended only to prove that a satisfactory level of degradation could be achieved in a single pass the pressure was developed with a hydraulic cylinder Consequently, only small quantities (~6 liters) of AMK could be degraded Furthermore although these experiments demonstrated the effectiveness of this approach for polymer degradation, metal screens and packed tubes cannot easily handle a wide range of fuel flow rates In this paper an improved degrader for AMK is described which uses the same principles as the earlier degrader, yet operates continuously and provides fuel over the range of flow rates that are required for aircraft fuel delivery systems Moreover the level of AMK degradation is evaluated in terms of performance in actual aircraft filters and combustors in addition to small scale tests

Degrader Tests

Description of Apparatus and Experimental Procedure

The essential components of the degrader are shown in Fig 1 An axial piston pump from a TF30 engine is driven by a 50 hp electric motor with a magnetic coupling device A needle valve is located immediately downstream of the pump so that the high pressure produced by the pump is dissipated within a very short distance This needle valve acts as a variable area orifice so that a constant pressure drop can be maintained over a wide range of fuel flow rates At the beginning of each test a closed flow loop of Jet A is used to set the flow rate and pressure drop across the needle valve The latter is measured with a gauge and a transducer attached to a strip chart recorder After the pump speed and pressure have stabilized, a pair of three way valves switch the flow from Jet A to a drum of AMK which is under a head of nitrogen (55 kPa) § The flow rate of AMK is obtained by weighing the sample and recording the time Flow rates were varied at a fixed pump speed by changing pump displacement Because of the speed limitations of the electric motor used, maximum flow rates were in the range of 1500 kg/h This is equivalent to cruise conditions for the JT8D engine However, the only minor modifications would be required to increase the capacity of the degrader to full take off flow rates (4600 kg/h) Experiments at temperatures other than ambient were conducted by cooling or heating a drum of fuel Temperatures in the drum of fuel and in the feedline to the pump and the fuel filters were measured with thermocouples

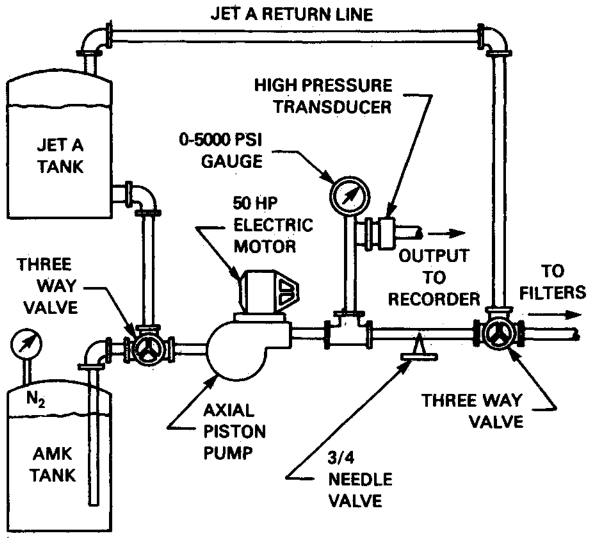

Fig 1 Schematic of AMK degrader (not to scale)

The filtration characteristics of degraded AMK were evaluated with aircraft engine fuel filters and a fuel control wash filter (see Fig 2) that were located immediately downstream of the needle valve (see Fig 3) A low pressure transducer immediately upstream of these filters monitored the pressure as a function of test time A valve located on the fuel control filter housing was used to vary the amount of through flow to the engine and wash flow (i e flow to the fuel controller)

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†This is a proprietary polymer provided by ICI Americas Inc

‡1 kWs/l = 145 psi

§1 0 psi = 6 895 kPa

Experimental Results

Full Scale Aircraft Filter Performance

Typical pressure time traces for successful degradation and filtration of AMK are shown in Fig 4 The transducer that measured the high pressure upstream of the needle valve increased from 3000 to 3300 psi (20 7 to 22 7 kWs/1) when the system was switched from Jet A to AMK However this higher pressure was maintained during the duration of the test (1 3 min) without any adjustment of the needle valve More importantly the low pressure upstream of the main fuel filter remained constant for the duration of the test

The results in Table 1 summarize experiments with the JT8D and CF6 engine fuel filters in which fuel (AMK and Jet A) was supplied to the pump inlet at ambient temperatures These results indicate that degraded AMK (21 kWs/l) can flow through these aircraft filters at flow rates equivalent to cruise conditions (1500 Kg/h) for the JT8D engine and at pressures close to those produced by Jet A A reduction in degrader power from 21 to 14kWs/l gave essentially identical performance; however at 7 kWs/l the pressure upstream of the filter rapidly exceeded the maximum capability of the low pressure transducer

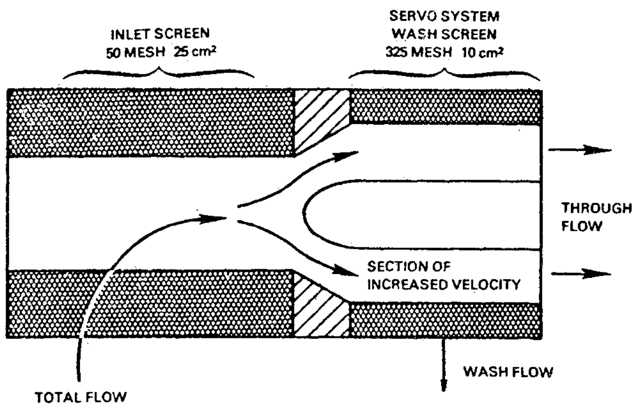

Fig 2 JT8D fuel control wash filter assembly

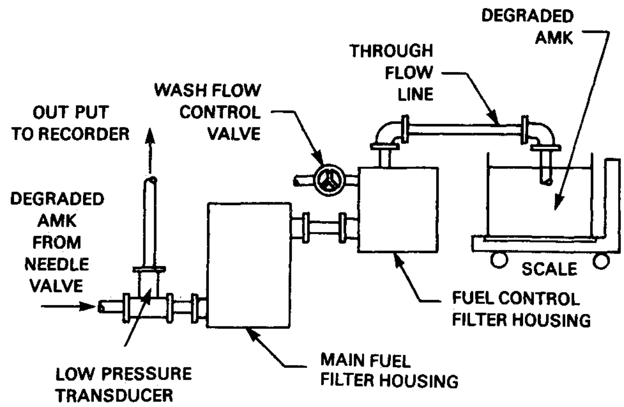

Fig 3 Schematic of fuel filter component test (not to scale)

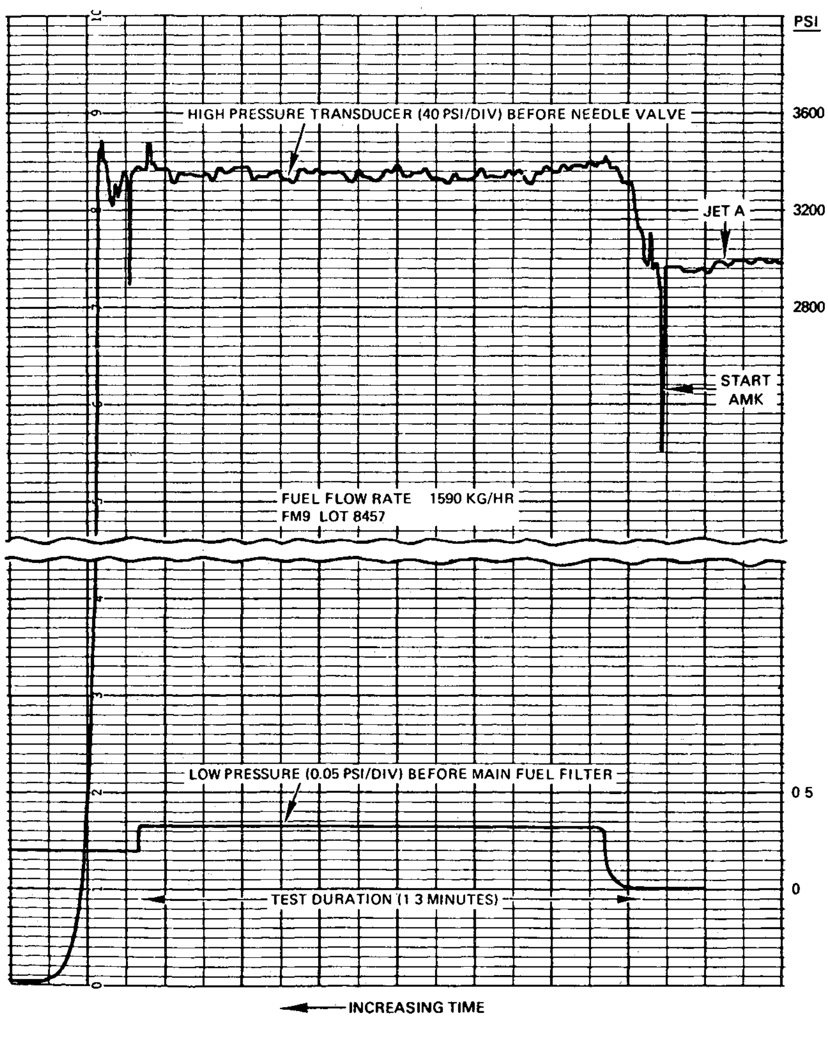

Fig 4 Pressure time trace for AMK with needle value and main fuel filter (JT8D)

Table 1 Flow of Jet A and degraded AMK through JT8D and CF6 main fuel filters

Fuel sample	Fuel temp pump inlet	Specific power kWs/l	Filter type	Fuel flow rate Kg/h	Filter ΔP kPa	Test duration min
Jet A	22 to 24 C	21	CF6[a]	550	0 8	3 3
AMK	22 to 24 C	22	CF6[a]	580	0 7	14 5
AMK	22 to 24 C	21	CF6[a]	1510	1 2	1 2
AMK	22 to 24 C	23	JT8D[b]	1580	0 8	1 3
AMK	22 to 24 C	14	JT8D[b]	1510	1 4	1 2
AMK	22 to 24 C	7	JT8D[b]	1460	35	0 8

[a]Main fuel filter wire mesh 74 μm absolute 3000 cm^2 [b]Main fuel filter paper 40μm 3900 cm^2

Table 2 Flow of Jet A and degraded AMK through JT8D main fuel filter and fuel control filter (specific degrader power of 21 24 kWs/l)

		Fuel flow rate (Kg/h)				
			Fuel control filter[b]			
Fuel sample	Fuel temp pump inlet	Main filter[a]	Through flow	Wash flow	Filter ΔP kPa	Test duration min
Jet A	22 to 24 C	1440	1440	0	43	1 4
AMK	22 to 24 C	1440	1440	0	56	1 5
AMK	22 to 24 C	1510	1150	360	30	1 7
AMK	22 to 24 C	1510	1190	320	36	3 5
AMK	22 to 24 C	1330	780	650	33	1 8

[a]Main fuel filter paper 40μm [b]Fuel control filter (see Fig 2) through flow screen (50 mesh 25 cm^2) wash flow screen (325 mesh 10 cm^2)

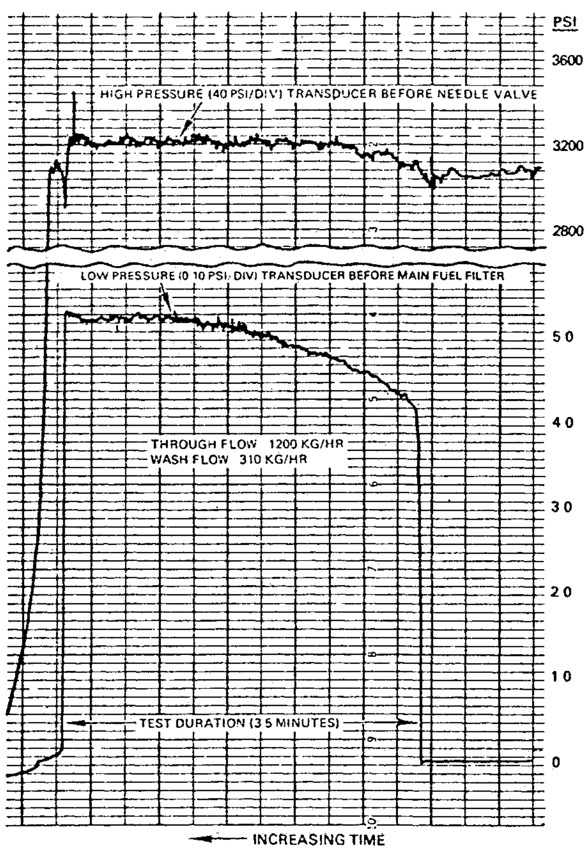

Fig 5 Pressure time trace for AMK with needle valve, main fuel filter and fuel control filter (JT8D)

The results in Table 2 summarize tests in which both the JT8D main fuel filter and fuel control filter were used The latter is a "last chance" filter that is intended to prevent large metal particles from entering the fuel controller The small areas of the wash screen filter (10 cm^2) would be more prone to plugging by particulates than the larger areas of the main filter (3900 cm^2) Therefore, in all tests on the fuel control filter the AMK first passed through the main filter as it would in the JT8D fuel delivery system The pressure drop was measured for the main fuel filter and fuel control filter in series (Fig 2) However the pressure drop across the main filter is negligible at these conditions

In the first series of tests the wash flow valve was closed so that all of the fuel (1440 Kg/h) flowed through a relatively coarse (50 mesh) screen The pressure drop across the two filters reached its maximum value within 10 to 12 s and remained essentially constant for the duration of the test The pressure level (56 kPa) was much higher than that observed for the main filter alone (1 7 kPa) and this was probably caused by the higher flow resistance of the fuel control filter housing and the smaller screen area Nevertheless the pressure drop for AMK was only slightly higher than for Jet A Furthermore, the pressure did not increase with time over the duration of the test (1 5 min)

In tests in which the wash flow valve was partially opened there was a slower build up pressure with degraded AMK than with Jet A (see Figs 5 and 6) Similar results with fuel that was degraded by three passes through a JT8D fuel pump have been reported and it was concluded that the degraded AMK resulted in unsatisfactory performance due to filter plugging [4] Since the steady state pressure drop in Fig 5 was only slightly higher for AMK (5 2 psi or 35 8 kPa) than for Jet A (4 2 psi or 29 0 kPa) in Fig 6 this observed time dependency does not appear to be due to filter plugging For example the pressure rise for degraded AMK relative to Jet A (i e , 5 2 psi/4 2 psi = 1 24) can be explained entirely by the slightly higher viscosity of degraded AMK relative to Jet A Nevertheless longer duration tests duration tests should be conducted to insure that filter plugging will not eventually occur

Experiments in which cold fuel (– 16 C) was supplied to the inlet of the pump degrader are summarized in Table 3 These results indicate that AMK is more difficult to degrade at low temperatures than at ambient It was seen (Table 1) that, at ambient temperatures and a specific degrader power of 14 kWs/l AMK could readily flow through the JT8D main fuel filter at flow rates on the order of 1600 Kg/h However, at low temperatures the results were quite different For example with Jet A at a specific power of 21 kWs/l the pressure drop across the JT8D fuel filter remained at a low value (1 5 kPa) for the duration of the test (4 3 min) On the other hand, with AMK the pressure upstream of the filter rose

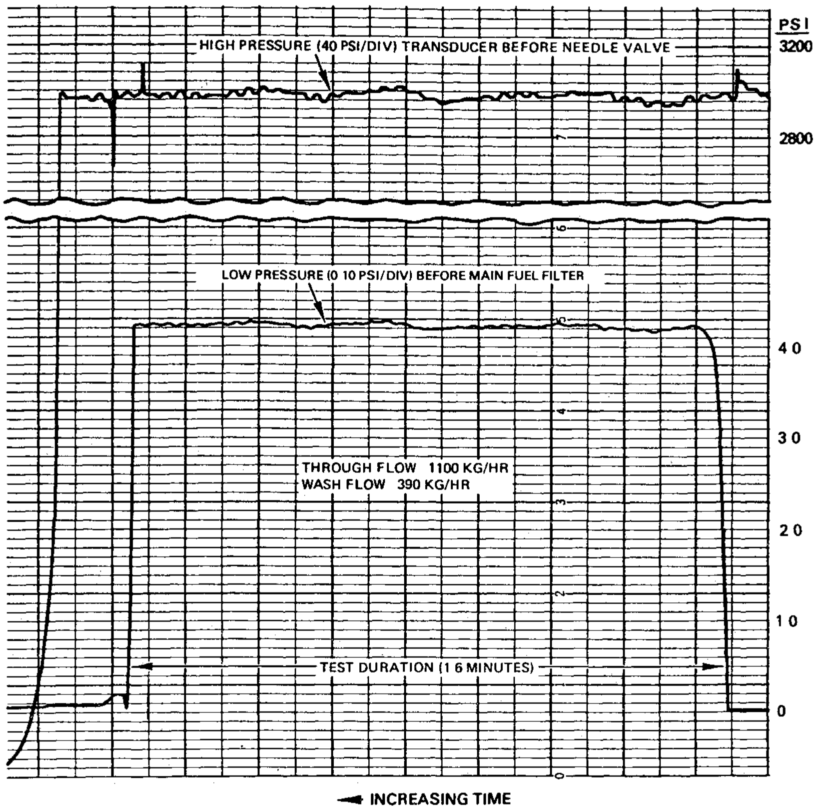

Fig 6 Pressure time trace for Jet A with needle valve, main fuel filter and fuel control filter (JT8D)

Table 3 Flow of Jet A and degraded AMK at low temperatures through JT8D and CF6 main fuel filters

Fuel sample	Fuel temp pump inlet	Specific power kWs/l	Filter type	Fuel flow rate Kg/h	FilterΔP kPa	Test duration min
Jet A	− 16 C	21	JT8D[a]	1590	1 5	4 3
AMK	− 14 C	23	JT8D[a]	1540	70	0 3
AMK	− 12 C	24	CF6[b]	1540	70	1 2
AMK	− 14 C	23	CF6[b]	1610	2 4	1 0
AMK	− 17 C	29	CF6[b]	1460	1 0	1 1
AMK	0 C	29	JT8D[a]	1740	0 9	1 0

[a]Main fuel filter paper 40μm 3900 cm^2 [b]Main fuel filter wire mesh 74μm absolute 3000 cm^2

so rapidly that it exceeded the maximum pressure capability of the transducer (i e $\Delta P > 70$ kPa) in less than 0 3 min

Similar experiments were conducted with the CF6 engine fuel filter (Table 3); but the results of these experiments were not consistent For example with cold AMK at a specific power of 24 kWs/l the pressure upstream of the filter in creased to more than 70 kPa in approximately 1 2 min However in a repeat test the pressure increased slowly and was only 2 4 kPa ($\Delta P = 1$ 5kPa for Jet A) after 1 min It is possible that increased test time would have eventually led to filter plugging; therefore longer duration tests are needed However the odd behavior of AMK with the CF6 engine filter can be partly explained by the complex rheological properties of AMK that lead to gel formation on the down stream side of a metal screen and will be seen in small scale filtration tests

Ignition Tests

Ignition tests of AMK degraded at ambient temperature were conducted with a T63 combustor rig In Fig 7 the ignition delay as determined from the time of rapid tem perature rise is plotted as a function of the fuel flow rate for a fixed air flow rate In these tests any increase in resistance to atomization will be reflected in a higher fuel flow rate required to obtain ignition Because of the statistical nature of the ignition process these data show a fair degree of scatter Nevertheless these data (which are an average of three runs) indicate no significant difference in the ignition delay of degraded AMK (25 kWs/l) and Jet A

In addition to the experiments with the T63 combustor rig the ignition characteristics of degraded AMK were also evaluated with small scale tests The results in Fig 8 show the effect of fuel temperature (at the inlet of the degrader) and specific power on mist ignition as determined by the Spinning Disc Test [3 5] For fuels degraded at ambient temperatures there is a measurable difference between the ignition of Jet A and AMK at a specific power of 7 kWs/l However at 14 kWs/l AMK is indistinguishable from Jet A The increased resistance of AMK to degradation at the lower temperatures is illustrated by the fact that at least 29 kWs/l are required to produce a fuel that ignites like Jet A On the other hand the absence of high temperature effects (at least up to 50 C) on specific power is clearly evident in the similar antimisting characteristics of AMK degraded at 22 and 50 C and at a specific power level of 7 kWs/l

Small Scale Filtration Tests

In small scale filtration tests with degraded AMK the pressure drop across a section of filter material was observed as a functin of time (up to 2 min) at increasing flow rates [5]

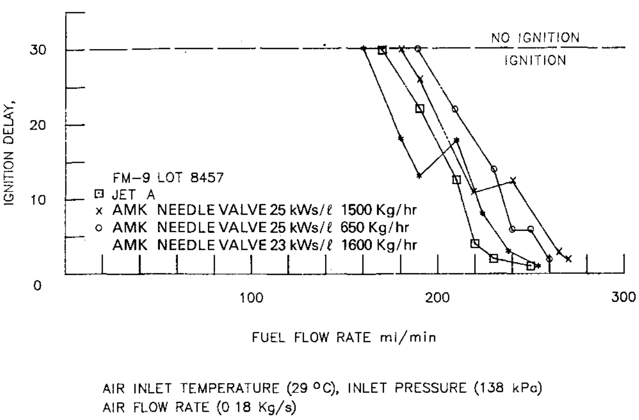

Fig 7 Ignition of Jet A and degraded AMK (T63 combustor)

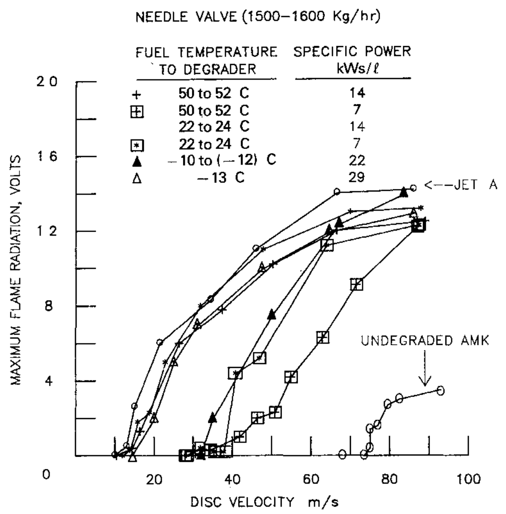

Fig 8 Effect of fuel temperature to degrader and degrader power on mist flammability of AMK

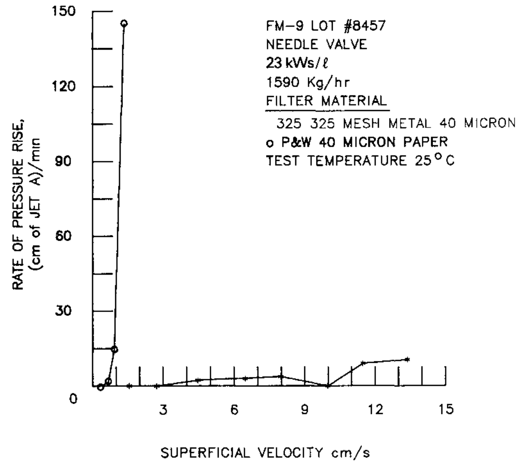

Fig 9 Pump filtration data for degraded AMK with different filter materials

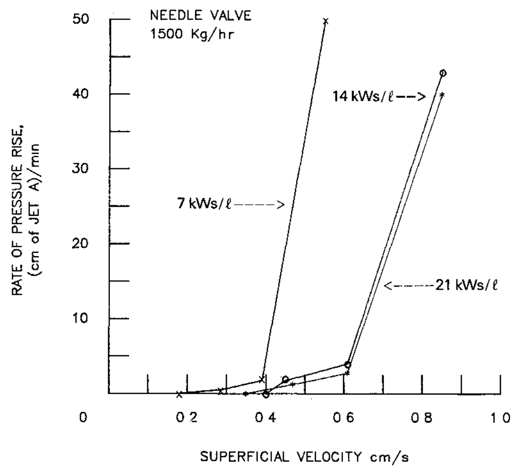

Fig 10 Pump filtration data for AMK degraded at different specific powers (22 24°C 40μm paper)

Because of the low dirt holding capacity of the small (0 1 0 4 cm^2) filter area samples were gravity filtered through a No 41 Whatman[R] paper filter prior to their use in this test

The filtration characteristics of AMK which has been degraded at ambient conditions and a specific power of 23 kWs/l are presented in Fig 9 The filter materials (40 μm paper and 40μm metal screen) used in these small scale tests were taken from the JT8D engine and fuel control filters that were used in the full scale tests (Tables 1 3) The sensitivity of the 40μm paper to clogging by AMK (even after severe degradation) is clearly evident in Fig 9 For example, at velocities below 0 5 cm/s the pressure drop across the filter remained constant However at higher velocities the rate of pressure rise increased dramatically It is important to note that the velocity through typical aircraft engine fuel filters is generally less than 0 5 cm/s even at take off rates The higher sensitivity of paper filters (compared to metal screens) to plugging by AMK has been well documented and can be explained in terms of at least three factors: 1) the pore size and shape distribution of a typical paper filter is broader than a metal screen 2) the effective open area of a paper filter is generally less than that of a metal screen and 3) a metal screen is only one pore deep while a paper filter has an ef fective depth of several pores This last factor is particularly important in that the increase in pressure with time for partially degraded AMK appears to be associated with gel forming on the downstream side of the screen

The lower sensitivity of the 40 μm screen to filter clogging by AMK is dramatically illustrated in Fig 9 Furthermore the erratic results observed for the CF6 engine filter (74μm metal screen) are also reflected by the data for the 40μm metal screen in Fig 9 For example while the 40μm paper rapidly clogged at velocities above 0 5 cm/s no measurable increase in pressure with the 40 μm metal screen could be observed at velocities up to 3 cm/s Between 3 and 8 cm/s a slight increase in pressure with time was evident; however at 9 cm/s filter plugging was again negligible These results suggest that the potential for filter plugging with AMK can be greatly reduced by the use of metal screens instead of paper filters

A comparison between the full scale and small scale filtration tests is provided by the data in Fig 10 The AMK samples in these experiments were degraded at a fixed flow rate of 1500 kg/h and different specific powers e g 21 14 and 7 kWs/l (see Table 1) Because of the effect of tem perature on filtration the small scale experiments were conducted at slightly different temperatures (38 35 and 32 C) that corresponded to the temperatures of the degraded fuel as it flowed through the filter in the full scale tests The critical filtration velocity¶ for fuels degraded at 21 and 14 kWs/l was not significantly different (0 4 cm/s see Fig 10) However at 7 kWs/l it was between 0 2 and 0 3 cm/s It is important to note that rapid plugging was produced in the

¶The critical filtration velocity is the highest superficial velocity (flow rate divided by filter area) at which AMK can flow through a particular filter without resulting in a measurable pressure increase in a 2 min period

JT8D fuel filter with degraded AMK (7 kWs/l) at a velocity of 0 13 cm/s (Table 1) The fact that plugging occurred in the aircraft filter even though the velocity was less than the critical filtration velocity is probably a result of the more complex flows that occur in a real filter The relatively poor agreement between aircraft filters and laboratory filtration tests illustrates the importance of using aircraft filters in assessing the feasibility of a full scale degrader for AMK

Summary

Single pass degradation of antimisting kerosene (AMK) has been accomplished with a system consisting of an axial piston pump from a TF30 engine and a needle valve which is able to accommodate a wide range of fuel flow rates The quality of AMK degraded by the needle valve method was assessed in terms of full scale fuel system component performance (JT8D and CF6 engine fuel filters and a T63 combustor) and small scale filtration and ignition tests The results of these ex periments indicate that AMK can be degraded to Jet A per formance standards Furthermore flow rates over the range of idle to cruise had little or no effect on the specific power required to obtain a fuel that would filter and ignite like Jet A; however at low temperatures AMK was found to be more difficult to degrade than at ambient temperatures While the results of these experiments have demonstrated the feasibility of continuously degrading AMK at reasonable power levels and flow rates additional experiments at higher flow rates longer flow times and lower temperatures are needed

Based on a filter area of 3900 cm^2 and a flow rate of 1460 kglh

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