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RHEOLOGY STUDY OF ANTIMIST FUELS

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FINAL REPORT

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16. Abstract

Two different rheological phenomena have been studied that may relate to the mechanisms by which high molecular weight polymers inhibit misting. The first of these is a shear thickening or antithixotripic phenomenon in which the liquid fuel develops a shear induced structure above a critical shear stress. The second phenomenon involves the sudden increase in resistance to flow in porous media that certain polymer solutions exhibit when the flow rate is above a critical value. This effect is quite different from the first in that the former can be induced by shear while the latter requires elongation.

While it is difficult to interpret these phenomena directly in terms of shear and elongational viscosities, it appears possible that the critical shear stress and the critical flow rate may be useful criteria for characterizing the condition of the antimist additive.

The theoretical significance of the critical flow rate in porous media has been discussed in terms of a fluid relaxation time which in turn may be related to the polymer molecular weight. A relationship between the critical flow rate and the intrinsic viscosity is presented that explains why the former is more sensitive to polymer degradation.

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Preface

This report was prepared by the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) at Southwest Research Institute (SwRI), San Antonio, Texas, for the Federal Aviation Administration. The work was performed from July 1, 1975 to December 31, 1976 under the management of Mr. T.G. Horeff, Aircraft Design Criteria Branch, Aircraft Safety and Noise Abatement Division, Systems Research and Development Service, Federal Aviation Administration, Washington, D.C.

Mr. B.R. Wright of SwRI designed the apparatus used in the ultrasonic degradation studies and Messrs. J.L. Jungman and G.W. Kuykendall of SwRI performed the rheological measurements.

INTRODUCTION

PURPOSE.

The purpose of this project was to demonstrate the performance of modified fuels when subjected to full-scale crash conditions in the presence of positive ignition sources and to determine the tendency of the fuels to mist and burn when forcibly expelled from ruptured airplane fuel tanks.

BACKGROUND.

In relatively minor aircraft accidents where airplane structures and occupants are subjected to forces that are not seriously destructive, volatile fuels are spilled and cause postcrash fires that result in severe property damage and loss of life. In an effort to reduce the destruction and loss of life caused by postcrash fires in survivable accidents, the Federal Aviation Administration (FAA) has been investigating various ways to either contain the fuel after a crash, or modify the fuel characteristics to reduce or eliminate the tendency to mist under impact conditions and burst into flame after contacting ignition sources such as friction sparks, hot surfaces, or flames that might be encountered during an actual crash of an air carrier airplane.

For the work reported herein, a reduction in postcrash fires was attempted by using modified fuels in the wing tanks of the test aircraft to reduce the tendency of the fuel to mist after being released under impact. In small-scale test work where 1- or 2-gallon quantities of fuel were used, it was discovered that the addition of as little as 0.3 percent of a particular additive would reduce the flammability of the fuel to a negligible amount when compared with normal jet-engine fuel, such as JET A. When larger quantities of modified fuel were catapulted into ignition sources, the flammability and flame propagation of the modified fuels was so slight, compared with unmodified fuels under the same test conditions, that it was decided to study the performance of modified fuels in a full-scale test environment.

DISCUSSION

TEST AIRPLANES AND LOCATION.

The RB66 airplane was chosen as the test vehicle over other available surplus aircraft because it had integral wing fuel tanks and jet engines that hung below the wing on pods similar to a typical air carrier jet airplane, such as the Boeing 707, and therefore the fuel spillage under crash conditions would be closely comparable.

Objectives

The primary objectives of this program were to develop methods of measuring the rheological properties of antimist fuels and to establish the relationships between these properties and fuel fire safety that are related to impact-survivable aircraft crashes.

Approach

Since dilatancy (shear thickening) and viscoelasticity (elongational viscosity) were thought to be important in preventing mist formation, these are the primary rheological properties that were studied; however other factors, such as intrinsic viscosity, that provide basic information pertaining to the size of polymer molecules in solution, were also considered. While it was originally intended to thoroughly investigate several candidate additives,* the supply of XD-8132.01 (Dow) was curtailed early in the program, and FM-9 (ICI) was not available until late in the program; consequently, our primary effort has been with AM-1 (Conoco). The shear viscosity of antimist fuels was measured with capillary and rotational viscometers, and viscoelasticity was determined from the onset of anomalous resistance to flow in porous media.

Results

A. Shear Viscosity

While a capillary viscometer is not ideally suited for characterizing rheologically complex fluids, important information concerning the shear viscosity can often be obtained if flow data are expressed in terms of the wall shear stress ($T = R\Delta P/2L$, where R is the capillary radius, ΔP is the pressure drop, and L is the capillary length) and wall shear rate ($D = 4Q/\pi R^3$, where Q is the volumetric flow rate). This latter quantity is the magnitude of the shear rate for a Newtonian liquid, however it is often a good first approximation even for non-Newtonian fluids. In these experiments flow data were obtained by applying a positive pressure to a fluid reservoir and measuring the mass flow rate by collecting and weighing a sample of fluid over a measured time interval (usually one minute). For very low pressures, the gas/liquid interface in the fluid reservoir could be adjusted to provide a fluid head relative to the centerline of the capillary tube which was held in a horizontal position (see Figure 1). Other than the room temperature being approximately constant (77-80°F), no special bath was provided to control the fuel temperature.

1. AM-1

The results presented in Figure 2 are for an antimist fuel consisting of 0.21% AM-1** in JP-8.*** Over the range of shear rates from 200 to 2000 sec^{-1}, this antimist fuel exhibits a slightly non-linear flow curve that is typical for most dilute polymer solutions, i.e., the

*These are proprietary polymers that generally have a molecular weight in excess of one million.
**wt% was determined by steam-jet gum (ASTM D-381).
***Typical physical properties of JP-8, Jet-A and Avtur are summarized in Table 1.

Summary

Antimist fuels, made with either the Dow (XD-8132.01) or ICI (FM-9) additives, have been found to form a gel-like solid above a critical shear stress. While it is difficult to interpret these measurements directly in terms of a shear viscosity, it appears possible that the critical shear stress can be used to distinguish between the relative effectiveness or degree of degradation of shear thickening additives.

Antimist fuels made with the Conoco (AM-1) additive do not shear thicken but have been found to exhibit a very high resistance to flow in porous media that is a measure of their viscoselasticity. By working with very dilute solutions, it has been shown that while the resistance can initially be predicted by the shear viscosity, it suddenly becomes very large when the flow rate exceeds a critical value. Although these two phenomena appear to be similar, they are actually quite different in that the former can be induced by shear while the latter requires elongation. These experimental results are again difficult to interpret directly in terms of an elongational viscosity, however it has been shown that the critical flow rate can readily discriminate between antimist fuels made with additives from different batches and with additives that have been partially degraded by flow or ultrasonic energy.

The intrinsic viscosity has also been found useful in characterizing antimist fuels and has the important advantage over the shear viscosity, in that it is independent of the polymer concentration and is only slightly dependent on the temperature and the shear rate. On the other hand, if the intrinsic viscosity is known, it has been shown that the dimensionless intrinsic viscosity can be used to estimate the polymer concentration. The important point is that the dimensionless intrinsic viscosity can be measured in the field while the antimist fuel is being blended.

The theoretical significance of the critical flow rate in porous media has been discussed in terms of a fluid relaxation time which in turn can be related to the polymer molecular weight. Furthermore, a theoretical basis for the correlation between the critical flow rate and intrinsic viscosity of partially degraded viscoelastic additives has been given that explains why the critical flow rate is more sensitive to degradation.

While preliminary results of fuel-spillage/air-shear tests indicate that both the critical flow rate and intrinsic viscosity are important factors in determining the relative effectiveness of viscoelastic additives, additional field and full-scale fire-safety tests are needed in order to determine the minimum values of these quantities that are needed for a fire-safety fuel specification.

LIST OF REFERENCES

1. Billmeyer, F.W., Jr., "Textbook of Polymer Science", 2nd Edition, Wiley-Interscience, New York, 1971.

2. Acierno, D. and Titomanlio, G., "Differences in Behavior Between Dilute and Concentrated Polymer Solutions in Elongational Flow", Chem. Engr. Sci., 29, 1739-1744, (1974).

3. Mannheimer, R.J. and Weatherford, W.D., Jr., "Investigation of Rheological Properties of Dilute Polymer Antimist Agents in Hydrocarbon Fuels", Interim Report AFLRL No. 59 (AD A013502), 1975.

4. Mannheimer, R.J., "The Effect of Solvent and Polymer Properties on the Uncoiling of Flexible Macromolecules in Elongational Flow", In-House Laboratory Independent Research Annual Report (1976).

5. Marshall, R.J. and Metzner, A.B., "Flow of Viscoelastic Liquids Through Porous Media", I&EC Fundamentals, Vol. 6, No. 3, 393-400 (1967).

6. Wright, B.R., et al, "A Technique for Evaluating Fuel Mist Flammability", Interim Report AFLRL No. 25 (AD 776965), 1973.

7. Rouse, P.E., "A Theory of the Linear Viscoelastic Properties of Dilute Solutions of Coiling Polymers", J. Chem. Phys., 21, No. 7, 1272-1280, 1953.

8. James, D.F. and McLaren, D.R., "The Laminar Flow of Dilute Polymer Solution Through Porous Media", J. Fluid. Mech., Vol. 70, Part 4, 733-752 (1952).