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Emulsified Gas Turbine Fuel

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The development of an emulsified JP-4 gas turbine fuel is described. Improvement in fire hazard prevention was indicated by sharp reduction in both flame propagation rate and volume of the fireball as determined during crash simulation tests. Associated emulsion properties are given.

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The hazards connected with the handling and usage of highly volatile and flammable JP-4 gas turbine fuels are well recognized. In-flight, crash, or post-crash fire hazards are a continued factor for the military, both in combat and in noncombat operations; these are also sources of major concern in commercial usage. Two Government agencies vitally interested in aircraft fire control are the U.S. Army Aviation Materiel Laboratories (AVLABS) and the Federal Aviation Agency (FAA). The FAA has taken the route of gelling the fuel to reduce vaporization, impact disintegration, and dissemination of the fuel in ruptured aircraft supply tanks, while the AVLABS have concerned themselves with highly viscous fuel emulsions. Emulsions were the subject of a fire hazard symposium in mid-1966 (1)¹ and for another conference in 1967 (2). These two meetings with the papers presented represent essentially all the published information on fuel emulsions.

Emulsions technology in general is well known, but fuel emulsions represent a new facet in this field. Their uniqueness lies in the fact that an extremely small external phase is used to emulsify a relatively large internal fuel volume. A literature search revealed only one general publication (excluding the two cited symposia) by Lissant (3) which applied to this new field. These fuel emulsions are characterized by their high ratio of internal fuel phase, i.e., at least 97 vol percent.

The authors presented a paper (4) at the National Aeronautical Meeting of the Society of Automotive Engineers which was a report of their progress in preparing a JP-4 emulsion meeting AVLABS requirements (5). Since that time the contract has been completed successfully, and this paper summarizes the findings. Another contract to improve and optimize this formulation is currently under way (6).

GENERAL REQUIREMENTS

A first requirement for these emulsions is that their apparent viscosity be of such an order that their flow be significantly retarded from a

¹ Numbers in parentheses designate References at the end of the paper.

container fitted with a 2-in. length of 0.5-in. id piping, simulating a 0.50 caliber bullet hole. Another prime requirement is physical stability at -40 F and +160 F. Stability to large acceleration and impact forces is required. Flammability as indicated by vapor loss, flame propagation, and dynamic impact is obviously a very important property. When the emulsion is engine-consumed the ash should not exceed that of liquid JP-4, and thermal value reduction must be minimal. Corrosion or deterioration of fuel systems components must be minimized. Finally, the emulsion must be of such a nature that essentially specification grade JP-4 can be recovered. Many of these requirements are apparently diametrically opposed, hence tradeoffs are necessary in the final product.

The course of the project comprised investigations of external phase, emulsifier, method of preparation, and method for recovery, during the course of which primary quality screening tests were used, followed by expanded characterization tests once an apparently satisfactory product was obtained.

EXTERNAL PHASE AND EMULSIFIER

The external phase will assume the water character of these oil-in-water emulsions. This phase also should exert high solvating action for the emulsifier which is necessary to maintain physical stabilization. The liquid portion of the external phase will be insoluble in the oil, but will result in dispersion of oil droplets. Of a number of potential candidates it was found that ethylene glycol (EG) was quite effective, and that water could extend its effectiveness. Incidentally, a 50/50 volume mixture of EG and water has a freezing point of about -30 F, aiding in low temperature stability. However, oil droplet stability in EG/water mixtures is low, and coalescence of the droplets quickly occurs unless an emulsifier is added.

There are literally a thousand or more potential emulsifying agents commercially available (7); hence, some means was necessary for screening and selecting those most applicable. Primary requirements are that the emulsifier be as nearly ash-free as possible, not adversely affect the fuel heat value, and be noncorrosive. Emulsifiers most

nearly meeting at least the first two requirements are compounds comprising carbon, hydrogen, nitrogen, and oxygen. A broad class of emulsifiers of this constitution are known as nonionics since they become effective by solvation in aqueous-type solvents by a (hydrogen) bonding effect. Another class of emulsifiers meeting those requirements are cationics (solvating as a result of the cation) and amphoterics which contain both cationic and anionic groups. Since each of these groups can consist of hundreds of varieties, a screening test was desired, and if mixtures of types are contemplated, a screening test becomes even more imperative.

An emulsifier screening test which has been used successfully is one based on the hydrophilic-lipophilic (water or oil loving) balance (HLB) of the molecule. Since the emulsifier will use the lipophilic portion for partial solubility in the oil, and the hydrophilic for partial solubility in the water phase, the ratio between these two groups may be used for optimum selection. Oil-soluble emulsifiers will have low HLB values, and water-soluble emulsifiers high values. Griffin (8) developed a simple procedure based upon water solubility which was used successfully in this work. We found that an HLB value lower than a 10-13 range was unlikely to be effective, thus permitting reduction in the number of emulsifiers to be tested further.

The emulsifier finally chosen after testing 69 different emulsifiers representing all available applicable types was a cationic type consisting of the acetic acid salt of hydrogenated tallow amine, HLB value 10-13.² Effectiveness of this emulsifier in the external phase is shown in subsequent evaluation data.

SCREENING TESTS

Having selected the external phase fluid, i.e., EG/water and potential emulsifiers, the next step was development of an emulsion preparation technique so that prepared emulsions could be subjected to tests to determine compliance with certain general requirements.

EMULSION PREPARATION

Emulsions were prepared on a volume basis, such that 97 vol percent JP-4 was combined with 3 vol percent external phase. The external phase comprised a 50/50 volume mixture of commercial EG/deionized water in which was dissolved 0.3 wt percent emulsifier.

² Alamac H26D by General Mills, Inc.

Of a variety of mixing devices investigated, most satisfactory results were obtained with a Hobart Kitchen Aid mixer (counter-rotating planetary action). Depending upon batch size, a maximum of 20 min was required for emulsion completion (JP-4 droplet size of ca. 10 microns). Materials were combined at ambient temperatures.

THERMAL STABILITY

A batch of emulsion was subdivided to permit thermal stability testing in closed 2-oz jars at -20 F, 77 F, and 135 F. A minimum of 7 days' stability was required to qualify for further advanced testing.

g VALUE

Another batch of emulsion was subjected to 500-g acceleration according to ASTM D 96, for 30 min.

APPARENT VISCOSITY

A Brookfield RVP Viscometer using a No. 7 spindle at speeds of 2, 4, 10, and 20 rpm was used for a rapid estimate of viscosity. Other investigations had indicated that a 90,000 cps value was a minimum to warrant further investigation.

CORROSION

Since the emulsion must be shipped, and possibly in steel drums, a partial immersion test with a mild steel strip in the candidate emulsion at 77 F was made.

If all the foregoing values were met satisfactorily and the emulsion were essentially ash-free, advanced confirmatory tests were made. A formulation meeting the screening requirements was a composition of the character described earlier (see Emulsion Preparation) whose emulsifier was tallow amine acetate. This formulation henceforth will be called MEF and its properties are described later.

ADVANCED CONFIRMATORY DATA FOR MEF

Yield Stress by Cone Penetrometer

A standard cone penetrometer conforming to ASTM D 217-65T specification was modified to provide a 49.5 g weight cone of polypropylene and aluminum. Emulsion was transferred to a 1-liter beaker, the surface smoothed with a straight-edge, and a 5-sec cone penetration time observed. The yield was calculated and is shown comparatively

with Brookfield values as a function of time in Table 1.

Table 1 Yield Stress

At Once		Several Days
Brookfield, cps	Yield Stress, dynes/sq cm	Yield Stress, dynes/sq cm
90M	2100	1400

Thermal Stability

These values were obtained for 2-oz emulsion samples in glass jars at the temperatures shown in Table 2.

Table 2 Thermal Stability

Temperature, deg F	Stability
-60	Broken in 1 day
-40	7 days
77	> 30 days
135	7 days
160	6 days

Gravity and Impact Values

The requirement that emulsions withstand a 500-g acceleration of gravity for 30 min (ASTM D 96) was one met by practically all the emulsions investigated.

A 10,000-g acceleration value for 1 min was attained using a DeLaval high velocity centrifuge.

A 150-g impact (shock) test was made using a machine conforming to Jan-5-44 and the emulsion was subjected to these conditions.

Vibration at 0.4 ± 0.1 g was attained over a specified time-amplitude schedule covering a 24-hr period. An MB Model C-10 Type E exciter was used in conjunction with a MB Model T-51-MC Type K control panel, the frequency applied and regulated by a Hewlett-Packard signal generator.

A slosh test was made by half filling 8-oz jars with emulsion and shaking 24 hr at room temperature at a rate of 240 cycles/min over a horizontal travel of $1\frac{1}{2}$ in.

The preferred MEF emulsion was stable under all the foregoing conditions of test.

FLAMMABILITY CHARACTERISTICS

A number of indirect and direct measurements of potential flammability were made to serve either as control procedures or as measures of improvement attributable to the emulsification of the JP-4 fuel.

Evaporation Rate

Gravimetric loss in fuel content of the emulsions was compared with that of straight JP-4 us-

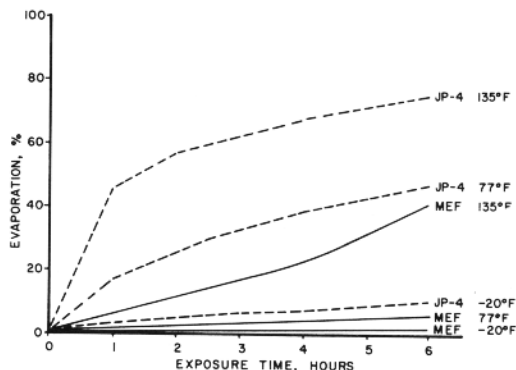


Fig.1 Evaporation rate

ing a specified exposed surface area. Temperatures at which measurements were made were 77 ± 2 F, -20 ± 2 F, and 135 ± 5 F. At the end of a 6-hr period the following reductions in loss were measured: At -20 F, one-fifth that of unemulsified JP-4; at 77 F, one-ninth that of JP-4; and at 135 F, approximately one-half the fuel loss. Complete data are shown in Fig.1.

Vapor Pressure

Using the Reid vapor pressure method at 100 F the vapor pressure for JP-4 was 3.15 psi and that of the MEF emulsion was 2.53 psi. The difference is attributable either to the protective action of the emulsion, or to loss of volatile fuel components (light ends) during preparation due to handling. Until the emulsion is formed under conditions where vapor loss can be prevented, either explanation may be valid.

Flammability - Open Cup

The Cleveland Open Cup method by ASTM D 92-57 was used to determine flash points. A variation of the test was used at 77 F in which the flame remained over the fuel until ignition occurred. Table 3 shows these data.

Table 3 Flash and Ignition Time Lapse Data

	Flash Point, deg F	Ignition Time Lapse, Minutes at 77 deg F
JP-4	77	1/30
MEF Emulsion	137	15 $\frac{1}{2}$

Explosivity

Using the Mine Safety Appliances Explosimeter Model 40, comparative JP-4 and MEF values were measured. A Petri dish containing fuel (as used in the evaporation rate tests) was transferred to a wide-mouth 5-gal jar and the Explosimeter probe positioned at the jar center. Measurements were

made at 5-min intervals and the lower explosive limit (L.E.L.) of JP-4 determined (0.6 percent L.E.L. for JP-4). These comparative data are shown in Fig.2. The emulsion never reached the 100 percent level in 100 min, while JP-4 attained this value in about 20 min.

Flame Propagation

The container for this test was a 10-ft trough of 1 1/2 in. angle iron. The tests were made at ambient conditions (about 75 F) in a large open room to minimize drafts. About two quarts of either JP-4 or MEF emulsion were transferred to the trough, using a straight edge in the case of the emulsion to level the surface. Ignition was obtained by a "spark-plug" device. Rate of propagation was measured as 2 sec/10 ft for JP-4, and 175 sec/10 ft for the emulsion.

Dynamic Crash Simulation

The objective here was to simulate a crash by firing containers into an open barrier grid behind which was located a flame source. A high velocity impact was attained using a controlled propulsive charge in 37-mm shells designed for use in a riot gun. The fuel containers were capped toothpaste tubes containing 3 oz of either JP-4 or MEF emulsion. The fireball diameter obtained was measured and an average obtained.

Those fireballs obtained with JP-4 had high radiation and burned almost explosively. In contrast, the emulsion fireball was much smaller (Table 4), and some of the emulsion passed through the flame unburned. The average fireball diameter of MEF emulsion was roughly one-third that of JP-4, and the area of the hemisphere base of the fireball was reduced to about one-sixth that of JP-4.

Table 4 Dynamic Crash Simulation

Approximate Fireball Diameter, ft

JP-4	7.2
MEF Emulsion	2.9

Average Area of Fireball Hemisphere Base, sq ft

JP-4	38.4
MEF Emulsion	6.6

ASH CONTENT

The ash content of the fuels was determined gravimetrically. A total of 350 ml in 50-ml aliquots was evaporated in a platinum crucible, and remaining tar was burned off prior to ignition at 1600 F in a muffle furnace. JP-4 had an ash content of 0.00016 percent, and MEF of 0.0013 percent.

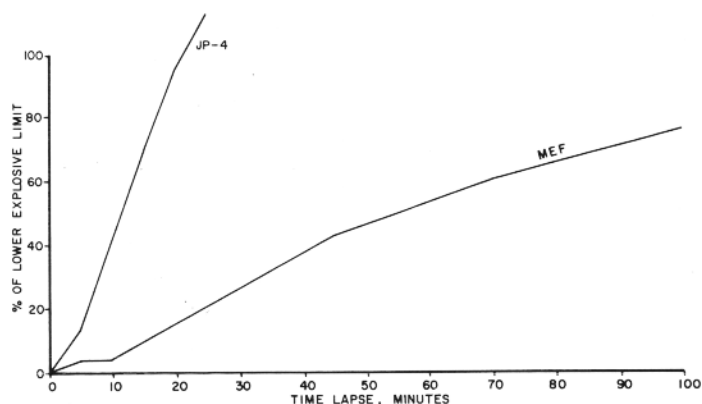


Fig.2 Explosimeter tests

Only a few parts per million of metals comprised the ash constitution.

CORROSION

Partial immersion tests with single metals and complete immersion tests with couples were made at 77 F for 30 days with single metals and 12 days with metal couples. The observations were qualitative. The data are shown in Table 5, indicating that MEF emulsion was essentially equal to JP-4, but that couples comprising brass or bronze resulted in considerable copper removal. Subsequent storage tests in mild steel drums showed moderate rusting of the drum, indicating need for improvement in corrosion protection.

Table 5 Corrosion Properties

Rating 1 to 10 in increasing severity

Metal	Emulsion	JP-4
Bare 2024	1	1
Clad 2024	3	10
Anodized Bare 2024	0	0
Bare 7075	5	10
Clad 7075	2	3
Bare 7079	0	1
Bare 6061	1	2
Steel AISI 4340	1	10
Magnesium	10	5
Brass I	5	6
Titanium	0	0

FUELS SYSTEM COMPONENT COMPATIBILITY

Laboratory immersion tests of O-rings, seals, and other elastomer components showed essentially no greater deteriorative effect than JP-4. Similar data were obtained during a bench test performed under subcontract by the Allison Division of General Motors.

PUMPABILITY

It is necessary that fuel be pumped to the gas turbine engine, and that the emulsion not be broken should a pressure by-pass be used. Since emulsions are made by using moderate shear, it is conceivable that excessive shear could break the emulsion. This does occur with high speed centrifugals, suggesting either that a slow speed centrifugal be used or that a positive displacement pump be substituted. Pumped fuel retains the shape of the aperture, and, incidentally, the emulsion does not tend to spread on or stick to either metal or glass. Fig.3 shows this effect on an aluminum sheet.

ACKNOWLEDGMENT

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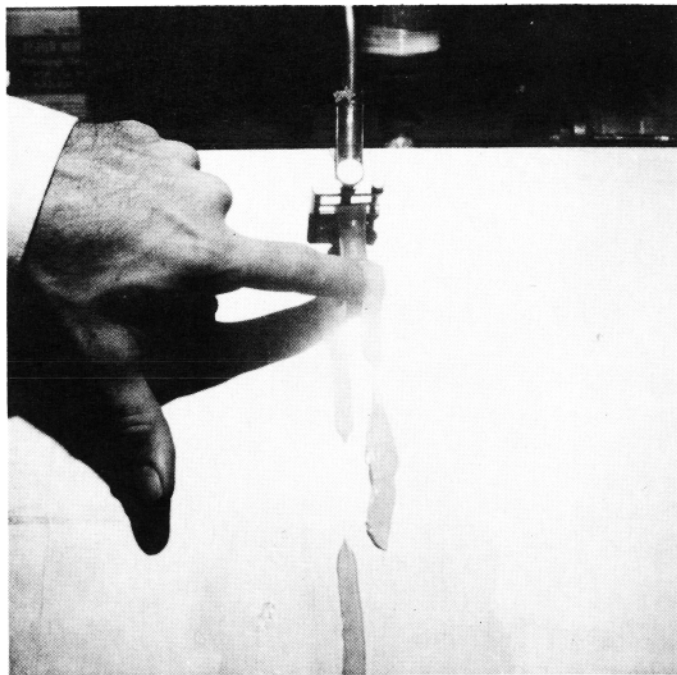


Fig.3 Pumped MEF emulsion

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