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PREPARATION OF BILIQUID FOAM COMPOSITIONS

(final report)

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I. APHRON TESTS WITH 2.5 L ENGINE

INTRODUCTION

Technology developed by the late Dr. Felix Sebba of the VPI Chemical Engineering Department by which an oil phase can be broken up into small droplets and encapsulated in a continuous water phase led to research on the possible merits of a fuel prepared by this procedure. The resulting mixture is called a polyaphron. Part I of this report describes the testing of polyaphronated gasoline in an automobile engine.

A baseline test using normal gasoline was conducted to obtain comparative data for tests using a gasoline-water polyaphron. The baseline testing was conducted using a four cylinder engine. Engine load was provided by an eddy current dynamometer. Nitrogen oxides (NO_x) emissions, total hydrocarbon (HC) emissions, and exhaust temperature were determined for various load and RPM combinations.

Similar tests were also run using polyaphronated gasoline. The theoretical advantages of polyaphronated fuels are as follows: reduced emissions of NO_x , reduced octane requirements, reduced gasoline consumption, and increased safety due to reduced flammability. (The fuel should be less prone to explosive fire in the event of a ruptured fuel tank.) One possible negative aspect of using polyaphronated fuels is increased hydrocarbon (HC) emissions.

ENGINE/DYNAMOMETER DESCRIPTION

Tests were conducted using an eddy-current dynamometer and a 1982 Pontiac 2.5 liter engine. This four cylinder engine is equipped with throttle-body, electronic fuel injection. The single throttle body

injector acts essentially as a carburetor. The fuel is injected past the throttle plate where it mixes with combustion air before entering the individual intake runners. The pulse interval of the injector is controlled by an electronic signal supplied by the electronic control module (ECM). The ECM monitors oxygen content in the exhaust, manifold absolute pressure, throttle position, distributor pulses, and engine temperature to determine the pulse interval necessary to maintain the stoichiometric air/fuel ratio of 14.7 to 1.

Fuel is pumped to the throttle body unit at approximately 12 psi. A pressure regulator in the throttle body unit maintains a constant fuel pressure to the injector by bypassing fuel to the fuel tank. The fuel passes through a plastic mesh pickup screen before entering the fuel pump. The fuel then passes through a fuel filter. The fuel is filtered again just before entering the injector. A pressure gage is installed above and below the filter to check for blockage and delivery pressure to the injection unit. A sight glass is installed above and below the filter to allow the condition of the fuel to be checked.

The engine is directly hooked to the dynamometer via a drive shaft from the flywheel. Therefore, the engine load and RPM are identical to the dynamometer load and RPM. The engine is cooled via a counter-flow heat exchanger. The stock thermostat controls flow to the heat exchanger, and the engine oil is continuously pumped through an air cooled heat exchanger.

TEST DESCRIPTION

Baseline tests were conducted using premium unleaded gasoline, the same gasoline later used to make polyaphronated fuel. Fuel consumption

rate (g/min), NO_x concentration (ppm), and HC concentration (ppm as methane) were noted for different engine load and RPM combinations. These combinations were based on road load and full load conditions.

Full load condition results were not reproducible due to poor engine performance. The engine/dynamometer also tended to overheat at full load. This was due in part to a flow restriction on cooling water to prevent flooding of the sump trenches in the lab. A recurring problem with exhaust leaks was worsened by full load/high RPM conditions. For the three aforementioned reasons, full load testing was discontinued.

Due to the problems with exhaust leaks, the exhaust system was modified twice. The present exhaust system includes a section of flexible exhaust pipe to prevent fatigue of the exhaust manifold. A new exhaust manifold and gasket was obtained from Pontiac Engine Operations. These two installations fixed the leakage problem.

Problems with the engine/dynamometer system caused testing to go more slowly than was anticipated. It was difficult to continually adjust the dynamometer to maintain a constant load/RPM combination while monitoring other engine data. The engine tends to over-speed at a given load setting as time passes. This causes drift in the fuel use rate and emissions data.

Road load conditions were based on a curb weight of 2500 pounds, a projected frontal area of 20 square feet, and a drive train ratio in fourth gear of 4.17:1. After repair of the exhaust system, speeds from thirty to one hundred miles per hour in ten mile per hour increments were investigated using approximately the calculated engine load and RPM. These combinations are shown below.

Vehicle Speed (MPH)	Engine Speed (RPM)	Engine Torque (ft-lb)
30	1251	19.7
40	1668	26.4
50	2085	34.5
60	2502	45.3
70	2919	57.5
80	3336	71.7
90	3753	87.8
100	4170	105.8

INSTRUMENTATION

A Bendix Model 8102B Oxides of Nitrogen analyzer is used to determine the NO_x emissions of the engine. The analyzer has a response time of approximately one minute. A sample pump on the analyzer draws a sample through the analyzer at a constant rate of 25 ml/min.

The sample is drawn through a cold trap and two filters in series. This ensures that a particulate-free, dry sample is supplied to the analyzer. Stainless steel or teflon tubing is used throughout the sample system to reduce NO_x adsorption and reaction. The analyzer is calibrated using 3100 ppm nitric oxide in nitrogen mixture.

A Horiba Model 22A Flame Ionization Analyzer is used to determine the total hydrocarbons emitted. The analyzer, sample, pump, and sample line are heated to prevent loss of high boiling point hydrocarbons and to reduce surface adsorption. The sample pump draws a sample from the exhaust pipe through a flow valve which reduces pulsations. The sample flows through two heated filters. A 0.3 percent mixture of methane in air is used to calibrate the analyzer.

Critical temperatures such as exhaust and oil are monitored using type K thermocouples. A data acquisition system reads the thermocouple output, dynamometer load output, and dynamometer speed output for computation and display by a computer.

RESULTS USING GASOLINE

Humidity and barometric pressure were monitored during testing to determine if fluctuations significantly affected test data. The effect seems to be negligible. Thus the data in the following graphs are not corrected to standard conditions.

The engine was unable to reach the one hundred mile per hour condition. This would have corresponded to the maximum rated power output of the engine.

The results of the baseline testing under road load conditions are shown in Figures 1-4. The average values are plotted against vehicle speed at road load for NO_x emissions, HC emissions, and fuel flow rate. Fuel flow rate per horsepower is also plotted versus vehicle speed (meaningless at idle). Speeds start at idle and increase to ninety miles per hour.

The measured NO_x concentrations decrease above sixty miles per hour. The NO_x emissions were found to be identical to NO emissions under the conditions that NO was checked. Hydrocarbon emissions decrease up to eighty miles per hour. Hydrocarbon emissions were highly dependent on the running condition of the engine. In near-stall situations, HC emissions increased by up to forty percent. The brake specific fuel consumption was found to decrease as speed increased up to eighty miles per hour.

RESULTS USING POLYAPHRONS

Preliminary tests using polyaphronated gasoline indicate a reduction in NO_x emissions by an average of ten percent at idle and an average of twenty-six percent up to sixty miles per hour. Total

hydrocarbon emissions increased by an average of eighteen percent. After correcting for the ten percent water in the polyaphronated fuel, the fuel was found to be burned more efficiently as evidenced by lower brake specific fuel consumption numbers.

However, the engine was just able to attain the sixty mile per hour load/RPM setting on polyaphronated fuel. At this setting, it stalled due to a lack of fuel pressure. The fuel pump resists pumping the polyaphrons because of the high viscosity and continuous water phase. The pump is designed to reject small amounts of water in the fuel. These problems could not be fully addressed within the resource constraints of the project.

CONCLUSIONS

Difficulties with the viscosity and separation of the water phase of the polyaphronated fuel have prevented complete testing at road load conditions. These problems increase with increased fuel consumption rate. Therefore, full load testing of polyaphronated fuel has not been achieved.

Baseline data for NO_x , HC, and BSFC for the 2.5 L engine have been generated at a range of speeds and loads. Initial tests with polyaphronated fuel showed NO_x reduction, HC increase, and worsened power output capability. Testing was hampered by the tendency for the polyaphrons to separate into aqueous and hydrocarbon macro phases, and this separation seemed to be due to passage through the fuel pump and/or its filter. Rather than continue with engine testing, a decision was made to do some bench tests of the polyaphrons to see the effect of various filtering processes on phase stability. These tests are reported in Part II of this report.

II. FLOW PROPERTIES OF POLYAPHRONATED FUELS

INTRODUCTION

Before polyaphron fuels are used in a conventional engine, significant experimentation should be conducted to determine how the mixtures will respond to pumping and filtration. Because the material is an emulsion, fuel filtration may cause the phases to separate, possibly resulting in interruption of combustion.

The purpose of this work was two-fold:

- o to measure the approximate viscosity and density of polyaphronated kerosine
- o to determine how polyaphronated kerosine mixtures respond to filtration.

VISCOMETER THEORY

The measurement of a Newtonian liquid viscosity can be made by allowing a liquid to flow through a small capillary tube while measuring the time for draining. The fully developed flow of a liquid through a small capillary tube is subject to the Hagen-Poiseuille equation for laminar flow:

$$Q = \frac{\pi d^4 \Delta P}{128 \mu L} \quad (1)$$

where Q is the liquid flow rate, d is the tube diameter, ΔP is the pressure drop along the tube, L is the length of the tube, and μ is the viscosity. If a reservoir is allowed to drain through such a capillary tube (Fig. 5) until the liquid level reaches the bottom of the reservoir, equation (1) can be integrated to give viscosity as a function of drain time:

$$\mu = \frac{-d^4 \rho g t}{32 L D^2 \ln(L/(L+H))} \quad (2)$$

In this Equation ρ is the fluid density, g is the acceleration of gravity, D is the reservoir diameter, t is time of draining, and H is the initial height of liquid.

A capillary tube viscometer was developed to measure the viscosity of polyaphrons, and filtration tests were also run. Procedures and results are discussed in the following sections.

PROCEDURES

1. Three mixtures of polyaphronated fuels (PVR-5, PVR-10, and PVR-15) were prepared in the Chemical Engineering Department for use in the experiment. The PVR, or phase-to-volume ratio, is the volume ratio of organic phase to aqueous phase in the mixture. All polyaphrons used in this experiment were composed of kerosine and water which contained several ppm of surfactant (sodium-dodecyl-benzene-sulfonate and Tergitol 15-S-3). The mixture compositions used in the experiments are presented in Table I.

TABLE I
Polyaphronated Fuels used in
Viscosity Experimentation

PVR	Organic Phase (Volume %)	Aqueous Phase (Volume %)
5	83.33	16.67
10	90.91	9.09
15	93.75	6.25

2. A syringe viscometer was set up with a 2" long, 0.101" inside diameter tube, as shown in Figure 5.
3. The polyaphron mixture was introduced into the viscometer and then allowed to drain. The drain time was measured using a stopwatch.
4. Step 3 was repeated for each of the polyaphron mixtures, and the viscosity of each mixture was determined by using equation (2).
5. The density of the polyaphrons was determined by measuring the mass of a known volume of each mixture.
6. Using the apparatus shown in Fig. 6, filtration tests were conducted with each polyaphron mixture, various applied pressures, and various filter sizes. In all filtration runs, 20 cm³ of polyaphron were filtered. Sintered metal (Nupro SS-4F) filters were used in all runs except No. 12. The operating conditions for the filtration runs are presented in Table II:

TABLE II.

Conditions During Polyaphron Filtration Runs

Run	Comments	PVR	Applied Pressure (psig)	Filter Size (micron)
1	Okay	5	4.0	15
2	slow, separation	5	4.0	2
3	slow, separation	5	4.0	2
4	negligible flow	5	9.2	1
5	slow, separation	10	4.0	15
6	slow, separation	10	4.0	15
7	slow, separation	10	4.0	60
8	quick, slight separation	10	4.0	90
9	quick, slight separation	10	6.1	90
10	slow, slight separation, air bubbles	15	4.0	2
11	faster than Run 1, slight separation, air bubbles	15	4.0	7
12	slow, slight separation	15	4.0	15

RESULTS

The results of the filtration tests consist of observations rather than numbers. These results are presented individually below:

- Run 1: Filtration proceeded quickly with no interruptions; no separation of phases.
- Run 2: Filtration proceeded slowly with immediate separation. Three phases result upon filtration, with the top being kerosine, the middle being polyaphron, and the bottom being water.
- Run 3: Repeat of Run 2; similar results.
- Run 4: Filtration did not proceed even with applied pressure of 9.2 psig.
- Run 5: Filtration proceeded slowly; leak developed around filter housing; filtered polyaphrons are similar to those of Run 2.

- Run 6: Repeat of Run 5; only two primary phases result, and the polyaphron is almost completely "broken."
- Run 7: Filtration proceeded slowly with immediate separation; filtered polyaphrons are similar to those of Run 5, but less pronounced; polyaphron phase (bottom) is more "puffy" than that in Run 6.
- Run 8: Filtration proceeded quickly with no interruptions; slight separation of phases.
- Run 9: Filtration proceeded quickly with no interruptions; slight separation of phases.
- Run 10: Filtration proceeded slowly, and still resulted in slight separation; resulting filtered polyaphrons contain air bubbles.
- Run 11: Filtration proceeded slightly faster than Run 9, and resulted in slight separation; resulting filtered polyaphrons contain air bubbles.
- Run 12: Filtration proceeded slowly with slight separation.

For the filtration runs which did not result in separation of the phases, the filtered polyaphrons compared well with the unfiltered polyaphrons when viewed under a microscope, showing no significant difference in size or structure.

The results from the density tests and the viscosity tests are presented in Tables III and IV. The temperature of the mixtures for all measurements was 23°C.

TABLE III

Polyaphron Densities

PVR	Mass (g)	Volume (cm ³)	Density (g/cm ³)
5	66.95	85.5	0.783
10	71.36	91.5	0.779
15	71.21	93.0	0.766

TABLE IV

Polyaphron Viscosities

PVR	Drain Time (s)	Viscosity (g/cm-s)
5	295.2	0.736
10	306.9	0.766
15	332.9	0.831

For comparison to Table III and Table IV data, the density of water is 0.997 g/cm³ and the coefficient of viscosity is 0.00926 g/cm-s. The fact that the measured polyaphron viscosities are two orders of magnitude greater than the viscosity of water indicates that fuel handling problems can be expected with conventional equipment. It is also possible that non-Newtonian behavior occurs with polyaphrons, but adequate resources were not available to explore this question.

The results of the filtration testing show that the lower PVR mixtures (lower volume percent of organic phase) were more subject to phase separation upon filtration. Furthermore, smaller pore sizes in the filter increase the separation. Upon filtration, the aqueous or continuous phase (higher volume percent in lower PVR mixtures) tends to

drain from the polyaphron structure, easily passing through the filter, while the organic phase (micron-sized kerosine droplets dispersed in the aqueous phase) remains on top of the filter. Because the aqueous phase no longer surrounds the organic phase, the kerosine droplets tend to coalesce and then pass through the filter. The result is a separation of phases. The presence of smaller pore sizes in the filter promotes increased separation of the phases.

CONCLUSIONS

This study has shown that the viscosities of polyaphronated fuels are much higher than that of water, gasoline, or kerosine. Special fuel handling equipment may be required in engine applications.

Separation into separate oil and water macro phases occurred to some extent during nearly all the filtration runs. Use of polyaphrons in practical situations will probably require equipment designs which can deal with some separation of phases. Additional work is required to determine the causes of the variable results of the filtration experiments.

Fig. 1. Tailpipe NOX Concentration
(fuel is unleaded premium gasoline)

Fig. 2. Tailpipe HC Concentration
(fuel is unleaded premium gasoline)

Fig. 3. Fuel Consumption Rate
(fuel is unleaded premium gasoline)

Fig. 4. Brake Specific Fuel Use
(fuel is unleaded premium gasoline)

Fig. 5. Capillary Tube Viscometer

Fig. 6. Apparatus for Filtration Tests

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