SPECIAL PRESENTATION

FIRE-SAFE DIESEL FUEL EMULSIONS

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INTRODUCTORY REMARKS

R. D. Quillen, Jr.

Messrs. LePera and Ecklund, long known for their modesty and generosity, have allowed me the privilege of introducing this subject. So, by way of introduction, I think that I should tell you the reason it is on the agenda. Many of you saw (at the end of August and the beginning of September) some reports by the news media (primarily the technical magazines) on the development of a fire-safe fuel by the Army. Some of these reports were a bit more complimentary about the (FSF) accomplishments than we expected them to be. In fact, we felt there may have been a few exaggerations about the accomplishments. Be that as it may, it did generate national publicity, and we found ourselves having to answer quite a few questions by phone.

There were some mistakes in the publications by the media, one of which was that there will be a conference held October 11-13 to discuss this fire-safe fuel accomplishment. We don't know how this interpretation appeared, but we had no intention at the outset of having this item on the agenda. But, since it is a conference and some of the attendees said that they would bring the subject up whether it was on the agenda or not, we felt obliged to show it on the agenda.

To report to you on this fire-safe fuel, we have divided the report into five pieces. The first report will be given by Mr. LePera, who will explain the Army program and the reason for the news release.

The second report will be given by Dr. Fodor, who is an organic synthesist and will report to you on the emulsion composition and on the way the fire-safe fuel is prepared.

The third report will be given by Dr. Weatherford, who is the leader of the team at Southwest Research Institute that developed the fire-safe fuel composition.

The fourth report will consist of comments by Mr. Gene Ecklund on DOE's thoughts regarding fuels of this kind relating to energy objectives.

The fifth report, if time permits, will be a report on the broader implications of fire-safe fuels as a hybrid fuel. I will give that report if there is time.

Regardless, we will try to complete these short presentations so that by 2:30, there can be an open discussion. So with that, let me introduce the first speaker who is Mr. Mario LePera.

FIRE-SAFE DIESEL FUEL EMULSIONS

M. E. LePERA, U.S. ARMY, MERADCOM

The US Army has produced a new hybrid diesel fuel called fire-safe fuel which is self extinguishing if ignited by incendiary projectiles or by accident. Although this fire-safe fuel is being developed for primary use in armored ground equipment operating in hostile enemy environments, its potential for reducing fires from highway accidents and from off-highway diesel operations such as in underground mines is very obvious.

This is not an overnight discovery but the result of a ten year R&D effort. The Army has been seeking a fuel which would be fire safe, stable and exhibit good performance in engines. United States combat forces would benefit from such a fuel through lives saved while also improving the survivability of combat equipment. A variety of methods have been tried in the past. Over the years these included fuel bricks, gels, fuel-in-water emulsions, inerting systems, halocarbon additives, and various kinds of water-in-fuel emulsions. The new hybrid fuel is practically clear and consists of up to ten percent water, six percent of an emulsifier additive, and the remainder diesel fuel. Its appearance is much like that of conventional diesel fuel. Preliminary laboratory and engine dynamometer performance tests have been successful and the fuel is now entering into a phase of advanced development.

The beneficial effects of added water on the combustion cycle have been reported for years in the open literature, but the method of dispersing the water and the stability of the mix have always been monumental problems. This new hybrid has proved stable for more than several months and experiments are continuing to learn the extent of its shelf life under a variety of temperature cycling modes.

Performance tests to date show the hybrid fuel can deliver approximately the same power as 100% diesel fuel. The fuel performs well in standard diesel engines without modification, and tests show a resultant reduction in diesel exhaust smoke. In addition, the fuel is self extinguishing at fuel temperatures below 170°F.

The self-extinguishing aspect of fire-safe fuel is explained in this manner. Most diesel fuels typically have flash points in the 125° to 150°F. range. ASTM D975 and VV-F-800B specify a 122°F. minimum for 2-D/DF-2 products. When heated to above its flash point, the diesel fuel creates a fire-threat problem for armored vehicles operating in battlefield combat environments similar to that when gasoline-fueled vehicles are being used. The heating of diesel fuel results from the commonly-used diesel fuel delivery recirculation systems (i.e., the fuel is used to lubricate the injector pumps/pintles/plungers and functions as a heat transfer fluid). Fuel tank return line temperatures have been recorded as high as 170°F. depending upon the level of fuel in the tank, outside ambient and mode of operation. For this reason, all our ballistic evaluations have been done with the fuel/mixtures heated to 170°F. before testing. These ballistic tests, to date, which involve use of 20mm High-Energy-Incendiary-Tracer (HEIT) and 3.5 inch Shape Charge projectiles have demonstrated that at fuel temperatures of 170°F., the fire-safe fuel is self-extinguishing.

The additive, which functions as an emulsifier/dispersant, is the key ingredient. This additive is a mixture of several chemicals, however, it can be produced from coal and agricultural sources which enhance the hybrid fuels potential to conserve petroleum energy.

The potential to conserve petroleum energy has not been accurately determined; however, there is a good probability that its conservation capabilities could be further improved by reworking the formulation for the specific purpose of conservation. It is for this reason that the Army chose to publicize this development so that organizations might begin work on the fuel for civilian application.

During this year, the optimization of the candidate fire-safe fuel will be finalized with attention being directed to the water quality requirement and fuel composition effects. Concurrently, full-scale laboratory dynamometer tests using military two-cycle and possibly four-cycle air-cooled turbo charged diesel engines will be completed for assessing long term durability effects and performance objectives. Since this effort involves the development of a total system, a prototype field mixing unit to prepare fire-safe fuel in the forward area is being fabricated. This prototype unit will be evaluated to assess its capabilities in blending, mixing, and delivering a fire-safe fuel possessing those optimized characteristics defined in laboratory fire-safe fuel blends.

For presentation at DOE's "Conference of Transportation Synfuels."

R.D. Quillian, Jr. (Comment):

You may not be aware of the very narrow technical envelope that we were working in to try to come up with this kind of fuel composition. Ideally, we wanted a fuel that would not burn unless metered into an engine. The objective was complicated somewhat by the requirement that these fuels must also burn satisfactorily as a heating fuel in camp stoves that the troops must use under combat conditions. So, we must provide a fuel that burns under ambient conditions with wick-type burning devices and yet must resist ignition from the severe combat fire that the vehicles are exposed to. So, there was really not much technical room to maneuver. The prime technical accomplishment was to get a fuel fit that would run okay in an engine, run okay in camp stoves, heat areas for the troops, and yet resist combat fire. I wanted to make that point to follow up the movie so you could appreciated what the accomplishment under Mr. LePera's program really has been.

FORMULATION TECHNOLOGY

G. E. Fodor
Southwest Research Institute

and

NARRATIVE: HEIT BALLISTIC TESTS

W. D. Weatherford, Jr.
Southwest Research Institute

FORMULATION TECHNOLOGY

G.E. Fodor

Past

The first aqueous diesel fuel emulsions prepared at our laboratory were stabilized by Atlas Chemical Company's Span-80 and Tween-80, used at a 9:1 volume ratio. These macroemulsions were stable for close to a month at ambient temperatures. Their properties and performance characteristics were described by Messers. Owens and Wright at the Coast Guard meeting in April of 1977. We found, however, that this surfactant mixture introduces high thermally-induced depositing tendencies. It became our primary objective to make more stable emulsions with depositing tendencies that are no worse than those for the neat diesel fuel.

Selection

We contacted a good number of surfactant manufacturers, described our goals to them, and asked them to send us their best candidates for our application. We received well over a hundred candidate systems. During the initial phase of our screening program, we were looking for emulsifying agents that give a microemulsion in a military referee grade diesel fuel.

The screening process lead us to the oleyl diethanolamide family of emulsifying agents. One mole of oleic acid is reacted with two moles of diethanolamine. The product consists of three major ingredients: the oleyl diethanolamide, the excess unreacted diethanolamine, and the soap that arises from reaction between the unreacted oleic acid and the diethanolamine. As you know, oleic acid is a nonpetroleum product, obtained by the hydrolysis of animal fats and oils and from tall oil, a byproduct of the wood pulp industry. Diethanolamine, the other starting material in the synthesis, need not be a petroleum-derived material. It is made by the ammonolysis of ethylene oxide. Ethylene oxide is made by oxidizing ethylene. While ethylene is thought of as a petrochemical, it may also be made by dehydrating ethanol, an agricultural product. The emulsifier, having a heat of combustion of approximately 75 percent of that of the neat diesel fuel, is, therefore, capable of extending petroleum products in an engine while helping to provide for fire safety in the fuel. Several companies market this kind of mixture for the cosmetics industry, but—to our surprise—we found that some of the products work better than others. The difference appears to be in the purity of the starting materials and/or the product. Our primary sources for the emulsifying agent are Scher Chemicals, Inc. of New Jersey and Clintwood Chemicals of Illinois.

Modifications of Emulsifying Agents

The commercial-grade emulsifying agents worked well in the presence of deionized water. However, if San Antonio tap water, with a total dissolved solids content of about 300 ppm, was used, the commercial emulsifiers produced a white sediment in the emulsion. The same result was obtained if a high molecular weight hydrocarbon antimist agent was incorporated into the emulsion. Both of these shortcomings were defeated by increasing the soap content of the commercial products by reacting some of the excess diethanolamine with up to 7 percent of oleic acid. When this modified emulsifying agent is dissolved in the diesel fuel, and water is stirred into it, a stable microemulsion results. Span and Tween produced an opaque aqueous macroemulsion with diesel fuel. In contrast, the new surfactant produced microemulsion at the same 10-percent water concentration ratios.

Candidates

We now have two alternate fire-safe diesel fuel candidates. One of the candidates contains 10-percent water and 5- to 6-percent emulsifier in the diesel fuel; the other contains one-half water and one-half surfactant, but it additionally contains 0.2 wt percent polymeric antimist agent.

Blending

Blending of the several components is accomplished by simple mechanical mixing, with no need for energy-intensive homogenization.

Problem Areas

The problem areas are the influence of fuel-component effects, as the emulsifier's composition may need adjustment to accommodate all grades of diesel fuels; and optimization of the surfactant package for best performance in terms of the emulsion stability, engine power output, engine exhaust emission quality, and price. Dr. Weatherford will now narrate a movie demonstrating the fire-safety characteristics of this emulsified hybrid diesel fuel.

NARRATIVE: HEIT BALLISTIC TESTS

W. D. Weatherford, Jr.

The following color motion picture illustrates 20-mm HEIT ballistic tests conducted at SwRI by the U.S. Army Fuels and Lubricants Research Laboratory with neat diesel fuel and two fire-safe fuel candidates, all at 170°F, which is 25°F hotter than the flash point of the base fuel.

In the case of the base fuel, the 20 gallons of fuel produce a huge transient fireball which approaches the movie camera located about 50 ft from target. The ensuing ground fire completely fills the target enclosure (which is approximately 18 ft wide, 10 ft tall, and 10 ft deep), and it develops intense vortex activity.

When the fire-safe fuel candidate containing 10-percent water, as a microemulsion, is heated to the same test, a detectably smaller transient fireball is formed, and the resulting ground fire self-extinguishes in a few seconds.

In the case of the fire-safe fuel candidate containing only 5-percent water, but also containing 0.2-percent polymeric antimist agent, the transient fireball is even smaller, and the initially smaller ground fire self-extinguishes even faster.

DOE PARTICIPATION

E. Eugene Ecklund

Thank you. I will make comments with regard to two portions of this. First, it is an academic situation, but it relates to the press releases and Murphy's law in action. The second portion would relate to our particular DOE interest.

There were several things that came together about the same point in time. As a result of the work that has gone on by Southwest Research Institute for the Army on this fire-safe fuel, the people at SwRI came up with some ideas on what is now termed hybrid fuels. Roy will speak on that in a few minutes.

We recently awarded SwRI a contract on the hybrid fuels to take advantage of the work that they had done with the Army and to carry them in some advanced directions. About the same time, the Army and SwRI got together on a publicity release. In actuality, when that came about, Roy Quillian contacted me and suggested the possibility of a joint release with the Army. We made some preliminary arrangements with the Army and SwRI for the release. The Army sent a proposed press release to DOE, but it got lost in the system, and our people couldn't find it. In the meantime, the Army write-up was released. Notice of our contract award was made about the same time, and an enterprising writer apparently did his job very well. He also found that this conference was going to be held. He put all three of these things together and started checking them all out. I don't know how many people he talked with, but he did talk to me, Roy Quillian, Mario LePera, and several other people. We all told him about the same thing. Here is where Murphy's law comes in. Without checking it out, I put two and two together and this is what I come up with. (I hope I am not doing the gentleman an injustice). Apparently, in addition to being a writer for Business Week, he was also a stringer for an energy digest. He came to us and we set him straight, particularly in reference to this conference which was a key point. We told him that there was no relationship between this conference and that particular fuel. It was Don Gray who tipped me off to the thing. He called up and wanted to know what was going on. This energy digest had already hit the street with the story. So, I suspect that as a result of that, the writer could not very well change his story in Business Week. So at any rate, that is how this misinformation got through the system.

In DOE, diesel fuels are of great concern to us. If we look down the line on things we need in alternative fuels, there are some short-term approaches as far as gasoline is concerned. Alcohol, for example, is a suitable fuel. It bothers us a great deal that we don't have very many options as far as diesel applications are concerned. In recognizing that our whole transportation system of goods in both rail and trucks moves on diesel fuel, we get concerned about diesel alternatives. This emulsified diesel fuel is therefore an attractive possibility.

We are interested in this emulsified fuel to the extent that it may save petroleum energy, and it may be economically competitive, but there is a long way to go to establish its potential. With regard to this fuel, we are really riding piggyback on the Army, and the Army is continuing with some fuel test work. Southwest Research Institute will certainly pick up those Army aspects that might be applicable to the civil sector. So, in essence, our contract with SwRI will supplement the work of MERADCOM.

What we are trying to do under the SwRI contract is to prepare fuels that can now be made and to prepare them with the technology that now exists. If you will recall the presentation that Ralph Fleming made yesterday, you will remember that this hybrid fuel is listed under the category we call advanced fuels. If we meet some of the optimistic projections that the people here at SwRI feel may be practical, then we can consider such fuels as part of our "new hydrocarbons" category. Under the right circumstances, we could move hybrids into a higher priority situation, but at this stage the hybrids are part of what we call our more speculative advanced fuels.

With that brief background, I will turn it back to Roy, and he can pick it up from here.

HYBRID FUEL SYSTEMS

R. D. Quillian, Jr.

I have two or three viewgraphs selected at random that may give you an idea of the broader implications that we visualize in hybrid fuels. At the same time, it can perhaps give you an indication of the scope that we have planned in this new DOE contract that Gene Ecklund just mentioned to you.

When we talk about hybrid fuel systems, we are talking in essence about a witch hunt—for shelf-item materials that are available today or, at least, for materials that we can recognize will be producible tomorrow—materials that do not need much additional process research. Such materials are charcoal, blacks, water, alcohol, cellulose, starches, and various other materials that either influence the combustion process or which will otherwise burn. We feel that these materials can be put together through the benefit of chemical additives. In most cases, some kind of broker-chemical is going to be required for a composition that will mix with petroleum fuels and thus make the hybrid fuels that Gene was talking to you about. It could result in a petroleum and carbon slurry, or it could result in the fire-safe fuel that you just saw, or in other compositions. The fire-safe now has a headstart toward becoming an operational fuel, as no process development work is required.

We feel that our hybrid project, while a bit Edisonian, could lead to unconventional advanced fuels that have no petroleum composition in them at all. We feel that this project is one of the first that seeks to define new fuels for highway transportation in three basic categories—two of which are still not too well recognized. These categories are the petroleum fuel category, a hybrid category (which means the mixture of nonpetroleum components with petroleum), and a nonpetroleum category. We feel the second and third categories have really gone unexplored. There are many possible finished fuel compositions that have yet to be brought to the forefront, put together with petroleum compounds, and evaluated. What we seek from this research are fuels that are not only energy efficient, but which may have several other lucrative features. I might add that there is not much of a technology base in this country for the development of hybrid fuels. There simply are not many people in the nation who are working on the formulation and composition of nonpetroleum components with petroleum components and have the chemistry background it takes to make these components compatible.

At any rate, these are some of the possibilities we feel that might come about from this kind of hybrid fuel research and development—and not necessarily from our project for DOE. Instead, I am speaking to you on behalf of hybrid fuels as a class and what they may develop to be at some time in the future. This relates somewhat to Dick Pefley's statement that fuels of the future should not be thought of as a step backward or as a fuel that is worse than the ones we have now. Here, in hybrids, is an opportunity now to find fuels that perform in excess of today's fuels.

Our immediate program for DOE will investigate the Army's fire-safe fuel composition for its possible conservation of petroleum fuel supplies. As you recall, only 84 percent of this fire-safe fuel is petroleum. In our experience (and we will be able to discuss this in just a moment), we have seen implications that you can actually conserve some petroleum, but we don't know how much. But we certainly want to discuss that with you.

We recently observed from work in our engine laboratory that smoke is reduced when using the fuel. This observation simply correlates with the work of a number of other investigators of macro, as well as micro, water-in-fuel emulsions. We have also observed an improvement in diesel engine efficiency. We are referring here to the actual thermal efficiency of the engine as a function of fuel heating value. We have detected improvements in thermal (or work cycle) efficiency ranging from near zero to as much as five percent. This correlates fairly well with the work of most other investigators, so we are not making any unusual claims in that regard.

We know, of course, that the water doesn't

burn, and we know that it is not penalizing the work cycle. It may therefore serve during critical shortages to derate diesel engine power. We don't really know how much fuel might be saved by derating, but this is a possibility that has not been investigated in any detail. We can visualize that a 200- or 300-horsepower diesel tractor engine might be derated to, say, 250 horsepower by using this technique. We are not proposing that such a derating technique would conserve petroleum, but it does represent an approach.

I have additional slides and could talk about this more, but I think there are some people who want to initiate some discussion on the subject. So, I will stop at this time and open the floor for discussion.

OPEN DISCUSSION

Question:

Does the water affect the cloud point and the pour point of the fuel?

Response (Fodor):

It doesn't seem to affect the pour point. However, the cloud point is usually obscured by the haziness of the microemulsion.

Question:

Have you conducted filterability measurements below the freezing point of water?

Response (Fodor):

At the time we made the test, the fuel had a pour point of -23°C. So, in order to test this effect, we used a JP-5. Dr. Mannheimer, who is in the audience, conducted the filterability tests. He was able to go to -18°C before the filter plugged. The fuel passed through the filter satisfactorily and, even though the water was presumably frozen, the filter did not show any effect until approximately -18°C. That test was made with a Span/Tween emulsifier. The particles we are working with now are even smaller. This work will continue in the coming year, and we will redo some of the filtration work in the 5- to 15-micrometer range.

Question:

From an unknown regarding stability and phase separation of the emulsion, and also about the possibility of corrosion and rust caused by the mixing water.

Response (Fodor):

In answer to the first about stability, at room temperature no fuel separation has been observed. In temperature cycling, we have conducted two different experiments. One experiment involved 3°-55°C temperature cycling. We conducted six test cycles with no fuel separation. If heated to 77°C, microemulsion becomes a macroemulsion. It looks about like the fuel sample we have had on display here. It becomes white in color and is likely to separate. If allowed to cool to room temperature, it becomes a homogeneous system again. I seem to recall that the base diesel fuel had a pour point of -23°C. If the microemulsion is rapidly cooled to the same temperature and held there for an hour or two, it will freeze. When allowing it to return to room temperature, it again becomes a microemulsion with no evidence of separation. If, however, the cooling is done slowly, fuel separation has been observed to occur.

Question (Quillian):

Do you feel that this composition would accommodate normal climatic and vehicular temperature extremes without separation?

Response (Fodor):

I expect so, but I don't know what would happen in the Arctic. In San Antonio, it most certainly would work. With regard to corrosion, we have completed only two tube-type tests. One is the standard copper strip corrosion test which the fuel passes with flying colors. The other one is the Navy corrosion test which also indicates a pass. The emulsion is, nevertheless, corrosive in the presence of copper, even thought not indicated by the tube tests. We are checking corrosivity with alloys from aluminum to bronze to brass as well as with copper and steel.

Question:

Are there any hard data that you can make available to us to show the results of your engine testing with these fuels with respect to the variety of emissions that we are concerned with, and specifically particulates?

Response (Quillian):

Yes, we would expect to be able to report some limited data to you, and we have fairly good single-cylinder engine experience with this fuel.

The results we have observed so far in terms of performance correlates quite well with the work of other investigators. By other investigators, I am talking about most of those who have reported at various conferences such as the one recently sponsored by DOT at Cambridge, Massachusetts.

I believe Mr. Walters of DOT is here in the audience somewhere (yes, there he is), and he is, in my judgement, an expert on the performance of the various emulsified fuel compositions in diesel engines. Perhaps he will comment later.

We've weighed our results against most of the work that was reported at the DOT conference. We have also loosely canvassed the literature (including some GMRL reports), and we find nothing adverse with our data. So, when we do publish our work, it will not be startling. I can tell you now that our results appear to be pretty much on dead center with the literature. The thermal efficiencies that we have seen in the literature are not unusual. We have also observed reports of reduced BSFC which can be translated into thermal or work cycle efficiency improvement. We have seen this variable in our own experiments range from 0- to about 5-percent improvement at the most. We have seen very few occasions, if any, where we have had a penalty in work cycle efficiency when using up to 10-percent water concentration. Invariably, there is a reduction in smoke which is one of the good results. Most investigators have also reported a smoke reduction using various smoke-opacity measuring systems. To convert the smoke measurements into something like percent values, I would say that a 25- to 50-percent reduction in smoke is observed (without rack adjustment to increase power). I am taking some liberties in reporting this data, and it may stand corrected later.

We have found either a decrease or an increase in NO_x. If you do get a decrease in NO_x (and unfortunately we have not seen as much decrease as we would like to see), it is usually with higher water concentrations.

The occasions when there have been increases in NO_x can almost invariably be traced to the use of additives that include nitrogen in their makeup. Such additives give the equivalent of fuel-bound nitrogen, which we all know is a big contributor to NO_x.

Your several other questions relate to injection pump wear and emissions. I can only report to you that we have completed a 250-hour endurance run on a single-cylinder version of the military's AVDS-1790, 12-cylinder tank engine. We are just delighted to have completed an endurance run of that length because it was that run that gave Mr. LePera the confidence that it was okay to issue a news release in behalf of the Army.

Insofar as our experience goes with injection pump performance during that test, we were observant only to the extent that the engine delivered power. It did produce satisfactory power without depreciation, and we were delighted with the overall performance of the engine. We took only cursory emission measurements, so I cannot comment on particulates or other emissions properties.

Comment:

Roy, I would like to make a suggestion. One of the things that drew us to this conference was the press release on the fire-safe fuel. We are very much surprised to learn of the apparent improvement in fuel consumption. Of course, this is the aspect that really caught our attention because we have some experience with specific fuel consumption from water inducted into the intake manifold and also with fuel emulsions. I would like to make the suggestion that in evaluating the effectiveness of these emulsified fuels, that you consider running what we call "time swings" so that you can get a trade-off between NO_x emissions and fuel consumption. We have done that in connection with our emulsified tests, and, invariably, we have found that the emulsified fuel gave us poor performance.

The only case where water in the combustion system actually helped us in respect to both efficiency and emissions was when we had separate injection of the water.

Response (Quillian):

You are referring to the work of your company by Valdmanis and Wolfhurst. You ran your emulsions at concentrations of 20-, 33-1/3-, and up to 60-percent inducted water, and I believe you used an in-line homogenizer for the emulsion. I also recall that your emulsifier was furnished by

Eubanks. Is that right? That's right! Okay! You reported at that time a 0- to 2-percent gain in BSFC using 20-percent water, a 0- to 5-percent gain using 30-percent water, and these were with emulsion dropsizes that were not recorded. I don't know much more than that, but our experience seemed to have correlated quite well with the reports by your laboratory. We cannot, of course, go into too much depth on this comparison of results. We are hopeful, however, that meetings like this conference might help stimulate the engine manufacturing industries to go ahead and take better looks at hybrid fuels such as these and publish as Cummins has done. The result will be a better consensus in the literature because we, as one laboratory, can conduct extensive research and still offer an opinion from only one laboratory. We feel like it is going to take more than this to get a better handle on it.

Since this meeting started, I've now learned that we have further reduced our data from the single-cylinder AVDS-1790 engine run and can now report more confidence in data that I just gave you. We are confident, now, that our engine gave between 2- and 3-percent improvement in thermal efficiency. We were unable to make that conclusion from the traditional oscilloscope instrumentation and the other data-acquisition equipment we used in the engine test cell. We came by this figure by using the total quantity of fuel consumed throughout the 250 hours and the cumulative horsepower recorded for a back-to-back comparison with diesel fuel. This treatment of data, while rather elementary, is nonetheless a very accurate measure of thermal-efficiency improvement; including the entire test period of 250 hours results in cumulative data that should be accurate. We know how much total fuel was used, and we know much horsepower was produced on a cumulative basis. So, unless I stand corrected by Ed Owens who was the engineer in charge of that project, I believe that should adequately summarize our experience with thermal efficiency.

Now, I want to give John Deere a chance.

Question:

You answered most of the questions I had. But I just want to check one point. Do your performance figures refer to one gallon of diesel fuel versus one gallon of the mix?

Response (Quillian):

No, sir. We should have cleared that up to begin with. We are talking about the heating value of the neat diesel fuel as compared to the heating value of the hybrid fuel including the mix as well. To state it another way, if you put this fuel in your diesel truck, you will get less miles per gallon... (tape was distorted)...gallons of water won't burn, it has got 10 percent water in it. But you don't lose 10 percent of your mileage, you only lose about 6 percent, you see. That is how you get the work cycle improvement. We are including the emulsifier factor because that is part of the heating value.

Question:

Your Institute publication on the fuel, which is being distributed at the registration desk, states that economy may be improved 10 percent. Can you explain this figure?

Response (Quillian):

Did you notice the word "may"? The statement in our paper did not refer specifically to this formulation, but the broader application of this particular technology does show promise of doing that. We have not yet attempted to reformulate to the best petroleum fuel economy, but I suspect that the 10-percent figure might be a fairly conservative estimate to make. My compliments go out to our own public relations people who wrote that article. They have a way (you people have public relations people too) of taking your words and making them read even better than you intended.

Question:

Regarding toxicity of the emulsifier (exact question unknown).

Response (Quillian):

It has not been tested. I will give this question to either George or Dub, but we don't expect any problem. Let me say that if you are worried about that, you had better be concerned about what brand of shampoo you use too, because this is one of the active ingredients of hair shampoo.

Question:

...10 percent water, you have a fuel there. The vapor is kept from coming out. You seem to surround the liquid fuel with the water so it can't burn. Is this the mechanism, or what is the mechanism that you think you have?

Response (Quillian):

You have just defined one of the problems with the national effort to develop alternate fuels. We need more basic research of that kind, and we are unable to suggest to you at this time what the chemical kinetics of combustion inhibition are. We can only speculate. Dr. Weatherford appears ready to do some speculation now.

Answer (Weatherford):

We became interested in this subject when the Army was looking at the use of 5 liquid vol % of bromochloromethane dissolved in diesel fuel as a way of rendering it nonflammable. As most of you know, there is a controversy as to the mechanism of even how the halogens work in preventing ignition or combustion. All of our data strongly indicated that the halogen worked by a physical mechanism either by heat-sink effects or by vapor blanketing. When the bromochloromethane program was coming to an end, we believed at that time it was a physical effect, and we figured that water might be as good or better than halogens. So, we tried the water. It gave us somewhat better suppression which suggests that it is a physical heat-sink and/or vapor-blanketing effect. But basic research is needed to answer this question adequately.

Question:

I want to get back to the fuel consumption again! Have you tried to look at the fuel consumption of the total system including the emulsifier? This includes the energy required to make the emulsifier. I took the *Business Week* article and made some calculations from it. If you are putting in diesel fuel at, say, 40 cents per gallon and save 5 percent of it because of improved thermal efficiency, that is about 2 cents per gallon. Now, according to the article, new diesel fuel will cost about 21 cents per gallon more. That means that about 34 cents of it is fuel and about 27 cents is emulsifier. So, we are paying almost twice as much as we did before. Now, if in making the emulsifier at 27 cents, say 10 percent of that cost is an energy cost, then we are using 2.7 cents just to make the emulsifier, and we have a net loss of Btu's rather than a net gain.

Response (Quillian):

That is a very good point, John, and something that we have not given enough thought to. Let me say again that the object of this program is to develop a fire-safe fuel composition for use in combat vehicles. You can afford some energy and cost intensiveness in doing this because our country does not get into combat very often. We are not advocating this composition as one that is either energetically economic or monetarily dollar economic. If you take the cost of these emulsifiers and add the low cost of water and the cost of the base stock of the fuel, you end up with the fuel composition in the 70 or so cent per gallon range as compared with 50 cents per gallon diesel fuel.

Insofar as petroleum energy is concerned, I don't want to appear extravagant. But if you can obtain this product from nonpetroleum energy sources using nonpetroleum energy to make it, then perhaps we can indulge ourselves on a cost basis for some period of time with the satisfaction that it is not consuming petroleum energy. That is about the best way I can squeeze out of that question.

Comment (Ecklund, DOE):

The comments made on both sides are very pertinent, John. As you can appreciate from the Army point of view, their goal was something different from what ours may be. If you remember my introductory remarks, I alluded to this situation. We, in DOE, are extremely sensitive to the net energy situation and in no way would we move ahead with an energy loss. But Roy has a point here due to the fact that one can at least consider the possibility of of using other forms of energy in place of petroleum. At this stage of the game, I

think that we still don't know really what this project has in store for us other than the fact that we can piggyback on the work done for the Army.

Question:

Pertaining to SWRI plans to publish on the work...

Response (Quillian):

I rather imagine that our future publications will be in bits and pieces at various technical societies because of the wide scope. There is the equivalent of a chemical product development activity here in our work on the emulsifiers. There is the base fuel formulation effects which is a subject of its own. Then the influence of the finished fuel properties on engine performance is still another area, so we will probably make some future publications, with Mr. LePera's permission, through the various technical societies such as SAE, ASME, and especially through The Combustion Institute where we have already published some of our prior work on emulsified fuels.

Question:

I assume the reaction products between the oleic acid and the diethanolamine is a basic aqueous solution. Or is it acidic?

Comment (Quillian):

We are going to cut the question period off at this time. I simply want to say on behalf of the team that has been working on the fire-safe fuel composition for quite some time that we appreciate the freedom that has been given us by MERADCOM under the management of Mr. LePera, who was your first speaker. We also appreciate the freedom to talk about it as we have done this afternoon, Mario, and I wonder if you have any summary remarks that you would care to make. After those remarks, we will have a coffee break.

Response (LePera):

I just have one comment to make. From what you have seen, I don't know whether the impression is that this fuel is going to be in the field tomorrow. Our current projections call for this total system to be put into the field by 1984 or 1985, at the latest. We have lots of work to do yet in terms of coming up with the total system that will actually deliver the fire-safe fuel to the troops in the field.