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SECOND SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTION

Robert Walter, Editor

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract This volume contains the proceedings of the second symposium on water-in-fuel emulsions held at the DOT Transportation Systems Center September 12 and 13, 1978. This symposium, sponsored by the DOT's U.S. Coast Guard and Research and Special Programs Administration, provided a forum for researchers involved in the use of water-in-fuel emulsions in combustion. Participants from academia, industry, and government contributed papers and discussed the properties, production, and utilization of water-in-fuel emulsions in boilers, diesels, and gas turbines. These proceedings contain the abstracts of 19 papers as well as the discussions on these papers and recommendations for needed research in emulsified fuel technology. Also included is a list of attendees.

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PREFACE

A symposium on water-in fuel emulsions was held on September 12 and 13, 1978 at the Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts to provide a forum for researchers in the use of water-in-fuel emulsions in the combustion process. This symposium was the second held on this subject; the first one was on April 20 and 21, 1977. The Proceedings from that symposium are available through NTIS (Report No. CG-D-12-78). Through invited paper presentations and subsequent discussions and comments among the symposium participants, valuable information was made available relative to emulsions in combustion and their practical application in boilers, gas turbines, and diesels.

The proceedings described in this document include abstracts of paper presentations, question-and-answer periods, and comments on the significance of the respective papers. The transcribed statements attributed to presenters and participating attendees have been edited, but only for clarification of the transcriptions.

Identification of the participants in the discussions and clarity of meaning in their statements often depended on the judgment of the editor. The editor apologizes for any misrepresentation or misinterpretation occasioned by this practice.

The editor acknowledges the United States Coast Guard as originator of the idea for setting up the symposium, and the DOT/Research and Special Programs Administration for support. He also thanks all contributors of invited papers, and all the attendees for their presence at the symposium and participation in the discussions. The contribution of Leon Tritter, Raytheon Service Company, in the preparation of this document is likewise greatly appreciated.

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SESSION 1

PHYSICAL AND CHEMICAL PROPERTIES OF EMULSIFIED FUELS IN COMBUSTION

Introductory Statement - Robert Walter, Symposium Chairman

Good morning. I am Robert Walter of the Transportation Systems Center of the U.S. Department of Transportation. I welcome everybody here to our second symposium on emulsified fuels in combustion. We had a very successful symposium last year, and judging by the number of people here today, I am sure we are going to have a very successful one this year. I now introduce the Director of the Transportation Systems Center, Dr. James Costantino, who will open these proceedings. Dr. Costantino.

WELCOME

JAMES COSTANTINO

Thank you very much, Bob.

I am glad to welcome you to the Transportation Systems Center. I recognize a number of you as having been here before. In fact, I think I may have seen many, maybe most, of you here last year at our first water-in-fuel emulsions conference.

This conference is sponsored jointly by the Coast Guard, Federal Railroad Administration, and the Research and Special Programs Administration. The Research and Special Programs Administration is a new administration in Washington; it has within it the Transportation Systems Center, Transportation Programs Bureau, and the Material Transportation Bureau. Formerly separate organizations, they now are all included in one administration headed by Dr. Jim Palmer, a former President of Metropolitan State University in Denver.

The purpose of these annual symposia is to bring together scientists, engineers, and others from government, industry, and academia to share their knowledge of the most recent advances in the production, combustion, and testing of water-in-fuel emulsions. We at TSC are extremely pleased to see this particular group here.

The Transportation Systems Center has been conducting extensive experimentation on the use of water-in-fuel emulsions in gas turbines and diesel engines as well as in boilers. Sponsored by the Coast Guard, this research has taken place in the Environmental and Test Programs Division of TSC's Office of Energy and Environment.

I am aware of your full schedule for the next two days, so I will take only a few minutes to present an overview of what the Transportation Systems Center is all about.

We are the Department's only multimodal transportation research, analysis, and development center. We have an annual budget on the order of $60 million and a staff of approximately feel free to visit and to communicate. During the day there will be plenty of opportunity to talk. I understand there will be a reception this evening; this will give you another opportunity to meet your colleagues socially, and I hope you will take advantage of that.

It is my pleasant duty, after welcoming you to the Transportation Systems Center, to introduce our first speaker, Admiral Benedict Stabile, Chief of the Coast Guard's Office of Engineering in Washington, D.C. Admiral Stabile is a graduate of the Coast Guard Academy Class of 1950, and also a graduate of the Massachusetts Institute of Technology, that "trade school" just across the street on our eastern border. In addition to being a qualified engineer, whose career in the Coast Guard has centered chiefly in the engineering field, he is also one of few admirals, and certainly one of the very few in the Coast Guard, who are also rated as shipboard commanders. He has, in fact, commanded a major Coast Guard cutter. This is indeed an unusual combination in the Coast Guard, and as I have already suggested, in an admiral. I am sure we will be seeing a lot more of Admiral Stabile in the years to come. It gives me great pleasure to introduce Admiral Benedict Stabile.

INTRODUCTORY REMARKS

RADM B.L. STABILE

Thank you, Dr. Costantino, for the introduction. I am here today actually representing Admiral Manning, our Chief of the Office of Research and Development. Admiral Manning deeply regrets not being able to be here for this conference, but he was called upon to head a promotion board for the selection of Commanders for the rank of Captain. Since that function in the military takes precedence over all other activities, Admiral Manning asked me to deliver some comments to you this morning. Basically, these are his remarks; and before I proceed with them, I would like to talk to you a bit more about myself.

I am a naval engineer by profession, with an electronics background; the rest you have heard from Dr. Costantino. I also served as Commanding Officer of the Coast Guard Shipyard at Curtis Bay.

I am pleased, on behalf of the Coast Guard, to welcome all of you to this TSC symposium. The success of last year's symposium and awareness of developments in the field of emulsions prompted the Coast Guard to suggest that a second symposium be held.

Research and the application of water-in-fuel emulsions to combustion systems in support of the Coast Guard's energy conservation program represent a small but important part of the overall operations performed by TSC for the Coast Guard. Here is a brief outline of what TSC is doing for us right now:

a. Studies on improved communications, improved location techniques, systems known as EPRBS

b. Use of satellites for search and rescue

c. Hose inspection technique program for deep water ports. In this program, hoses will be tested in a nondestructive mode prior to installation in the facility.

no corrosion or other deleterious effects are noted in either boiler or diesel engine applications. Frankly, from the engineering viewpoint, I would like to see a greater number of tests and more data from the test results before accepting these claims. I have to be convinced that we can put it into the field, and, in fact, reap the benefits that we think we are going to reap.

Perhaps the greatest advantage in burning emulsions lies in the substitution of low-quality fuels for high-quality fuels. As we all know, there is a very large inventory of industrial furnaces, heaters, boilers, diesel engines, and gas turbines which are designed to burn the higher quality fuels. The cost of replacing these machines to burn lower quality fuels is prohibitive. At least, from what I have been told, I would assume so. The potential for being able to retrofit or modify a very expensive plant to burn lower quality fuels is very attractive.

The Coast Guard became interested in water-in-fuel emulsions about three years ago after it became aware of the advances attributed to these emulsions with regard to improved efficiency and emission reduction. Concern for emission reduction is so great that one Coast Guard skipper was actually brought to court for making too much smoke in port. Still another was hauled into court for polluting one of the Great Lakes. Our sailors have a direct interest in this matter.

Consider the following data, which will give you a greater insight into the Coast Guard point of view. The Coast Guard fleet consists of about 250 cutters and 2,000 boats. The majority of these cutters and boats use diesel engines for main propulsion. Many have diesel-powered generators. Some have auxiliary boilers. We have, at the moment, five steam-propelled high-endurance cutters, but they will be phased out shortly and replaced by newer diesel cutters. Now, at a fuel usage reduction of five to ten percent, the use of emulsions for both diesels and boilers could result in a fuel saving for us of several million gallons per year. This is on cutters alone. A large saving in the symposium, our diesel test results, and awareness of field applications by others caused us to change the direction of our program from laboratory research to systems demonstration.

In 1979, if current testing is successful, we expect to demonstrate the advantages of emulsions on board some of our 82-foot patrol boats powered by Cummins diesels and 95-foot patrol boats being re-engined with General Motors diesels. They formerly had the same engine as the 82-foot boats.

Our interest has expanded to the boiler systems. A demonstration is being planned for a boiler at the Coast Guard Academy in New London. This application to shore boilers is an attractive one, though benefits seem indirectly related to cleaner firesides and reduced excess air. It does, or we hope it will, result in longer intervals between soot blowings, reduced stack emissions including smoke, less maintenance, and, we hope, improved economy. If these benefits relating to the shore plan can be obtained at locations, for example, such as Kodiak, Alaska, one of our largest shore installations with an annual fuel consumption of over three million gallons, or even at a location such as Yorktown, which has an annual fuel consumption of about one million gallons of fuel, then obviously the savings would be substantial. I might add that the Coast Guard physical plant ashore entails about 25 million square feet of Coast Guard-owned space. That kind of plant would indeed involve a very large heating demand.

We were also having TSC conduct a feasibility study on the application of emulsions to gas turbines, since our 378-foot cutters and the new Polar Class ice-breakers have a combined diesel and gas turbine plant. When they run on high power, they run on the gas turbines.

I have a few comments to make about university research. Additional water-in-fuel emulsion research is being provided for us through the Office of University Research. That office awarded a contract to the University of Michigan last year for research

To those of you involved in emulsion research and application, on behalf of the Coast Guard, I express appreciation for all that continues to be learned from your efforts and for your participation in these symposiums.

To those of you who are here to gain a greater awareness of what we are doing, I am certain you will find the next two days of great interest. Thank you very much.

(End of Admiral Stabile's Presentation)

Chairman Walter: Thank you, Dr. Costantino and Admiral Stabile.

We are already running a little bit behind schedule, so I will keep my program overview remarks as brief as possible. I am not going to dwell too much on the technical aspects of what you are going to hear in the next two days. You all have the abstracts that were included in your handouts. These abstracts summarize the papers for which Admiral Stabile has so well prepared you by running through the topics that they are going to cover.

PROGRAM OVERVIEW

ROBERT WALTER

The past year has been a very productive one in the field of water-in-fuel emulsions. We are fortunate in having here today a group of participants who are going to bring us up-to-date on the recent improvements with respect to the procedures and applications in this field.

I would like to emphasize the need for more research and development in finding answers to problems related to water-in-fuel emulsions. In particular, we must improve communication within the community of people interested in the development of emulsified fuels. Take this very group as an example. For those of you who have a number of acquaintances here, I know you will agree with me when I refer to the wide diversity of interests in which they are engaged in this branch of technology. People are interested in emulsified fuels from many different aspects, and it is important for us all that we keep each other informed about the overall picture.

The question arises as to how we can keep each other informed. We at this conference are going to investigate many of the problems inherent in the field, problems which must be either solved, or at least clarified, in order to insure improvements necessary for continued application, or for new applications, of the emulsified fuel. We will investigate the physical-chemical properties of the fuel and its use in boilers, gas turbines, and diesels. We will summarize the advantages in the use of emulsified fuels: reduction of thermal NO_x and of particulates; efficiency improvements in boilers and diesels, particularly in boilers on the basis of removal of emission constraints and the resulting reduction of excess air; improved fireside cleanliness in boilers; the possibility of burning off-spec fuels in marine-type gas turbines and diesels; and greater fire safety with use of light distillates.

SESSION 1

PAPER 1

PHYSICAL PROPERTIES AND STABILITY OF WATER-IN-FUEL OIL EMULSIONS

H. S. FOGLER AND S. R. REDDY
University of Michigan
Ann Arbor, MI

Mr. Reddy

We solved the stability question by having the model take care of creaming and coagulation. We chose an initial size-distribution on the basis of our experience with paraffin oil in water, and determined the effect of water in influencing the stability of various emulsions. In essence, we explored the effect of viscosity and density difference on creaming and coagulation.

Mr. White

Right, but your model is essentially a sedimentation model. Am I correct?

Mr. Reddy

It takes care of both sedimentation and coagulation.

Mr. White

And coagulation?

Mr. Reddy

Right.

Mr. White

Thank you.

Chairman Walter

Any other questions? If not, then I will thank Mr. Reddy and introduce our next speaker. But before I do, I will ask the members of the audience to identify themselves when asking questions. Since we are recording these proceedings, identification of questioners will be most helpful. With that out of the way, I will introduce our next speaker, Dr. C. K. Law of Northwestern University. The paper to be presented is jointly authored by Dr. Law and Mr. C. H. Lee, also of Northwestern University, and is titled "Fundamental Studies on the Combustion of Emulsified Fuels." Dr. Law.

FUNDAMENTAL STUDIES ON THE COMBUSTION OF EMULSIFIED FUELS

C. K. LAW AND C. H. LEE

ABSTRACT

Further theoretical studies on the combustion of water-in-oil droplets have been conducted, allowing for liquid-phase transient effects and also near-critical combustion. Results show the limits on the attainment of micro-explosion, the occurrence of early extinction due to excessive water accumulation in the droplet, and the dependence of other pertinent combustion characteristics on the emulsion properties. Experiments on single droplet combustion have also been conducted and their results compared with the theoretical predictions. Vapor pressures of the emulsified fuel have also been measured. Results from other studies on the combustion of coal-oil-mixture, with or without water addition, are also presented.

(End of Abstract)

Chairman Walter

Thank you, Dr. Law. Are there any questions?

Mr. Chin

In the droplet experiment, what is the size of the water drop? Can you give a rough estimate on that?

Dr. Law

Well, yes, you mean the coal oil-water?

Mr. Chin

Right.

Dr. Law

Coal oil-water. Okay. We put in only five percent water, so water just really sticks to coal powder.

Dr. Law

Yes, well, there are obviously changes of viscosity. That does something to the motion. And there can be selective radiative absorption, because, in this case, coal powder can absorb radiation. And then it can by itself enhance vaporization even internally, because coal powder gets hotter. As for radiation absorption, the oil particles wouldn't absorb that much, because they are rather transparent, while coal powder, which is black, does absorb.

Let me also mention what I think is an interesting point. Coal powder absorbs radiation. It seems that absorption of radiation by coal powder causes activity by the coal powder itself. We have done some work with chalk powder rather than with coal powder. We have a lot of chalk in the schools, of course, and it's white. Chalk explosion is much milder, and it seems to show something more readily.

Mr. Chin

On your vaporization versus temperature curve, do you measure vaporization by using the curve of the mixture or of the single droplet?

Dr. Law

Single droplet.

Mr. Chin

Single droplet. I see. Well, are you referring to the inside or outside droplet pressure?

Dr. Law

We have a single droplet suspended on a fiber, and we ignite it. As it burns, its size decreases, and with high-speed photography we can measure the instantaneous size.

Mr. Chin

No, I'm talking about vapor -- you say you have pressure measured.

Dr. Moses

The last two are the same?

Dr. Law

Yes.

Dr. Moses

Whether you put the water in the coal or---

Dr. Law

Yes, the sequence of mixing does not make any difference.

From the Floor

Is there an emulsifier present?

Dr. Law

We didn't use an emulsifier, and it's not necessary; that's why we do it very quickly. They seem to stay in suspension just a few minutes. For water and oil we had an emulsifier, but for coal and oil we didn't use any emulsifier.

Dr. Naegeli

Do you feel that the water is absorbed in the coal, or that the water is dispersed in the fuel?

Dr. Law

I don't know.

Dr. Naegeli

In places where you put the water in.

Dr. Law

I really hate to speculate here. It must wet the coal somehow. Definitely.

Dr. Naegeli

You have as much trouble with stability as well.

SESSION 1

PAPER 3

DYNAMICS OF EXPLODING DROPS

T. MORRONE, R. LIPPMAN, AND D. WRIGHT
Adelphi Center for Energy Studies
Garden City, NY

Dr. Morrone

Well, we can't be absolutely sure. We think it does. Take that second film, for example. It seems as though there are a lot of little bubbles on the surface. We have taken photomicrographs of emulsions formed by steam atomization. There is no attempt to inject water or emulsifiers or anything, just regular steam atomization. If you look closely, you seem to see a lot of air bubbles, or at least little spheres that we can't account for by any other way. So, I think that at least with steam atomization you do get a lot of sites.

Dr. Shaler

Thank you.

Dr. Moses

I have two questions. To begin with, in the movies it's hard to tell what the time scale is because they are high-speed movies. So my first question is, what's the time scale of the burning relative to droplet lifetime in practical combustion systems?

Dr. Morrone

Well, the whole film takes a couple of seconds for the burning of a thousand-micron drop. The explosions take place in a couple of frames, and their duration is about a ten-thousandth of a second.

Dr. Moses

Well, the point is that in some instances, such as in aircraft-type turbine engine combustion, the droplet lifetime is in milliseconds, and we have had time scales even much larger. Is that because we have larger droplets? I am trying to get some perspective on what's occurring.

Dr. Morrone

Yes, these are very large drops, but, you know, otherwise you couldn't see them. I imagine that for small drops it's similar. Nucleation occurs, and the calculations apply. We have done calculations with small drops, and there's no fundamental difference from large-drop calculations.

SESSION 1

PAPER 4

COMBUSTION OF EMULSION DROPS

M. L. RASMUSSEN AND
S. R. GOLLAHALLI
University of Oklahoma
Norman, OK

Dr. Rasmussen

Yes, Professor Gollahalli has done this with a sort of semi-empiric theory based upon what Jacques did, and he included, I think, another effect, based on heat of vaporization, that I think Jacques did not have. On the other hand, it's crude, and subject to a fair number of objections, especially if you want to look at precise theories that we've established. I haven't shown them, although I do have his curves. We have decided that even though there is agreement, we could probably have been lucky. We would like to have more sophisticated theory that demonstrates the physics involved.

Chairman Walter

Yes, sir?

Mr. Stewart

Have you considered experimenting with residual fuels rather than with No. 6? This is where all marine fuels are pointing to. It seems that some experimentation should be centered on improving the burning of that kind of fuel.

Dr. Rasmussen

Well, our intentions now are in the direction of diesel simulation. The other experiments are in the back of our minds, but right now we are working hard on some problems involved with high pressures in the experimental arrangement.

From the Floor

With regard to the methanol emulsions, methanol residual oil, what was the lifetime of the emulsion? Did you observe whether the methanol was soluble in the residual oil, and did you---

Dr. Rasmussen

The methanol emulsions were unstable, and they had a short lifetime. I don't know what they were; that's why there is a need for more experimental data. I don't recall for sure, but I think I have that information in my notes. I can get that.

Dr. Rasmussen

No, I don't. It's just---

Dr. Naegeli

Sometimes it's purely---

Dr. Rasmussen

You can get it from the pictures, but that wasn't measured. The ignition time wasn't measured, or at least it wasn't recorded here. Professor Gollahalli has the ignition time, but I didn't show it here. If you remember, on the picture I showed X and Y. The picture appears to show nothing there, but actually, if you look closely, you see a little white drop and the flame sparked. That can be correlated with the time on the motion picture frame. That is available, but I don't have it.

Dr. Rifkin

Would you please repeat what you said about the effect on disruption time of the fraction of water in the droplet?

Dr. Rasmussen

Yes. As a fraction of the water in the droplet increased, the disruption time increased. That was true of both water and methanol.

Dr. Rifkin

Disruption time increased?

Dr. Rasmussen

Increased. It took longer for the droplet to disrupt when there was more water in it. And the same for methanol, except that less time was involved for the methanol.

Dr. Rifkin

So if you try to plot disruption time versus percent water in the droplet, you get a curve with a minimum.

SESSION 1

PAPER 5

RECENT RESULTS ON THE USE OF COAL/WATER/OIL EMULSION AS A CLEAN LIQUID FUEL

J. P. DOOHER AND STAFF
Adelphi Center for Energy Studies
Garden City, NY

Now in order to do that, you have to look at a number of factors. For example, consider the rheology factor. Pumping over a long distance will require a lot of energy, especially for those viscous mixtures. And a key factor is the question of stability. The matter of length of storage capability is extremely important.

But certainly you can visualize the day when at least central plants will be built in areas that have capabilities for coal handling, and the fuel will be shipped within a 50-, or 100-, or 200-mile radius to more populated areas where coal handling facilities can not be installed. So, perhaps you may not see the initial mine head operation right away, but you may very well see central plants going up with the capability for selling this fuel to customers, in populated areas, who do not want to install coal handling facilities in their immediate environment.

Chairman Walter

Any questions? There being none, I thank you, Professor Dooher, and proceed with the next presentation. The next paper, to be presented by Dr. J. O. Stoffer, is titled "Emulsions - Microemulsions: Structural Considerations." Dr Stoffer, who is from the University of Missouri - Rolla, was assisted in the preparation of this paper by S. Friberg and R. Johnson, also from the University of Missouri - Rolla. Dr. Stoffer.

EMULSIONS-MICROEMULSIONS: STRUCTURAL CONSIDERATIONS

J. O. STOFFER, S. FRIBERG, AND R. JOHNSON

ABSTRACT

When hydrocarbon and water are mixed, the system will be unstable due to the pronounced interfacial free energy component of the total free energy. The recent technology within the surfactant area has enabled the production of spontaneously forming so-called microemulsions. These systems look transparent, or slightly hazy, to the eye, and contain particles with a diameter between 50 and 800A. Such microemulsions will give a different combustion process in the engine compared to normal emulsions, in which the particle size is greater than 10,000A. Preliminary results have indicated the microemulsions to be promising as diesel fuels compared to normal emulsions, giving a considerable reduction of the content of nitrous oxides in the exposed gas.

This paper explains the differences between these two kinds of emulsions, and mentions the preliminary results from motor tests.

(End of Abstract)

Chairman Walter

Thank you. Any questions?

Dr. Lawson

How much alcohol did you have in your emulsions?

Dr. Stoffer

In diesel methanol?

Dr. Lawson

Diesel methanol, yes.

Dr. Stoffer

Those were run with about 10 percent methanol and, I think, with seven or eight percent higher alcohol, just to get them to be

From the Floor

Could you describe the diesel engine that you used, and also, in the alcohol, did you have any water when you made the alcohol diesel emulsions?

Dr. Stoffer

The diesel engine was a four-cylinder John Deere diesel engine, and the alcohol methanol was probably 99 plus percent. We will go back and look at added water. Another thing we would like to investigate is what happens when the run-of-the-mill alcohol would be something other than 100-percent alcohol.

Mr. Swanson

What was the variable in the previous first set of slides you showed on single-cylinder, NO_x versus fuel consumption? What was the variable of that curve?

Dr. Stoffer

On the first set of data we determined NO_x versus smoke.

Mr. Swanson

What is the variable? What's the second variable on the graph?

Dr. Stoffer

We used as variables percent water and injection timing.

Mr. Swanson

Thank you.

Mr. Owens

Did you look at the effects of alcohol on diesel fuel?

Dr. Stoffer

No, we will have to.

Mr. Owens

In your slides that you showed on fuel consumption, was that total fuel?

Mr. Becker

Will you repeat, please, what was the effect of the microemulsion, the water microemulsion, on smoke?

Dr. Stoffer

There is a decrease in NO_x.

Mr. Becker

On smoke.

Dr. Stoffer

Yes, with no change in smoke content; you decrease NO_x with no apparent change in the amount of smoke.

Mr. Becker

Well, forgetting the NO_x.

Dr. Stoffer

Okay. Let's go back to the overlay then. We will have to compare each data point, each injection timing setting, to get the answer to this. Now we see percent smoke versus NO_x. If we consider the reference fuel to be one, then with fuel 1 having 10 percent NO_x there is a slight increase in smoke for fuel 2, and for Reference Fuel 3 it drops off somewhat. So, there is a slight increase in smoke with a given setting of ignition timing.

Mr. Becker

Slight increase with microemulsion.

Dr. Stoffer

With microemulsion.

Mr. Becker

Would you care to estimate the changes in efficiency with microemulsion?

Dr. Stoffer

I couldn't give you an answer.

From the Floor

We don't make stable emulsions. We run them as a kinetic system.

Dr. Lawson

We have been doing some preliminary work on fuel and emulsifier with methanol diesel. We are just looking for sufficient stability to get the emulsion through the injectors and back. Larger programs will be starting up in about a month. I think it's probably the way to go. And I think there's been a lot of trouble trying to--

From the Floor

You are not going to get stability.

Mr. Cole

On this matter of alcohol, we should take a pretty good look at the energy requirements in making the alcohol, because if I remember correctly, the net balance is negative. Petroleum fuel with alcohol is possible; it can be accomplished, although the engines will run on it derated. However, it takes more energy to make the alcohol than the petroleum to replace it.

Chairman Walter

Anybody like to comment on that?

Dr. Moses

That's a very good point, except that the alcohol supplies aren't as limited as petroleum supplies are, and if you look at it strictly as a petroleum extender, then that's not necessarily a limiting factor.

Mr. Phoebe

What? You say that you have a negative BTU by making alcohol, but you can use this as a petroleum extender? Will you explain this to me?

large supplies of sugar cane and starchy materials are available, but certainly not in the United States.

The State of Nebraska is now making large quantities of ethanol from grain sources and using it to make gas at home. Actually, it's more expensive to make the alcohol, but, on the other hand, we are using a United States resource, and that's an extension. We are extending our petroleum supplies, and that's the whole idea.

Mr. Phoebe

Will you comment on the energy balance of this?

Dr. Naegeli

If we could take the grain of the biodegradable material and burn it directly, we'd be way ahead. But, of course, we can't burn grain inside of an engine. Then, too, when we convert something like this to alcohol, we lose about 50 percent of the energy in the starch, or sugar material.

Chairman Walter

Anything else? Nothing else. Let's break for lunch.

(End of Session 1)

SESSION 2

EMULSIFIED FUELS IN BOILERS AND GAS TURBINES

SESSION 2

EMULSIFIED FUELS IN BOILERS AND GAS TURBINES

Chairman Walter

Welcome back to the second session of this conference. This period will deal with the different aspects of the topic of interest, namely, emulsified fuels in boilers and gas turbines. We'll start off with a paper by G. Boquet and C. Delatronchette, both of ELF-Union, Paris, France. The title of their paper is: "New Developments in Heavy Fuel-in-Water Emulsions," and the paper will be presented by Mr. Boquet. Mr. Boquet.

NEW DEVELOPMENTS IN HEAVY FUEL-IN-WATER EMULSIONS

G. BOQUET AND C. DELATRONCHETTE

ABSTRACT

The recent petroleum crisis has emphasized the necessity for proceeding with research regarding the utilization of new energy sources and the rationalization of the uses of the so-called "fossil fuels." Since 1967 ELF has developed, as part of a research program for the protection of the environment and the more economical uses of hydrocarbons, a fuel-in-water emulsion process, the results of which are most spectacular. This process makes possible, on the one hand, limiting the emission of polluting substances; on the other, it provides for obtaining, in the long run, considerable reductions in fuel consumption, depending on the heat exchanging surfaces of the cleaner boilers.

(End of Abstract)

Chairman Walter

Thank you, Mr. Boquet. Are there any questions?

From the Floor

What is the sulfur content of the fuels you are using over there?

Mr. Boquet

In heavy fuel?

From the Floor

Yes.

Dr. Thompson

I would also like to ask a question on the efficiency. It appears that you do not show an improvement in combustion efficiency, although over a period of time you save fuel.

Mr. Boquet

Yes.

Dr. Thompson

Would you explain that?

Mr. Boquet

To counterbalance the losses due to the fact that we vaporize the water, we have two possibilities. In the first instance, with emulsion we decrease the temperature of the fuel oil by as much as 15, and sometimes 20, degrees. It is not necessary to raise the fuel to more than from 110 to 120 degrees, whereas with fuel alone it is necessary to obtain a temperature up to 135 degrees. Secondly, we have less excess air. It is possible to reduce the amount of excess air to about one-half or one-third, so you win some calories by this loss of excess air.

Chairman Walter

Anything else?

Mr. Becker

What fuel savings do you have when you use an emulsion with steam atomization rather than mechanical atomization?

Mr. Boquet

We did not make any tests with steam atomization, but we think that we must obtain the same results.

Chairman Walter

Thank you, Mr. Boquet. I think it is getting rather late. Let's take a coffee-break now. Please try to get back by 3:00 o'clock; if you do, we'll get two, and possibly three, papers in this afternoon.

(End of Discussion on Mr. Boquet's Presentation)

SESSION 2

PAPER 2

EMULSION FUEL STUDIES USING LOW AND HIGH SULFUR FUEL OIL

S. MOON, J. P. DOOHER, ET AL.

Adelphi University
Garden City, NY

fly ash. The efficiency of SO_2 removal was very high, approaching 100%. The direct application to heavy residual fuels with a high sulfur content is apparent.

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[1]Hall, R., ASME paper, 75-WA/APC-1

[2]Sjogren, A., "Burning of Water in Oil Emulsion," presented at the 16th International Symposium on Combustion, Cambridge, MA, August 15-20, 1976, pp. 297-306.

(End of Abstract)

Chairman Walter

Any questions?

Mr. White

Previous investigators have noticed the difference in the deposits. In burning oil they would get a black, sooty deposit, whereas in burning emulsions they would get a whitish deposit, grayish. Have you noticed the same thing here?

Dr. Moon

What we did was to take a great number of pictures of the inside of a boiler. We also put some steel bands in the boiler, and we did see some difference. We don't have any quantitative results, and at this point we don't quite know what the difference really means. However, we are continuing our study in that field.

Mr. White

Did you determine the size of the water droplet that was dispersed in the oil emulsion?

Dr. Moon

We did some photographic study of that, and came up with a droplet size of ten microns.

From the Floor

What was the longest period of time you ran the boiler on straight emulsion?

SESSION 2

PAPER 3

TOTAL-BERTIN EMULSIFIER

D. S. VOLKMAR
B. CARRUETTE
L. TRANIE

Compagnie Francaise de Raffinage
Paris, France

Dr. Moses

In the last picture in today's presentation you had the picture of cenospheres. What grade of oil was burned?

Mr. Volkmar

Those are all No. 6 grade oil. At first we worked with No. 2 oil. The concept then was to make a package which could be built into a domestic fuel oil burner. We found, however, that the improvement which we could realize was just as easily obtained by keeping the boiler clean and properly adjusted. We therefore looked around and determined, from other experiments, that more than likely the area of interest is in heavier oils. In those pictures you saw heavier oils.

Chairman Walter

Any further questions? If not, then thank you, Mr. Volkmar, and let's continue with our next presentation. The next speaker will be Dr. D. Naegeli of Southwest Research Institute. The title of his paper is: "A Correlation for Soot Formation in Turbine Combustion that Includes Emulsified Fuels." I should mention that the paper is coauthored by Dr. C. A. Moses, also of Southwest Research Institute. Let us hear now from Dr. Naegeli.

A CORRELATION FOR SOOT FORMATION IN TURBINE COMBUSTION THAT INCLUDES EMULSIFIED FUELS

D. W. NAEGELI AND C. A. MOSES

ABSTRACT

The sensitivity of combustor performance to the physical and chemical properties of a variety of fuels including emulsified fuel blends has been examined in a T63 turbine combustor rig. The purpose was to determine the impact of broadening fuel specifications and using non-specification fuels in emergencies. The fuel properties of special concern were composition, viscosity and the distillation curve. The first property is associated with the chemistry of soot formation, while the latter two are related to the physical aspects, atomization and vaporization, which affect mixing. To provide a data base for comparison of emulsified fuels, six fuels blended from JP-5 base fuel were used to determine the effects of aromatic content, aromatic structure, and end point. Three JP-5s derived from coal, shale oil and tar sands were used to see if they correlated the same as the petroleum-derived fuels despite their different chemistry. Seven more fuels that were blends of marine diesel, JP-5, and gasoline were used to examine all aspects, but with emphasis on viscosity and the distillation curve. Four emulsified fuels containing 5, 10, 20, and 30% water were prepared with one of the above high aromatic JP-5 fuel blends. Two more emulsified fuels containing 10 and 20% water were prepared with the shale-oil-derived JP-5. The emulsions were made with a homogenizer and stabilized with 2% span 80/tween 80 surfactant blend (HLB = 5.3). Other fuels examined consisted of methanol and mixtures of 25% and 75% methanol with a blend of aromatics.

The combustor was instrumented for flame radiation, exhaust smoke, and gaseous emissions. Measurements of these items were made at the full power condition.

The hydrogen/carbon ratio was the most effective correlating parameter for radiation and smoke; sensitivities to molecular structure appeared to be secondary. Similar to the syncrude fuels,

Dr. Naegeli

If you look back in the literature, you'll note that no exact mechanism has been decided on in the matter of soot formation. However, the mechanism does indeed appear to be a chemical one for soot formation in hydrocarbon type fuels.

Now recently, since emulsified fuels have become of interest, it has been considered that the microexplosion phenomenon increases atomization and causes secondary atomization, and that this process is what improves fuel mixing and prevents fuel-rich zones from developing where soot is formed. Well, that microexplosion process is not expected to be a function of the hydrogen-to-carbon ratio. There is just no good reason for it; it appears, then, that the same mechanism for soot formation with emulsified fuel holds for petroleum fuels or for any fuels.

From the Floor

But in the figure you showed us of exhaust smoke versus hydrogen-to-carbon ratio in the case where you include water, there is a definite decrease in the soot as you increase the hydrogen in the carbon. This results in more water, which means that there is a greater probability of microexplosions. You could argue that way, too.

Dr. Naegeli

Yes, you could, but tell me, would you expect the points to fall in exact correlation with normal neat petroleum fuels? I agree that if the smoke disappears, and if its disappearance has been caused in some different way, then, of course, I would say it is a microexplosion event. But the fact that soot reduction occurs almost exactly the same way as petroleum fuels indicates that it is chemical. That is the same mechanism that occurs in petroleum type fuels.

Mr. White

I first want to congratulate you for having discovered what I think is a significant phenomenon. It might give some indication

Dr. Shaler

Steam - carbon reaction.

Dr. Naegeli

Steam-carbon reaction, yes. There is no indication that you form acetylene in that reaction. That is a heterogeneous reaction. I am talking about a non-heterogeneous reaction where you have soot particles, and you put water in there to react the soot away. What I am really considering is the act of putting the water molecules right there where the free radicals originate, and are actually the prelude to soot formation. That is where the water plays an important chemical role. It enters into the chemistry.

Consider the process of carbon monoxide oxidation, for example. If I take all of the water out of the air and try to burn the carbon monoxide, the flame propagation rate is about two centimeters per second. It just doesn't burn. If, now, I add just a trace of water to this mixture, the flame propagation rate will jump to seventy-five centimeters per second. The water doesn't enter into the combustion process, but most definitely it enters into chemical kinetics, and that is where it probably occurs here.

Dr. Dryer

I am sorry. I came in a little bit late for your paper, and I don't know whether you measured size distribution or not, but I would like to comment with regard to the fact about acetylene. Since you left us awhile back we have done some runs on ethylene oxidation. We found that there was absolutely no effect, by the presence of water vapor, on the concentration of acetylene, so there is something suspicious about that fact.

We have been doing some soot formation studies, and we have been looking at the effects of water vapor. While that work is incomplete to the extent that I would not want to detail it, it looks at present as though the results are pointing toward the physical effect of changing the temperature in the zone rather than changing the chemical kinetics of the zone through a direct interacting chemistry. But the question I have for you today is with

Dr. Dryer

How do they compare with No. 2 fuel oil?

Chairman Walter

Cliff, maybe you can answer that.

Dr. Moses

The marine diesels use fuel very close to No. 2 fuel oil. Some of them had gasoline blended in with the diesel marine, and in one case, which wasn't shown here, we ran pure gasoline itself and pure methanol, so in some cases a few of the fuels were more volatile in water.

From the Floor

I would like to comment that at least in the cases of those elevated pressures microexplosions would be unlikely, and I think you have a good way of testing the chemical effect.

Dr. Naegeli

Well, this is highly controversial. According to Dr. Law's hypothesis, the microexplosions are more attainable at increased pressure, so it is a questionable sort of thing.

Chairman Walter

Anything else. Thank you, Dave. We have about a half hour to leave the floor open for general discussion. If anybody has any points he or she wants to bring up, or any comments about any papers, or any questions of any of the authors, please let that individual feel free to speak up right now.

From the Floor

We have heard a lot about the microexplosion theory. Would anybody like to substantiate it when we talk in terms of high pressure combustion as opposed to free combustion?

Most of the topics heard today have invariably discussed boiler applications. When we talk about diesels, we have a substantial pressure involved in the combustion. Would you consider the microexplosion theory still valid?

SESSION 2

PAPER 5

FURTHER STUDIES ON THE SUPERHEAT AND MICROEXPLOSION OF EMULSIFIED FUELS

F. L. DRYER ET AL.
Princeton University
Princeton, NJ

Dr. Law

In your first conclusion you said that the suspended droplet is not suitable for studying multi-component combustion. I guess we discussed this point once before.

Dr. Dryer

Yes, we did.

Dr. Law

Well, let me clarify it further. I think that when using a suspension fiber with multi-component combustion to which emulsified fuel also belongs, there are two effects. First, it provides a heterogeneous nucleation site for microexplosion to occur; obviously, then, it's not suitable to study microexplosions. Secondly, as you have shown, it provides some place for collisions of the water droplets that tend to interfere or to change the structure of the emulsion. That, of course, can be avoided if you don't have any internal motion within the droplet material.

Now, in your experiments, there are external convection --

Dr. Dryer

No. That is not true.

Dr. Law

There could be some internal motion -- natural convection, not forced convection.

Dr. Dryer

There is natural convection, yes.

Dr. Law

So, in that case, I agree with you that it will help with the collisions. I would minimize the external convection, natural or forced. For example, this is what we have done in a very low pressure environment. I think there is still merit in suspended droplet combustion as long as you don't look into microexplosion. I think that if you look into quiescent behavior it is still possible.

droplet lifetime is very long compared to what we see in a practical combustor. Do you think that the time scale would have an effect on your results relative to the superheat limit?

Dr. Dryer

In the column experiment time has little effect upon defining what the absolute superheat limit is. If it were a very rapid experiment, it would be very difficult to define the absolute superheat limit in that system, because one would achieve nucleate vaporization at temperatures below it. For a rapid heating situation in the case of free droplets, it is probably easier to attain superheat limit conditions than it is in the slow experiment, but as I said, in the slow experiment analysis there is a range of temperatures over which droplets explode, and what we have done in defining the superheat limit is to pick the maximum temperature at which that occurs.

Dr. Moses

Would you not think, though, that in any faster experiments the temperature could get above that before --

Dr. Dryer

No, I don't think so.

Dr. Moses

Because that is what happened in the opposite case.

Dr. Dryer

Well, let me give you some experimental evidence that that probably isn't the case. We have made observations on N-dodecane, and found no microexplosions. The theory predicts that very close to the statistical limit for tetradecane one would find microexplosions, and, indeed, you do. That is not predicted by Dr. Law's theory, or, in essence, the thermodynamic theory. The thermodynamic theory suggests that the first fuel which should microexplode at atmospheric pressure is N-hexadecane.

Dr. Moses

They have to be close, though.

Dr. Dryer

That is absolutely correct.

Dr. Law

In the kinetic theory, you have to know, for example, surface tension, which is not always readily available.

Dr. Dryer

Your point is absolutely correct. It is much simpler to use the thermodynamic theory, and, in fact, that was pointed out in the literature quite a while ago with regard to pure substances. However, our problem at the beginning of those studies, at about the time you were at Princeton, was that we did not know whether those same arguments that have been applied to pure studies could be applied without corrections to the case of emulsified fuel structures. What we have done is to prove that, indeed, that is the case.

Dr. Law

What you have proven appears to me to be that it is still close, although we disagree as to whether 20 degrees is close.

Chairman Walter

Thank you for this interesting exchange. We will now hear from Mr. Richard Kinney. Mr. Kinney, who is Technical Director at the Gaulin Corporation at Everett, Massachusetts will present a paper titled "Research Results on Emulsions in Boilers." I also must remember to acknowledge the help given Mr. Kinney by Mr. Peter Lombard, also from Gaulin, in the preparation of this paper. Mr. Kinney.

RESEARCH RESULTS ON EMULSIONS IN BOILERS

R. KINNEY AND P. LOMBARD

ABSTRACT

The physical effect of the microexplosion phenomena of water-in-oil emulsions reducing coke cenospheres and the chemical effect of reducing gas-phase soot result in marked reductions of total carbon formation, and can: (1) reduce excess air requirements; (2) facilitate the burning of degraded fuel; (3) alleviate boiler slag problems.

Where excess air requirements are reduced, improvement in boiler efficiency from one to four percent is achievable.

Gaulin high-energy homogenizers have been widely used (for over 60 years) for preparation of diverse products, both emulsions and dispersions. Typical applications are blast furnace, milk, food products, pigment dispersions, titanium dioxide, paper coatings, and wax emulsions. These applications and many others require from us, as the largest manufacturer of high-energy homogenizers, the ability to process viscous, abrasive and non-lubricating fluids in industrial environments. Attributes required for these markets include dependability, reproducibility, on-line process design, low maintenance, and R&D capability.

Although water-in-fuel emulsification is a comparatively new application to Gaulin, the following presentation will demonstrate our abilities in fuel emulsion preparation, system design, optimizing water quantity and droplet size, integration into combustion systems, and field application data.

References:

1. C. A. Moses, "Reduction of Exhaust Smoke from Gas Turbine Engines by Using Fuel Emulsions," AFLRL #68, U.S. Army Fuel and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, Texas.

Mr. Kinney

Well, if you look at the BTUs required to evaporate one percent water, you will find that by reducing the excess air one percent, you will regain the BTUs. In other words, it is a trade-off. The BTUs required to evaporate one percent water can be regained by reducing the stack loss, i.e., by reducing the excess air one percent. This is just in approximate numbers.

Dr. Law

Approximate?

Mr. Kinney

Yes. That depends, obviously, very dramatically on stack temperature, whether it is 300 to 700.

Dr. Law

A kind of rule-of-thumb thing?

Mr. Kinney

Very, very definitely. That is an average number, assuming a stack temperature around 450.

Dr. Moses

Dick, you talked about an optimum size for the water dispersion characteristic size, and the previous question addressed that also. In the work I did a couple of years ago, the work that you took that one slide from, there were some data in that report on the effect of drop size, characteristic drop size of the dispersion for our combustor system. In one case we ran your homogenizer at a high-energy level, and in another case at a lower energy of homogenization. As I remember, the characteristic droplet sizes for the high energy were about one to two microns, whereas in the other case we had at least a number of drops that were up to 10 microns, or of that order. I don't remember how many of them, or what fraction it was, but that's about an order of magnitude change in the dispersion size. There was no size effect on the soot reduction in our experiment. We have also run some microemulsions

Dr. Moses

In that report the conclusion from that particular graph was that with the low surfactant concentrations, it was possible that the emulsion was breaking down before it got to the combustor. I think the difference --

Dr. Dryer

If that is so, then the conclusion of that slide is still true.

Dr. Moses

Yes. I think that the difference in the two situations, as far as droplet dispersion size is concerned, is in the stable emulsions. Where we had a good stable emulsion, it didn't make any difference, because the dispersion size was very much smaller than the characteristic fuel droplet size in the spray. The fuel droplet size was on the order of 75 to 100 microns. The dispersion size is 1 to 10 microns, one to two or more orders of magnitude smaller.

When the emulsion begins to break down, the dispersed water agglomerates inside the fuel. We then have very large sizes of water that are, perhaps large compared to the fuel droplet, or about the same size, and would not result, perhaps in the same phenomena. For example, if the microexplosion occurs, you may not be spraying emulsion any longer.

Dr. Dryer

Would you continue to make the same argument when changing the surfactant concentration from two percent to three percent? I cannot see a two-percent emulsion breaking from dynamic stressing.

Dr. Moses

The data leveled out right about two percent emulsion.

Dr. Dryer

Actually, it was a little bit beyond that. I guess what we are arguing about is that one says the data apply in terms of internal phase size distribution effect on microexplosion on that curve.

SESSION 2

PAPER 7

THE PRACTICAL EFFECTS OF BURNING EMULSIONS IN MARINE GAS TURBINES AND BOILERS

M. WINKLER
Seaworthy Engine Systems, Inc.
Essex, CT

Mr. Stewart

Did you notice any reduction in NO_x production, or didn't you make that measurement?

Mr. Winkler

Not in this particular case. As I mentioned, smoking in port is the only requirement that a ship must face, and operating on distillate fuels, that is not a problem in port. We have run some tests in other applications, and we are doing continuing work in that area.

In general, the results that I have seen on this type of engine show that for a given water-to-fuel ratio we can improve the NO_x reduction on the order of 40 percent by using an emulsion as opposed to water in whatever other form we would use it. However, I would also subscribe to comments made that we must use a surfactant with that or the emulsion will separate before we can burn it.

Professor Agosta

With the boilers, did you have steam atomization?

Mr. Winkler

Yes.

Professor Agosta

If you had steam atomization, did you then vary the amount of steam in the burners when you used an emulsion, and if you did, what results did you get?

Mr. Winkler

We did not change the operation of the boiler other than to request that in all cases, both in the base line mode and on test, they should reduce the excess air to as low as they could practically. They had continuous reading oxygen meters, as well as a means of determining smoke in the stack, generally a periscope, and they also had instrumentation that allowed them to hold the excess air down. The only thing we requested was that they do that throughout base line and operational modes.

Dr. Dryer

Really, the removal of the gas turbine is more a matter of convenience for service than an actual limitation imposed by the combustion technique - isn't that true?

Mr. Winkler

Yes. In 30 ship-years of service in which these engines have been operating on residual fuels, there has been a total of 100 engine-related lost hours. So, there is very little impact on the program. There is really no impact on the operation of the ships. These ships are normally in port for eight to ten hours maximum.

Mr. Kinney

On the question of steam atomizing and ΔP, the work we have done in comparing emulsions versus neat fuel with the same steam or oil ΔP adds up to this: - on three installations we tried to reduce the oil to fuel ΔP, and found that the emulsion, apparently, had a very different effect. In other words, we could not get a significant reduction of the steam ΔP versus neat fuel without getting an adverse effect on primary atomization. So, evidently, emulsions have a separate and distinct secondary effect, and we still must have the primary effect of good steam atomization.

Chairman Walter

Thank you. We will now hear from Professor Ray Thompson, of the University of Newcastle-upon-Tyne, England. Professor Thompson's paper is titled "Emulsified Fuel Work in England."

APPLICATION OF EMULSIFIED FUELS TO DIESEL AND BOILER PLANT

R. V. THOMPSON

ABSTRACT

Results are detailed for an extensive series of experimental programs, undertaken over the past five years by staff of the Department of Marine Engineering, University of Newcastle upon Tyne, to determine the effect of applying water-in-oil emulsions to boiler installations and a variety of diesel engines both in England and in the U.S.A. Indications are that the process of combustion can be improved to the extent of reducing fuel/air consumption and maintenance requirements and permitting some measure of control over exhaust emissions to be exercised. The type of emulsion produced is fundamental to any improvements derived. Due to normal practical problems associated with bunkering and the like, additives, i.e., surfactant-derived emulsions, were eliminated in deference to mechanically produced 'fuels'.

Although the results shown in the tests are confined to a variety of medium- and high-speed diesel engines, further data applicable to slow-speed engines currently under test are included in the presentation.

(End of Abstract)

Chairman Walter

Thank you, Professor Thompson. Now for any questions. Yes, sir.

Dr. Murayama

I would like to question you about the effects on startability, and the probable damage from corrosion.

Professor Thompson

We ran a diesel engine on emulsified fuel for approximately a year and a half, and the engine was torn down, and there were no signs of corrosion. There were some deposits in the injector area, not using any surfactants. We tried 37 different brands of surfactants, and we have a whole set of results on that, but time doesn't allow me to say anything about it.

Mr. Becker

You said you had a tendency for fuel savings in the large engine. Would you care to amplify on that statement?

Professor Thompson

Well, the test results we had were obtained only on a two-day basis because, obviously to obtain one of these engines on a longer term is rather expensive.

We hope to be able to repeat the test over a two-week period, which will be much more definitive. I feel that you can anticipate that the optimum performance of the slow-speed cross-head diesel engine will provide a one-and-a-half percent fuel savings.

Mr. Becker

How much water?

Professor Thompson

On the order of two to three percent water. Actually, you don't really have to flash off much water.

Dr. Lawson

When you made the general statement about the British truck engines and reduction in NO_x, what type of diesel engines were you talking about?

Professor Thompson

The work that we have done has been on Perkins diesel engines, British Leyland diesel engines, Gardinar diesel engines, and four-stroke, high-speed diesel engines.

The thing that has come to mind actually is particulate emissions. We are now getting results which indicate to us that particulates can be reduced from 50 grams per hour to approximately engine at Southwest that John Storment is going to talk about, the savings come from an improvement in atomization and combustion characteristics.

I think it is simply that we are bringing down the temperature and preventing so much dissociation, and therefore, getting more efficient combustion. That appears to me a fundamental point, one where more work really needs to be done.

Mr. Storment

Since you are running the big engine, you must be making emulsions with residual fuels. Did I understand you to say that they have a lifetime stability of several months?

Professor Thompson

Yes.

Mr. Storment

Have you studied the water droplet size distribution?

Professor Thompson

That is being done now. The oil is being tapped on a day-by-day basis, and it is being analyzed by the chemical engineering department. I don't have any data on that with me.

One thing I would like to mention. I have seen a lot of slides on emulsions in the last day or two, and I remember seeing, in the middle of them, a couple of globules of water. We don't get that.

Professor Agosta

If I may answer or comment on the question that was just posed, we have been doing some work in Europe, in Italy in particular, with Algerian oil, which is like Number 5, and have made emulsions with that and with about 20 percent water. The stability of that emulsion is well over a month, as determined by microscope. The water particle sizes are smaller than three microns. In fact, after three months one is unable to determine the deterioration in the quality of the emulsion by eye, although under the microscope one can see some conglomeration.

SESSION 2

PAPER 9

EXPERIMENTAL REDUCTION OF NO_x SMOKE AND BSFC IN A DIESEL ENGINE USING UNIQUELY PRODUCED WATER (0% TO 80%) TO FUEL EMULSION

T. MURAYAMA
N. MIYAMOTO
(Hokkaido University)
M. TSUKAHARA
(Muroran Institute of Technology)
Y. MORISHIMA
(Toray Co., Ltd.)
JAPAN

4. Among these effects of emulsified fuel on diesel combustion, two main effects are worth considering. They are: the effects of dilution and cooling of the reaction zone by the water vapor, and the effects on the mixing improvement due to water explosion phenomena.

(End of Abstract)

Chairman Walter

Are there any questions? Apparently not. Therefore, we will thank Dr. Murayama and continue on with our next paper. Mr. Storment, of the Southwest Research Institute in San Antonio, Texas, will present a paper titled: "Single-Cylinder Diesel Engine Tests with Unstabilized Water-in-Fuel Emulsions."

SINGLE-CYLINDER DIESEL ENGINE TESTS WITH UNSTABILIZED WATER-IN-FUEL EMULSIONS

J. STORMENT

ABSTRACT

A single-cylinder, four-stroke cycle diesel engine was operated on unstabilized water-in-fuel emulsions. Two prototype devices were used to produce the emulsions on-line with the engine. More than 350 test points were run with the baseline diesel fuel and emulsified water-in-fuel. The water content of the emulsified fuel varied from about 2 percent to more than 23 percent by volume. Statistically significant decreases in fuel consumption, ranging from 1.5 percent to 5 percent, were obtained with emulsions in 20 out of 36 speed/load conditions at which the engine was operated. An increase of 2.5 percent was measured at one condition only. Use of the emulsified fuels decreased oxides of nitrogen by up to 60 percent and Bosch smoke numbers by up to 70 percent, whereas unburned hydrocarbons increased up to 130 percent. Carbon monoxide changes with emulsified fuel varied from a decrease of 50 percent to an increase of 170 percent, depending on speed, load, and water content of the fuel. No problems were encountered in engine operation at any test point with the water-in-fuel emulsions used.

(End of Abstract)

Chairman Walter

Let us have some questions, now. Yes, please.

Mr. Hilden

You studied fuel consumption here. I don't have much feeling for the energy cost for the emulsors. Have you looked at the energy efficiency of the overall system, especially in the system for use on board a ship? Would that significantly change your conclusion as to the efficiency of the whole package?

Mr. Hilden

That was the question.

Mr. Storment

Yes.

Mr. Wilson

In your summary slide, how much water was used for those test points that you report?

Mr. Storment

That is the whole spectrum. As I said, the water went from about 2 to 20 percent by volume. The fuel consumption reduction there, 3.9 and so on, are the average of all points where there was a statistically established change without consideration of engine speed and load and water content. That is why I added the remarks about what loads we saw improvements at, and the water content that we saw them at. I didn't have a slide for that information.

Chairman Walter

Now we'll turn our attention to two gentlemen from the Research Foundation of Ontario, Canada. Each will present a paper, and after the second presentation, the floor will be open for discussion. The first paper, titled "The Hydroshear-Diesel Fuel/Water Emulsions," will be presented by Mr. A. J. Last, and the second, "Diesel Fuel/Water Emulsions for Underground Use," will be presented by Dr. Alex Lawson. Let us start, then, with Mr. Last.

THE HYDROSHEAR-DIESEL FUEL/WATER EMULSIONS

A. J. LAST

ABSTRACT

History, development, theory, and present design of the Hydroshear are given. The Hydroshear is a fluid shear device with no moving parts; it is designed to produce the maximum shear of the second phase liquid with the minimum applied pressure. It is a comparatively small device, and is well suited for retrofit onto diesel engines. Diesel fuel/water emulsions in the <3 microns range can be produced in a simple recirculating system, and chemical emulsifiers or stabilizers are not required.

(End of Abstract)

DIESEL FUEL/WATER EMULSIONS FOR UNDERGROUND USE

A. LAWSON

ABSTRACT

The results of injecting diesel fuel/water emulsions without stabilizers into a Detroit Diesel 8V 71N direct injection two-stroke engine are given. Particular attention is paid to particulate and gaseous emissions for the possible use of these engines in underground mines. Comparison of water induction through intake manifold and emulsions are made, and interesting results due to the two-cycle nature of the engine are discussed.

(End of Abstract)

Chairman Walter

Now for the questions. Yes, sir.

Mr. Wilson

I just want to ask you to clarify your units on the timing. You said 1.5 --

Dr. Lawson

Oh, yes. I think in round figures it would be about 10 degrees.

Mr. Wilson

Just one other question. On the graph showing the emulsion effect on 40-percent water, you have on the graph "Estimated from LS Data." Can you tell me what that means?

Dr. Lawson

Yes. It was an estimated point from the LS, or load/speed, data. It was giving a trend rather than a specific data point. That is another data point that we have got there. It is a reasonable estimate that we think is satisfactory.

On the question of the fuel consumption figures, we looked at them at the Detroit Diesel. There was no difference at all within the measurement data on the fuel consumption figures. We could see no difference in terms of diesel fuel savings with that engine. We don't yet have data on the Deutsch engine.

Mr. Storment

But you show on the graph of the Deutsch that you put in 26-percent emulsion and suffered only an 11-percent drop in horsepower.

Dr. Lawson

That is because the governor compensated for it automatically. You can control the Detroit Diesel with a hand throttle. You can move that forward to increase the fueling rate. You change the rack on the injector to increase the fueling rate. On the Deutsch it is done automatically for you. The governor moves, i.e., when the power drops, the governor moves to increase the diesel fuel rate.

Mr. Swanson

Could it boost it up to recover that much?

Dr. Lawson

Yes.

Mr. Swanson

So, there was no net change in the specific fuel consumption for that engine?

Dr. Lawson

We don't have the actual measurements on that yet, and so we can't tell whether there is or not. I am saying that it has increased the fuel rate to the value that we have determined. We still have to do that. We measure our fuel consumption gravimetrically.

Mr. Swanson

Did you have any reliability problems with injectors when running the emulsions?

SESSION 2

PAPER 13

FUEL FLAMMABILITY HAZARD REDUCTION BY USE OF WATER-IN-FUEL EMULSIONS

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Mr. Swanson

Mr. Weatherford, or Mr. Owens, or anybody else, do you care to comment on the fuel economy aspect of this?

Mr. Weatherford

Ed, would you care to comment on that?

Mr. Owens

On the engine work we have done so far, we have looked at four different engines. On all of these engines, we have never seen a decrease in thermal efficiency. In other words, we have not seen a decrease in fuel consumption when we consider the heating value change in the fuel.

In some cases we have seen a small increase. However, I think that for the Army the most important thing is that we have seen no loss in fuel economy, although there would be a decrease in range because of the limited fuel tank's capacity.

Mr. Weatherford

I neglected to say at the beginning that the Army's objectives were for fire safety. All of the other side effects were beneficial as far as the Army is concerned.* That is why we have a scarcity of engine performance data. This will be determined later in our DOE program that Dr. Moses will be conducting. In that program we will be working it out in detail. Is that not right, Cliff?

Dr. Moses

Yes.

Mr. Weatherford

The claims that appeared in the articles that were published were based partly on the fact that we had seen, at times, efficiency improvements. We knew what John Storment was getting, and we knew

*Editor's Note: It was later determined that the formulation is somewhat corrosive to copper-containing alloys.

Chairman Walter

Well, we have heard all the presentations, and have engaged in most interesting discussion periods, and now we have reached the end of our scheduled proceedings. For myself and for the TSC, I take this opportunity to thank the presenters as well as all the other participants for helping to make this conference a successful one. With that, I declare the proceedings ended.

(End of Symposium)

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