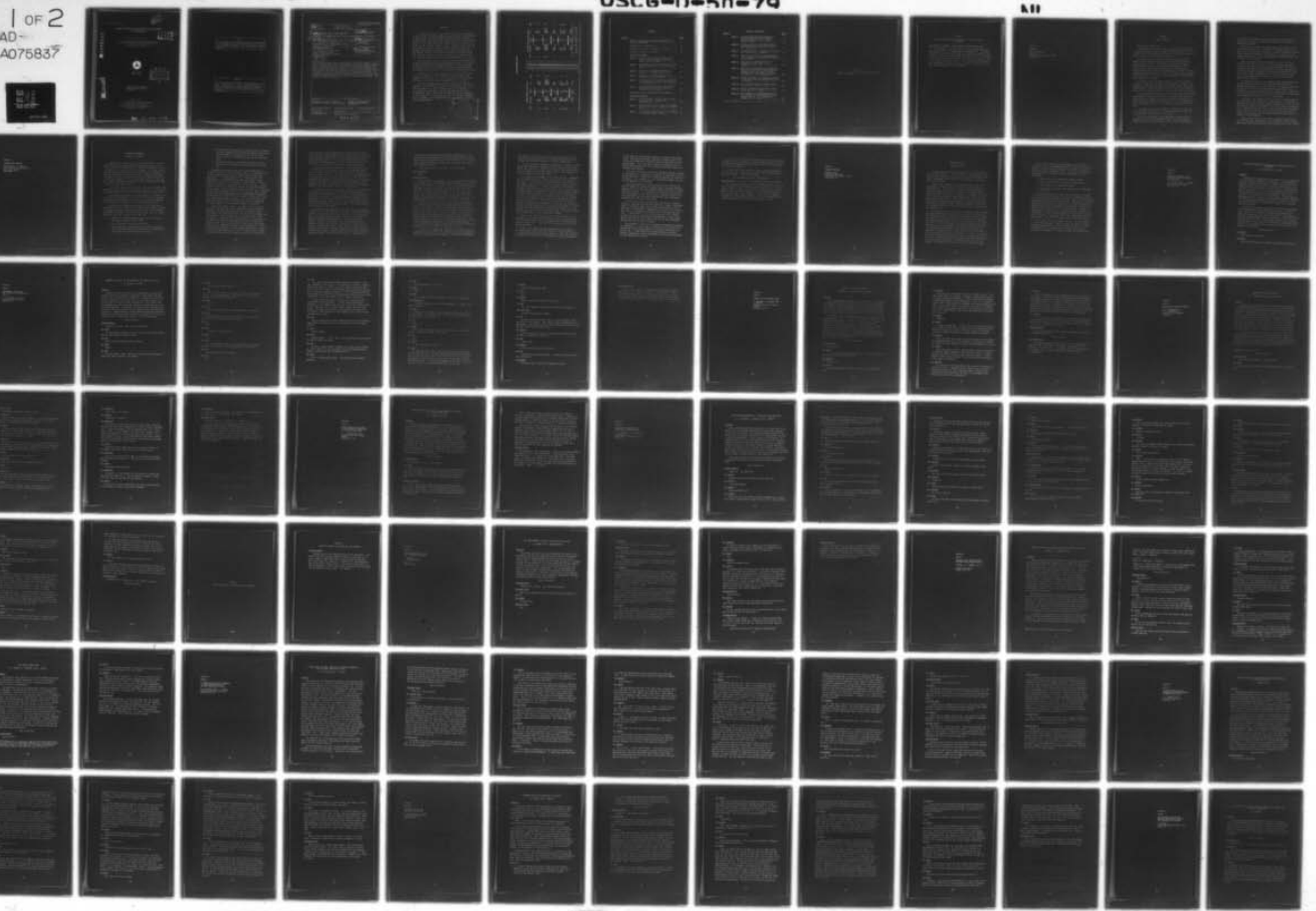
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REPORT NO. CG-D-50-79

SECOND SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTION

LEVEL II

Robert Walter, Editor

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

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AUGUST 1979
FINAL REPORT

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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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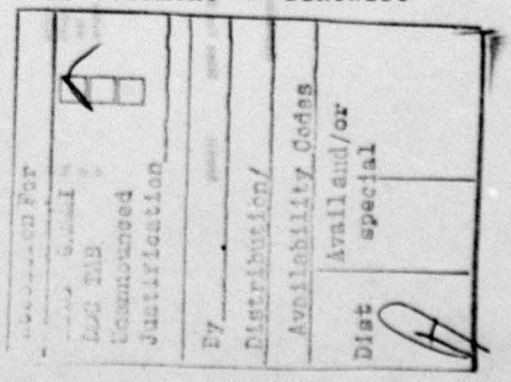
PREFACE

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.



METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SESSION 1

PHYSICAL AND CHEMICAL PROPERTIES OF EMULSIFIED FUELS IN COMBUSTION

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.

SESSION 1

WELCOME

JAMES COSTANTINO
Director
Transportation Systems Center
Cambridge, MA

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

1,000 Federal government employees and support contractors who work with us inhouse. Of that number, about 650 are Federal government employees.

We work in all areas of transportation. We support all of the administrations in the Department of Transportation, and we have a staff of engineers, scientists, computer specialists, operations researchers, analysts, psychologists, sociologists, and economists who work on these transportation-related problems. We are truly a systems center.

Much of our output is paper-oriented; that is, we issue studies in the form of reports. On the other hand, perhaps 50 percent of our effort is in the hardware category. We also investigate integration of transportation technology through state-of-the-art research development, including consideration of the social and economic ramifications of our work. Quite possibly, some of these considerations may get into this discussion on water-in-fuel emulsions.

An important feature of the Transportation Systems Center is that the results of all the work done here lead directly to national policy decisions by the Secretary of Transportation, such as the one reflected by our automotive research effort, and, ultimately, to certain decisions made by the President. Work done at the Center and various kinds of cost studies also find their way into Congressional reports as well as legislation.

I am sure I don't have to spell out for you the importance of the work that you are involved in. Nevertheless, I would like to state for the record that the potential benefits to be derived from your efforts cannot be overstated, for if this emulsion phenomenon can be made practicable for use in vehicle engines and ship propulsion, it will not only help to conserve our dwindling fuel and energy resources, but will also reduce transportation-related pollutants in the atmosphere.

While you are here, you may wish to see other parts of the TSC. We have many laboratories, and, in addition, there are many people here whom you may know and whom you may like to see. Please

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.

SESSION 1

INTRODUCTORY REMARKS

RADM BENEDICT L. STABILE
Chief, Office of Engineering
U.S. Coast Guard
Washington, DC

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.

d. Utilization of TSC expertise in human factors on analysis of watch standing activities and development of measures and improvements in productivity for vessel traffic centers. This is a mushrooming activity for the Coast Guard.

e. Assessment studies on facilities and capabilities in the area of oil pollution response and aids to navigation.

Although my experience with water-in-fuel emulsions is relatively limited, I am sufficiently aware of the possibilities for me to show interest in the potential returns from their application. As I understand it, this subject involves the development of a fundamental technology that applies to the combustion of fossil fuel emulsions in steam boilers, industry furnaces and heaters, diesel engines, and gas turbines. I understand also that it is basically a medium- to high-risk endeavor at this point, that the potential returns are very good. There has been a modest investment on the part of relatively small businesses and individual entrepreneurs in the development of hardware to make and successfully burn water-in-fuel oil emulsions. However, there will probably continue to be insufficient private capital to support the research necessary for this technology. It's quite apparent that government support is essential.

I mentioned returns before. The returns that I would be looking for in this type of a program would include improved efficiency, improved operating lifetime, reliability, modest requirements for system maintenance by Coast Guard personnel, and substitution of lower quality fuels for higher quality fuels. For example, a reduction of two to ten percent in the pounds of fuel burned per pound of steam generated has been reported by reliable sources in the application of emulsions in stationary steam boilers. Reductions in specific fuel consumption of two to six percent are reported in diesel engine applications. Again, I am told that where emulsions are used in steam boilers, cleaner firesides are noticed, soot blowing is drastically reduced, and

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

cutter life cycle operating costs obviously would result. The side benefit of reduced emissions is viewed with interest by the naval engineering community and by those skippers that I told you about, because the emission constraints in various ports would be more readily satisfied.

I have to tell a sea story here. Do I have time?

Dr. Costantino

Sure.

Admiral Stabile

During operations in Honolulu, and as skipper of that ship you were talking about, I had problems with my Fairbanks Morse diesels making a lot of smoke. Every time I went out of port my ship was enveloped in smoke. On several occasions the RCC called me by radio and said, "We have reports that you are on fire." And I said, "No, my diesels aren't warmed up." It got so bad that I finally had to leave port on the gas turbine, which was a lot cleaner and kept me out of trouble. Now that's a real story. In Honolulu they get upset about the kind of thing I described.

Preliminary research for diesel applications conducted for us at TSC consisted of burning stabilized emulsions on a GM 6-71 diesel. The results verified our expectations for emissions reduction, but it did not verify the anticipated efficiency improvement, and because of that we went to a single cylinder diesel test with an unstabilized emulsion at Southwest Research Institute. Partial results of that work were presented at last year's symposium and the final results will be presented tomorrow, I presume. I wish to emphasize that on the 6-71 we used stabilzed emulsions, whereas on the single cylinder job we used the unstabilized emulsions; that will probably be of interest to you.

Now last year's symposium, suggested by the Coast Guard and cosponsored by the Office of the Secretary, had a considerable impact on the Coast Guard's R&D program. The technical exchange at

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

on the stability and physical properties of water-in-fuel emulsions. The contract has been continued for another year to explore other properties of emulsions such as compressibility and corrosiveness. The first year's efforts on properties such as density and viscosity will be discussed in the first paper to be presented this morning.

This year the Office of University Research awarded a contract to the University of Oklahoma for research on combustion of water-in-fuel emulsions. Combustion of emulsion droplets and sprays will be studied. This research is in the preliminary stages, but will also be reported on this morning.

The Coast Guard will continue to follow with interest all efforts related to research of emulsification, and the potential application of off-spec fuel and heavy fuels and blends to various combustion systems. It's reasonable to expect that in the event of a fuel embargo or any other situation creating a need to consider alternate fuels, the ones available and their combustion characteristics will have to be known.

At this point, while stressing the importance of adequate research, I ask that we avoid the temptation to jump in and demonstrate a successful application on one or two machines, and on that basis to forge ahead. Temptations such as this are around us every day in the engineering business and in the operating business. I think that it is vital to the success of this program to make sure that we understand everything about it that we can. That is the only way we can insure that we will make meaningful applications of this type of concept.

The attendees at last year's symposium exchanged much meaningful information. I trust that this symposium will be equally rewarding for the present attendees and for those working in this area at TSC. I look forward to the presentations providing valuable information for the development of systems and procedures for our demonstration efforts.

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.

SESSION 1

PROGRAM OVERVIEW

ROBERT WALTER
Conference Chairman
Transportation Systems Center
Cambridge, MA

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.

Now I would like, with the cooperation of this group, to establish a set of recommendations which, at the end of this conference, we can distribute throughout the country to users or potential users of emulsified fuels. I propose to achieve this by having all of you submit to me written answers to these questions:

1. What are our basic combustion research needs?
2. What are the practical combustion research needs?
3. What should be our funding priorities?
4. How can we, as a group, best influence these needs and priorities?

One final item before we begin with the papers of the day. It seems to me desirable that the end of this conference should not also terminate the potential for this group as a unit to issue communications relating to the technology. Therefore, it would be interesting to take note of suggestions as to how the means for communication could be maintained. Specifically, should we talk about setting up some sort of standing committees? Perhaps we should have a newsletter that we could distribute quarterly, or semiannually. Kindly include suggestions with the answers to the other questions. I'll present them to the group before the conference ends. Possibly we'll come up with something definite.

Well, that's it for my program overview. We will continue now with the first paper. The first paper is titled, "Physical Properties and Stability of Water-in-Fuel Oil Emulsions," and is authored by H. S. Fogler and S. R. Reddy, both from the University of Michigan. Mr. Reddy will make the presentation.

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

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

H. S. FOGLER AND S. R. REDDY

ABSTRACT

Three physical properties of four fuel oils to be emulsified were determined as functions of temperature. The dependence of density, viscosity, and interfacial tension against water were measured between 20°C and 50°C for regular leaded gasoline, and between 20°C and 90°C for No. 2 diesel fuel, No. 4 heating oil, and No. 6 fuel oil. The viscosities of octacosane in water and hexatriacontane in water were characterized as functions of particle size and particle size distribution. This was done by employing acoustic cavitation to produce the emulsions, immediately cooling the emulsion after irradiation so that the oil droplets would solidify, and examining the sample with a scanning electron microscope.

The stability of water-in-fuel oil emulsions was determined by the coalescence of the dispersed particles as a function of time. Particle size analyses, turbidity measurements, and viscosity measurements were used in this study. The densities of water in gasoline emulsions were determined at 0°C and 30°C while densities of water in No. 2 diesel fuel, water in No. 4 heating oil, and water in No. 6 fuel oil emulsions were determined at 30°C and 60°C, all as functions of the volume fraction of water contained in the emulsion.

(End of Abstract)

Mr. Reddy

Are there any questions?

Mr. White

What was the nature of your model for predicting stability?

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.

SESSION 1

PAPER 2

FUNDAMENTAL STUDIES ON THE COMBUSTION OF EMULSIFIED FUELS

C. K. LAW AND C. H. LEE
Northwestern University
Evanston, IL

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.

Mr. Chin

You said you had 30 percent---

Dr. Law

Coal. Thirty percent coal powder, and then five percent water. It's a minimum amount. That amount of water would be present in any coal powder anywhere.

Mr. Chin

I see.

Dr. Law

Just due to natural moisture there would be five percent.

Mr. Chin

Another thing, because those particles are inside those drops, you think in your convective model---

Dr. Law

Yes.

Mr. Chin

---during the heating process--

Dr. Law

Yes.

Mr. Chin

---you think maybe there is even evaporation or something internal, or that there is some relationship to the motion?

Dr. Law

You mean presence of the powder?

Mr. Chin

Yes.

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. Law

Oh, vapor pressure. I'm sorry.

Mr. Chin

Right.

Dr. Law

It is a vapor pressure measurement. Yes, as a containment.

Chairman Walter

I think we have time for one more questioner. I think I saw a hand over here.

Dr. Moses

I wonder if you would clarify a couple of things for me on the experiment. In the first case, did you dry the coal particles and then drive out the water?

Dr. Law

Yes.

Dr. Moses

And in the second case, was it just natural coal, where the water is inside or absorbed in the coal---

Dr. Law

Yes.

Dr. Moses

---not emulsified in the fuel.

Dr. Law

We have done it two ways. First of all, we tried the experiment without the water. We didn't want the water because we didn't know how much water was there. Then we did two things. Our first approach was to put the water in the coal, mix them, and then put the mixture in oil. In the second approach we put water in oil and then put the coal in. Qualitatively, they are the same.

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.

Chairman Walter

Well, we were ahead of schedule, but time appears to have caught up with us. Before we take our coffee break, I think we will get the next paper in: "Dynamics of Exploding Drops," by Terry Morrone, Robert Lippman, and Donald Wright, of the Adelphi Center for Energy Studies. Dr. Morrone will give the presentation.

SESSION 1

PAPER 3

DYNAMICS OF EXPLODING DROPS

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

DYNAMICS OF EXPLODING DROPS

T. MORRONE, R. LIPPMAN, AND D. WRIGHT

ABSTRACT

This investigation for the first time considers the dynamics of explosions in water-in-oil emulsion drops. The investigation was intended to develop a criterion for the occurrence of explosions, and to find out if explosions are caused by evaporation of single drops of water or by the simultaneous evaporation of many drops. Computer models were developed based on each possibility.

The results show that single water drops are capable only of exploding emulsion drops of roughly 10 times their diameter. The many-drop model assumes a cavity is formed and grows because of evaporation of water on its boundary. Both models predict velocities of drop fragments close to those observed. Fragment velocities and explosion characteristics were determined by observation of single frames of high-speed (20,000 pps) moving pictures of drop explosions. The information developed should be of interest in determining optimum water content and water drop size in water-in-oil emulsions.

(End of Abstract)

Chairman Walter

Any questions?

Dr. Shaler

Is there much difference between a No. 6 oil-water droplet and a No. 2 coal-oil-water droplet?

Dr. Morrone

Not too much.

Dr. Shaler

I'm asking whether, in fact, No. 6 has its own nucleation sites.

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.

Dr. Moses

The other question is with respect to some of the results of your model. You indicated that it appeared that as you increase the ambient pressure you decrease the probability of microexplosion taking place. If I remember correctly Dr. Law's work, just the opposite is true. He indicated in findings on work he conducted last year that as probability went up and pressure increased, you would have to have a minimum pressure of at least five or six atmospheres before you could possibly have a microexplosion.

Dr. Morrone

Yes. Well, there are two effects. He pointed out one effect, which results from the boiling point going up. But there exists another effect, namely, that pressure hampers expansion. Frankly, it's unclear which effect is larger.

Chairman Walter

Any other questions? Well, since there are none, let's have a 15-minute coffee break.

(Session resumes)

Chairman Walter

The next paper will be presented by Dr. M. L. Rasmussen, of the University of Oklahoma. This paper is coauthored by Dr. Rasmussen and Professor S. R. Gollahalli, also of the University of Oklahoma, and is titled "Combustion of Emulsion Drops." Dr. Rasmussen.

SESSION 1

PAPER 4

COMBUSTION OF EMULSION DROPS

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

COMBUSTION OF EMULSION DROPS

M. L. RASMUSSEN AND S. R. GOLLAHALLI

ABSTRACT

Experimental measurements of the time taken for disruption of unsupported residual oil/water and residual oil/methanol drops passing through hot combustion gases at atmospheric pressure are presented. The effects of varying the weight fraction of internal phase, initial diameter of the drop, size of internal phase drops, initial temperature of the drop, ambient temperature, and relative velocity have been investigated. A simple, semi-empirical analysis, which predicts these effects in qualitative agreement with the measurements, is also described. The results indicate that the role of internal phase in decreasing the heat available for liquid phase pyrolysis reactions of oil is not significant.

This presentation also includes a description of the experimental setup for studying the combustion behavior of diesel oil-water emulsion drops and sprays* in a high-pressure combustion chamber. The work in progress up-to-date on the experimental part of the project and the application of the above-mentioned theoretical model to diesel oil-water emulsions are discussed.

*Project sponsored by DOT.

(End of Abstract)

Chairman Walter

Thank you, Dr. Rasmussen. Any questions?

Mr. Chin

Have you tried to correlate the disruptive time with heating time?

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.

From the Floor

Are methanol emulsions soluble at all?

Dr. Rasmussen

They are soluble, but very unstable. So, in order to get our data, we had to perform our experiments very fast. The other emulsion, on the other hand, was very stable.

Dr. Naegeli

I noticed in your pictures that the catastrophic event was accompanied by a bushy flame in the case of emulsions, but that the catastrophic event appeared to curve almost at the end of the burning time of the droplets. Is that---

Dr. Rasmussen

I am not sure that's really true. That appeared so just in the last picture. There were more pictures after that, and although I'm not sure what those look like, I think that there was a burst into small fragments which continued to burn.

Dr. Naegeli

I was comparing that strip with the---

Dr. Rasmussen

Well, they were not to be compared time for time.

Dr. Naegeli

They are not---

Dr. Rasmussen

No, they are meant simply to demonstrate the trends and the shape of the flame and the disruptions. If you would like to look at the picture I have, you are welcome to look at it.

Dr. Naegeli

Do you have any estimate, though, of how much of the drop burning has to occur in order to achieve a microexplosion?

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.

Dr. Rasmussen

Yes, I think that's right. The range of our experiments did not show that, but I think that makes sense.

Chairman Walter

No other questions? Thank you, Dr. Rasmussen.

Our next paper is entitled "Recent Results on the Use of Coal/Water/Oil Emulsion as a Clean Liquid Fuel," and is authored by Professor John P. Dooher and the staff of Adelphi Center for Energy Studies. I would like to give the staff due credit for their contribution, and so I will list them here: Richard W. Genberg, Sung Moon, Donald Wright, Steven E. Jacquette, Barbara J. Gilmartin, Joseph Scurra, and John Lepore. Professor Dooher will make the presentation.

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

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

J. P. DOOHER AND STAFF

ABSTRACT

Results of recent investigations at the Adelphi Center for Energy Studies into the feasibility of using a coal/water/oil emulsion as a clean liquid fuel are provided. Rheological studies demonstrating a pseudoplastic, thixotropic behavior are reviewed, and their application to Pouseuille flow in pipes is discussed. Data on correlation between static stability using a physical pendulum and the rheological properties are analyzed. A series of combustion studies has been completed. Data will be presented on thermal efficiency of various coal/water/oil mixtures as compared with oil. Data will also include efficiency of fuel additives for precipitating out SO_x in the combustion gases. A review of plans for larger scale programs is provided, along with the necessary experiments that must be done.

(End of Abstract)

Chairman Walter

Any questions? Yes, in back, there.

Mr. Borie

Can you visualize the day when the slurring can be made at the mine site and pumped a long distance to the boiler or where the electricity is produced, or is there a limitation to what can be done instead of using coal cars and locomotives and shipping by rail?

Professor Dooher

Right. You really pinpointed the question that everybody would like to be answered. The whole goal of these studies is to see if that could be done. If you could make it at the mine head and pipe it, then, of course, the associated economies would look very attractive.

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.

SESSION 1

PAPER 6

EMULSIONS-MICROEMULSIONS: STRUCTURAL CONSIDERATIONS

J. O. STOFFER, S. FRIBERG, AND R. JOHNSON
University of Missouri-Rolla
Rolla, MO

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

homogenous. For that reason I think we can use surfactants, and drop that number for the added materials. It's a whole new area. I am not sure if the microemulsion phenomena hold here. That's one thing we have to look at.

In terms of heat content, or an alternate source of fuel, we are putting in 20 percent less diesel fuel, and if we have methanol available from other materials or other alcohol sources, it may be an alternate supply. Another question? Yes?

Dr. Law

Have you measured smoke emission on the methanol diesel?

Dr. Stoffer

On the methanol one?

Dr. Law

Yes, methanol diesel.

Dr. Stoffer

We ran some preliminary data with smoke emission, and, by sampling the exhaust gas with filters we saw a decrease in smoke.

Dr. Law

Was it significant?

Dr. Stoffer

I think it was 10 or 15 percent in the series that we ran.

Dr. Law

So it's not as significant as if we were comparing part diesel and part water?

Dr. Stoffer

I can't answer that. We did not perform a similar comparison with similar engines. I would almost, but not quite, characterize this as comparing apples with oranges.

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?

Dr. Stoffer

Which set of slides?

Mr. Owens

The slides with the water emulsions. You had grams of fuel.

Dr. Stoffer

That would be probably the hydrocarbon fuel base.

Mr. Owens

Just the hydrocarbon?

Dr. Stoffer

Well, I don't know right now. I did not do that particular work. That was done about a year or so before I got involved. I can't answer that.

Chairman Walter

Anything else? I was sort of hoping we would get another paper in, but I don't think we are going to make it, so I would just like to throw the -- we have another question?

Mr. Schnakenberg

Could you clarify your definition of "smoke"? Are you concerned with total particulates, or are you only concerned with visible smoke?

Dr. Stoffer

It was with total particulates in the first microemulsion water system. That was particulate matter.

Mr. Schnakenberg

In the future, are you going to be looking at total particulate matter?

Dr. Stoffer

Yes, I intend to be involved with that, and with smoke opacity-meters, and such things.

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.

Mr. Becker

One to three percent, or one to two percent? What order of magnitude?

Dr. Stoffer

A sheer guess. At best you are going to be approaching two, three, four, or five percent. That's a guess at best.

Mr. White

If you look at the injection timing, 13, you will find a decrease in smoke. So you have to watch your timing.

Dr. Stoffer

Yes, the smoke content is a function of timing.

From the Floor

Where is that published?

Dr. Stoffer

This was presented at an ACS meeting in San Francisco about two years ago. I can get you some copies of the graphs if you wish.

Chairman Walter

Any other questions? Well, we have a little time. If there's anybody who wants to bring up anything or wants to go back and question any of the presenters this morning, we have roughly 15 minutes before we have to take a lunch break. If there is nothing more, we can opt for an early lunch. I see someone who'd like to say something. Yes, please.

Dr. Law

Since there is some interest in methanol diesel emulsion and we have been looking into it, and there may be some difficulty in making it, I am just throwing this out for possible consideration. Can we use some surfactant that would help us to come up with a stable methanol diesel emulsion? Would anybody want to assist me in this matter?

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?

Dr. Moses

It depends on how much petroleum you have to use to make the alcohol. But if you can replace petroleum in diesel fuel with alcohol, then you can have a net saving in petroleum. You don't use petroleum as your only energy source in making alcohol.

Mr. Phoebe

What are you going to use?

From the Floor

You are making alcohol from natural gas or coal or some substance. That's where extender comes from.

Chairman Walter

Dave?

Dr. Naegeli

I think the issues are confused. Methyl alcohol could be derived eventually from coal or from biodegradable materials, bioaged, and so forth. This is a means of extending our supplies in energy. It is certainly not going to be important immediately, but in the future it could very well be. This is a good reason why one might consider studying methyl alcohol in engines. But naturally, making it from petroleum is a negative process.

Just one other point. If you are familiar with Longwell's paper on synthetic fuels, it's been shown that obtaining synthetic methyl alcohol from coal, synthetic gas from coal or synthetic petroleum from coal, all of these processes, when it really comes down to the bottom line, are about 55 percent efficient. So, then, methanol is not really such a bad way to go.

Mr. Phoebe

Would you care to comment on ethanol?

Dr. Naegeli

Well, ethanol is an important possibility in tropical countries such as Brazil, Philippine Islands, and Indonesia, where really

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.

SESSION 2

PAPER 1

NEW DEVELOPMENTS IN HEAVY FUEL-IN-WATER EMULSIONS

G. BOQUET
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Paris, France

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.

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Mr. Boquet

In France I think it is three to four percent sulfur.

From the Floor

Were any of the burners in those small package type boilers steam atomizing burners, or were they all mechanical burners?

Mr. Boquet

I think that all these burners are mechanical burners, but we also use burners with atomization. It is possible, but in this case you put in less water.

Dr. Thompson

Your results appear to be at variance, or let me rather say that your conclusions are at variance with your results. I notice, however, that your CO_2 readings without emulsion are somewhere around 13.7, and with emulsion, 13.6, which means that your combustion efficiency is marginally decreased. Would you therefore suggest that the improvement in fuel consumption is due to the boiler now operating in a cleaner form?

I would like your opinion on a further point. Most of the boilers which you have shown have worked with a fairly high excess air, i.e., of the order of twenty percent and above. I am sure that a majority of people here would be interested in marine applications with the excess air, say at five, or even three, percent. Would you consider that the application of your device would show any benefits in that area?

Mr. Boquet

Yes. They use burners with three to five percent of excess air, and we have worked some in emulsions with only 0.5 percent of excess air, but that is only with very special burners that we use at ELF in France. Even when we use the burners only, we can work with five percent of excess air with fuel alone.

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)

Chairman Walter

Well, the break is over, and we're ready to hear our next presenter. The next paper has been prepared by a group from the Adelphi Center for Energy Studies, consisting of S. Moon, J. P. Dooher, R. Genberg, D. Wright, and S. Jacquette. The paper is titled "Emulsion Fuel Studies Using Low and High Sulfur Fuel Oil," and will be delivered by Dr. Moon.

SESSION 2

PAPER 2

EMULSION FUEL STUDIES USING LOW AND HIGH SULFUR FUEL OIL

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

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EMULSION FUEL STUDIES USING LOW AND HIGH SULFUR FUEL OIL*

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

ABSTRACT

Thermal efficiency and the production of particulate emissions were studied as functions of emulsion fuel composition using low and high sulfur oils in a boiler furnace rated at 35×10^6 BTU/hr. The fuels used were (1) No. 2 oil, (2) a blend of No. 2 oil and high sulfur No. 6 oil, and (3) high sulfur No. 6 oil. After base-line data were gathered for each oil, water/oil emulsions were generated with 10, 15, and 20% water by an in-line ultrasonic emulsifier. The results of a series of 32 separate 4-hour tests are presented. For each test, thermal efficiency was determined by the input-output method as a function of load and excess air. In addition, a complete gas analysis was conducted to provide a determination of heat losses. This analysis yielded a check on the procedure; generally, the results were within approximately 7% of achieving a heat balance.

Particulate emissions were reduced approximately 10% and 13% when using emulsions made with low and high sulfur oils, respectively. This reduction, which is less than that reported elsewhere, may result in part from the lower pre-heat temperature in the present study. However, the present study utilized steam atomization, which fact may explain the more significant difference between this work and that of references 1 and 2, and which may also account for the differences in reduction of particulate emissions.

In addition, an eight-hour test was conducted to remove sulfur dioxide from the combustion gases using an emulsion of the high sulfur oil. Soda ash was dissolved in the water prior to generating the emulsion, and during combustion produced a sodium sulfate

*Work performed under NASA Contract No. NAS5-23688.

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?

Dr. Moon

About seven hours. In a seven-hour run it actually takes a couple of hours to adjust the firing rate and fuel-air ratio and attain a state of equilibrium. Our work took us to about 11:00 at night. We decided to let the run continue overnight. This in effect extended the run from seven hours to about fifteen hours.

From the Floor

I was under the impression it would take perhaps even several weeks to reach a steady state within a boiler of that size.

Dr. Moon

From our experience, actually only two or three hours ought to provide a pretty good equilibrium state. You see, we took the data every minute. At the beginning we noticed a lot of changes in thermal efficiency and other parameters, but after about two hours we saw that the data had pretty much stabilized. Then, when we let it go overnight, we saw that the data hadn't changed much. Actually, I think that if you really want complete equilibrium, it might take about five days.

Chairman Walter

One more question.

Mr. White

Was your load constant during these tests, or did you have varying steam rates?

Dr. Moon

The load was constant. We varied the pressure from 13,000 to 24,000 pounds. At the 13,000 pound level they were all pretty steady. We were very careful to keep the load constant, within about a couple of hundred pounds.

Chairman Walter

Thank you very much, Dr. Moon. We will now hear from Mr. D. S. Volkmar, of Compagnie Francaise de Raffinage, Paris, France. Mr. Volkmar will present a paper, titled "TOTAL-BERTIN Emulsifier," which is coauthored by Mr. Volkmar and Messrs. B. Carruette and L. Traine, also of the same French company. Mr. Volkmar.

SESSION 2

PAPER 3

TOTAL-BERTIN EMULSIFIER

D. S. VOLKMAR
B. CARRUETTE
L. TRANIE

Compagnie Francaise de Raffinage
Paris, France

TOTAL-BERTIN EMULSIFIER

D. S. VOLKMAR, B. CARRUETTE, AND L. TRANIE

ABSTRACT

The functions and capabilities of the TOTAL-BERTIN emulsifier were discussed in a paper* presented at the first symposium on emulsified fuels in April 1977 at the Transportation Systems Center, Cambridge, Massachusetts.

The emulsifier uses the self-generated vibration of a metallic diaphragm. Some industrial installations are equipped with this technology. Intensive controls were exercised in France on two industrial boilers (2 years operating time on a 10 t steam/hour boiler, and 6 months on a 5 t/hour boiler). They all confirm the results obtained during many tests performed since 1968: drastic reduction of particulate emissions (60-80% in the case of residual fuel oil) and consequent possible decrease of the excess air. Special attention was given to the overall industrial thermal efficiency: the boost of the combustion efficiency, the possible decrease of excess air, the reduction of heat-exchange area fouling, limiting heat losses due to flue gas temperature increase, and steam use for soot blowing. All these effects more than compensate for theoretical loss due to water vaporization. Scanning electron microscope comparison of cenospheres from fuel and oil and water/oil emulsion combustion confirm that, in addition to the physical atomizing effect of water on fuel droplets, water influences the combustion/cracking phenomena.

(End of Abstract)

Chairman Walter

Any questions?

*D. S. Volkmar and B. Carruette, "Emulsion Production and Boiler Performance with the TOTAL-BERTIN Emulsifier." Presented at the Symposium on Water-in-Fuel Emulsions in Combustion, Transportation Systems Center, Cambridge, MA, April 20-21, 1977.

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.

SESSION 2

PAPER 4

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

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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,

the water/fuel emulsions and methanol/aromatic blends correlated in the same way as petroleum fuels. Higher end points did not affect the correlation, indicating that soot formation was due to gas phase reactions, not liquid phase pyrolysis. The results suggest that the mechanism for soot reduction by water in emulsified fuels has chemical origin rather than the physical one involving the microexplosion process.

(End of Abstract)

Chairman Walter

Thank you. Any questions?

Mr. Husted (DOT)

Do you think your results would apply to diesel engines or piston engines?

Dr. Naegeli

I think they would apply to diesel engines to some degree. It is questionable as to where the soot is formed in a diesel engine. If you consider that it is formed in a spray combustion process, and that you are not talking about carbonization, or hanging on a wall or decomposing fuel on a wall, but, rather, if it is in the gas phase, I expect that they would apply. The problem with studying soot in diesel engines is that there are so many other parameters that also have to be taken into account. The turbine function, on the other hand, is very easy to handle, because you have a spray, and everything else remains constant. You don't have cyclic changes and so forth; I think that agrees with some of the results that have been obtained in diesel engines, where soot is reduced by water/fuel emulsions.

From the Floor

You argued that water played more of a chemical than physical role in the soot formation based on the hydrogen-to-carbon ratio. What was that argument again?

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

as to why burning emulsions result in reduction of smoke and soot. At what pressure were you running the combustion chamber?

Dr. Naegeli

Approximately 4.

Mr. White

I am not familiar with all of the fuels that you have worked with, but there is some question as to whether you would get a microexplosion with the lighter distillate fuels. Were some of these fuels originally heavy enough so that you could have reduced them to the No. 6 level, where we would normally expect to get a microexplosion?

Dr. Naegeli

No. They weren't as heavy as No. 6 fuel. I am not ruling out microexplosions. I am just saying that microexplosions don't seem to be the controlling parameter.

Mr. White

I agree. I just wanted to point out that you might have been able to rule out microexplosions as an element in your results because you won't expect --.

Dr. Naegeli

I have got some experiments planned for that.

Dr. Shaler

If you find that the water is behaving only as a chemical, then do you not have to postulate that prior water gas reactions are in there? Do you find an intermediate water gas in the immediate formation of acetylene in the water-gas reaction?

Dr. Naegeli

No. I don't. I don't know of that. I read about the water-gas reaction. That is an old chemistry problem, and there is no indication that acetylene forms when water reacts with carbon. Are you talking about the water-gas shift reaction where you react water with carbon monoxide?

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

regard to some work that was presented by Goite, at the 17th International Symposium, in which it was stated that the presence of sodium and potassium substantially affects the size distribution produced in soot formation through chemical effects; that is, the rate of conglomeration of particles formed in gas phase soot formation chemistry is slowed substantially, to the point that the particle size distribution changes tremendously. Now, I believe that I am correct in saying that the emulsifiers that you are using in these studies are still those generated by I.C.I., and these contain both sodium and potassium. I wonder if you looked at the size distribution.

Dr. Naegeli

No. We didn't look at the size distribution of the smoke. We simply measure smoke number. The smoke number refers to a material absorbed or filtered out on a piece of filter paper, followed by observation of the transmittance and reflectivity of the filter paper.

Dr. Dryer

If it is done by reflectance, that is a function of particle size.

Dr. Naegeli

I am not sure whether that is a function of particle size. If we do an opacity measurement, we are definitely involved with the opacity function, but after the material is put down on a piece of filter paper, literally filtered onto it, the particles are now conglomerated, and we are looking at a solid mass of blackness, so I don't know. Perhaps it does have something to do with particle size, but I am rather uncertain about it.

Dr. Dryer

Were the fuels more volatile in water?

Dr. Naegeli

No. No, they weren't; much less volatile. They are all relatively --.

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?

From the Floor

As I pointed out this morning, there were two effects. At high pressures the boiling points of the constituents in the fuel increase, and we can get a higher temperature. At the high pressures and higher temperatures there are more violent explosions, but at the same time the high pressure keeps the drop from expanding. For example, start out with water at a high vapor pressure, say at forty atmospheres. It starts to vaporize, and so we have forty atmospheres pushing on the water. Now, as the cavity expands and the pressure decreases to say ten atmospheres, the water stops gaining kinetic energy. So, in that case, the pressure decreases the amount of energy that we can gain. As for the two effects, I am not sure that one can predict with certainty which will be larger. It will depend on the type of fuel involved, how high the pressure is, and so on. I think it is unclear as to how much effect an increase in pressure actually has.

Chairman Walter

Well, I guess that's it for today. We'll adjourn for the day and continue with the second part of Session 2 tomorrow. Good day.

(Continuation of Session 2)

Chairman Walter

Welcome back for the second and final day of this conference. We will continue Session 2 by starting off with a presentation by Dr. Fred Dryer, of Princeton University. Dr. Dryer will present a paper titled "Further Studies on the Superheat and Microexplosion of Emulsified Fuels." First, though, I want to give due credit to colleagues of Dr. Dryer for their part in the preparation of this paper. I refer specifically to J. C. Lasheras, T. Avedisian, and A. C. Fernadez - Pello, all of Princeton University. And now, for the paper. Dr. Dryer, please.

SESSION 2

PAPER 5

FURTHER STUDIES ON THE SUPERHEAT AND MICROEXPLOSION OF EMULSIFIED FUELS

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

FURTHER STUDIES ON THE SUPERHEAT AND MICROEXPLOSION OF EMULSIFIED FUELS

F. L. DRYER ET AL.

ABSTRACT

The potential impact for the use of water/fuel emulsions in spray combustion systems is the possible prevaporization of the internal phase which results in the secondary atomization (microexplosion phenomenon) of the fuel spray droplet, leading to better energy utilization/emission characteristics. For the microexplosion to take place, the superheat temperature of the internal droplets of water must be smaller than the fuel saturation temperature. Thus, for a given fuel and environmental pressure, it can be theoretically predicted whether secondary atomization will occur.

In this work a study is presented of experimentally observed secondary atomization of free droplets of distillate hydrocarbon/water emulsions burning in a hot convective environment at ambient pressure, and a comparison is made with theoretical predictions. Experimentally, droplets of the emulsified fuel are injected vertically upward into a hot oxidizing gas flow provided by a flat-lean-premixed flame. The existence of secondary atomization (microexplosion) is reported as a function of the hydrocarbon order and percentage of water in the emulsion. Still and high speed photography are used to qualify the characteristics (delay time between ignition and microexplosion, intensity of the microexplosion, and burnout time after onset of the microexplosion) of the droplets as a function of the initial properties of the emulsion. Theoretically, a model for the kinetic limit of superheat for the internal water phase is used to predict the onset of the secondary atomization as a function of the hydrocarbon order.

(End of Abstract)

Chairman Walter

Are there any questions?

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.

Dr. Dryer

Let me clarify my statement a bit. We have looked at multi-component structured combustion using free droplet techniques like this, and have seen substantial differences in the result when comparing it to suspended droplet combustion experiments of the same fuel. I agree with you that if one limits the interactions of buoyancy with the droplet surface and with buoyancy in the interior of the droplet, one might be able to get away from the problem which you are addressing.

Two important points, I think, need to be made: disruptive combustion plays a very large role in the combustion of multi-component structured fuels, and disruptive combustion, through the presence of the suspending filament, is substantially perturbed in terms of its occurrence during multi-component combustion.

Now, I agree with you that you can do some very specific, although limited, experiments using suspended filament combustion techniques, but I would not want to suggest that therefore we should never look at suspended combustion tests again. The point I made -- and maybe I made it a little too strongly -- was directed at the area of disruptive combustion: when it occurs; when it does not; and with what violence, even in suspended-type situations.

Dr. Law

I think that is true.

Dr. Dryer

Well, we still don't agree about the surface tension effects, but we could argue all day about that.

Dr. Moses

Fred, in some work that I did a number of years ago on nucleation in condensing gases -- it is the opposite problem -- the amount of supercooling in that case depends upon the speed at which you do the experiment. In your experiments with liquid droplets rising through the glycol, it is a very slow experiment, and so your

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

They are different by fairly substantial amounts. The obvious way to get the answer to that is to lower the pressure.

Dr. Law

There are two theories of homogeneous nucleation. One is the thermodynamic limit theory, which says that for the equation of state you investigate the criterion at which the liquid would absolutely not exist, i.e., becomes absolutely stable. That is the thermodynamic limit. There is another limit, the kinetic limit, which really gives you the rate of probability at which this liquid won't exist. So, the thermodynamic limit gives you an upper bound on whether these liquids will exist or not. In the realistic case, I agree with you, Fred, the kinetic limit determines it. But, it has been shown by a lot of chemists and through a lot of experiments that first, the thermodynamic limit gives you an upper bound, and secondly, they don't differ that much. You say that tetradecane and hexadecane do differ by about 20 degrees. To me the degree of uncertainty and a lot of other things happen that might make the 20-degree difference not that significant.

Dr. Dryer

I wish you would not be so emphatic about its having been shown. It has been shown with pure materials, and not with emulsion structures, in which the nucleate vaporization phenomenon does not occur in the homogeneous phase. So, the data that have been produced are not that clear.

Dr. Law

But that is why I suggest that you have shown C-15 and C-16. First of all, to me they are pretty close, with only a 20-degree difference. Secondly, there is some advantage in using this thermodynamic limit, even if it gives you an upper bound and even if it may not be that accurate, because you can use that estimate very easily. For the thermodynamic theory, all you need is Van der Waal's constant. As long as you know the equation of state, which you know for any liquid, you know the A and B of the Van der Waal equation.

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.

SESSION 2

PAPER 6

RESEARCH RESULTS ON EMULSIONS IN BOILERS

R. KINNEY AND P. LOMBARD
Gaulin Corporation
Everett, MA

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.

2. F. L. Dryer, "Water Addition to the Practical Combustion Systems - Concepts and Application," Proceedings of the Sixteenth International Symposium on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania.

(End of Abstract)

Chairman Walter

Thank you. Are there any questions?

Mr. Gincavage

Have you developed a mathematical relationship between the oil particulate size and the water droplet particle size so that when you go to an application you know what particle size you are looking for?

Mr. Kinney

No. What we are basically saying is that with the high-energy homogenizer you can adjust the particle size by changing the ΔP through it. We have run different homogenizing pressures for different particle sizes and have found specifically that the gas turbine required a very small particle size. Certain steam atomized boilers are better with a relatively large particle size. But at this point, it has been a pragmatic process rather than an effort to achieve any statistical data or specific analysis in trying to get a ratio of water to oil. I think that is going to vary several ways, in the type of atomization, and steam versus rotary cup. There are certainly some very substantial differences that we know about between a gas turbine and a small steam-atomized boiler, for example. There is an "optimum."

Dr. Law

I probably missed your argument. Could you explain to me why, if you are putting in five percent water, you would reduce excess air five percent? Why are those two numbers the same?

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

which are distinctively much smaller in size than the macroemulsions that you are talking about, and preliminary data indicate that there was no significant difference when we ran the microemulsions.

Mr. Kinney

Well, I suspect you are talking about two phenomena with the light fuels. Probably the microexplosion phenomenon is relatively small or nonexistent. In other words, the primary effect of the water would be in reducing the gas phase soot. We know that we have some data with residual fuels showing that there are distinct advantages and disadvantages, so to speak, related to different droplet sizes. It may be that the water droplet size for a distillate fuel is less important, since its effect is in the gas phase.

Dr. Dryer

Cliff, I have a question for you. I believe that your argument about homogenization pressure changes and particle size in your experiment and the way you determine what the particle distribution size was is true. I also believe the figure that Dick showed from my water addition paper, in which there is a definite function of surfactant on the particulate reductions achieved with constant water concentration. If that is so, it has to come from one of two sources: one, the surfactant chemically affects the soot formation, which yesterday Dr. Naegeli suggested it did not, and which in conversations later last night you also suggested that it did not; or else, it affects the amount of interface which an emulsion in a dynamic situation can support (that is, in the flowing situation reaching the atomizer), and thus affects the soot formation through changing the internal particle size distribution at the atomizer. I can't think of any other good reason as to why the surfactant changes the soot formation. Can You?

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.

I agree with you that zero to one percent is the effect. What really concerns me, though, is that I know we had enough surfactant, from your static test, to produce a good emulsion structure. We then took it at two percent with distillate type fuel and put it through shear systems, and still had a very nice prime emulsion. In other words, it did not break. But yet, I still see from your curve that there is an effect on soot formation.

Dr. Moses

As I remember, it levels out at right about two percent. That is where we were able to achieve a good stable emulsion. That is where, approximately, it leveled out to where there was no further improvement in soot reduction.

Chairman Walter

Let us continue now with our next presenter. Mr. Matt Winkler of Seaworthy Engine Systems, Inc. will present a paper titled "The Practical Effects of Burning Emulsions in Marine Gas Turbines and Boilers." Mr. Winkler.

SESSION 2

PAPER 7

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

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

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

M. WINKLER

ABSTRACT

This paper describes techniques that permitted the world's first successful program to burn blends of heavy oil, through the use of water-in-fuel emulsions, in aircraft-derivative gas turbine engines. Also described are the effects on marine boiler efficiency and deposits when using a variety of different types of fuel oil additives and water-in-fuel emulsions made with two different techniques.

(End of Abstract)

Chairman Walter

Thank you, Matt. Are there any questions for Mr. Winkler?

Dr. Morrone

You mentioned that the thermocouple readings were more uniform when you used the residual fuel with emulsion. Could you rule out the possibility that this was just because of the type of fuel that, perhaps, was burning slow and therefore burned over a wider, or larger, section of the chamber?

Mr. Winkler

Experience has proved that fuels that burn much slower than the distillate would end up putting into the turbine larger droplets of unburned fuel particles. The spurious droplets from the spray that are several times, in many cases, what the nominal numbers are, would end up impacting the turbine, and would cause deposit problems in the turbine. So, I would rule that out as an observation just on the basis of my work experience with gas turbines for the past 18 years.

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SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTION (2ND), 12-13--ETC(U)
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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.

We did not try, in any way, to impact the everyday operation of the ship, because we found that in the long run they will operate the ship more or less as they want to operate it. Trying to make subtle changes in a test program was not our purpose. The program was intended to see if we could take everyday people and everyday systems, and impact the economics. This was not a test program as such. It was a demonstration.

Dr. Dryer

Regarding the gas turbine test that you spoke of, how, and at what time intervals, were those engines mechanically refurbished, with and without combustion emulsions, that is, on distillate fuels and on residual fuels with emulsions?

Mr. Winkler

The engines are normally removed from the ship for inspection on intervals of approximately 2,000 operating hours, give or take probably several hundred hours either way.

These engines are capable of being removed from the ship in five hours and replaced. So, there is no advantage to doing work in the ship. If for any reason we want to inspect it, we remove it and inspect it in the dockside facility.

The maintenance interval on these engines has probably decreased by about 18 percent. So, if we say 2,200 or 2,300 hours for distillate and 2,000 hours for residual fuels, that is approximately the trade-off.

In terms of dollars and cents, there is a saving of about 30 percent, not in actual fuel reduction, but in the fuel cost difference between distillate and the residual blend. If we take into account additional maintenance cost, we still arrive at a net saving of about 27 percent in fuel cost. When we consider a spending of $18,000,000 a year for fuel, we realize that that is a very significant saving.

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."

SESSION 2

PAPER 8

APPLICATION OF EMULSIFIED FUELS TO DIESEL AND BOILER PLANT

R. V. THOMPSON
University of Newcastle-upon-Tyne
Newcastle-upon-Tyne, 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,

but that was simply because the water comes from a reservoir. There were deposits in the water, anyway, but it was simple tap water.

As far as stability of emulsions is concerned, I think it is now common knowledge that in terms of high distillates, you can anticipate about 30 seconds stability time.

Dr. Murayama

Excuse me. I asked you about the startability of the engine.

Professor Thompson

Oh, the startability of the engine. Yes, that is one point that is worth mentioning. First, with boilers we were asked to safeguard the boiler by having a startup sequential control. We started up on oil, introduced the emulsion, switched off the emulsion, and switched off the oil. Then, after about three weeks, we switched off the control mechanism, and just let it start up by itself. There have been no problems. We have not had any failures. There has been no failure to pumps, or components like it.

To come back to the stability point, high distillates have short times. Therefore, we want an in-line emulsifier which can operate over a whole range of pressures. This particular emulsifier, that was shown there on the big engine, in fact, has zero impedance. There is no pressure rise, and there is no pressure drop through it, whether it is running or otherwise, and it goes directly in the fuel line. It doesn't have to produce an emulsion somewhere else.

If we use the heavy crude oils, say, in terms of as much as 7,000 redwood seconds, then we would obviously anticipate -- and we can demonstrate this -- that the stability of the emulsion will last for months. So, in this case there is no real problem. However, if we are talking about bunkering throughout the world, then surfactants really are going to be a problem, and therefore, we are

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

20 grams per hour by the judicious application of the right ratio of water to oil. I think that is beginning to get significant now.

Dr. Shaler

I wonder if the petrol emulsions were stabilized. If so, did you have a look at the possible safety of these fuels compared with plain petrol?

Professor Thompson

Well, the only way that we could get the emulsion to enter the combustion space in a reasonable form was to make the emulsion in the carburetor bowl itself. The stability of the emulsion is on the order of about 10 seconds; so, it has to be in the carburetor bowl. But if you are thinking in terms of fire safety, then possibly the people from Southwest Research are in a far better position to tell you about the work that is going on than I am. In the United States, people are using surfactants and adding water to prevent unwanted separation. As far as we are concerned, however, if you use petrol, there is a very short stability time. It has to be undertaken in the carburetor itself.

Dr. Moses

You made a passing comment about the savings in diesel engines being due to dissociation as opposed to microexplosions. Would you care to elaborate on that?

Professor Thompson

I did not say as opposed to microexplosions. I said microexplosions are rather irrelevant at the present time, when I am talking about macroexplosion within a combustion space. What I am interested in at the present time is obtaining some economic savings. I feel that when we work on low-pressure combustion such as a boiler and see the spark, we can probably see the microexplosions without too much of a problem.

I think there is a fundamental difference when we operate diesels at high power. We demonstrated that at very low powers on a conventional engine as opposed to the specifically designed

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.

Dr. Moses

Everything is under three microns as determined by microscope.

Professor Thompson

In fact, in the heavy fuel oils, they are the ones that you get the time to look at under the microscope. If you are talking about high distillates, they disappear before you get to them.

Chairman Walter

We are ready now for our next presentation. We are going to hear from Dr. Tadashi Murayama, Professor of Mechanical Engineering at Hokkaido University in Japan. Dr. Murayama will discuss the topic which is covered by the title: "Experimental Reduction of NO_x Smoke and BSFC in a Diesel Engine Using Uniquely Produced Water (0% to 80%) to Fuel Emulsion." Dr. Murayama.

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

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

T. MURAYAMA ET AL.

ABSTRACT

With the aid of a static mixer and non-ionic emulsifying agent, a comparatively stable water-fuel emulsion was obtained. Engine performance in a 4-cycle, direct injection using these fuels was studied.

A large reduction of NO_x concentration was obtained over the wide range of engine operation, in spite of increased ignition lag and rapid combustion. Furthermore, improvements of economy and reduction of NO_x concentration, fuel consumption and smoke were even more remarkable when compared with operating the same engine with water fumigation.

The results derived in this study may be summarized as follows:

1. When an emulsion of water-in-gas/oil ratio of 0.8 was used, starting the engine without any starting aids became possible when the cooling water temperature was about 36°C, the room temperature was 10 - 12°C, and the lubricating oil temperature was about 10°C. As would be expected, if the water content of the emulsion was decreased, startability improved.

2. In a direct injection engine, the No_x and smoke reduction (60% and 48% at rated output) and improved BSFC (16% at rated output) occurred most often with retarded injection timing (11.3°CA BTDC) and in the heavier load range. In contrast, HC concentration was increased about 62% at rated output. However, the amount of HC was quite small in the tested engine, so the influence of HC increases on NO + HC (g/PS-hr) was negligible.

3. Comparing water fumigation and water emulsion in the same engine under the same operating conditions, the NO_x, CO, smoke and BSFC were lower in the case of emulsified fuel.

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."

SESSION 2

PAPER 10

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

J. STORMENT
Southwest Research Institute
San Antonio, TX

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. Storment

Yes. It could substantially alter the decision of the Coast Guard or anyone to go into this area. I should say that this following program that we are going to do does not necessarily use either of these two emulsification devices. We are looking around, but we will set down certain criteria for selection, and one of them will be that it will have to be fairly efficient. The Daedalean device, obviously a very early prototype, had, I believe, a 5-hp electric motor on it. I don't know how much power we got out of the CLR, maybe 10 hp. Obviously, that is not a very good trade-off, but note that the Dynatrol device had a very small motor. If we assume it to have produced a comparable emulsion, we would say it was fairly energy effective. That is a definite consideration in the ultimate application of these things.

Mr. White

I would like to make a comment with regard to the two devices tested. The purpose of the test was to just burn an emulsion. In no sense were we evaluating emulsors designed for that engine, or for any engine. We were just burning emulsions. So, it is not fair to try to draw any sort of conclusion about how much power was expended for the two devices tested, or even to determine whether the two devices were, in any sense, suitable for that engine. We were after an answer to the question: Can you save fuel by burning an emulsion? We were satisfied that we determined that.

When we go into this development of the system to put on board a patrol boat, then we will definitely be looking for an emulsion produced by the smallest amount of energy possible.

Mr. Storment

That point has been stressed several times in the report, about not comparing emulsors. I extrapolated your question to the real world rather than to the laboratory. That is what I was discussing. I didn't mean to say anything about these two.

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.

SESSION 2

PAPER 11

THE HYDROSHEAR-DIESEL FUEL/WATER EMULSIONS

A. J. LAST
Ontario Research Foundation
Mississauga, Ontario (CANADA)

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 retro-fit 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)

SESSION 2

PAPER 12

DIESEL FUEL/WATER EMULSIONS FOR UNDERGROUND USE

A. LAWSON
Ontario Research Foundation
Mississauga, Ontario (CANADA)

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.

Dr. Tuteja

What was the base level of NO_x mass emissions on the Deutsch engine?

Dr. Lawson

I'm not sure I can give that figure offhand. I would say that the 600 ppm label would indicate about three to four grams/hr.

Dr. Tuteja

That will be very low.

Dr. Lawson

It is, yes. It is a very low emission engine. That is why they are used largely underground just now. These engines are all derated engines, too. As you know, with the B-5 injector, the Detroit Diesel is good when you have to derate the engine. The peak power is only 230 horsepower for the V-8, and the same is true with the Deutsch six-cylinder engine. It would be 130 horsepower, which is derated from about the normal value. The surface diesel for that engine, I think, would be closer to 160-180. So, that is probably the reason you feel it is a very low emission engine.

Mr. Swanson

I have two questions. First, could you shed any light on the fuel consumption question that has been raised by others, and secondly, are all these comparisons made with the derated injectors, or are you comparing equal horsepowers?

Dr. Lawson

Equal horsepowers. When you put the emulsion in, the RPM and the power drop. So, you have to increase the fuel rate to get back the same RPM/power ratio. That's where the comparison is made. That was the point I was making about the B-5 injector. If you put too much water in, you can't increase the fuel rate sufficiently, under some circumstances, to get sufficient power out of the engine to make a comparison with neat fuel.

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?

Dr. Lawson

Not that we have noticed yet. It is a little complex, you know. We will be running some alcohol through that engine, as well, and it gets difficult to sort out what effects there are.

Mr. Swanson

You didn't suffer any sudden failures?

Dr. Lawson

Oh, no, no sudden failures at all. There may be some sort of a wear problem that we haven't identified, but we just don't know yet.

Chairman Walter

Thank you. Now we will have a presentation by Mr. W. D. Weatherford, of the Southwest Research Institute. Mr. Weatherford had the cooperation of several colleagues from Southwest in the preparation of the paper titled "Fuel Flammability Hazard Reduction by Use of Water-in-Fuel Emulsions." These include Messrs. G. E. Fodor, B. R. Wright, and E. C. Owens. Mr. Weatherford, please.

SESSION 2

PAPER 13

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

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

W. D. WEATHERFORD, JR. ET AL.

ABSTRACT

The U.S. Armed Forces and the transportation industry have a continuing need for a "fire-safe" fuel for ground vehicles and aircraft. Toward this end, the U.S. Army and other Government laboratories have been conducting research on "fire-safe" fuels for over a decade. This paper documents the early Army studies, and presents experimental results on the Army's current, sixth-generation, "fire-safe" fuel--the one which offers the most promise for successful field application.

The sixth-generation "fire-safe" fuel comprises two alternate formulations. The candidate receiving most attention to date is diesel fuel containing 10%(v) water and 6%(v) surfactant. The alternate "fire-safe" fuel candidate contains only half these quantities of water and surfactant, but it also contains 0.2% (wt) antimist agent. Both of these "fire-safe" fuel candidates are clear-to-hazy microemulsions, which remain unchanged indefinitely in storage at room temperature, and also survive freezing and repeated temperature cycling between 3°C and 55°C.

Extensive flammability, ballistic, and diesel engine performance evaluations and phase stability measurements consistently point to the feasibility of developing a practical fuel which will reduce the vulnerability of combat vehicles. Toward this end, the Army has intensified its modified fuel research and development program with the objective of fielding a "fire-safe" combat fuel within a few years.

(End of Abstract)

Chairman Walter

Are there any questions?

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.

what was published by Professor Murayama. This all was considered in our press release, as far as the actual numbers used were concerned.

Dr. Law

Did emulsions introduce any emission problems?

Mr. Weatherford

We haven't investigated that, so I don't have a definite answer.

Dr. Law

Can you tell whether these effects depend on micro or macro-emulsion? Have you looked into that?

Mr. Weatherford

Within the last week, we have uncovered an extremely interesting phenomenon, namely, that by using this new base fuel we find a 50-degree-average lower boiling point than we did with the fuel we were using last year. We have found that the autoignition temperature (AIT) of the 10-percent water blend is about 800 degrees Fahrenheit; whereas the base fuel is around 475.

Dr. Dryer

What about the flash point requirement?

Mr. Weatherford

The flash point cannot be measured below the boiling point of water. In other words, the water has to have boiled out before you get a flash point.

Dr. Stoffer

Is the continuous phase oil or water?

Mr. Weatherford

This is water-in-oil.

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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