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Microwave Monitoring of Sea Water Contamination of Navy Fuel Oils

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ABSTRACT

Sea water contamination of Navy Special fuel oil is a major problem in oil-burning naval ships. The main cause of the contamination is the use of the fuel bunkers for ballast by filling them with sea water when they are emptied of fuel. Thus, even though "Burner fuel oil - Navy Special" is supplied under Mil-F-859E specification, which permits only 0.5% water content, much higher percentages are experienced in the fleet. This contamination is one of the major factors causing slag deposits on boiler tubes which lower efficiency, reduce ability to get under way rapidly, and increase maintenance costs. Under certain conditions of severe contamination it has even caused furnace explosions. The detection and accurate monitoring of the degree of salt water contamination of Navy Special fuel oil is therefore of prime importance in the readiness and efficient operation of Navy marine boilers.

Prior approaches to electronic monitoring of the contamination, that have been investigated at uhf and lower frequencies, have given insufficient accuracy in that the percentage sea water could be determined only within several percent. The major problem is that boiler fuel oils, including Navy Special fuel oils, are extremely impure and relatively uncontrolled mixtures of compounds. The oil comes from all parts of the world differing greatly in content, and consequently dielectric constant, from one source to the next. With the stipulation that the source of the oil be an unknown, the difference in characteristics of oils from different sources masks the indication used to sense the water content.

Studies of microwave monitoring techniques have resulted in a potential method of monitoring the percentage of sea water contamination to an accuracy of ±0.25%. Investigation was made of both the dielectric constant and the dissipation (microwave energy loss) characteristics of contaminated fuel. The dissipation measurement gave the greater accuracy which improved with increasing microwave frequency. The dissipation measured for all samples of uncontaminated fuels was very small compared to the sensitivity to water, so that the effects of the differences in the different sources of fuel were minimized. Testing of samples from all parts of the world with accurately mixed percentages of sea water showed that this microwave technique can be used to monitor the percentage of sea water to within ±0.25% of the actual value regardless of the source of the oil. The ability to measure to this order of accuracy was limited, in part, by the difficulty of preparing sufficiently precise sample mixtures for testing the technique. The microwave technique also lends itself readily to convenient practical implementation of continuous monitoring of fuel flowing to the furnaces.

PROBLEM STATUS

This is an interim report on the problems; work on the problems of boiler fuel slagging is continuing.

AUTHORIZATION

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MICROWAVE MONITORING OF SEA WATER CONTAMINATION OF NAVY FUEL OILS

INTRODUCTION

The combustion of Navy Special fuel oil contaminated with sea water is one of the major factors in the slagging of boiler tubes in Navy marine boilers. Although "Burner fuel oil - Navy Special" is supplied under Mil-F-859E specification which permits 0.5% water content, considerably more water is added in the ship's fuel tanks as described below. The combustion of contaminated fuel oil results in the deposition of combustion residues, known as slag, which collect on the boiler tubes and lower boiler efficiency to a marked degree; this affects both cost of operation and the ability to get underway.

The importance of determining the degree of sea water contamination of boiler fuel can be better realized if it is understood that sea water is one of the primary sources of sodium and other metal salts that cause slagging. These salts are volatilized during combustion and react with the sulfur oxides from the combustion of the fuel. They subsequently condense on the relatively cooler portions of the boiler. By controlling the ingestion of such salts the rate of slagging can be reduced.

Under the present system of bunkering fuel oil, it is impossible to eliminate sea water from the oil. When the fuel bunkers have been emptied of fuel, it is necessary to refill them with sea water for ballast; this is a major source of contamination. Experiments have shown that the combination of ship motion and irregular shape of the inside of the fuel bunkers causes a shearing action which readily mixes any remaining water in the bunkers into a fine emulsion of the fuel oil. This presents a serious tactical problem in fleet readiness. The detection and estimation of the degree of salt water contamination of Navy Special fuel oil are, therefore, of prime importance for the efficiently and readiness of the operation of Navy marine boilers.

Present analytical methods, such as distillation and chemical separation, are accurate and precise, the degree of precision depending on the technique used (1-3). Although highly accurate, these methods are unsuitable for shipboard operation where continuous monitoring is necessary.

Other approaches to sensing water contamination of fuel oil have been investigated at this Laboratory (4) by measurements of the dielectric and dissipation properties of various oil and water emulsions at uhf and lower frequencies. Although dielectric constant measurements have been used to follow the progress of oxidation in petroleum products, to determine impurities in transformer oils, for the detection of water in hydrocarbons, etc. (5), it should be noted that such determinations are made on highly refined, essentially nonpolar materials where the impurity usually represents only a trace or at least a very minor constituent of the product under examination. In contrast, boiler fuel oils, including Navy Special fuel oils, are extremely impure and relatively uncontrolled mixtures of compounds, representing neither highly refined nor nonpolar materials. They are very complex mixtures of variable composition and cannot be classified as pure substances. Although chiefly hydrocarbon in nature, Navy Special fuel oil contains appreciable amounts of polar compounds. In addition to aromatic and paraffinic compounds known to be present, it contains large amounts of asphaltic and resinous materials of unknown

composition, oxygenated bodies, sulfur and nitrogen compounds, organometallic compounds, and adventitious material picked up in the course of refining or delivery.

Typical of many proposed methods is the suggested use of the dielectric properties of a sea water and fuel oil emulsion. Since the dielectric constant is approximately 80 for water and about 2.5 for Navy Special fuel oil, it appears logical to determine the dielectric constant of mixtures of fuel oil and sea water and to develop an instrument based on this characteristic of the mixture. Such an instrument must be able to distinguish between water and a mixture of complex and impure hydrocarbons, yet it must not be sensitive to variations in composition of the hydrocarbon mixture. The dielectric constant method at uhf and low frequencies fails to do this, as is evidenced by the wide variation found in the dielectric constant values of the original Navy Special fuel oils.

The determination of the sea water content of Navy Special fuel oil by use of the power factor or other methods fails for the same reason that the dielectric constant method fails, namely, the variations in composition of the fuel oils frequently have a greater effect than variations in the amount of sea water. Variations in composition of the boiler fuel oils are inherent in their make-up.

To extend this investigation the Fuels Branch of the Chemistry Division considered the possibility of measurements in the microwave frequency range. Measurements at lower frequencies showed a trend of decreasing spread of dielectric constant values for the different sources of oil and as the frequency increases. To assist this investigation the Tracking Branch of the Radar Division made sufficient measurements at microwave frequencies to test the feasibility of using the higher frequencies to improve the accuracy of percentage water determination.

Two microwave techniques for determining the amount of sea water contamination of Navy Special fuel oil were investigated: (a) The change in dielectric constant produced by sea water contamination was measured in the 4.0 Gc* to 4.5 Gc frequency range. This measurement was very sensitive to water such that, for any one type of oil of known characteristics, the contamination could be measured with an accuracy of about 0.1% or better. However, because of the large variation between the dielectric constants of the uncontaminated oils from different sources, oil from one source with 4% water, for example, looked like oil from another source with 1% water. Thus, accuracy of monitoring the dielectric constant of contaminated fuel was limited to approximately ±1.5%. (b) The second technique investigated was the measurement of the dissipation or loss of microwave energy propagated through a sample. This provided a great improvement in accuracy. Fortunately, the dissipation of the uncontaminated fuel oil was found to be low and relatively independent of frequency over the frequency range measured (up to 75 Gc). In addition, the sensitivity of dissipation measurement to water contamination gave the expected increase with frequency; thus the higher the frequency, the better the accuracy. The accuracy at 75 Gc was approximately ±0.25%, limited mainly by the problem of obtaining accurately mixed samples to evaluate the system for the fuel oils tested. Higher frequencies could possibly provide greater accuracy; however, the accuracies obtained were sufficient for a monitoring system, and the cost and complexity of equipment at microwave frequencies over 75 Gc becomes prohibitive.

Both methods of monitoring lend themselves to convenient continuous monitoring of fuel flowing as desired for a shipboard system. Possible configurations will be discussed.

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*Gc - a gigacycle is 10^9 cycles per second.

EARLIER MEASUREMENTS BELOW MICROWAVE FREQUENCIES

The monitoring of the sea water content of Navy Special fuel oil at frequencies below the microwave range was studied earlier by the Fuels Branch, Chemistry Division (4). The methods investigated were based on well-established electrical properties of hydrocarbons and water and included the following:

- determination of the dielectric constant of the emulsion,
- change in dielectric constant as a function of salt water content,
- change in power factor,
- change in dielectric loss factor,
- change in conductivity.

It was readily demonstrated that, over the range of frequencies from 50 kc to 75 - 100 Mc, the characteristics of the individual oils varied greatly, although the individual emulsions responded to changes in sea water content in an orderly fashion. However, these relationships were of no practical value in measuring the water content of the fuel, since the actual values obtained depend on the characteristics of the original dry fuel oils from which the emulsions were made. Since variations in the composition of the fuel oil have a greater effect than variations in the amount of sea water, this approach was abandoned.

The trends determined by this investigation showed that with increasing frequency the dispersion of dielectric constant values for dry oils from the different sources decreased, while sensitivity to water contamination increased. Thus, it was expected that monitoring of the dielectric constant at higher frequencies could provide useful accuracy of determining percentage water contamination.

DIELECTRIC CONSTANT MEASUREMENTS AT MICROWAVE FREQUENCIES

The dielectric constant measurements at microwave frequencies can be made in several ways. The method chosen was to fill a section of waveguide* with the fuel oil sample and measure the effects of the oil on the transmission characteristics of the waveguide. The waveguide will allow an almost lossless flow of microwave energy as long as the microwave frequency is sufficiently high. As frequency is decreased a point is reached called the cutoff frequency. As the microwave frequency is decreased below cutoff frequency, the loss (or attenuation) in the waveguide increased rapidly. The cutoff frequency is determined by both the dimensions of the inside of the waveguide and the dielectric filling the interior of the waveguide. Thus, the region of rapidly changing loss just below cutoff frequency is very sensitive to the dielectric constant of the medium within the waveguide.

Since the dielectric constant of the dry oil is near 2.5 and that of sea water is in the vicinity of 80, it was expected that small percentages of water would be readily sensed by measurement of waveguide loss or attenuation in the frequency region just below the cutoff frequency.

Other methods could be used for measuring dielectric constant such as measuring wavelength of a microwave signal in oil filled waveguide. However, the wavelength change as a function of dielectric constant is small, requiring precision measurements. This measurement is not a sensitive indicator and is not readily adapted to a convenient monitoring system.

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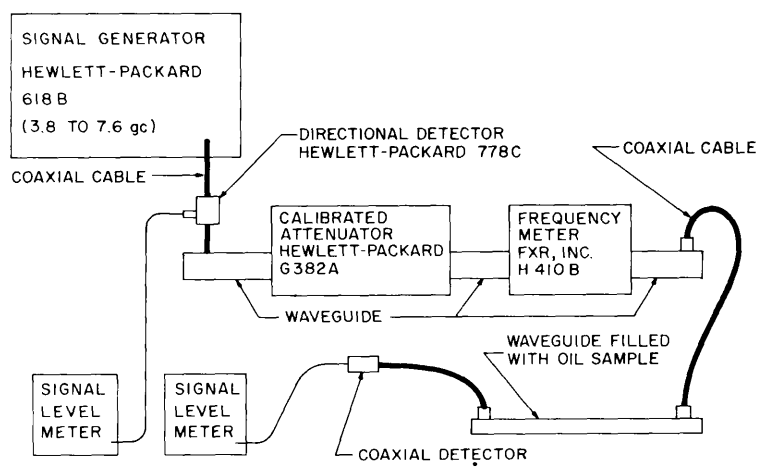
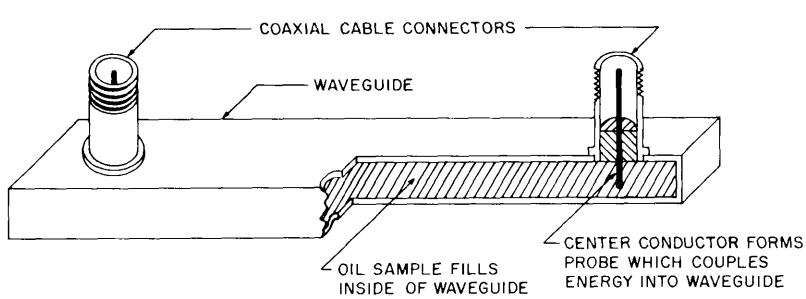
*Waveguide - a hollow pipe, usually of rectangular cross section, through which microwave energy is fed from one point to another.

Measurement of cutoff characteristics provides choice of sensitivity by selecting the appropriate length of waveguide. It is also readily adaptable to continuous monitoring; the oil pipeline can be used as the waveguide (circular cross section waveguide would be satisfactory), and simple fixed probes would couple microwave energy into and out of the pipeline.

The experimental setup is shown in Fig. 1, where a microwave energy source is coupled to the dielectric-filled test waveguide section through coaxial cable. The energy is coupled out by a similar probe and coaxial cable to a device for measuring microwave energy. An accurately calibrated attenuator is used between the source and the experiment. As the frequency of the source is decreased and a reduction in output of the test section of waveguide is observed, the calibrated attenuator is adjusted to remove sufficient attenuation to obtain the original output reading. The amount of attenuation removed, which may be accurately read from the calibrated attenuator dial, is equal to the increased loss of the test section of waveguide resulting from the change in frequency. Other equipment is used to measure frequency and check and account for any other loss external to the experimental section of waveguide.



(a) Circuit layout



(b) Detail of test section of waveguide

Fig. 1 - Test setup for measuring the cutoff characteristics of oil samples to determine their dielectric constants

To verify the experiment theoretically the equation for theoretical attenuation $A(f)$ in dB (logarithmic units of loss), as a function of frequency was examined using the same parameters as in the experiment. This equation for $A(f)$ is

$$A(f) = 54.5\sqrt{\epsilon}\ L/c\ \sqrt{(f_c^2/\epsilon) - f^2} \tag{1}$$

where

- L is distance the signal travels in the waveguide,
- f_c is cutoff frequency, in cps, of the waveguide when filled with air,
- ϵ is the dielectric constant of the material filling the waveguide,
- f is the frequency of the signal in cps, and
- c is the velocity of light in free space, in units of length per second, where the unit of length is the same as that for L.

Since f_c is the cutoff frequency of the waveguide when air filled, the cutoff frequency when the waveguide is filled with oil will be $f_c/\sqrt{\epsilon}$. This is observed in Eq. (1), where it is seen that $A(f) = 0$ when the operating frequency is equal to $f_c/\sqrt{\epsilon}$, the actual cutoff frequency. Equation (1) is good only when $f \leq f_c/\sqrt{\epsilon}$, and $A(f)$ is assumed to be zero for $f > f_c/\sqrt{\epsilon}$. This neglects another loss, called dissipation or dielectric loss, which is a loss of energy in the dielectric, related to characteristics other than the dielectric constant, that exists both above and below cutoff frequency. It is relatively constant over the frequency range of the dielectric constant experiments. The dissipation is small in this frequency range as compared to the cutoff phenomenon attenuation described by Eq. (1), and its effects are negligible for small percentages of contamination. However, at high percentages of contamination it becomes significant, and a secondary coarse-reading monitor would be needed to cover the high-percentage contamination range.

An example of $A(f)$ is shown in Fig. 2 for a dielectric constant of 2.3 and a waveguide with a rectangular cross section with inside dimensions of 0.90 in. by 0.40 in. having an f_c = 6.56 Gc and length of 17.4 cm.

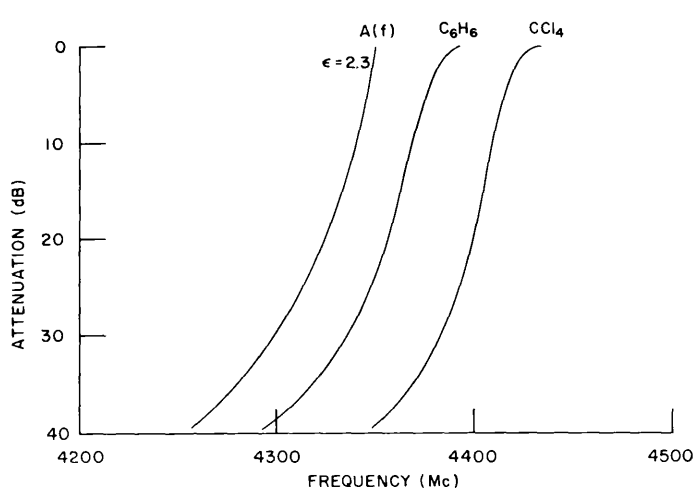


Fig. 2 - Cutoff characteristics measured for benzene and carbon tetrachloride compared with a calculated cutoff characteristic using a dielectric constant slightly higher than that of the two chemicals

Microwave frequency energy was provided by a variable-frequency signal generator and fed to a precision frequency meter. The output from the frequency meter was split into two parts. A small percentage of the power was used to monitor the input power to the section of waveguide under test. The greater part of the energy was transmitted through the section of waveguide filled with the material under test. The output power was then measured at the other end of the test chamber. The experimental procedure was to fill the test chamber with an oil-water emulsion and vary the frequency of a constant-amplitude microwave signal introduced into the chamber. The resultant transmitted energy as a function of input frequency was then recorded. The measured curves do not have the sharp transition at the cutoff frequency(where $A(f) = 0$) like the theoretical curve $A(f)$, because near the cutoff frequency the impedances seen by the signal are changing rapidly. However, the major portions of the measured curves agree closely in shape to the theoretical.

The next step was to verify the experiment by comparing the experimental values of ϵ in Eq. (1) with known values. The value of ϵ was selected such that the theoretical curve $A(f)$ coincides with a measured curve; this value was then assumed to be the dielectric constant of the fluid giving the measured data. The accuracy is greatly enhanced because many points are compared for each sample by matching curves rather than a single point for each unknown fluid, as would be the case for other measurement techniques Values of ϵ were determined for benzene and carbon tetrachloride, and comparison with handbook values (6) is shown in Table 1. The close agreement demonstrates the validity of the experiment.

Table 1
Dielectric Constants of Benzene and
Carbon Tetrachloride

Dielectric	Dielectric Constant	
	Experimental	Handbook
C_6H_6 (benzene)	2.24	2.28
CCl_4 (carbon tetrachloride)	2.19	2.17

The samples listed in Table 2 were obtained from Navy supply depots throughout the world to present a representative variation in the characteristics of Navy Special fuel oil used by the fleet. The cutoff characteristics of each fuel sample listed in Table 2 were measured and are shown in Fig. 3. Values of dielectric constant were determined by matching the cutoff characteristic of each sample with a closest fit theoretical curve using Eq. (1). These values are listed in Table 2.

The effect of water contamination in the fuel oils was measured in a similar manner. The water contaminant was synthetic sea water (SSW) (7). Although SSW was used experimentally to approximate shipboard conditions, the procedure can be used with fresh or brackish water. SSW was mixed with the oil in the required percentages using a high-speed kitchen blender which provided the desired shearing action on water droplets to produce a fine particle emulsion. Microscopic examination indicated that a uniform emulsion was obtained and that few air bubbles were introduced. Measurements indicated negligible effect due to any air bubbles. The emulsions themselves were periodically checked for actual water content by distillation (8) and were never found to be in error by more than ±0.1% SSW.

Table 2
Tabulation of the Samples Measured and the Dielectric Constant Determined by the Measurement

NRL Designation	Fuel Sample Designation	Source	Dielectric Constant (ϵ)
A	Reference I	Middle East via Bayonne, N.J.	2.41
B	No. 6	Long Beach, Calif.	2.46
C	No. 26	Long Beach, Calif.	2.43
D	No. 10	Long Beach, Calif.	2.30
E	Guam U-14	Ras Tanura, Saudi Arabia	2.30
F	Japan	Sasebo Arabian American Oil Company Saudi Arabia	2.30
G	Guam 3	Black Oil Farm Ras Tanura, Saudi Arabia	2.30
H	Seattle C	Standard Oil Co., Richmond, Calif.	2.43
I	Seattle A	Mobil Oil Co., Terminal Island, Calif.	2.38
J	Subic Bay 48	Arabian American Oil Co., Saudi Arabia	2.33
K	Midway Tk-26	Mixture - 75% Awali - Bahrein 25% Ainway - Venezuela	2.37
L	Subic Bay 63	Bahrein Petrol Ltd.	2.33
M	Seattle B	NSCO Point Molate, Richmond, Calif.	2.41
N	Subic Bay 73	Arabian American Oil Company Ras Tanura, Saudi Arabia	2.33
O	Japan 5	Arabian American Oil Company Hokosaki Terminal, Japan	2.30
P	Guam 1	Black Oil Farm Ras Tanura, Saudi Arabia	2.30
Q	Eastern 1	Texaco Oil Co., Norfolk-Trinidad, B.W.I.	2.33
R	Western R-1	Long Beach, Calif.	2.43
S	U-1	Long Beach, Calif.	2.44
T	Reference H	Middle East via Bayonne, N.J.	2.27

Cutoff characteristics of contaminated samples of fuel oil are shown in Fig. 4 for samples of oil, type T, accurately contaminated with the indicated percentages of SSW. This shows a high sensitivity to the SSW contamination with a correspondingly high accuracy of monitoring if the fuel were known to be this type of oil. The technique is very flexible, in that the position of these curves with respect to frequency may be changed by using different sized waveguides, and the slope changed by use of different lengths. The accuracy is demonstrated by an example where it may be desired to sense when the oil exceeds 3% contamination. A frequency of 4.15 Gc, as shown in Fig. 4, could be used with a threshold set at a 15-dB attenuation. If the oil causes less then a 15-dB attenuation, it would be assumed to have greater then 3% contamination. The example as demonstrated in Fig. 4 shows that a 2% contamination would give 28 dB, a 3% contamination would give 15 dB, and a 4% contamination would give 3.5 dB. A system could readily hold its threshold with ±0.1% error, which is considerably better than the needed accuracy.

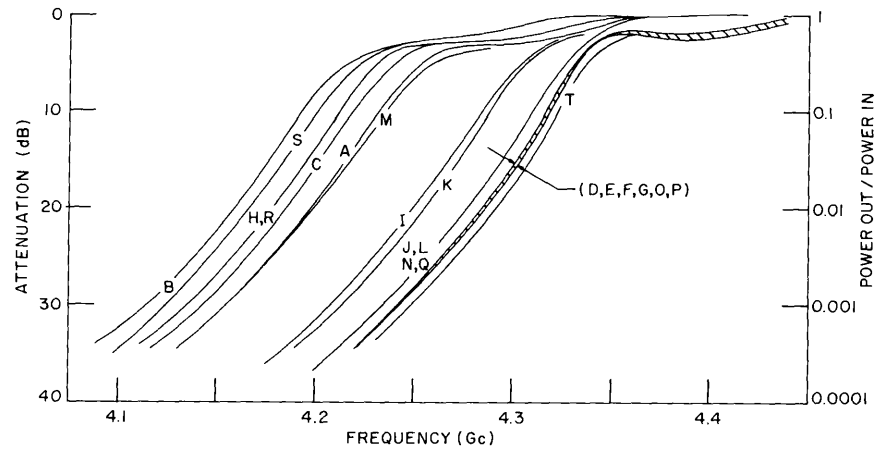


Fig. 3 - Attenuation vs frequency for each oil listed in Table 2 measured in the cutoff region with the experimental apparatus shown in Fig. 1

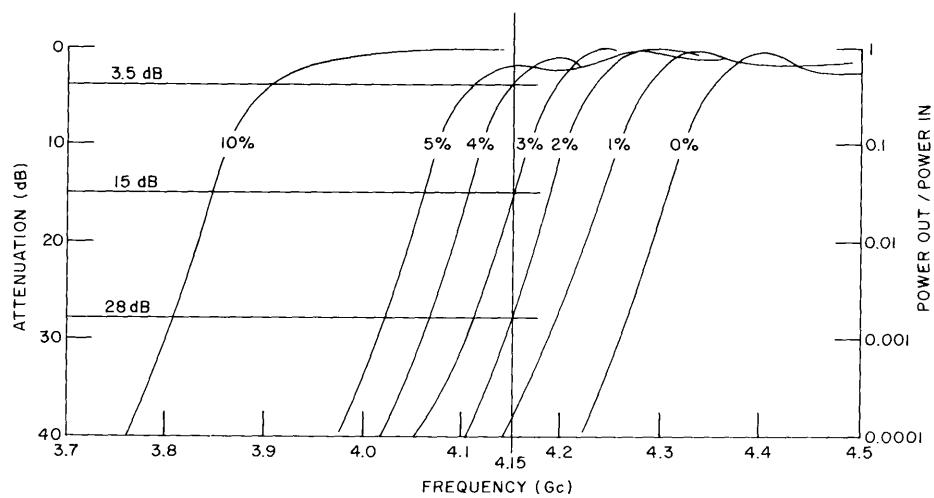


Fig. 4 - Cutoff characteristics of oil T with different percentages of SSW contamination demonstrating the sensitivity of this measurement technique

However, since the type of oil is rarely known, accuracy is greatly diluted by the variation in dielectric constant between the different types of oil shown in Fig. 3. The extreme in loss of accuracy, for the samples measured, is demonstrated in Fig. 5, where attenuation for calibrated values of SSW contamination of oil T is shown together with similar data for oil B. It is observed that a given monitor system setup could not distinguish, for example, the difference between fuel B with 1% SSW contamination and fuel T with about 4% SSW contamination. Since the type of oil is rarely known, it is stipulated that a monitoring system must function without information on the type of oil. This results in low accuracy because of the variation in characteristics of the fuel oils from different sources.

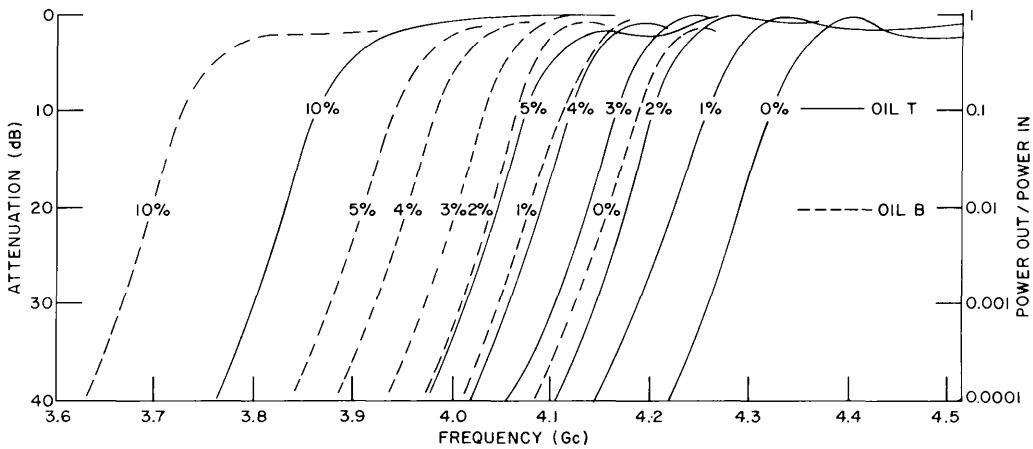


Fig. 5 - Cutoff characteristics of oils T and B with different percentages of SSW, superimposed to demonstrate the loss of accuracy caused by the large difference in characteristics of the oils from different sources

Although accuracy is low, in the order of ±1.5% water, it is significantly better than at low frequencies, and the dielectric constant measurement might be useful where high accuracy is not necessary. Continuous monitoring could be done with simple instrumentation, including probes in the fuel pipeline using the pipe as circular waveguide. By selecting different diameters and lengths the location and slopes of the cutoff characteristics may be adjusted as desired. The dielectric-constant microwave measurement, therefore, could provide a convenient moderate-accuracy monitor.

MONITORING OF THE DISSIPATION FACTOR AT MICROWAVE FREQUENCIES

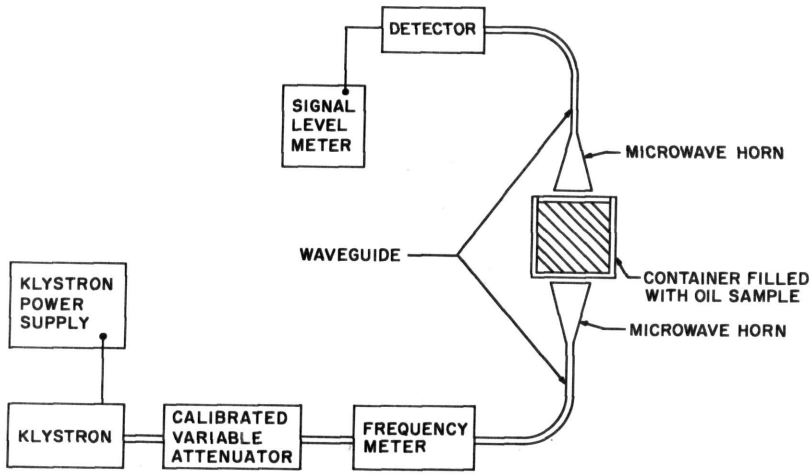
The second characteristic of a material that can be measured at microwave frequencies is the loss or dissipation of microwave energy. This loss caused by dissipation may be measured separately from the effects of dielectric constant by using frequencies above the cutoff frequency or with an experimental setup where the dielectric constant has little effect on the experiment. The difference in dielectric constant of each sample will, for any experiment, have some effect on the dissipation measurement, but by proper design of the experiment the effects of this difference can be made negligible.

It should be pointed out that the dissipation loss similarly affects the dielectric constant measurements discussed in the preceding section. However, in the vicinity of 4 Gc, the effects are small compared to the more dramatic cutoff characteristic and have negligible effects except for very high percentages of water.

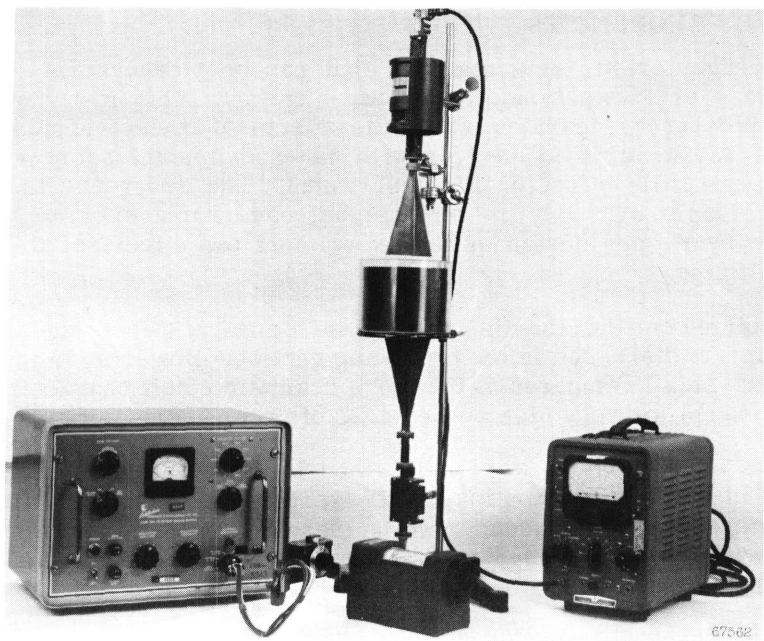
Measurements of dissipation were performed initially with fuel oil in a waveguide guide. It was found that the dissipation in all types of uncontaminated oils was low and relatively independent of frequency, while there was significant sensitivity to water contamination which increased with frequency. Thus, the effects of the difference in characteristics of the oils remained low, while the desired sensitivity to water improved with frequency.

At high frequency the waveguide size becomes inconveniently small. Consequently, experiments were more difficult, and the waveguide size at these frequencies did not lend itself to a practical implementation of a monitor. A simple cylindrical test chamber was devised as shown in Fig. 6, so that energy could be radiated through the chamber by a microwave horn (a directive energy radiating device) and received in a similar horn, where the energy received could be measured. The chamber was constructed of polystyrene, a

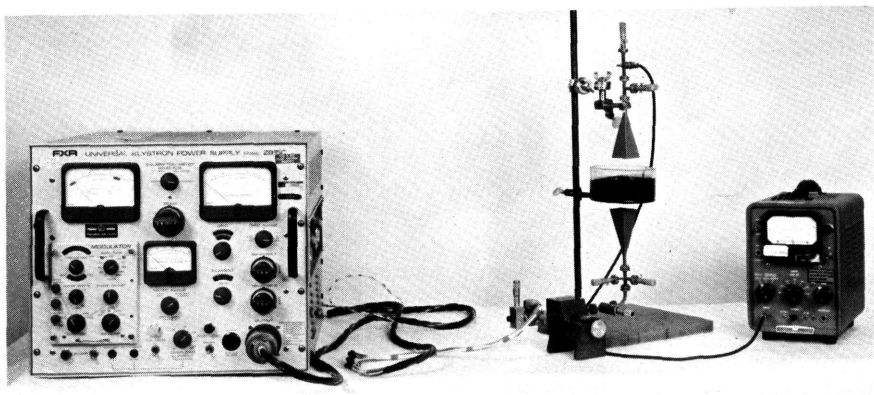
very low loss material, with an inside diameter of 11.4 cm and a height to accommodate a sample of oil 10-cm deep. The diameter is sufficiently large so that essentially all the energy traveling from one horn to the other goes through the full depth of the oil. This method, using a simple test chamber external to the waveguide, lends itself to a convenient shipboard experiment for continuous monitoring of the fuel flow to the furnaces as described later.



(a) The equipment layout with the open top cylindrical test chamber



(b) Photograph of the test setup for measurement up to 25 Gc with a chamber for sample depths to 10 cm



(c) Photograph of the test setup for measurements at 70 Gc with a chamber for sample depths to 5 cm

Fig. 6 - The test setup used for obtaining the data in Figs. 7 and 8

The dissipation loss is a result of microwave energy being converted to heat in the oil sample. The test chamber, being transparent to microwave energy, allows an additional loss due to scattering by water particles. This loss aids in the sensing of water contamination, so there is no attempt to reduce its effect or separate it from dissipation loss. For simplicity the two losses combined will be referred to as dissipation.

The increasing sensitivity of the dissipation loss measurement to water contamination with increasing frequency is shown in Fig. 7 by plots of the general trend of loss vs frequency for different percentages of contamination. The steepness of the trend is suppressed in Fig. 7 because of the logarithmic vertical scale (in dB), but power loss values change from a factor of 10 at 24 Gc for 10% SSW to about 10,000 at 70 Gc. There is a gap in information from 40 Gc to 70 Gc, because equipment is not available in this region. Although water vapor does produce resonant peaks in the microwave range (6), these peaks do not occur for water in liquid form because of the short mean-free-molecular-path, and the trends are expected to be close to that shown in Fig. 7. Beyond 75 Gc the equipment becomes more complex and expensive until one reaches the optical range, where solid state sources of energy are available. Although the visible region is obviously poor, because of lack of light transmission through the oil, there may be useful regions in the low-frequency portion of the optical range. Small variations in measured data about the straight line trend are caused mainly by discontinuities and resultant energy scattering where the microwave energy goes through the transition from air to the test chamber and from the test chamber to air. These variations have little effect on the accuracy of monitoring at any one frequency, where they are essentially constant.

The results of dissipation as a function of percentage SSW are shown in Fig. 8. The three curves for each frequency are for the three types of oil which gave the extreme results. In Fig. 8 the two horizontal lines indicate attenuation readings on the monitor. Assuming the monitors are calibrated for the average characteristics of all oils (i.e., 3% in this case), the largest error if the oil happened to be one of the types having the most extreme characteristics would be ±0.5% at 20 Gc and ±0.25% at 70 Gc. These results verify that satisfactory monitoring could be performed by dissipation measurement in the upper microwave range.

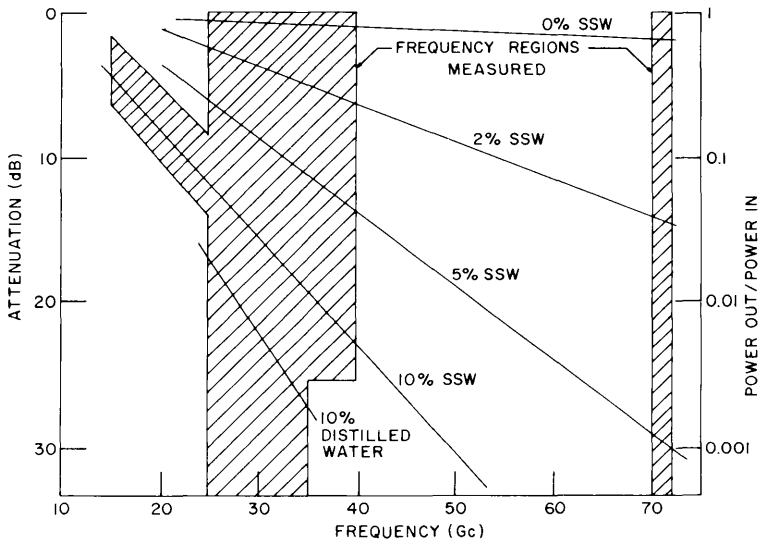


Fig. 7 - The trend of increasing sensitivity of the dissipation measurement with increasing frequency using the experimental setup of Fig. 6

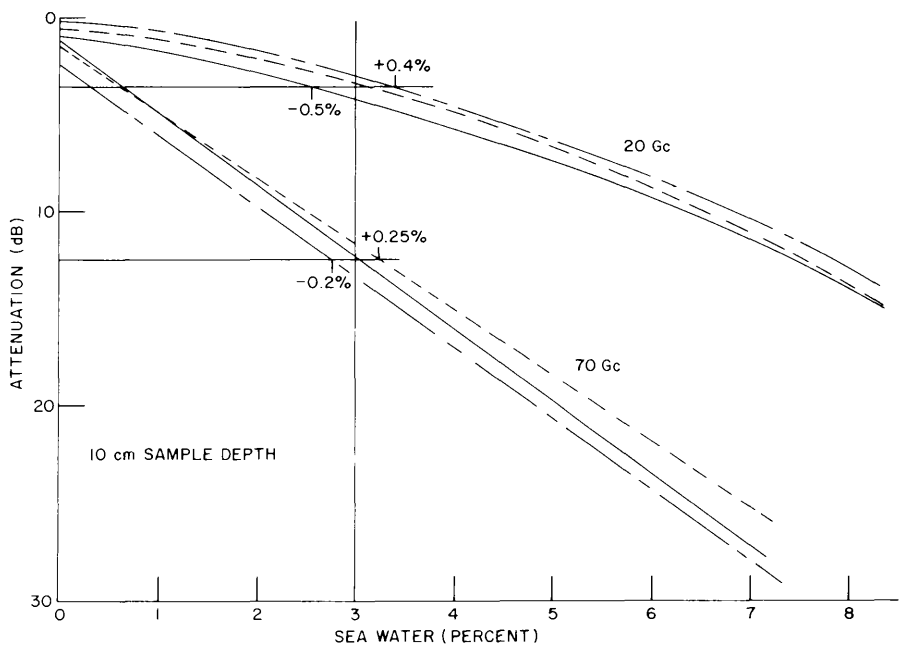


Fig. 8 - Attenuation caused by dissipation and scattering vs percentage SSW contamination shown for two microwave frequencies

This technique for monitoring the water contamination of fuel oil can be adjusted to provide almost any desired sensitivity by use of different depths of the fuel sample. In practice it may be useful to have more than one test chamber because of the large dynamic range of signal levels to be measured.

FACTORS WHICH CAN AFFECT MONITOR RESULTS

In a shipboard monitoring situation there are possible practical differences from these experiments which can have some effect on results. One possibility is that of fresh water

contamination in addition to sea water. Experiments performed with distilled water show a slightly higher sensitivity in the 15 Gc to 40 Gc range, which will give a higher percent contamination reading than that which actually exists. Figure 7 shows a sample of data taken using distilled water. If condensation is expected to be a significant contributor to contamination, the accuracy of the readings will be somewhat degraded.

Particle size of the contaminant may also affect results. No conclusive measurements have been made using different sizes of water particles in the oil; preliminary experiments indicate an increasing sensitivity with increasing particle size in the order of a few hundredths of an inch or greater. However, shipboard pumps will tend to mix the oil and contaminant so that, except for large percentages of water, relatively small particles consistent with these experiments are expected.

An additional factor to consider is that no matter how many types of oil are measured, there is always the possibility of a new type of oil with characteristics falling outside the range of characteristics of those sampled. Since dissipation of dry samples of all types of oil measured is low, it is not expected that fuel oils will be found which would significantly change these results. Considerable effort was made to obtain a realistic representative sampling of all sources of Navy Special fuel oil.

The effects of temperature on the performance of the monitoring technique have not been measured. It is not expected that the temperature ranges of the fuel flowing through pipelines will be sufficient to cause a significant change in monitor readings. This is based on other investigations, where the dissipation of microwave energy in different states of water is found to be mainly dependent on the mean-free-path of the water molecules. Consequently, there is a significant difference in dissipation depending upon whether the water is a liquid or a vapor; when it is in a vapor state, resonant peaks are observed (6). It is expected that as long as the water remains in liquid droplet form, where temperatures are not sufficiently high to vaporize the droplets, the resultant dissipation of water will be essentially temperature independent. Similarly, the low dissipation caused by the oil is not expected to be temperature dependent, although even a 10% to 20% change in dissipation of the oil would significantly affect the results.

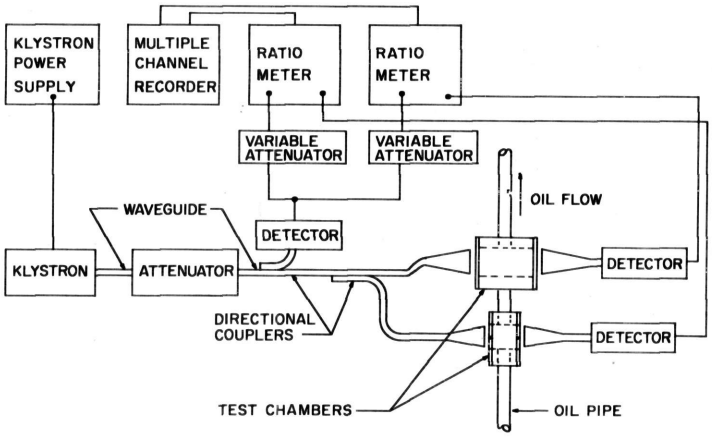
A PRACTICAL MONITORING SYSTEM FOR FIELD USE

The described method of monitoring dissipation with a test chamber is relatively adaptable to a shipboard monitoring system. A full flow chamber was constructed mostly of metal, as shown in Fig. 9. A cylindrical hole was machined in a block of metal, and low loss dielectric plates were used as windows at the ends of the cylinder forming the test chamber. Two sides were drilled and tapped for pipe fittings to allow the full flow of oil. A vertical mounting is desired to avoid accumulation of water in the chamber.

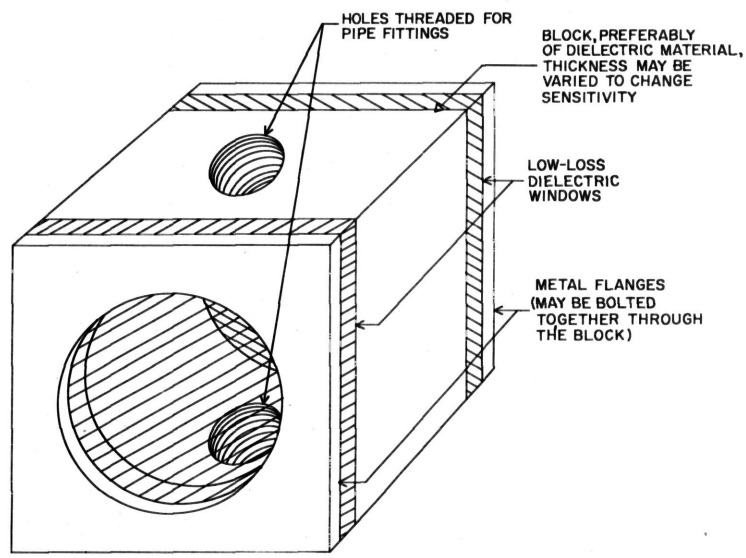
The thickness of the chamber will determine the sensitivity. Possibly two chambers of different thicknesses are desirable, depending on the range of percentage of water to be covered. An additional simple conductivity monitor could be added to monitor for high concentrations of even 100% water.

For the relatively large chambers used in the experiment, focusing of the two waveguide horns to each other in the near field was not necessary and would not have significantly changed results. However, as a refinement to conserve microwave energy and confine the microwave fields to smaller chambers, focusing with dielectric lenses, for example, should be considered for maximizing coupling between the horns.

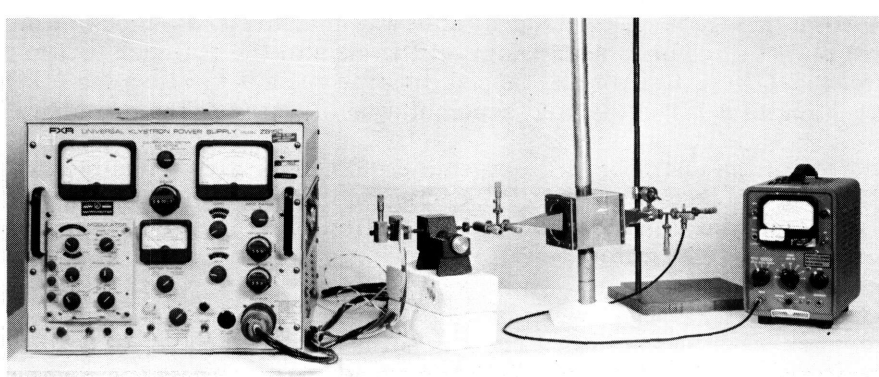
Further studies of an engineering nature will be required to determine the necessary monitoring requirements compatible with accuracy, convenience, and cost.



(a) The circuit layout



(b) Detail of the test chamber



(c) The full flow test chamber used in the experimental tests

Fig. 9 - The proposed full flow monitor of water contamination of Navy Special Fuel oil

SUMMARY

The monitoring of sea water contamination of Navy Special fuel oils by use of techniques which sense the dielectric constant has been investigated from the audio to the microwave frequency range. Although accuracy of monitoring can be high for a given sample of fuel oil, there is a large variation in composition of Navy Special fuel oil depending on its source; consequently, there is a large variation is dielectric constant. This variation in dielectric constant between oils from different sources is minimized in the microwave frequency region with accuracy of about ±1.5%. The dielectric constant measurement does provide a simple means of continuous monitoring, and in applications where this accuracy would be acceptable it could be considered for use.

The best accuracy was obtained by measuring the dissipation characteristics of the fuel oil at the upper end of the microwave frequency range. Dissipation in this range is very low for all samples of uncontaminated fuel and very sensitive to water contamination. Accuracies of ±0.5% and ±0.25% were demonstrated at 40 Gc and 70 Gc respectively. The dissipation technique readily lends itself to convenient mechanization of continuous monitoring of fuel oil as it flows to the furnaces.

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13. ABSTRACT

Sea water contamination of Navy Special fuel oil is a major problem in oil-burning naval ships. The main cause of the contamination is the use of the fuel bunkers for ballast by filling them with sea water when they are emptied of fuel. Thus, even though "Burner fuel oil - Navy Special" is supplied under Mil-F-859E specification, which permits only 0.5% water content, much higher percentages are experienced in the fleet. This contamination is one of the major factors causing slag deposits on boiler tubes which lower efficiency, reduce ability to get under way rapidly, and increase maintenance costs. Under certain conditions of severe contamination it has even caused furnace explosions. The detection and accurate monitoring of the degree of salt water contamination of Navy Special fuel oil is therefore of prime importance in the readiness and efficient operation of Navy marine boilers.

Prior approaches to electronic monitoring of the contamination, that have been investigated at uhf and lower frequencies, have given insufficient accuracy in that the percentage sea water could be determined only within several percent. The major problem is that boiler fuel oils, including Navy Special fuel oils, are extremely impure and relatively uncontrolled mixtures of compounds. The oil comes from all parts of the world differing greatly in content, and consequently dielectric constant,

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Contamination						
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Monitoring						
Microwave monitoring						
Dielectric constant						
Dissipation measurement						

from one source to the next. With the stipulation that the source of the oil be an unknown, the difference in characteristics of oils from different sources masks the indication used to sense the water content.

Studies of microwave monitoring techniques have resulted in a potential method of monitoring of the percentage of sea water contamination to an accuracy of 0.25%. Investigation was made of both the dielectric constant and the dissipation (microwave energy loss) characteristics of contaminated fuel. The dissipation measurement gave the greater accuracy which improved with increasing microwave frequency. The dissipation measured for all samples of uncontaminated fuels was very small compared to the sensitivity to water, so that the effects of the differences in the different sources of fuel were minimized. Testing of samples from all parts of the world with accurately mixed percentages of sea water showed that this microwave technique can be used to monitor the percentage of sea water to within 0.25% of the actual value regardless of the source of the oil. The ability to measure to this order of accuracy was limited, in part, by the difficulty of preparing sufficiently precise sample mixtures for testing the technique. The microwave technique also lends itself readily to convenient practical implementation of continuous monitoring of fuel flowing to the furnaces.