

Evaluation of IMO and Naval Type Bilge Cocktails

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ABSTRACT

The need to evaluate the effectiveness of OWS performance and post OWS polishing technologies has emerged in recent times as a significant issue in the effort to develop oily bilge water treatment systems which can conform to increasingly stringent discharge standards. In this regard a number of test oily bilge cocktail formulations have been developed. Development of such a cocktail is problematic due to the varying nature of actual oily bilge water. This paper discusses the procedures and properties associated with IMO bilge cocktail and a Naval type bilge cocktail. Particle sizes are calculated for the two types of emulsions at 40F and 70F and the behavior of the emulsions is evaluated utilizing the IMO test procedure and in a scaled up version employing a simple oil water separator. The effectiveness of polymeric surfactant filters (PSF) and coalescers as a post OWS polishing device is evaluated for both types of oily bilge cocktails. Results are discussed in relation to field experience.*

INTRODUCTION

In recent times it has become important to develop meaningful test solutions in order to evaluate the performance of oily bilge water treatment systems. This is not a simple task due to the complex and variable nature of oily bilge water and the role that environmental conditions at sea play in the properties of emulsions formed in the bilge. Two of the more ubiquitous test formulations are the IMO test cocktail and the Naval type test cocktail. In this paper we compare the formulations and some of the properties of the emulsions formed by these formulations. We also evaluate the behavior of the formulations when treated with a rudimentary OWS coalescer system and with a polymeric-surfactant polishing device post OWS.

Background

Of the oil released by vessels, 25% is reported to come from spills and 75% from operational discharges. Oily bilge discharge is second only to oily ballast tank discharge in its contribution. There has been much work conducted to determine the discharge standards for oily bilge water and how best to detect and monitor the discharge. The result appears to be that 15-ppm will be the standard of discharge for oily bilge water, although, within localities, more stringent limits often

exist. Historically, oily bilge water has been treated using Oil/Water Separator technology (OWS) or discharged with minimal treatment. OWS technology alone is not capable of meeting current oily bilge water discharge standards in many cases. Specifically this is true when the bilge water is emulsified. Oil/water separators are generally gravity separation devices that operate on the principle of the difference in buoyancy between the oil and water. When oil is sufficiently emulsified in water the miniscule difference in buoyancy between suspended droplets and the water makes it difficult for a gravity separation device to operate efficiently. Nature of Discharge (NOD) Reports indicate a typical influent into an OWS system might range from 200 –2000 ppm and post OWS effluent can range from 15 ppm – 1000 ppm. Out of spec operations and degree of emulsification of the influent are the primary factors that contribute to the large range of post OWS effluent concentration.

*** For the purpose of this article MYCELX filters are referred to as polymeric surfactant filters (PSF). MYCELX PSF are patented products utilized in a variety of applications for removing organic compounds and oils from aqueous influent streams.**

Any post OWS effluent polishing system must be robust enough to handle concentrated slugs of oil without clogging and yet be efficient enough to remove emulsified droplets. A variety of technologies have arisen to fill the gap between OWS capability and discharge standards. Among these are systems based on gravity separation (centrifuges), size separation (membrane systems), chemical affinity separation (polymeric surfactant infused filtration devices), flocculation and adsorption.

There has also been a gap between regulation and enforcement. Unregulated discharges have been problematic. There have been significant advances in the ability to detect such discharges in the past few years; the most salient development is Synthetic Aperture Radar (SAR).

The IMO (International Maritime Organization) has been the leader in development of regulations pertaining to discharge of oily bilge water from ships. The International Convention for Prevention of Pollution from Ships (MARPOL 73/78) sets the standard in regard to bilge water and other forms of ship-generated pollution. The Act to prevent pollution from ships (33.U.S.C. # 1901 et seq.) is the US legislation implementing certain provisions of MARPOL. Coast guard regulations (33 CFR # 151,153 and 155) as amended by the Oil Pollution Act (OPA) and the Clean Water Act require oily wastes discharged within 12 nautical miles of shore, to have an oil content fewer than 15-ppm. Various localities have more stringent requirements and some don't allow any discharge at all and require off shore treatment.

The National Defense Authorization Act of 1996 amended Section 312 of the Federal Water Pollution Control Act (also known as the Clean Water Act) (CWA) to require that the Secretary of Defense and the Administrator of the Environmental Protection Agency (EPA) develop UNDS (Uniform National Discharge Standards) for vessels of the armed forces. (Section 312, (n) (1)).40 CFR Part 9 and Chapter 7 (EPA), 40 CFR Chapter 7 (Department of Defense) completes the first phase of the three phases to set UNDS for armed forces vessels. The phase 1 rule determines the type of vessel discharges that require control by MPCD's (Marine Pollution Control Devices), which includes surface bilge water/oil water separator discharge. This rule creates a new 40 CFR part 1700 establishing UNDS that apply to discharges. This regulation is promulgated under the authority of section 312 and 502 of the Clean Water Act (333 U.S.C. 1322 and 1362). Any new device must conform to MEPC .60(33) (Marine Environmental Protection Committee) as promulgated by MARPOL in which the standards of performance are set for oil filtering equipment.

Now, a word about emulsions. When two immiscible liquids (i.e., oil and water) are present in the same container, two distinct layers will form with an interface and an accompanying characteristic interfacial tension. Surfactants (contraction for surface-active-agent, i.e., detergents) are organic compounds which reduce interfacial tension. When sufficient surfactant is present one phase will tend to form droplets (micelles) in the second phase. The concentration of surfactant at which this occurs is referred to as the CMC (Critical Micellar Concentration). Bancroft's rule (Bancroft 1913) states that the phase in which the surfactant is more soluble becomes the external phase of the emulsion. Although detergents and soaps are conventionally considered to be emulsifiers, solvents and even particulate matter can act as emulsifying agents. In many emulsions, particulate matter, solvents and detergents often act in unison to cause emulsification. Most common detergents, which tend to be more soluble in water than in oil, will form oil in water (O/W) emulsions. Occasionally conditions for W/O emulsions are met. These types of emulsions are called mousses. Emulsions fall into three categories, namely, macroemulsions, microemulsions and miniemulsions. For the purposes of this paper when we refer to an emulsion we mean macroemulsion, which is defined as an emulsion with droplet size in excess of 0.4 micron.

One way of classifying the characteristics of surfactants is through the use of the HLB (Hydrophile-Lipophile balance) method (Griffin 1949). The HLB scale goes from 0 to 40 with 0 being completely oil soluble and 40 being completely water soluble. The HLB can be determined from calculation based on molecular structure or through empirical techniques. Essentially the HLB is a weighted average of the water soluble portion of the surfactant molecule to the oil soluble portion of the surfactant molecule. When one knows this ratio Bancroft's rule can be applied to determine the type of emulsion which is formed, namely, O/W (oil in water) or W/O (water in oil). Similar determinations of the effective HLB can be made for substances that are frequently emulsified. If one matches the HLB of the surfactant to the material to be emulsified maximum emulsification is achieved. The effective HLB of an emulsified system and therefore the HLB of the surfactant or emulsifying agent can be approximated by the emulsion's behavior in water (Beceher 1965). Table 1 illustrates the above.

Table 1 can act as a rough guideline in estimating the robustness of an emulsion and therefore the difficulty in treating. OWS residence times can be gauged based on the behavior of the emulsion as listed in the table.

Table 1

| Behavior in Water | HLB Range |
|---|------------------|
| No dispersability | 1 - 4 |
| Poor dispersion | 3 - 6 |
| Milky dispersion after vigorous agitation | 6 - 8 |
| Stable milk dispersion (upper end almost translucent) | 8 -10 |
| From translucent to clear | 10 -13 |
| Clear solution | 13 + |

From Milton Rosen – Surfactants and Interfacial Phenomena, Second edition, John Wiley and Sons, 1989.

Based on our observations both types of bilge cocktails are approximately in the 8-12 HLB range.

Formulation, Preparation and Monitoring of IMO and Naval type bilge cocktails

For the purposes of this paper, blending operations of the cocktail formulations were done in accordance with recommended IMO procedures which state that the blended test cocktail should be recirculated with a centrifugal pump whose throughput equals total sump capacity per minute for one hour or until no oil is seen floating on the surface of the fluid. As an example a test conducted with 50 gallons of test solution would require recirculation with a 50 gpm centrifugal pump for one hour or until no visible oil is seen on the surface. Once a pseudo-stable emulsion is achieved the test solution is recirculated through the technology to be tested and the influent and effluent concentrations are monitored and recorded utilizing an oil content monitor (OCM) that conforms to the requirements set forth in MEPC .60(33). For the purposes of this paper OCM readings are verified utilizing hexane extraction per EPA method (EPA 1664) for oil and grease.

Two strengths of each type of emulsion are formulated at surfactant concentrations of 200ppm and 700 ppm. The formulations are as follows:

IMO 1, 2

Marine lube oil: 7 gms
Marine distillate fuel oil: 7 gms
Sodium dodecyl benzene sulfonate (SDS): 2 gms (1),
7 gms (2)

Iron oxides: 0.35 gms
Water q.s. 2 gallons

Naval Bilge 1, 2

Marine lube oil: 7 gms

Marine distillate fuel oil: 7 gms
Allied P-98 surfactant: 2 gms (1), 7 gms (2)
Iron oxides: 0.35 gms
Water q.s. 2 gallons

Each formulation evaluation was performed at 40 F and 70 F.

Characteristics of Emulsions

The IMO procedure allows for coalescence of oil droplets twenty minutes after termination of agitation, resulting in an oily layer on the top of the container. This component of the cocktail is amenable to removal through enhanced gravity separation techniques (i.e., centrifuge). Our purpose in this paper was to investigate the component of these emulsions that is not susceptible to spontaneous gravity separation for over forty-eight hours. Therefore, our bench scale evaluations were done utilizing IMO procedure prepared cocktail which was subsequently recirculated through a rudimentary coalescer until a twenty-four hour stable emulsion resulted. Droplets size tests were performed on solutions prepared in this way. On the scale up tests droplets size determination were made on the cocktails in their unaltered state and after recirculation through rudimentary OWS. In both bench scale and scale up evaluations it was found that emulsions prepared per IMO procedure were approximately 20-micron mean particle diameter. Post OWS mean droplet diameter of both type of emulsions at 70F was approximately 1 micron. We considered this component the gravity separation resistant phase of the emulsion and therefore the phase that any polishing technology must address.

Preparation of Emulsions for Mean Droplet Diameter and Terminal Velocity Calculations

Two gallons of each type of emulsion were prepared for initial evaluation. The IMO technique of preparing the test emulsion was employed wherein the full quantity of the test solution must be re-circulated through the centrifugal pump at a rate equivalent to one turnover per minute of the full amount of emulsion for one hour or until no oil is seen floating on the surface of the fluid. We utilized this technique for preparation of emulsions for bench scale testing.

Determination of Mean Droplet Diameter

After emulsions are formed, 100 ml of the stable emulsion is poured into a graduated cylinder and the rising rate of the interfacial zone is observed over a period of 24 hours. The rising rate and depth of the interfacial zone formation are plotted against time. The

curve is fitted for the best fit using Power Law regression and the slope of the tangent to the curve is calculated yielding the terminal velocity (dh/dt) of the droplets within the emulsion. The mean droplet diameters of the emulsions are then calculated using the Stoke's equation. Each emulsion type is evaluated in this way at 40°F and 70°F.

Calculation

The slope of the tangents to exhibits 1 and 2 give the terminal settling velocity, (dh/dt) or (Vs), of the droplets in the emulsions.

The mean droplet diameter is then calculated using the Stoke's law for hindered settling which is given as:

$$V_s = g (P_p - P) D_p^2 / 18 U$$

- V_s Terminal settling velocity (cm/s)
- G Acceleration due to gravity (cm/s)
- P_p S.G. of water (0.997)
- P S.G. of wastewater (0.923)
- D_p Mean diameter of the particle
- U Viscosity of wastewater taken as -0.01 poise

Table 2 documents the results of the above experiments. The mean droplet diameter for the Naval type formulation in each case is smaller than the mean diameter for the corresponding IMO formulation. Increase of surfactant concentration at equal temperatures reduces the droplet size. The most interesting result is the noticeable effect temperature has on the droplet size considering that neither of the IMO tests, nor the Navy tests, specify temperature.

For instance, the 70°F, 200-ppm Naval type emulsion droplet size is only reduced by 20%, as compared to the 70°F, 700-ppm embodiment. By comparison, the 70°F, 200-ppm Naval bilge emulsion droplet size is 70% larger than the same emulsion at 40°F, 200-ppm. The results are as drastic with the IMO emulsion, in which case, increasing surfactant loading from 200-ppm to 700-ppm only results in a 7% reduction in the droplet diameter, whereas reduction in temperature from 70°F to 40°F results in a 66% reduction in droplet diameter. One explanation for this observed phenomenon is that the CMC (Critical Micelle Concentration) of the surfactant decreases due to lower surface tension of the oil droplets. At higher temperatures the effective surfactant concentration is greater than the CMC at lower temperature, thereby, decreasing the stability of the emulsion.

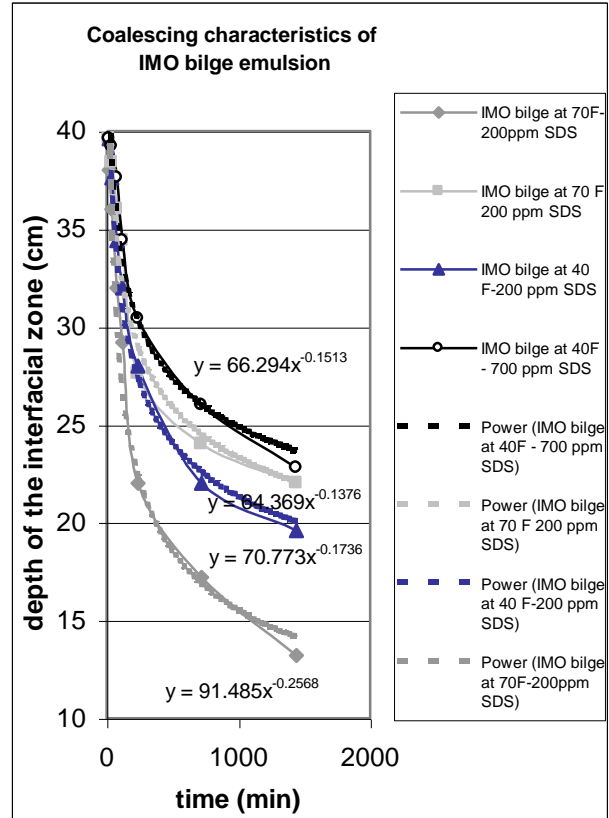


Exhibit 1

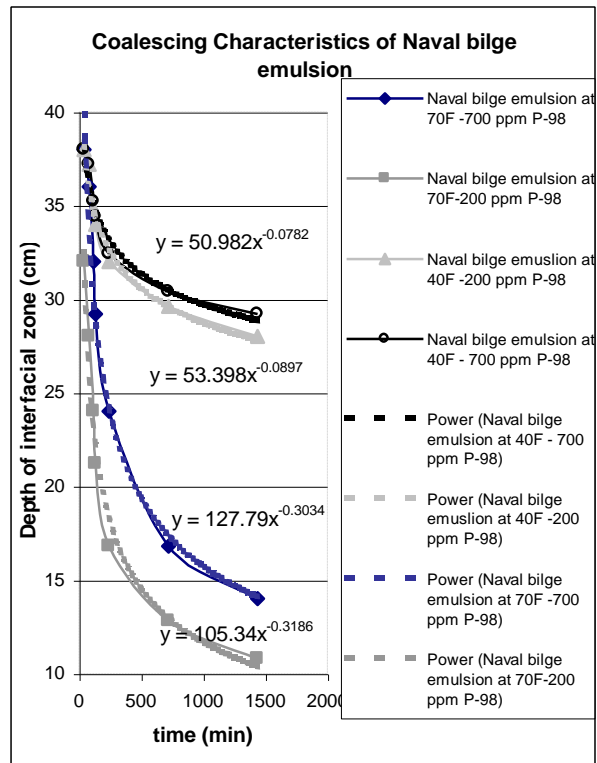


Exhibit 2

Table 2

| Naval Bilge Emulsion | Dh/Dt Cm/s | Mean Diameter Micron |
|---------------------------|---------------|-------------------------|
| P-98 (200 ppm) | | |
| Temp: 70F | 0.0002130 | 0.747210 |
| Temp:40F | 0.0000167 | 0.209224 |
| P-98 (700 ppm) | | |
| Temp: 70F | 0.000133 | 0.590444 |
| Temp: 40F | 0.000010 | 0.161902 |
| IMO Bilge Emulsion | | |
| SDS (200 ppm) | | |
| Temp: 70F | 0.000416 | 1.045074 |
| Temp: 40F | 0.000177 | 0.682650 |
| SDS (700 ppm) | | |
| Temp: 70F | 0.00033 | 0.934743 |
| Temp: 40F | 0.00008 | 0.457929 |

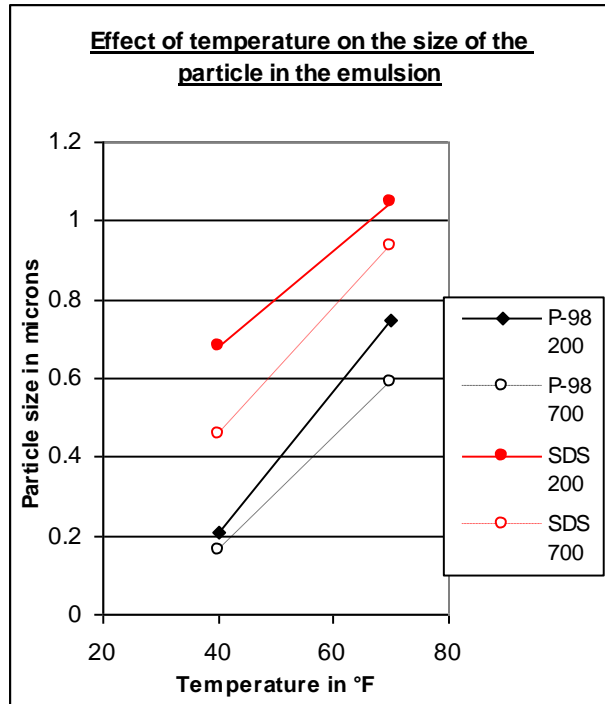


Exhibit 3

Exhibit 3 and 4 illustrate this point. These exhibits show the variation in particle size of the emulsion with respect to temperature and the concentration of surfactants. When one takes the slope of the temperature vs. particle size it is found to be approximately in the order of 0.01-micron/°F. The slope of the surfactant concentration vs. particle size graph yields a ratio approximately of 0.001-micron/ppm of surfactant. The ratio of the two slopes yields the relationship in ppm/°F =0.1 or, °F/ppm =10, indicating tenfold greater effect of temperature on particle size as compared to the surfactant concentration.

Scale Up Tests

It was our desire to observe how these emulsions behave in larger volume. All procedures were conducted equivalently to the bench scale tests. OCM readings were verified by hexane extraction per EPA method - 1664 for oil and grease. Testing was conducted at 70°F to compare the performance of the OWS alone, the OWS followed by polymeric surfactant filters as coalescers, and the OWS followed polymeric surfactant filters as final polishing filters. The apparatus depicted in exhibit 5 was constructed for this purpose, and is comprised of two 60-70 gallon fish tanks configured in series in an underflow weir type assembly. Sixty-gallons of test solution is recirculated

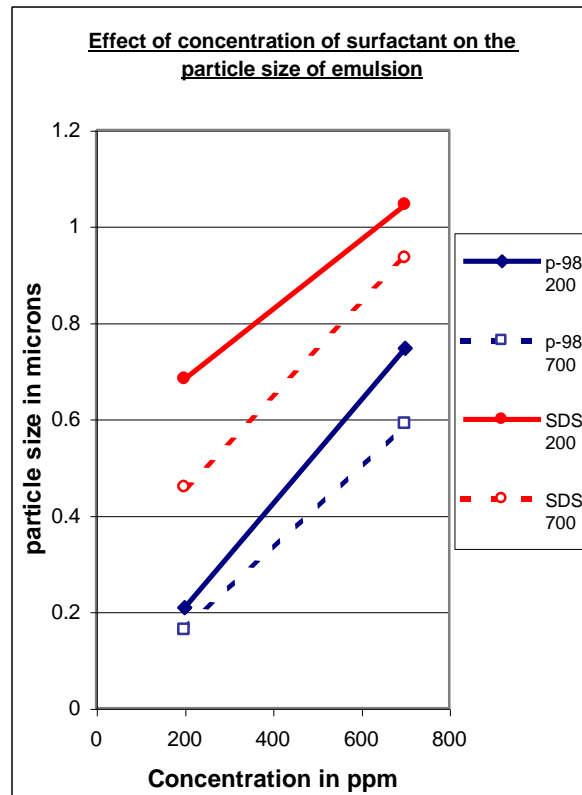


Exhibit 4



Exhibit 5

at 60-gpm. The emulsion is formed by re-circulating through the pumps, until no visible oil is floating on the surface. These emulsions are compared to the previously determined emulsions from the bench scale experiments in order to assure uniformity. Additionally the system is able to accommodate post OWS filtration devices for evaluation and pre and post OWS oil concentrations are monitored using EPA 1664 and OCM.

Initially two test emulsions were formulated to simulate bilge compositions similar to bench scale compositions. Oil loading and surfactant concentration are shown in table 3. Each of these formulations was re-circulated through the system containing the rudimentary OWS until a stable post OWS emulsion results. The results are shown in table 4. We found it necessary to recirculate through the rudimentary OWS in order to achieve a stable emulsion. We did not find that the IMO recommended procedure, by itself,

Table 3

| Type | Influent Average Droplet size | Influent Concentration |
|------------------------------|-------------------------------|------------------------|
| IMO emulsion- 1000 ppm SDS | 20 micron | 6000-6500 |
| Naval emulsion- 700 ppm P-98 | 18-20 micron | 6000-6500 |

Table 4

| Type | Mean Droplet Diameter In Microns | Post OWS Concentration |
|----------------|----------------------------------|------------------------|
| IMO emulsion | 1 | 1000 ppm |
| Naval emulsion | 0.85 | 1000 ppm |

resulted in a stable emulsion, even with prolonged recirculation.

We took this step because we felt that it is not possible to obtain a consistent result without a stable emulsion. The author would like to note that other groups working on the IMO emulsion have also noticed that stable emulsions do not form with the IMO procedure as it is written. Most people doing this work ignore this fact and proceed with testing even though they are never able to achieve a surface free of visible oil. In each case the resultant stable emulsions are approximately 1-micron mean droplet diameter and 1000-ppm total oil concentration.

These emulsions remain stable indefinitely or for at least a day with continuous recirculation through the OWS. In tests performed with emulsions with mean droplet sizes over 1-micron, our rudimentary OWS was successful at separating out some of the oil until a stable emulsion of approximately 1000-ppm oil at 1-micron mean particle diameter was achieved. These tests are being repeated at 40°F but unfortunately the data will not be available until early March. The author estimates that oil loading in the emulsion will be higher at 40°F. Note: In order to achieve a stable emulsion of 1000-ppm with surfactant loading as specified in the IMO standard, a total of 10,000-ppm of oil must be added while continuously recirculating through the OWS. This is necessary due to the high rate of coalescence of the oil droplets in the IMO cocktail. It is interesting to note that the O/S ratio of the IMO emulsion is approximately 5, as compared to O/S ratio of the Naval bilge emulsion, which is closer to 10. The Naval emulsion is more stable even at lower surfactant loading than the IMO emulsion because the Naval P-98 bilge cleaner is a superior emulsifying agent that contains both surfactant and a solvent. Often the most stable emulsions are formed when multiple emulsifying agents and solvents are present.

Testing Coalescing Ability of Polymeric Surfactant-Infused Filters

The OWS resistant stable emulsions from the previous section were passed through a 5-micron polymeric surfactant infused filter in order to determine if the chemical affinity of the modified filter surface could accelerate coalescence in the same way

temperature increase does. Filter micron size greater than the droplet size was selected in an attempt to isolate the effect of chemistry on enhanced coalescence. Sixty gallons of each type of stable emulsion was processed through one bank of surface modified filters at 10-gpm resulting in an estimated contact time of less than one second. The results are as seen in table 5.

After passing through the polymeric surfactant-modified filter a visible layer of oil could be seen to form in the test solution. The still emulsified portion was evaluated and the mean particle diameters were increased by 40% to 50%. Considering that the initial emulsions were stable, it appears that the chemical affinity of surface modified filters for the micellar interfacial membranes was successful in destabilizing the emulsion, thereby enhancing coalescence. As noted earlier emulsions with droplet sizes greater than 1-micron tend to coalesce under the effect of gravity.

MYCELX Filters as Post OWS Polishing Devices

When the same tests as above are performed with sufficient filters contained in the filter bank to provide a 5-second contact time, the filters are able to absorb and assimilate the emulsified oil. The results of surface modified devices used in post OWS polishing are seen in table 6.

It is an interesting to note that as oil loading and oil to surfactant ratio varies, single pass efficiency and average effluent concentration remain constant. The parameter that is affected is total oil holding capacity. Generally, as the degree of emulsification increases, total filter holding capacity to saturation decreases. Exhibit 6 illustrates this effect. One will notice that as oil to surfactant ratio decreases the total oil holding capacity of the filter decreases. Interestingly, oil loading seems to have a relatively small effect compared to oil to surfactant ratio. This highlights the observation that any post OWS polishing device performance is dependent on initial conditions and OWS operation must be efficient in order to enhance

Table 5

| Naval Bilge Emulsion | Pre Filter Dh/Dt Cm/s | Pre Filter Mean Diameter Micron | Post Filter Dh/Dt Cm/s | Post Filter Mean Diameter Micron |
|-----------------------------|-----------------------|---------------------------------|------------------------|----------------------------------|
| P-98 (700 ppm) Temp: 70F | 0.000283 | 0.861283142 | 0.000593 | 1.246752 |
| IMO Bilge Emulsion | Dh/Dt Cm/s | Mean Dia Micron | Dh/Dt Cm/s | Mean Dia Micron |
| SDS (1000 ppm) Temp: 70F | 0.000333333 | 0.934742742 | 0.001 | 1.6190219 |

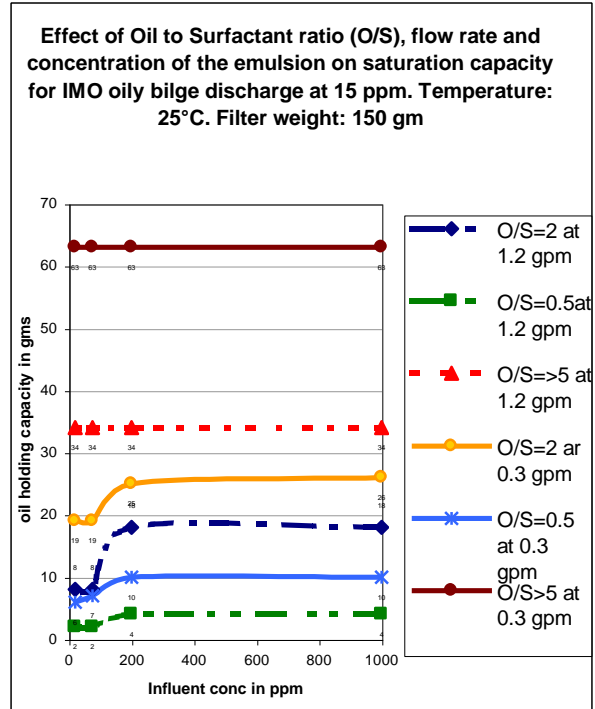


Exhibit 6

post OWS polishing.

The data indicates that oil to surfactant ratio is a more important parameter than total oil loading in regard to the robustness of the emulsion which is formed.

DISCUSSION

Development of test solutions and procedures in order to produce meaningful performance results for bilge water treatment systems is a tall order. The extreme variability of bilge compositions, thermal cycling, weathering, and vibrational and translational agitation, all of which are encountered in shipboard applications, are difficult to simulate in the laboratory.

Table 6

| Emulsion Type | Concentration Surfactant | Average Influent Emulsified Oil | Average Effluent | Flow Rate GPM | Gallons Treated | Weight Oil Removed (gms) | Single Pass Efficiency |
|----------------------|---------------------------------|--|-------------------------|----------------------|------------------------|---------------------------------|-------------------------------|
| Naval | 200 ppm P-98 | <i>1000 ppm</i> | <i>3 ppm</i> | 10 | 53000 | 199000 | >99% |
| | 1000 ppm P-98 | <i>1000 ppm</i> | <i>3 ppm</i> | 10 | 39750 | 150100 | >99% |
| | 15000 ppm P-98 | <i>1000 ppm</i> | <i>3 ppm</i> | 10 | 24380 | 100000 | >99% |
| IMO | 1000 ppm | <i>1000 ppm</i> | <i>8 ppm</i> | 10 | 34380 | 140000 | >99% |

The combination of these effects often produces emulsions with unique characteristics. As these temporal conditions are difficult to simulate emulsifiers are often used to replicate the types of droplet size distributions encountered in the field. The two most common such formulations are the IMO test cocktail and Naval type bilge cocktail. It was our goal in this work to evaluate the static and dynamic properties of these test solutions. Static properties were evaluated using bench level experiments per IMO guidelines. The dynamic properties were evaluated by simulating a rudimentary underflow weir type OWS (arguably one theoretical plate) and by processing through an oleophilic affinity type filter. The ability of the filter to coalesce and to remove the emulsion from the solution was evaluated. Both types of bilge cocktails require agitation, surfactants and solvents in order to achieve an emulsion. Temperature is not specified in the formulation of either type of cocktail. The difference in droplet size between emulsions formed at 40°F and those formed at 70°F are notable and in line with theoretical considerations. One of the reasons marine engineers might be skeptical of the claims made by equipment manufacturers regarding efficiencies could be due to the fact that shipboard bilge water is often cooler or warmer than formulations utilized during testing. If this is indeed the case and bilge water in ships is closer to 40°F than 70°F then the mean particle size distribution on shipboard oily bilge water would be about half the size of the droplets produced during laboratory testing. Our work did not address formation of smaller droplets at higher temperatures due to higher activity coefficients of solvents involved in emulsification. This is also a possibility depending on the solvents and surfactants present and other temporal

conditions. With the particular emulsion that we evaluated, we found that lower temperature yields smaller droplet sizes.

The effect of salt water is also not addressed in the IMO tests. Adding this variable could also have an effect on droplet size distribution with temperature.

The tests conducted in this work seem to indicate that mean particle diameter is a much greater factor than total oil loading in regard to the stability of the emulsion. The amount of surfactant and solvent, in addition to temperature, plays a role in this regard. The P-98 naval bilge cleaner is by far the most potent emulsifier of any of the components we have encountered in these formulations. It appears that stable emulsions formed by the use of these formulations produced by cycling through gravity separation tend to have mean droplet diameters in the 1-micron and less range. These less than 1-micron emulsions are relatively impervious to gravity separation techniques and require additional help through flocculation, coalescence, temperature, pH, or through chemical affinity filters.

The effectiveness of chemical affinity filters was evaluated on these stable emulsions in regard to coalescence and de-mulsification. It was found that chemical affinity filters altered the pernicious 1-micron droplets to greater than 1-micron, thereby producing phase separation and enabling gravity separation devices to be effective. When contact time in these types of filters is increased from 1-second, 5-second de-mulsification and adsorption into the filter takes place resulting in less than 15-ppm effluent (In the case of these tests, approximately 3-ppm). It appears that droplets less than 1-micron in size require assistance through manipulation of physical and or chemical

parameters such as temperature, pH, and or reduction of interfacial tension of the membrane through the use of surface-active agents permanently cured into the coalescer or filter substrate.

It is interesting that our field experience with surface modified filters in bilge water applications on cruise ships and in a variety of other marine environments seems to exceed laboratory based performance results based on IMO tests by about 3-5 times. In other words, filters remain effective in the field three to five times longer than based on estimates from IMO emulsion tests. We believe that one of the reasons for this could be that actual bilge water goes through the engine room, which is heated. Other contributing factors could be that O/S ratios are not as high as indicated by test cocktails. Other temporal factors may also play a role. The solubility of the surfactant in water along with temperature is the greatest factor in the robustness of the post OWS resultant emulsion. Lower water solubility of the surfactant results in greater fraction of it being removed in the OWS leading to a less robust emulsion with a lower O/S ratio. Obversly higher water solubility of the surfactant results in a greater fraction of it passing through the OWS causing a more robust emulsion with a higher O/S ratio. In the case of this paper the Naval P-98 emulsifier is more water soluble than the IMO SDS emulsifier. This is the primary reason for the smaller droplet size of the Naval bilge emulsion at equivalent temperatures.

CONCLUSION

- IMO and Naval type bilge emulsions, when prepared according to IMO method result in emulsions with mean droplet size of approximately 20 microns. When allowed to settle the greater part of these emulsions undergo gravity separation and result in a layer of oil in the top of the container. In both IMO and Naval type bilge emulsions the phase which remains after gravity separation is approximately 1000 ppm oil with mean droplet diameter of approximately 1 micron or less. This phase does not undergo gravity separation for at least 24 hours.
- Recirculation of IMO and Naval bilge emulsions through a rudimentary underflow wier apparatus results in stable emulsions with droplet size approximately 1-micron.

- The non-gravity separable component is the most important for post OWS polishing device to address
- Mean droplet size in test emulsions is affected by concentration of surfactant, water solubility of surfactant and temperature. Water solubility of surfactant and temperature contribute to a greater extent to reduce the mean droplet diameter than total surfactant loading.
- A simple underflow weir type OWS is not effective at producing phase separation in emulsions with mean droplet diameter of 1-micron or less
- Equipment performance evaluations utilizing test bilge cocktails should be performed at defined temperatures in order to have standardized results
- The use of chemical affinity filtration devices aides in lowering the surface tension and raising the CMC of the emulsion resulting in larger droplets and destabilization of the emulsion with a 1-second contact time.
- Surface modified filters are effective in treating bilge emulsions with mean droplet diameters of less than 1-micron and surfactant loading of up to 20,000-ppm in a single pass. Greater surfactant loading results in lower filter capacity but does not reduce single pass efficiency.

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EPA CFR Part 9 Chapter VIII