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MICROBIAL DEGRADATION OF MARINE LUBRICATING OIL

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Over the past two years, ten vessels on intercontinental routes have been examined and found to have suffered varying degrees of microbiological deterioration of the main engine lubricating oil. In one case, the emulsification of the oil had caused severe corrosion, necessitating a crankshaft regrind. In several cases the oil was unsuitable for further use and had to be discarded. The paper briefly outlines the mechanism of oil degradation by micro-organisms and reports practical experience of the types and origin of organisms found in affected ships and the appearance of the oil and bearing surfaces suffering this form of attack. Practical recommendations are given for identification of the problem at the early stages and tested methods used to eliminate the bacterial infection are discussed.

INTRODUCTION

The problem of bacterial infection and consequent degradation of marine lubricating oils in main propulsion systems would appear to be a fairly recent phenomenon, the earliest case (of which we are aware) being about seven years ago. The problem is not restricted to a particular oil, type of diesel engine (though "wet" engines will be at higher risk) or area of service and it would not be unreasonable to suppose that most older marine engines could become infected unless careful housekeeping is strictly adhered to.

Growth on Hydrocarbons

Hydrocarbons as a class of compound are an excellent source of energy, the percentage of carbon in hydrocarbons varying from 80 to 89 per cent. Micro-organisms grow in the water phase in hydrocarbon-water systems. "Dry" hydrocarbons do not support growth; microbial spores will survive in dry oil, germinating when a water phase is formed. Microbial growth on hydrocarbons has been studied since the turn of the century[1]; indeed that bacteria have a role in the production of hydrocarbons is generally accepted by microbiologists[2]. In general microbes utilize the straight chain hydrocarbons, being able to grow on gasoline, kerosene, light and heavy mineral oils and paraffin waxes. Aromatics are not utilized as rapidly as aliphatics. The organisms are not necessarily confined to environments containing hydrocarbons; for example, practically all *Pseudomonas* can utilize light oils and kerosenes. Bacteria isolated from abscesses, animal faecal matter and water are able to degrade hydrocarbons, though those isolated from oil-bearing soils, water bottoms of oil storage tanks and oil-polluted waters understandably show more rapid growth.

The types of organisms able to utilize hydrocarbons are very varied and include *Bacillus, Pseudomonas, Flavobacterium, Mycobacterium, Bacterium, Enterobacteriacea, Aspergillus, Penicillium, Cladosporium* and in particular circumstances, the sulphate-reducing bacteria.

The organisms oxidize hydrocarbons largely to carbon dioxide and water. The ratio between carbon dioxide produced and hydrocarbon used (respiratory quotient) varies from 0·3 to 0·7, but no direct correlation between hydrocarbon type and the quotient has been clearly demonstrated. There is evidence that the organisms produce long-chain organic acids and sometimes unsaturated hydrocarbons. The process can occur over the range pH 6 to pH 9·5, optimum activity usually being at or near to neutral. Alterations in pH during growth are usually small, the weak organic acids produced having little effect[3].

Growth Requirements

All organisms require nitrogen, phosphorous and sulphur and other traces of elements for growth, though in most situations, these materials are present in sufficient quantities. *Pseudomonas* in particular has a high phosphate requirement, in systems containing low concentrations of phosphate, (below 50 ppm), growth is severely restricted[1].

Changes in Hydrocarbons

The most important effect of microbial growth on hydrocarbons is emulsification of the hydrocarbon-water system. The saponification number is increased, probably due to the production of long-chain fatty acids. The refractive index and iodine number of the hydrocarbons are also altered by microbial growth. In kerosene and light oils, a rise in boiling point has also been observed to occur. The overall effects of microbial degradation of lubricating oil in the ship engine environment can be seen diagrammatically in Fig. 1.

CAUSES OF INFECTION

Water

In the cases dealt with by Corrosion and Protection Centre Industrial Services (CAPCIS), all infections resulted after water ingress into the crankcase. Some types of engine leak water constantly in operation. In two cases, dry sump systems were examined and found to be affected. Water ingress in these cases had occurred through accidental contamination. Despite attempts by ship engineers to drain the water from the oil, sufficient had remained to provide a habitat for the organisms. The volume of water needed for bacterial growth is extremely small in proportion to the total volume of the lubricating oil. If lubricating oil could be maintained dry, the problem of microbial infection would not arise. However, even assuming that no leakage occurs, the water content in the oil may rise over time due to condensation effects; this can also occur in fresh oil storage tanks. In most cases, the design of lubricating systems is such that water cannot be easily removed, if at all, without a major and costly effort by engineering staff. Fig. 2 illustrates schematically the lubrication system of one dry sump ship. The placement of the tank drains is above the water bottoms, and thus any water in the system cannot be fully drained.

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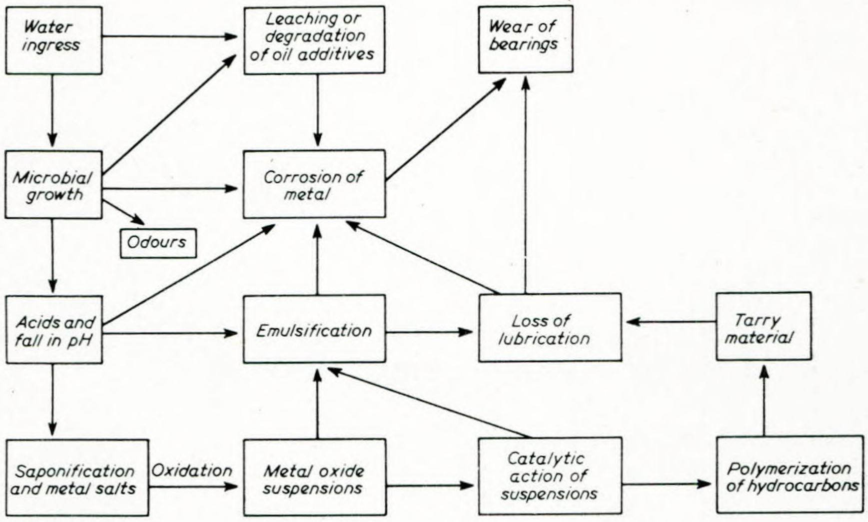

FIG. 1

In general, the water ingress is from the main engine cooling water jacket, entering the sump by accidental spillage, by leakage from telescopic arms or during engine servicing. Typical counts of microbes in main engine jacket water are high (10^4 to 10^6 cells/ml) and are predominantly *Pseudomonas.* These organisms are transferred into the sump or oil storage tanks. Despite the high bulk temperatures of the oil in circulation, the water bottoms are in general considerably cooler as the water settles onto the lower steel surfaces in sumps or tanks. Temperatures are warm, 30 to 40°C, the optimum temperature for growth of these organisms. Measurements of growth rate of organisms isolated from infected systems at different temperatures and also incubation of water samples at different temperatures showed that the bulk of the organisms were mesophilic (moderate temperature). Both numbers and growth rates decreased as the test temperature increased from 30°C, through 45°C to 50°C. Measured pH values of water taken from sumps and circulatory oil holding tanks were found to be in the range pH 8 to 9. As most additives to cooling water systems increase the water alkalinity to above pH 9, either the water treatment has not been rigorously observed or growth of the organisms has reduced the pH. *Pseudomonas* do not produce large quantities of acid from carbon sources. The lowering of alkalinity may result from saponification of the oils by reaction with the alkaline additives in the water treatment.

Water Additives and Quality

The water treatment additives are of considerable importance, see Table I. The emergence of this specific problem in recent times could possibly be dated to the change-over by operators from chromates to nitrite phosphate based additives for the water treatment. Chromates (a hazardous corrosion inhibitor) are toxic to micro-organisms at the concentrations generally used in these systems. Nitrite phosphate containing additives are, however, supplying the microbes with essential growth materials. Nitrites are themselves usually biocidal, but several organisms can reduce them to ammonia and they degrade to ammonia by reaction with the steel surface when passivating:

$$2Fe + NaNO_2 + 2H_20 \rightarrow \gamma\ Fe_20_3 + NaOH + NH_3$$

Alternatively, the nitrite oxidizes to nitrate which is non-toxic to micro-organisms and can be reduced and assimilated.

The high pH, usually maintained in the water system, limits the growth of the bacteria. It may be that failure to maintain high alkalinity is one reason for the onset of microbial infection, though this is speculative at present. An alternative source of high initial water infection is unavoidable poor quality of water used in the cooling water system. It was general practice to use distiller water or whistle steam drain water. However, with the increasing need for very high-quality water for boilers in modern ships, the need to store large quantities of high-quality water in the event of condensor tube failure and also the growing shipboard trend in minimizing high-quality water production facilities, the ship operators are often forced to use lower grade water than is desirable. Even drains cooler water can be infected unless frequently flushed and maintained clean: it was noted in one case high bacterial population (10^5 cells/ml) in water from this source. Water taken from quaysides is also suspect, as median level infections are found in indifferent supplies (3 to 4×10^3 cells/ml). The usual contaminations were bacterial, though in cases where initially clean distilled water was stored in unflushed and uncleaned tanks, the slight acidity of distilled water (usually about pH 6 to 7) had encouraged low populations of yeast to develop.

Oil

Dry oil is practically sterile though it may contain non-vegetative spores awaiting addition of liquid water to germinate. Table I shows the effects of adding slightly infected water to fresh sterile oil.

Some organisms isolated from affected ships cooling water took some time to adapt to specific hydrocarbons in laboratory tests, although similar organisms were also isolated from contaminated sump oil samples. This suggests that the organisms may acquire their oil-degradative ability after passage from the cooling water into the engine sump.

Once infection develops, bacterial populations can be high ($>10^6$ cells/ml). Tests in the laboratory indicate that marine lubricating oils will support growths to 10^8 to 10^9 cell/ml. Also mixed cultures of organisms taken from infected ships grew on an extremely wide range of pure hydrocarbons, alkanes up to C-24, benzene, napthalene and many branch chain compounds to C-26.

EFFECTS OF CONTAMINATION

Oil Emulsification

The oil becomes tightly emulsified and centrifugation will not separate out the water. Dependent on the stage of

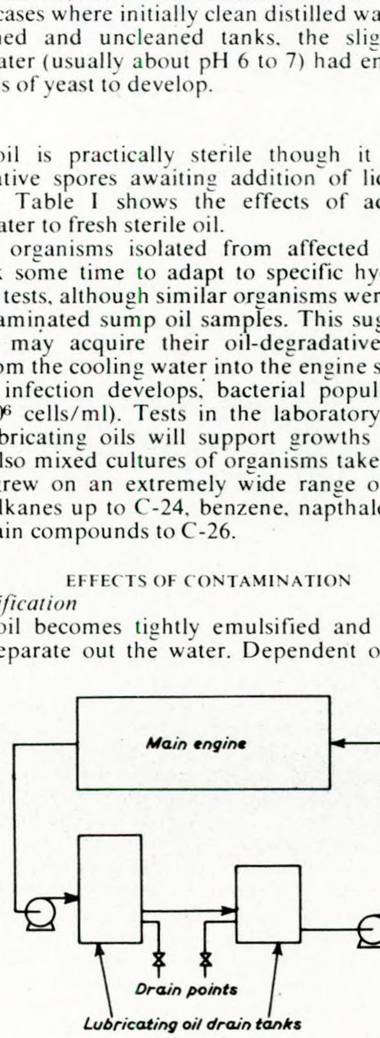

FIG. 2

TABLE I—GROWTH OF BACTERIA IN OIL SYSTEMS AFTER 14 DAYS INCUBATION AT 30°C, CONTINUOUSLY SHAKEN

System		Initial microbial count per ml.	Final microbial count per ml.
1. Fresh lubricating oil (1ml)	Jacket water (10ml) Quayside water (90ml)	100 to 500	$3{\cdot}2 \times 10^6$
2. Engine sump oil (1ml)	Quayside water (100ml)	100 to 500	$1{\cdot}0 \times 10^6$
3. Engine sump oil (1ml)	Quayside water (100ml) Water additive A	100 to 500	$7{\cdot}0 \times 10^6$
4. Engine sump oil (1ml)	Quayside water (100ml) Water additive B	10^3 to 10^4	$6{\cdot}8 \times 10^3$

degradation, use of modified renovation techniques may be successful. At this point where the oil can be initially seen to be affected, the additives are usually depleted. Lubrication properties are markedly affected by the emulsification and wear of bearings would be expected to be severe.

The metal particles worn from the engine will circulate in the lubricating oil. Some metal salts will be produced and oxidation of the metal will result in a colloidal suspension of metal oxides. Colloids of this type will increase the emulsification of the oil and also increase its stability. Iron oxides are particularly able to produce emulsification of normally stable water-shedding oils.

Corrosion

Systems affected show two distinct phenomena. Firstly, the presence on interior engine steelwork of a fine golden brown or honey coloured film. If the engine is stripped, this film is also found to be present on the journals and crossheads. Analysis of material from one vessel showed it to be mainly potassium and calcium sulphates with traces of iron, copper, nickel, magnesium, sodium and zinc also present. Minute traces of vanadium were suspected to be present. Secondly, journals and bearings were finely pitted. The pits were deep but very small in cross-section. Areas around oil holes were smooth and uncorroded: this indicates that the flow pattern of the oil affects the corrosion, high areas of flow preventing deposition of the film.

A reasonable explanation of the pitting attack is corrosion attack when the engine is stopped. The golden brown film may be acting as an electrolyte between the journal steel and the more noble bearing material. The galvanic action would be intensely localized leading to pitting attack.

No viable micro-organisms were isolated from the golden brown film: this is to be expected, since the high pressures and temperatures within the annulus would probably kill viable organisms. It was not possible to determine whether dead bacteria or bacterial residues were incorporated into this film.

One vessel which had suffered an extreme infection required an engine overhaul, including crankshaft grind and bearing replacement. Other problems had occurred prior to the infection such that the rate of deterioration could not be estimated. Inspection of the stripped engine suggested that the area of oil entry was possibly worse affected than further along the lubricating oil circuit.

REMEDIAL ACTION

Oil Replacement

In extreme cases, this is probably the only solution. Drained oil should be discarded remote from other ships and should not be mixed or contacted with fresh oil. Burning of the oil, if possible, would be a suitable method of disposal.

The system should be thoroughly cleaned by steam lancing of engine walls and structures to remove slimes and deposits followed by opening of the sumps and scouring out of deposits. The most practical way of cleaning out oil lines is to flush out the lines using a light flushing oil. The flushing oil can be dosed with biocide, but because lubricating systems and oil types vary so widely, it is not possible to recommend an universally suitable biocide for this application.

Oil storage tanks should also be inspected and cleaned if necessary.

Water Side

Since the primary source of infection may be located in the cooling water jacket, the water system should be drained and filled with fresh water containing a biocide of high strength. Panacide has been successfully used for this purpose at a concentration of 0·5 per cent, though for initial flushing there are many biocides of equal value. The treated water should be allowed to stand in the system for 24 to 48 h minimum. Attention should be paid to blanked lines and by-pass loops to ensure that these are adequately cleansed. The system should then be drained and the water and slimes discarded.

The water used to replenish the system after draining should contain a biocide to prevent future infection in the system. Panacide has been used at concentrations of 0·02 to 0·05 per cent. The level of Panacide should not be allowed to fall below 0·01 per cent. Other biocides are probably equally effective and possibly at lower concentration and cost.

The choice of water additive to prevent corrosion should be carefully considered, particularly if no biocide is to be used. Additives low in phosphate are recommended as this is a requirement for *Pseudomonas*. Some corrosion inhibitors are claimed to contain biocides, but these are often biostats, (i.e. they prevent growth rather than kill microbes). They do offer advantages however over conventional materials. Attention should be paid to reducing and eliminating leaks from the water side into the oil.

Oil Additives

Benzyl Cresols as a class of compounds have been used at concentrations of 0·02 per cent. Other aromatic biocides can be used but attention to the particular oil characteristics is necessary as not all materials will be compatible with oil formulations. The development of oils containing biocides is an advance, but as the biocide must pass into the water phase to be effective, in engines which run "wet", the biocide will be fairly rapidly exhausted. The use of biocides in oils is probably most effective for oil in long-term storage rather than in the engine system. Dry sump engines with low leakage of water would benefit from this type of treatment.

Use of Renovation Tanks

With medium infections, where the oil is just beginning to cause water-separation difficulties, the oil can often be saved by use of the renovating tanks. The oil should be heated to as high a temperature as possible (advice should be sought from the supplier) for 1 to 2 hours. A temperature of 80 to 90°C will sterilize the oil. Water bottoms should be drained and tanks cleaned thoroughly. Regular use of this process and attention to the water side will prevent the infection of the oil.

Good Housekeeping

This point cannot be overstressed. Attention to corrosion inhibitor treatments, cleanliness and regular drainage of water bottoms will reduce the risk of oil degradation.

Certain modifications may be necessary to allow proper drainage of oil storage tanks and engine sumps, as ship engine design often overlooks this factor.

Bilge water is always heavily infected with micro-organisms and should never be allowed to contact cooling water or engine oil.

Regular use of renovating tanks will maintain the oil. Care should be taken however, that supplier's recommendations on temperature are not exceeded.

For engines which run wet, maintenance of a biocidal concentration of a compatible biocide in the cooling water will prevent infection. Choice of anti-corrosion additives should take consideration of the problem of microbial infection. Water leaks into dry sumps should be avoided and the water removed as soon as possible. Particular attention should be paid to closed or dead end sections of pipework.

Methods of Detection of Infection

There are several methods of detection of micro-organisms which are suitable for ship-board monitoring of oil and water[4]. The most important factor is the point of sampling: poor choice of sampling will give false results. The other principal drawback to most methods is the need for frequent checks. Even if microbial infection could be detected reliably by ship-board tests, a problem remains if a ship is for example in mid-ocean when infection is noted. The rapidity with which infection increases is a feature of many of the cases which have been examined, and incapacitation of a ship could occur within a single voyage. Yet it would seem likely that most ship engines are "injected" with potentially harmful infections from time to time and the vast majority apparently are unharmful. It is, therefore, required to determine the combination of oil, water, contamination factors which give rise to the rapid increase in infection, i.e. the "trigger" conditions which result in a slight infection becoming serious. A knowledge of these conditions should enable potentially dangerous combinations of, e.g., water inhibitor plus oil additives to be avoided and may also enable the approach to the "trigger" conditions to be detected by ship-board tests. From surveys of infected ships' records there is no immediate correlation between standard test data in the various cases in the period immediately preceding rapid infection. There are, however, some similarities which deserve further investigation.

CONCLUSIONS

Accidental or regular leakage of water into the ship lubricating oil system can lead to rapid failure of the oil by microbial infection. Detection of the early stages of infection is possible but difficult. Most ship oil systems are prone to oil degradation, but the low frequency of occurrence suggests that specific factors must combine to "trigger" the bacterial infection. The determination of these "trigger" conditions is important if bacterial infection is to be reliably avoided.

Meanwhile, attention to choice of cooling water anti-corrosion inhibitors and addition of biocides to the water will reduce the likelihood of infection. Water bottoms should be drained frequently. Regular use of renovation tanks will maintain the oil in good condition. Quality of water used for the cooling system should be as high as possible.

ACKNOWLEDGEMENTS

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Discussion

Mr. R. O. Keyworth, F.I.Mar.E., congratulated the authors for the considerable work they had done in bringing to notice this interesting subject. From the information provided there would seem to be no doubt that there was a marine industry problem of microbiological attack. If one was prepared to admit there were trends in marine engineering it would seem that "Bugs" were the "in thing".

His company had first experienced bacterial infestation on a cargo vessel in early '69. Because of reported crankcase rusting a check of the main engine system oil had indicated depletion of the rust inhibitors. A new charge of oil was supplied in Australia with a double dose of rust inhibitor. On arrival at the UK six weeks later both the double dose of rust inhibitor and the anti oxidant inhibitor had completely disappeared. It had been reported that filters frequently became blocked.

The crankshaft was corroded and because a fungus was observed in the cooling water drain tank, samples of both oil and water were submitted to the microbiological department of the University of South Wales. The results of their tests confirmed what a poker player would call a "full house". He then quoted from the report received: "Mr. Hill's letter of the 14th March 1969 states that the sludge from the detuner was heavily infected with gram negative aerobic bacteria, principally *pseudomonas spp.* and moderately infected with anaerobic bacteria. There was also a heavy infection with the fungus *aspergillus* and a few yeasts", and Mr. Keyworth would suggest that a glossary of terms be appended to such reports.

As it was only a chance remark by a junior engineer that had led his company to fungus in the first place there did seem to be a need for ships engineers to be able to identify bacterial infestation, particularly as it was often associated with very costly crankshaft corrosion.

Referring to the section in the paper headed "Corrosion": the authors had stated that systems affected by bacteria showed the phenomenon that, on interior engine steelwork, the presence of a golden brown or honey coloured film could be observed. Mr. Keyworth followed up this remark by showing a colour slide of a crankcase where just such a honey coloured film could be noted on the connecting rod. Certainly there was no corrosion or bacteria present in that system. It was the company's opinion that the golden colour was caused by a trace of oxidization of the lubricating oil in this engine which had very high temperatures in the oil cooled piston cooling spaces.

The authors' analysis of elements such as calcium sulphates found in the golden film observed by them, would indicate alkaline calcium additives which had reacted with sulphurous acids of combustion and found their way into the crankcase. The other metals mentioned could also be found as constituents of residual fuel. In his company's experience where bacteria had been determined in systems in appreciable concentrations, steelwork had been dull, almost rusty in appearance and often but not always grey or black sludges or slimes were also present. Sometimes, but again not always, unpleasant odours of hydrogen sulphide — the schoolboys' "bad eggs" — smell had been encountered.

In a second colour slide Mr. Keyworth had shown a corroded crankshaft journal which was orange coloured in streaks around the circumference but the type of corrosion there was considered to be caused by either fresh or salt water attack. There was slight pitting beneath the orange surfaces but white metal pick-up was readily seen adhering to these surfaces. This was because that particular engine was a modern highly rated unit and the slightest deterioration of the micro finish surface from rusting or corrosion of any sort resulted in white metal pick-up and ultimate bearing failure.

A third slide showed the well known strong acid corrosion which attacked journals on earlier engines when residual fuels were first utilized on a widespread basis in the mid '50s. While this form of corrosion was often seen, Mr. Keyworth's company had no records of tests having been made for bacterial contamination in conjunction with this form of attack.

With regard to remedial action: the authors' suggestion that the use of renovating tanks to sterilize the oil at 90°C plus was a good idea, but in the large systems found on board ship it was impossible to even manually clean out the contaminated oil entirely from double bottom tanks and piping etc., therefore such sterilized oil would inevitably be re-infected when it was re-circulated through the system. The use of a biocide would seem to be necessary to thoroughly cleanse a contaminated system.

Regarding biocides the use of Panacide had been recommended to a number of infected vessels and used with some success. Another biocide, trichlorophenol sold as 245 TCP, was also recommended and used with some success on a number of vessels. Recently in the USA, however, when recommended to use this in a contaminated system, the shipowner had asked the advice of the supplier who had advised that under certain hot conditions such as those which could be experienced in a diesel engine this product could give off chlorine gas. This was quite a frightening revelation, as a hot bearing could easily reach the temperatures necessary for such a gas to be vaporized. Therefore apart from the obvious compatibility requirements of biocides with lubricating oils in use in the main engine systems the question of toxicity and any other health hazards must be fully investigated before such biocides were recommended for use on board ship.

The company's main concern was to lubricate the engine including the prevention of any form of corrosion. In all cases where such corrosion had occurred, following flushing and sometimes disinfecting of the system, an alkaline detergent anti-corrosion oil had been introduced and no further problems had occurred.

Mr. Keyworth then referred to the beginning of the paper where it was stated that bacterial activity was usually greatest at or near a neutral pH value and he had quoted a figure of 9·5 pH as being the upper limit for effective growth. If this was so it would seem that the introduction of an alkaline crankcase oil was a step in the right direction.

The authors had referred to the investigation of ten ships over the last two years. No mention had been made of the types of engine in these ships or of the types of lubricating oils in use. This was unfortunate, because, as Mr. Keyworth's company saw it, the main problem resulting from bacterial infestation would appear to be crankshaft journal or crosshead pin corrosion.

From their observations and reports collated on over 50 vessels afflicted with main engine corrosion problems a definite pattern had emerged. Only slow speed main engines had suffered crankshaft journal or crosshead pin corrosion and only about five of these had also suffered white metal bearing corrosion at the same time.

Unfortunately, not all these engines were tested for bacterial infestation but certainly a great number of those tested did have high bacterial counts. However, in each case either fresh or sea water was always present.

One interesting factor which did emerge was that all the corroded slow speed engines were using oils of negligible alkalinity, although various combinations of anti-oxidant and anti-corrosion or rust inhibitors were in use.

In two cases following a crankshaft regrind, the same non-alkaline oil was re-introduced into the engine and journal corrosion had reappeared within six weeks. Whereas in every case where a four to six TBN alkaline oil had been introduced following a regrind no further corrosion had been reported, even after four or five years, and despite, in some cases, periodic "floodings" by piston cooling water.

Not one single case of crankshaft journal corrosion had been noticed on medium speed engines, and it seemed to be significant that such engines used lubricating oils with TBNs ranging from 12 to 40. The only corrosion reports received on medium speed engines were of two vessels which, following continuous sea water ingress, suffered copper lead corrosion of bearing shells.

Because of the possibility of microbial degradation of lubricating oil and the attendant dangers of corrosion many responsible oil companies were having their marine system oils evaluated in relation to microbial attack by the various bacteria likely to infest marine systems. These evaluations, of course, were undertaken by the microbiologists but because of the number of variables involved this was a lengthy process.

The authors had stated that there were many tests suitable for shipboard use and here was a simple one: Water from the cooling system or from the lubricating oil system was placed in the vial and maintained at a temperature stated on the instructions for a period of 24 hours. The degree of bacterial infestation could be estimated from the appearance of the material on the paddle. This test was originally designed for humans — and it was possible to obtain a clean bill of health on the chief engineer as well as his main engine system at the same time, but, of course, not with the same sample.

In the event of excessive infestation being noted it was recommended that further samples be taken — in sterilized containers, sealed and air freighted — directly to a microbiologist so that he could determine the types of bacteria and make his recommendations as to remedial measures to be taken and which biocides to use. Speed was essential as bacteria could die quickly in unfavourable conditions.

MR. C. BELAND, M.I.Mar.E., said that this was a highly topical and also easily understood paper for both the research chemist and the practical engineer.

Up to the present time his company had not been closely involved in any completely verified cases of microbial degradation of shipboard main engine crankcase oils and therefore, they had not had the opportunity to study that condition or its effect upon machinery components. This meant that their experience was rather limited. They were, however, concerned about the increase in reports of microbial degradation and subsequent severe engine damage. Furthermore as this appeared to be an industry problem they would be pleased to participate in any work being carried out to try and find a solution. Because of the limited experience already mentioned it was not possible to contribute significantly to the authors' work. However, study of the paper had presented some thoughts which the authors might wish to comment on.

It was noticed with interest that the authors had stated "The most important effect of microbial growth on hydrocarbons was emulsification of the hydrocarbon-water system". Whilst not disputing their findings, Mr. Beland would like to question the authors on this point. It was accepted that the emulsification of a marine crankcase oil was most serious — however, this problem was fortunately very rare. This must have been due, not just to the quality of the oil and the standard of oil treatment on board ships, but also because normally there was very little water in the system. It could be thought that there was too little water to give rise to the major solidification noticed after a crankcase oil had been subjected to microbial degradation. It had been assumed by Mr. Beland's company that the solidification was due to the gross volume of dead bacteria as, when reproducing under ideal conditions, they rapidly divided and divided again to produce vast numbers of cells. Coupled with this, it had also been observed that the problem associated with the bacterial infection of cutting oils was a failure of the oil's emulsifying characteristics rather then the reverse. Mr. Beland said that the authors' thoughts on this point would be welcome.

The authors had postulated that the change in cooling water treatment from chromate to nitrite phosphate based additives had been a possible cause of the increase in cases of microbial degradation of crankcase oils. His company had no argument with their reasoning but would like to put forward another point for consideration. In recent years some engine builders had stopped recommending the use of soluble oils as inhibitors in cooling water systems. In normal use as cutting fluids these oils were emulsified with water and therefore usually contained biocides, albeit at a low concentration. Could the authors comment on whether their research had included the study of bacteria growth in oil contaminated by water inhibited by soluble oils. Had they considered that the increase in reports of microbial degradation of crankcase oils might also have been due to the lessening use of soluble oil cooling water inhibitors?

The authors had also stated that if a high pH was maintained in the cooling water system then this limited the growth of bacteria. There were currently available on the market a range of alkaline crankcase oils for use in marine slow-speed engines. Had the authors any experience as to whether this type of crankcase oil had a sufficiently high pH to control the growth of any bacteria entering the crankcase? If these oils could limit the growth of these unwelcome organisms it would appear that their use could be a simple solution to the problem.

MR. E. C. HILL, M.Sc., stated that a paper presented at the Institute of Petroleum in April* described the role of micro-organisms in straight oil degradation. The microbes could be demonstrated to grow on and deplete the oil additives, to increase the acid number of the oil, to attack certain hydrocarbon chain lengths preferentially, to change the viscosity and viscosity index of the oil, and to reduce the demulse properties of the oil. The last effect alone was a known corrosion hazard.

To kill microbes in straight oils with chemicals was not too difficult: however, most biocides had some activity which might not be desirable. For example they might increase the alkalinity of the oil, reduce its demulse properties or interfere with the extra pressure additives. It was, therefore, of the greatest importance to check that before a biocide was added to an oil, tests had been run to ensure that it was chemically compatible with the oil, did not affect the functional properties of the oil, and was a practical proposition with regard to stability, toxicity, smell and handling.

Similar criteria had to be applied before biocides were added to a cooling water. In "wet" engines, it was likely that the P and J system was not only the source of water necessary for microbial growth in the oil, but also the source of organisms. It was, therefore, of great importance to control the growth of microbes in the associated coolants.

There was no perfect biocide for use in oil or coolants, and the selection of the most suitable for any particular system should be done with great care. Unfortunately, the marine industry was a long way behind land based industries, and the aviation industry was investigating and selecting biocides for their particular problems.

On-site test methods for detecting infection were now available and described in the authors' Reference 4.

MR. J. J. EVANS, had some general comments and observations to make.

1). Why had this problem only surfaced in the last seven years, could the authors suggest any reasons for this. It was rather strange that no problems seemed to have been experienced before this time: he supposed it could be that the problem did exist but was not recognized.

2). As pointed out by the authors the problem was not restricted to a particular type of engine, although wet engines would be at a higher risk, and those who had experienced the problem would agree with this. However, it was a pity that the engine builders who made engines which constantly leaked water into the crankcase had not taken steps to rectify the problem.

3). It would be interesting to hear from the authors whether there were any symptoms which could be recognized before the "trigger" mechanism occurred. Mr Evans understood that an obnoxious smell from the crankcase, or rapid rusting and staining were some of the symptoms.

4). Did the micro-organisms deplete only one additive or all of them?

5). Although the authors had said that it was impossible to recommend a universally suitable biocide for adding to the oil, would it be possible to short list suitable biocides which could be added to the oil?
It would seem that a "Which" type research project was required in order to compare the lubricating oil reaction with different biocides, ending up with a list of biocides which were compatible with particular oils. What were the authors' views on such a project?

6). What were the similarities of combinations of water inhibitor plus oil additives to be avoided which deserved further investigation? Information on this point would be most helpful.

7). Were there any possible health hazards to personnel who might have to handle the infected oil?

Some of those present at the meeting might be aware that the General Council of British Shipping had sponsored a project on microbiological deterioration in the shipping industry, and the results were now contained in a report, copies of which were available from the GCBS.

Leading on from this work the GCBS had commissioned a handbook on microbiological aspects of corrosion in the shipping industry. The aim of the book was to help the reader recognize the problem on board ship and to assist where possible in applying a remedy.

Part of the work had been concentrated on actual case histories of microbiological corrosion. It was worth mentioning that six cases of microbiological degradation of ships' lubricating oil had occurred since the work started earlier this year. This had surprized the GCBS and the owners who had had the problem.

Finally, he would just add that the handbook would be available to GCBS members early in 1977 and, hopefully, to non GCBS members as well.

MR. J. MCNAUGHT, F.I.Mar.E. stated that for the Fleet of which his organization were technical managers, one ship had had serious damage in the crankcase about 15 years ago, before anyone was aware of the phenomenon of bacterial damage to lubricating oils.

In that ship, there was water present in the oil which was a straight mineral oil, and the damage was so severe that every main bearing journal, crankpins and crossheads etc., had had to be machined.

This year, there was a second case in a similar class of ship. In the latter case, a main bearing was found to be worn down and was renewed in the UK. Oil samples were taken which were proven free from bacterial infection and were declared fit for further use by the oil company.

After a 6000 mile voyage, the bearing was examined again and was found to have worn down 1·5 mm. It was decided to hold the ship and investigate fully. The up-shot was that every steel bearing surface in the engine had to be machined or polished. There was considerable sludge and it took some days after completion repairs to clean up the system. The results from laboratory samples were conflicting in that one laboratory found traces of bacteria whereas others stated the oil was sterile.

A further point was that crankcase paint had lifted and corrosion was taking place below the point at the base metal with the presence of acidic water in oil emulsion.

During the next period of the voyage, close attention was paid to the oil condition and it appeared to create sludge rather more rapidly than expected considering the extent of the cleaning of the system and the complete renewal of lubricating oils.

However, further samples taken by specialists and tested in their laboratory had proved that the oil was sterile but that there were traces of infection in the engine circulating water. Biocides were being applied.

As a result of this incident, other ships in the Fleet were being examined whether they bore signs of degradation or not, and so far, out of a further four ships examined, the oil had been proven free of infection, but in all cases the circulating water was found to be infected and in one case rather heavily.

In these vessels, it was comparatively easy to use a biocide because there was no fresh water generator. In other ships, especially bulkcarriers, where there were fresh water generators supplied with heat from the jacket circulating water, there could be a problem in using biocides because any water treatment had to have the approval of the Department of Trade. There was always a risk of leakage and contamination of the water produced. Had the author any knowledge of a method which could prevent or kill an infection in such a system without the use of biocides?

Could the authors say whether a high water temperature — say 90–95°C — would kill all the bacteria, and which direction research could take in order to learn more about the "trigger" action referred to in the paper.

The paper was interesting, but all the shipowner really wanted to know was what he could do in order to avoid being afflicted, and to find that any treatment or tests required for control were as simple as possible and the materials used for treatment were non-toxic and safe to use.

The latest information on the incident concerning the

* Ref: Hill, E. C. and Al-Haidary, N. K. 1976. "Some Aspects of Microbial Corrosion in Rolling Mills". *Proc. Inst. Petrol.*

serious weardown indicated bacterial growth in the water phase of the lubricating oil giving rise to the formation of sludges and slime within the engine system. These deposits could give rise to differential effects causing local corrosion.

MR. S. CROSBY, F.I.Mar.E., asked Dr. King to confirm that bacteria required the presence of water in lubricating oils in order to be active. If this was so, would it not now be necessary for lubricating oil chemists to extend the nature of sample testing to determine water content to a much greater degree than was at present normally being employed. For instance, perhaps the Dean and Starke method should be carried out to measure ppm of water rather than the normal percentage by volume. The writer's company had not, fortunately, experienced microbial degradation of marine lubricating oil but had recently known of a case of infection within a piston cooling water system treated with soluble oil. Could it now be that the engine builders who, at present, employed water as a coolant should consider the use of lubricating oil as the cooling medium.

MR. A. SPIRO asked firstly if microbial degradation was an equally major problem in normally land-based industrial applications.

Secondly was there any connection between microbes and the formation of carcinogens in lubricating oil.

MR. N. S. SWINDELLS, F.I.Mar.E., asked whether Dr. King would give some information regarding the ten vessels which had been investigated, with the thought that this might give some indication of the type of vessel most likely to be affected. For instance, did the list include any large tankers with long steady voyages at more or less constant speed and with stable engine conditions, or were they mainly cargo ships making frequent stops. It seemed more likely that, with fluctuating engine temperatures and loadings with consequently more susceptibility to contamination with water and combustion residue, cargo vessels would be more prone to attack.

It would also be of interest to know the types of crankcase lubricants being used in these ten ships. Were they of the straight mineral type, straight mineral with rust and oxidation inhibitors, or the alkaline type? This was important, as a major factor of the attack related directly to the acidity of the system. It would appear that alkaline type oils were less likely to be affected by microbial attack.

Correspondence

MR. R. E. H. ORR wrote that in view of the authors' concluding remarks stating that detection in the early stages was possible but difficult, and that the low frequency of occurrence suggested that specific factors must combine to "trigger" the bacterial infection, it would be useful if they would comment on whether they would regard regular sampling for microbial contamination of diesel engine lubricating oil to be worthwhile.

With the improvement of additives in lubricating oil it had become less common to centrifuge diesel engine oil, yet the one thing a centrifuge did was to remove water from the scene: it would be interesting to learn whether any of the ships which had suffered from this problem had had lubricating oil centrifuges.

The flexible suction entry shown in Fig. 3 was developed a number of years ago to provide a means of conveniently extending the end of a suction pipe to the bottom of a tank. It was effectively a synthetic rubber bellmouth, moulded with feet to keep the skirt about 1 cm above the tank bottom, and was clipped to the pipe end. Its flexibility allowed the base to conform to sloping tank bottoms. It was primarily intended for use in fuel tanks with good shapes, for drainage to a low point, and had ensured the efficient removal of settled water.

Where lubricating oil tanks and sumps could not be arranged so as to have suctions taken from the underside, the use of the flexible suction entry could be a useful contribution to good housekeeping.

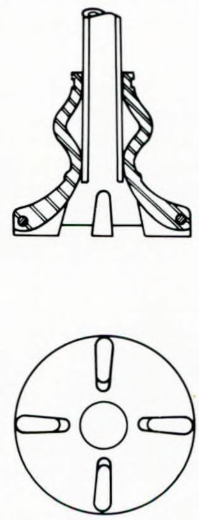

FIG. 3

Authors' Reply

DR. KING, on behalf of the authors agreed with Mr. Keyworth that there was nothing magical about the golden brown film observed on the engine steelwork, and stated that they were also aware that this film was probably caused by slight oxidation of the oil. The important point, however, was that this golden brown film was observed present in vessels with high populations of micro-organisms in the oil and water. This might be coincidence, but it might also mean that slightly oxidized oil was a factor in encouraging rapid growth of the organisms dormant in the engine crankcase. Once massive infection was demonstrated, corrosion and bearing damage would have occurred: under these circumstances the corrosion products would be liberally spread over the steelwork and with respect to appearance, a little rust went a long way. The odour of hydrogen sulphide was characteristic of sulphate-reducing bacteria and would indicate that areas of the sump are anaerobic (devoid of oxygen). Since lubricating oils were normally high in dissolved oxygen, the establishment of anaerobic areas must indicate extremely severe infection of the oil, such that the dissolved oxygen was all consumed by other microbes. Sulphate-reducing bacteria required large quantities of sulphate to grow, (hence their name) thus again the possible connexion here with oxidized oils or, of course, seawater leakage. The most probable sulphate arising from alkaline calcium additives reacting with the sulphurous acids of combustion, as pointed out by Mr. Keyworth.

It was accepted by the authors that all the infected oil could not be removed from double-bottoms, piping and storage tanks: for this reason biocides must be used. Renovation of the oil did remove copious quantities of water and suspended solids, and as discussed during the lecture, there would seem to be some sort of link between suspended solids and bacterial growth. Ships with mild infections had been "cured" by renovation of the oil, though in all cases biocides had been used in the cooling water.

Use of alkaline oil would appear to be a possible solution. However, there were still some unknowns. Firstly, what was the pH of the water in the water bottoms: if this water was highly alkaline, no growth would occur. For the water to become alkaline implied passage of alkaline material from oil to water and in a wet-running engine, it must only be a limited period before the alkalinity was exhausted.

The authors rather liked the new dip-tube systems developed for on-site testing, but had reservations about the probable techniques used for sampling. Considerable care must be taken to ensure that a representative, meaningful sample was taken. To assist to this end, it was thought that there was a need to develop auxiliary systems to enable reliable sampling to be carried out on a routine basis.

In reply to Mr. Beland: When growth on hydrocarbons occurred, the process generated water, thus there would be an increase in quantity of water in the double bottoms. It was unlikely that solidification was caused by gross volume of dead bacteria, as the normal highest counts of microbes would be in the region of 10^9 cells per ml, which was still a very fluid suspension. Fungal growth could cause apparent solidification because of the tangled mat produced during growth. The only other process which could lead to solidification was the production of tarry polymeric material. There was, fortunately, an upper level to the number of bacteria possible in a closed system, as an essential nutrient would be depleted. In the lubricating oil system, this was probably nitrogen or phosphorous.

Replying to Mr. Hill: Addition of biocides to oils was useful, but might not make economic sense when dealing with wet-running engines. As noted above (Mr. Keyworth), this was dependent on the partition coefficient of the biocide used. The micro-organisms only grew in the water phase (this might however be well distributed as droplets) and biocide must pass from the oil to the water before it was effective. Thus wet engines would deplete the biocide quite rapidly, dependent on engine characteristics. It might well make far more sense to treat the cooling water system with biocide; in fact with a biocide which was preferentially soluble in the water and would not enter the oil. This method treated the source of infection (as most water leakage was from piston and jacket cooling systems) and the biocide compatibility with the oil was of much less importance.

The same concern regarding the on-site tests described by Mr. Hill was felt as for those tests previously mentioned by Mr. Keyworth.

To Mr. Evans' comments and questions Dr. King stated that:

1). The quote of seven years was merely the date up to this time of which a definite date could be fixed for the microbial problem. The authors had recently heard of ships which had suffered this problem fourteen years ago, i.e. 1963. They could not give a definite answer to the reason for the recent spate of problems, but would suggest that the change from chromate water treatment to nitrite/phosphate treatment might be one factor.

2). Problems on engine types recognized as low water leakers had been encountered; even so, accidental spillage could also lead to problems.

3). The symptoms mentioned here i.e. smell, rusting and staining, were signs that the problem had gone beyond simple solutions. The build up of factors to the "trigger" situation still required elucidation. A reasonable research project should lead to a better understanding.

4). Data was limited on this point. Experience to date did indicate that somewhere there was a bacterium or fungus which given the opportunity would degrade or affect any additive type.

5). There was not at present a short list of biocides accepted to be used with particular systems. This was because it was possible to add biocides to the oil, to add biocides to the cooling water, and also to add biocides to both. Each possibility might demand a different biocide; if added to the oil, the biocide type and concentration would depend on the particular oil and its additives, if added to the water, on the corrosion inhibitor being used, etc. There was a pressing demand to determine the compatibility of biocides and oils to assist ship operators, but there were considerable problems to overcome regarding the long-term effects of biocides on oil properties and a need for testing under a close simulation of working conditions., e.g. temperature and pressure. As discussed elsewhere, the authors felt that the more promising line of approach was to dose the cooling water. Studies had been started along these lines.

6). Again this was a matter requiring research into the potential hazardous combinations. It was felt, however, that there were other factors involved apart from the blend of oil + inhibitor.

Referring to the contribution made by Mr. McNaught: Checking for micro-organisms in oils containing small quantities of water required different techniques to normal microbiological practice, where the principal fluid was aqueous. In these systems, enumeration of populations was not as precise, thus some conflict could arise between different laboratories using different techniques. Part of any research project on this problem would, it was considered, be to define the most suitable methods of detection and enumeration and put these forward for acceptance as standard tests. This was one of the authors' major objections to shipboard dip tube systems — the variability of testing which could lead to false reports.

The problem of reducing microbial infection without the use of biocides was an interesting one, and they had some thoughts on this which, if successful, would have a far wider application than shipboard, e.g. in certain central heating systems. Whether these techniques would be suitable for shipboard use would await further development.

A high water temperature would kill most micro-organisms, but to attain sterility temperatures greater than 90–95°C were necessary. It had been noted that ships with serious infections had a higher content of thermophilic organisms than those with low level infections. The presence of gross numbers of organisms able to tolerate high temperatures (45–50°C) might indicate potentially hazardous infections.

The authors had quite definite ideas about the lines of research needed to elucidate the "trigger" action. They were prepared to discuss these with interested parties.

The answer to Mr. Crosby was that all micro-organisms, including bacteria, required an aqueous phase in which to live and multiply. Measuring water content of oil was a useful pointer, but there were more factors than this contributing to gross infection and oil demulse failure.

To Mr. Spiro's first question the answer was: Probably yes, given the same rate of water leakage into the oil. There were several reports available concerning lubrication failure of land-based systems. It was probable, however, that different factors were at work.

The answer to the second query was not known as their work had not involved this aspect of lubricating oil degradation. Wildly guessing, they would say that it was unlikely, but would warn that there were other health hazards associated with infection of oils, e.g. dermatitis.

For the information requested by Mr. Swindells the authors would require clearance from their clients before giving complete details of the vessels involved. They had dealt with quite large vessels, some of which were medium size tankers, some vessels were regularly on long sustained intercontinental voyages, others were stop-go freighters. Most vessels were on transoceanic voyages however, but they had seen too few vessels to make authoritative statements.

All oils so far dealt with had been straight mineral with rust and oxidation inhibitors. As discussed above (Mr. Keyworth) alkaline oils might be effective in certain circumstances only, i.e. low leakage or occasional accidental leakage only.

To Mr. Orr's written contribution Dr. King replied: Yes, at the present state of the art, there was no other way of gaining any indication as to the possible hazard. Types, numbers and characteristics of the micro-organisms gave some clues as to the possibility of a rife infection occurring.

All vessels sampled had centrifugation systems which were used regularly; the first indication of trouble in some cases being the failure of the centrifuges to separate the oil and water.

Any device or technique which ensured that oil for centrifugation or renovation was taken from the lowest drain point of a tank would contribute to good housekeeping, in that water bottoms were minimized. In most cases, however, this was not possible to arrange easily because of bad design.