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INTERACTION OF OUTBOARD MOTORS WITH THE AQUATIC ENVIRONMENT

CAUSATIVE FACTORS AND EFFECTS

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State-of-the-Art Report for Division of Water Pollution Control, Massachusetts Water Resources Commission. Contract Number 15-51451.

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PREFACE

The following state-of-the-art report is the first in a series of in-depth progress reports prepared for the Division of Water Pollution Control, Massachusetts Water Resources Commission, Contract Number 15-51451, "Effect of Outboard Motor Exhausts on Water Quality and Associated Biota of Small Lakes."

This report represents a critical search of the literature on the subject matter of outboard motors and their interaction with the aquatic environment. Two review papers are presented in this publication. The first section represents a review of the factors involved with the operation of outboard motors and is entitled: "Causative Factors Concerning the Interaction of Outobard Motors with the Aquatic Environment - A Review". Section two relates the effects that outboard motors may have on the aquatic environment and is entitled: "The Effects of the Interaction of Outboard Motors with the Aquatic Environment - A Review." Together, these reviews represent a portion of the research activities accomplished from mid-October 1971 to early June 1972 by the authors.

This report will be brought to the attention of various agenices, organizations, companies, industries, and individuals interested in the preservation of our natural resources.

SECTION ONE

ABSTRACT

Various aspects of outboard motor operation including the magnitude of watercraft usage, operation of a two-cycle engine, efficiency of operation, factors influencing efficiency of operation, composition of outboard motor fuels, and compounds emitted during operation are reviewed. Compounds emitted into receiving waters from outboard motor operation originate from the drainage of liquids from the crankcase and from unburned or partially burned fuel passing through the combustion chamber. In some instances, over half the original fuel mixture for outboard motors may be emitted unburned into receiving waters. The factors affecting the quantity of compounds ejected by outboard motors into receiving waters includes the horsepower rating, size of crankcase, composition of the fuel mixture, tuning of the engine, and speed of operation. Some of the compounds measured in water recipient to outboard motor exhaust include volatile oil, non-volative oil, lead, and phenols.

CAUSATIVE FACTORS CONCERNING THE INTERACTION OF OUTBOARD MOTORS WITH THE AQUATIC ENVIRONMENT - A REVIEW.

by Thomas P. Jackivicz, Jr. and Lawrence N. Kuzminski

I. GENERAL CONSIDERATIONS

There has been an increasing emphasis on the possibility that outboard motor operation is a significant nationwide source of pollution[1]. An exposure to the reasons why this problem may exist and the current research into the problem will prove beneficial to those concerned with the preservation of the nation's natural resources. This review will restrict itself in scope to a discussion of the reasons why outboard motor usage has become a concern to those interested in the preservation of our natural resources. It is recognized that air-borne exhaust gases and noise (pollution) are associated with the discharge of outboard motor exhausts (OME) and may in themselves cause (pollution) problems; however, these will not be included in this review. Water safety is still another affiliated concern with outboard motor usage but will not be dealt with hereinafter.

Magnitude of Watercraft Usage

The Boating Industry of America (BIA) and the National Association of Engine and Boat Manufacturers' (NAEBM) annual estimated boating figures for 1968 and 1970 are given in Table 1[2,3]. These figures show that over 85 percent of the recreational boats in use were in the outboard boat and row-boat class which are generally powered by outboard motors. Sailboats which do not use inboard power are often propelled by outboard motors in harbor areas. Inclusion of these as possible users of outboard motors would bring the total to over 92 percent of all recreational boats which use or are capable of using outboard motors as a means of propulsion.

Perhaps the most interesting figure in Table 1 is that of gasoline consumed. *This figure does not include oil which is premixed with the gasoline* for lubrication of two-cycle engines. At a conservative ratio of fifty parts of gasoline to one part of oil, this would mean that an additional twenty million gallons of lubricating oil were also consumed annually by outboard motors during operation in 1968 and 1970.

Table 1. BIA and NAEBN Estimates of Boating and Outboard Motor Usage[2,3]

Item	Year	
	1968	1970
Persons participating in recreational boating	42.2×10^6	44.1×10^6
Total recreational boats	8.4×10^6	8.8×10^6
Outboard boats plus rowboats	7.3×10^6	7.6×10^6
Sailboats with no inboard power	0.6×10^6	0.6×10^6
New outboard motors sold	0.50×10^6	0.43×10^6
Outboard motors in use	7.0×10^6	7.2×10^6
Gasoline consumed (gallons)	1.0×10^9	1.05×10^9 (Estimated)

Operation of a Two-Cycle Engine

Over 98 percent of all outboards in use are of the two-stroke cycle type[1,4]. The remaining 2 percent of the engines are four-stroke cycle type and electric. A description of the operation of a two-stroke cycle engine and the sites of emissions from such engines will be presented.

Both four-stroke and two-stroke engines derive their power in similar ways. The combustion of a gasoline/oil and air mixture within the cylinder results in appreciable gas pressure on the piston resulting in a downward motion. This energy is transmitted to the drive shaft by the crankcase and connecting rods. The drive shaft in turn has a propeller connected to it which accepts the drive shaft torque and propels the watercraft.

In the two-stroke engine every downward stroke is a power stroke; whereas, in the four-stroke engine only alternate downward strokes produce power. The two-stroke engine must combine in one stroke, exhaust and intake, and in the other stroke, compression and ignition. Since intake and exhaust are accomplished in the same stroke, a deflector is often constructed on the piston to prevent the incoming fuel/air mixture from passing directly across the cylinder and out the exhaust manifold along with the burned gases that are being exhausted. Even with the use of the deflector, efficient charging of the cylinder is difficult to achieve without excessive fuel losses[4-7]. This unburned fuel is released along with the exhaust gases below the surface of receiving waters and may be one reason for the smoky exhaust of two-stroke engines[4]. Figure 1 shows the intake and exhaust arrangements for two outboard motors, each of different manufacture[8,9]. The deflection techniques to prevent mixing of incoming fresh fuel with the exhaust gases are different for the two engines which may result in varying efficiencies of cylinder scavenging between engine manufacturers.

In addition to the number of strokes per cycle, two-and four-stroke engines differ in the manner of lubrication of internal parts. In a two-stroke engine the fuel/air mixture is forced into the cylinder by the pressure that the downward power stroke of the piston places on the fuel vapors in the crankcase. This is commonly called 'crankcase scavenging' and requires that the crankcase be airtight; consequently, a lubricant cannot be admitted directly to the crankcase. For this reason the lubricating oil for a two-stroke engine must be mixed directly with the gasoline (in the fuel storage tank) in a ratio recommended by the manufacturer to insure smooth operation of the engine. When

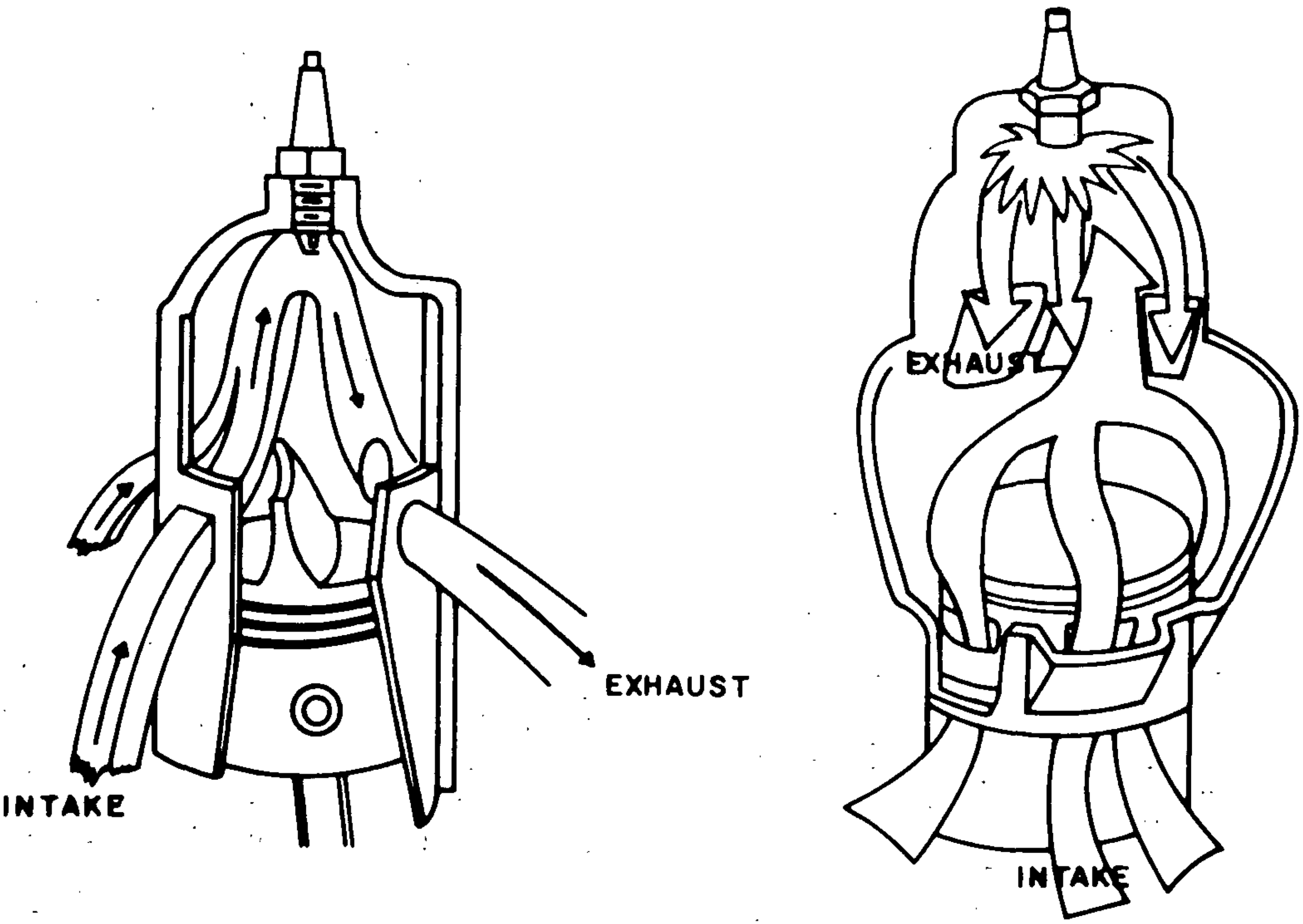

FIGURE I DIAGRAMMATIC REPRESENTATION OF VARIOUS INTAKE AND EXHAUST DESIGNS FOR TWO-STROKE OUTBOARD MOTORS[8,9].

the fuel/air mixture enters the crankcase prior to entering the combustion chamber, some of this fuel mixture will condense on the internal parts of the engine inside the airtight crankcase. The gasoline (volatility greater than that of oil) partially revaporizes, leaving a thin oil film coating the engine parts which then serves to lubricate these parts. During the operation of the engine this process goes on continuously and if an excess oil film were allowed to build-up a pool of oil and gasoline would accumulate at the bottom of the crankcase. Eventually this excess would cause a condition known as 'hydraulic lock' and lead to malfunction resulting in engine damage. To avoid such damage most two-cycle engines are provided with valves in the crankcase for the drainage of this extra gasoline/oil mixture. A 1969 study by Stillwell and Gladding, Inc., sites the two-cycle engine's open crankcase design or crankcase scavenging as highly inefficient[10]. In many of the older models this drainage is discharged directly into the receiving waters. The Outboard Marine Corporation has pointed out[11] that all of their engines of 40.0 horsepower and above, have for several years, recycled their crankcase drains. Devices which direct this drainage back to the crankcase will be incorporated industrywide into all 1972 models[1,12,13]. This recycling of crankcase drainage may decrease the quantity of materials that the new outboard motors discharge into the receiving waters; however, there would still be over 7 million outboards that operate without any recycling of crankcase drainage. Compounds from these outboard engines could be emitted into receiving waters by the passing of unburned or altered fuel across the cylinder and from the drainage of excess liquids in the crankcase.

Efficiency of Operation

It has been shown by numerous investigators that various compounds can pass through an outboard engine and into receiving waters without being burned within the cylinder[4,15-19]. Various engine liquid and solid (in the form of particulate matter) emissions, along with exhaust gases are passed into the receiving waters in the vicinity of the propeller. The propeller's mixing action rapidly disperses these materials throughout the receiving waters. The quantity of these substances discharged is dependent upon several variables and also upon conditions which are prescribed by the manufacturer. These variables and conditions can be summarized as follows:

Manufacturer's conditions -
1. Size of motor (horsepower rating)
2. Deflector design
3. Intake and exhaust design
4. Size of crankcase
5. Recycling apparatus

Operator's variables -
6. Fuel mixture (gasoline/oil ratio)
7. Speed of operation (trolling to full throttle)
8. Tuning of engine.

A discussion of the manufacturer's conditions and operator's variables and how they relate to the quantity of compounds emitted by outboard motors into receiving waters will be presented. It has been pointed out that the recycling apparatus (crankcase drainage recycle) is to be installed by outboard motor manufacturers in all new engine models[1,12,13]. In many of the older models the recycling apparatus was not installed by the engine manufacturer but in recent years recycling devices[14] have been made available to the boating public which recycle crankcase drainage back into the engine for burning. Therefore, recycling devices for older models can be included both as an operator's variable and a manufacturer's condition.

Several investigators have attempted to assess the quantity of liquid emissions which pass their way through the two-stroke outboard motor engine and into receiving waters[4,15-18]. Table 2 is a summary of their findings and points out the relative inefficiency of two-cycle outboard motor engines that do not practice recycling.

Table 2. Percent of Original Fuel Found in Outboard Motor Exhaust

Investigator	Percent of Fuel Unburned	
	Range	Average
Parker[15]	up to 56	-
Snell[16]	10 - 33	-
Muratori[4]	up to 40	10 to 20
Shuster[17]	4 - 30	-
Ferren[18]	1 - 55	27 (mean)

Variations in Engine Efficiency

The range of percentages of original fuel found in outboard motor exhausts is rather broad and the causes for such an extensive range can be related to the manufacturer's conditions and operator's variables. A review of various investigators' findings is presented which relates the contribution of each engine variable and condition to the quantity of unburned fuel passed into receiving waters.

Size of Motor

The size of motor in this review shall be synonymous with the horsepower rating assigned to the outboard engine by the manufacturer. Investigators in Florida[19] noticed that the most inefficient burn of fuel occurred with the smallest (4.0 horsepower) outboard motor tested for emissions. Shuster's tests[17] showed that the lowest quantity of emitted materials (4 percent of original fuel) came from a higher horsepower outboard motor (33.0 horsepower) when it was tuned and speeding. Ferren[18] collected data on the quantity of fuel wasted by outboard engines of different age, horsepower rating, crankcase size, and engine speed. This data appears in Table 3 and indicates that for a given crankcase size and engine speed, the higher horsepower rated motors waste a greater amount of fuel than do the lower horsepower rated motors. In a similar series of experiments[18] two 1965 outboard motors (9.2 and 50.0 horsepower) were tested over a range of engine speeds. This data appears in Table 4 and indicates that there are differences in fuel wasted between the two horsepowers at given identical speeds. From the literature reviewed it appears as though a limited amount of data is available on the relationship of horsepower rating and the quantity of fuel emitted into receiving waters. The results obtained by the Florida investigators[19] contradicts those of Stillwell and Gladding's as interpreted by Ferren[18].

Table 3. Percentage Fuel Waste for Various Age and Horsepower Outboard Motors[18]

Regular Crankcase*			Smaller Crankcase**		
Year	HP	Fuel Waste Percentage	Year	HP	Fuel Waste Percentage
1963	5	1.57	1967	95	2.34
1965	33	31.25	1966	50	1.56
1964	60	54.7	1959	40	1.56
1959	50	53.1	1968	125	2.00
1961	40	31.25			

*All motors operated at 1500 rpm ± 100 rpm.

**All motors operated at 600 rpm ± 100 rpm.

Table 4. Percent Unused Fuel vs. Engine Speed of Operation[17,18]

RPM	Percent Unused Fuel			
	9.2 HP Motor* from Ferren[18]	50 HP Motor* from Ferren[18]	Untuned 1968-33 HP Motor**[17]	Tuned 1968 33 HP Motor**[17]
800	20	14	--	--
1000	19	25	30.51	26.06
1250	21	15	--	--
1500	--	14	--	--
2000	18	--	7.11	6.00
2500	14	--	7.45	--
3000	9	0.5	--	2.97
4000	5	--	--	--
4800	3	--	--	--
5000	--	0.5	--	--

*Outboard motors were 1965 models[18].

**Test conducted by Shuster for the Environmental Protection Agency[17].

Deflector Design, Intake and Exhaust Design, and Size of Crankcase

To prevent the incoming fuel vapors from passing directly across the cylinder and out the open exhaust ports, two-stroke cycle engine manufacturers often construct a deflector on the top of the piston. A review of the literature has failed to produce any data on the relationship between deflector design and the quantity of fuel vapors which pass unburned through the cylinder. The intake and exhaust design for fuel vapors into and exhaust gases out of the cylinder may have a significant bearing on the quantity of unburned fuel vapors from the cylinder that reach the receiving waters. Figure 1, which was presented earlier, depicts two different intake and exhaust schemes for two leading manufacturers of outboard motors. The relative effectiveness of each scheme is unknown, since the manufacturers have not published any data on the merits of either system of intake and exhaust.

Other techniques are available which are designed to prevent fuel vapors from passing into the exhaust ports. One such technique is called pressure-pulse tuning[20] and employed by a leading outboard motor manufacturer. This pressure-pulse tuning is achieved by timing the exhaust ports so that a controlled amount of fresh fuel charge is momentarily forced out into the exhaust manifold. This allows additional fresh fuel to enter from the intake side. Then, at a precise instant just before the exhaust ports close - a reverse pressure pulse is fed back into the manifold - forcing the escaping fuel back into the cylinder, trapping it inside just as the port closes, creating a "super-charging" effect from the exhaust side. The manufacturer notes that "the net power gain from the recovered fresh scavenging fuel - plus the increased combustion efficiency from the super-charging effect - adds as much as 20 percent more power - and a cleaner exhaust". No substantiating data is presented with the publication[20] to demonstrate that the pressure-pulse tuning technique does produce a "cleaner exhaust". Possibly this data exists in other published or unpublished reports.

Ferren[18] noted from data supplied by Stillwell and Gladding which appears in Table 3 that the outboard motor engines with smaller crankcases were markedly more efficient. A possible explanation for the smaller crankcase engines being more efficient is that the fuel vapors are not retained for as long a time period within the smaller crankcases as they are in the regular crankcases. With a decreased detention time, fuel vapors have less time to condense on the walls of the crankcase and in time form a gasoline/oil pool at the bottom of the crankcase. Ferren[18] ran the regular crankcase engines at 1500 ± 100 rpm and the small crankcase engines at 600 ± 100 rpm but it is felt by the reviewers that this difference in engine speed may have had a bearing on the test results. This conclusion is based on the plots of fuel waste versus engine speed for a 9.2 and 50.0 horsepower outboard motor as shown in Figure 2 (derived from the data of Ferren[18] in Table 4). This plot indicates that the percent of fuel wasted at 600 (by extrapolation) and 1500 rpm for both engines is not identical; therefore a comparison of Ferren's[18] data in Table 3 for large and small crankcase outboard engines must be reviewed with caution. The differences in fuel wasted between engines operated at 600 (by extrapolation) and 1500 rpm's from Figure 2 appear to range from 5 to 10 percent. When comparing average values for the data presented in Table 4, the difference in fuel wasted between regular crankcases (avg = 34.37 percent) and smaller crankcases (avg = 1.89 percent) was 32.48 percent. This difference is considerably greater than the 5 to 10 percent difference due solely to engine speed; with this in mind, the reviewers concluded that the crankcase size did

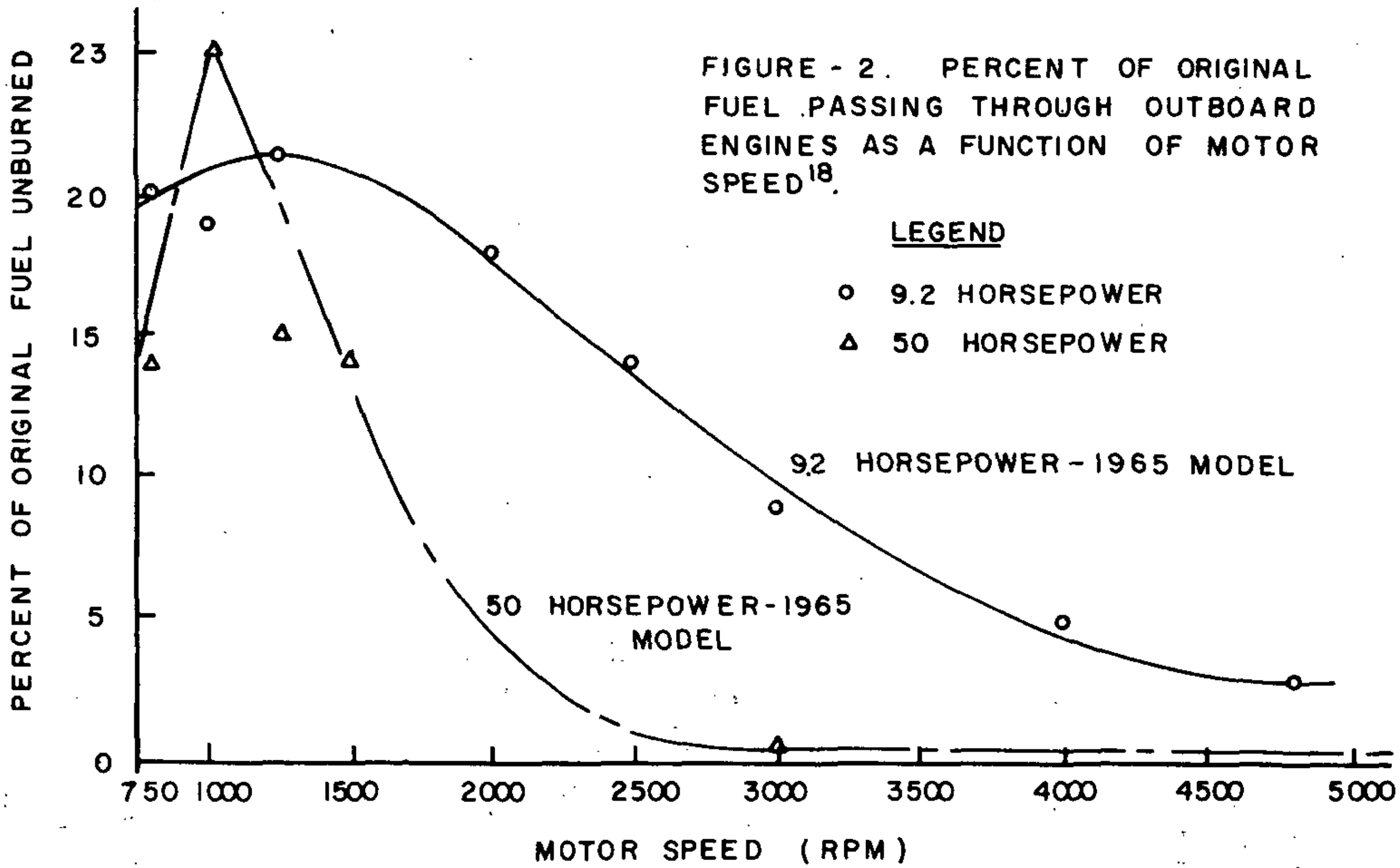

FIGURE - 2. PERCENT OF ORIGINAL FUEL PASSING THROUGH OUTBOARD ENGINES AS A FUNCTION OF MOTOR SPEED[18].

become an important factor in the quantity of liquid emissions released by outboard engines into receiving waters.

Recycling

Recycling as used in the context of this paper shall mean the recycling of crankcase drainage back to outboard engine, fuel tank, or any other chamber and therefore not into the receiving waters. One such recycling device is manufactured by the Goggi Corporation[14] and is called "Kleen-X-Zaust" (K-X-Z). With the K-X-Z system, the unburned fuel or bleed-off from the crankcase is drained under pressure, from the bottom of the crankcase before being discharged into the exhaust housing and forced, under pressure, into the K-X-Z mixing chamber. Within this mixing chamber the drainage from the crankcase is combined with fuel entering this chamber from the normal fuel storage tank. The resultant metered fuel is then drawn into the engine in the normal manner and reused. The K-X-Z unit is essentially just a metering chamber, completely separate from the outboard motor and the fuel storage tank[14].

The procedure that one of the leading outboard manufacturer utilizes to accomplish recycling was briefly described in a public relations release on April 27, 1971[13]. The release states that "according to C. F. Alexander, Vice President Engineering Kiekhaefer Mercury, the oil that normally accumulates in the crankcase of two-cycle outboards is now forced through a system that returns the excess lubricant to the combustion chamber. There it is mixed and burned with the regular fuel charge."[13]

Muratori[4] states that the reason why crankcase drainage is not recycled directly back to the fuel tank is due to the heavy portion of oil in the drainage liquid. Normal gasoline/oil ratios generally range from 25/1 to 50/1. Analysis of crankcase drainage shows the ratio generally varies from 5/1 to 10/1 and, in some cases (at higher speeds), the proportion of oil in crankcase drainage can be even greater[4]. Lussier has reported[21] that the oil content of the fuel mixture discharged from the crankcase into receiving waters varies from 22 to 65 percent of the total oil fed the two-stroke cycle engine. If this mixture were to be collected and added directly to the fuel storage tank it would eventually cause rough operation and quickly fouled plugs. This practice of adding the drainage directly back to the fuel storage tank was actually tried by several experimenters who soon abandoned the idea because of poor results[4]. It has been only during more recent years that engine manufacturers have recommended the lighter 50/1 mixes. With the increased use of these lighter mixes, it has become more practical to reuse the wasted fuel by metering it into the fuel flow at some point between the tank and the carburetor (the Goggi device operates in the same manner). This results in supplying an engine, using an original mixture of 50/1, with a mixture of approximately 40/1 using the reclaimed fuel. Such a mixture is perfectly acceptable to the engine and actually results in improved lubrication[4]. The same author reports that the cost of installation of a recycling unit will normally be recovered through savings on fuel in one season's operation.

Snell[16] conducted tests on the amount of fuel saved and the increase in running time for two crankcase drainage recycling devices manufactured by the

Goggi Corporation. The trade name for the devices were KleenZaust and PetroSave and the following summary of findings was presented:

"1. At engine idling speeds of 650 ± 100 rpm, the KleenZaust Device returned over 30 percent of the fuel drawn in by the engine.

2. At engine speed of approximately 1,000 rpm, under load in gear by a test propeller, running time using the PetroSave Device was approximately 68.8 percent greater than running time without this device.

3. At engine speed of 2,000 rpm, running time using the PetroSave Device was found to be 66.7 percent greater than running time without this device.

4. At engine speed of 3,000 rpm, running time was found to be 41.7 percent greater with the PetroSave device connected.

5. Concentration of oil in the fuel mixture remaining in feed tank was found to remain unchanged while the motor is running, and to increase by an amount considered insignificant when the motor was stopped."[16]

From the data available on recycling devices it appears as though the incorporation of such devices on older outboard motors will greatly reduce the quantity of compounds emitted into receiving waters. Senator Gaylord Nelson (D.-Wisconsin) has submitted a bill[1] before the Congress of the United States of America entitled "Outboard Motor Pollution Control Act of 1971", which would require that two-cycle outboard motors used on vessels or any other watercraft on the navigable waters of the U. S. be equipped or modified in such a manner as will use the latest available technology to prevent such motors from polluting such waters. Nelson[1] also states that the recycling of fuel technique reportedly is already being manufactured in all motor sizes and will be used industry-wide in the 1972 models. The Outboard Marine Corporation has pointed out that all of their engines of 40.0 horsepower and above have, for several years, recycled their crankcase drains[11].

J. Swift, Public Relations Director for Kiekhaefer Mercury, during an annual press conference[12] related that for the past four years (at least) a majority of engines down through 40 horsepower have been drainless. He further adds that "all major brands in all horsepower ratings, are now being manufactured with a feature eliminating crankcase drains".

Speed of Operation

The speed of operation of an outboard motor engine, usually indicated in revolutions per minute (rpm), has been shown to affect the quantity of compounds emitted into receiving waters[4,17,18,21]. Schuster's[17] tests on a 33-horsepower motor showed that the greatest quantity of original fuel released into receiving waters was over 30 percent and occurred when the engine was untuned and running at a low engine speed of 1000 rpm, while the least amount of fuel was under 3 percent and was experienced at a higher engine speed of 3000 rpm. Schuster[17] noted from his experimental data in Table 4 that the quantity of compounds emitted from both a tuned and untuned 1968 33-horsepower Evinrude engine decreased with increasing engine speeds.

From the experimental data supplied by Stillwell and Gladding, Ferren[18] reported that for two-1965 outboard motor models (data appears in tabular form in Table 4 and graphical form in Figure 2) crankcase drainage from both a low and high horsepower engine increased at lower speeds of operation and seemed to peak at engines' speeds around 1000 to 1250 rpm (idling and trolling speeds). Muratori's[4] studies revealed that at trolling speeds as much as 40 percent of the original fuel mixture could be wasted into the exhaust manifold. Muratori[4] also found that at these low speeds of outboard motor engine operation some compounds (referred to as 'pollution') could be detected because of their taste, odor, and visibility.

Lussier reported[21] on tests that were run at different engine speeds on marine outboard engines of different model, age, horsepower rating, and motor condition. The engine speeds for these experiments varied from 600 to 5000 rpm and the results obtained on fuel wasted (passing into receiving waters) appear in Table 5. At engine speeds less than 1000 rpm, 50 percent of the engines wasted above 10 percent of the original fuel; whereas at speeds greater than 2500 rpm, 100 percent of the engines tested wasted over 10 percent of the original fuel. This indicates that engines run at speeds less than 1000 rpm appear to be more efficient than engines run at speeds greater than 2500 rpm. This contradicts the findings of other investigators[4,17,18]. Based on the findings of these various researchers[4,17,18,21], the reviewers concluded that outboard motors appear to run more inefficiently at lower engine speeds than they do at higher speeds.

Fuel Mixture, Age of Engine, and Tuning of Engine

Most outboard motors are designed to operate at peak efficiency for a certain gasoline/oil ratio. Should a lubricating oil not specified for use in two-cycle engines or an insufficient quantity of oil be added to the fuel. mixture the following problems may occur: the engine does not idle properly,

Table 5. Percent Original Fuel Wasted During Outboard Motor Operation in Relation to Engine Speeds[21]

Speed of Operation (rpm)	Percent of Engines Tested Above or Below Percentage Fuel Wasted Figure
Less than 1000	50% Engines below 10% Fuel Wasted
1000-2500	40% Engines above 30% Fuel Wasted
Greater than 2500	100% Engines above 10% Fuel Wasted

the motor speeds are lower than normal, and the motor overheats. In addition to these problems, should a non-recommended gasoline or an excess of oil be added to the fuel mixture, the outboard motor engine could run irregularly or miss[22]. This contradicts the earlier statement of Muratori[4] that a mixture of approximately 40/1 using reclaimed fuel is perfectly acceptable to an engine and actually results in improved lubrication of engines whose original fuel mixture was recommended at 50/1. Lussier reported[21] that misproportioning the gasoline/oil mixture could result in improper fuel combustion through fouling of the spark plugs. Improper idling and misfiring of an outboard motor engine could cause the fuel mixture in the engine's cylinder to be partially burned and/or unburned, resulting in an increase of compounds being discharged into receiving waters.

Ferren[18] concluded from the data presented in Table 3 that the age of the motor manufactured prior to 1968 had little to do with the quantity of fuel wasted. In earlier sections of this review, discussion has been addressed to the fact that outboard motors which practice recycling of crankcase drainage are markedly more efficient and therefore emit fewer compounds into receiving waters. For engines manufactured prior to 1968, age may have no bearing on the quantity of compounds emitted; however, this may not hold true when comparing the pre-1968 engines with the more recently manufactured outboard motors which practice recycling.

Lussier has reported[21] that the operation of an improperly tuned engine resulted in fuel wastage as much as 15 percent greater than that obtained from normal operation of the same engine in a perfectly tuned condition. Lussier further stated that failure to make necessary replacements -- spark plugs, ignition points, and other fuel system parts -- results in further incomplete fuel combustion, as does a carburetor which is adjusted to feed a mixture too rich in fuel. A reconnaissance study by Shuster[17] showed that at low speeds of operation (1000 rpm) a tuned 33 horsepower outboard motor emitted 26.06 percent of its fuel. This figure increased to 30.51 percent when the motor was untuned. However, at a higher speed of operation (2000 rpm) the differences in tuning were not so pronounced (7.11 percent fuel wasted for the untuned motor and 6.00 percent fuel wasted for the tuned outboard engine).

It was concluded by the reviewers that, based on limited data, the quantity of compounds emitted by outboard motors into receiving waters is less for engines that are tuned and utilized a fuel mixture recommended by the manufacturer than engines operating in an untuned condition and utilizing a fuel mixture other than that recommended by the engine manufacturer. The age of the engine prior to 1968 (when recycling devices were installed by some engine manufacturers) apparently has no bearing on the quantity of compounds emitted.

Outboard Motor Fuel

Although outboard motors have been in use for many years, the majority of research on the emissions of outboard motors has been conducted in the past decade. With recent advances in analytical instrumentation, it is anticipated that current research will add more significant contributions to the understanding of the quality and quantity of outboard motor derived emissions and on the fate and effects of these emissions in the aquatic environment. All substances emitted by outboard motors are derived from the fuel mixture which consists of gasoline with or without its additives and lubricating oil.

Gasoline contains mainly hydrocarbons from the C_6 to C_{10} range. Over 100 compounds have been identified in gasoline and these include normal and branched alkanes, cycloalkanes and alkylbenzenes[5,23,24]. The detonation characteristics of hydrocarbon fuels are improved by the addition of various chemicals. The most common additive is tetraethyl lead usually in the range of 1 to 3 cubic centimeters per gallon[23,25]. The average lead content of gasolines sold in the United States has been placed at 2 grams per gallon[26]. To prevent accumulation of lead oxides in the combustion chamber, scavengers such as ethylene dibromide and ethylene dichloride are added to commercial antiknock fluids[23-25].

Lubricant oils used in four-stroke engines vary in the number of carbon atoms from 26 to 38[23] and contain elements such as zinc, sulfur, phosphorus and other unspecified additives[27]. The lubricating oil most commonly used in two-cycle outboard motors is different in detergent composition from oils utilized by four-cycle engines. Outboard motor oils employ organic detergents which are biodegradable while oils for four-cycle engines employ metallic detergents which are not biodegradable[12].

Manufacturers of outboard motors recommended the use of leaded gasolines in two-cycle outboard motors because unleaded gasoline has caused numerous problems[28]. An official of BIA[28] has been quoted on the use of unleaded gasolines in two-cycle outboard motors as follows, "In a two-cycle engine - especially the high-powered, high-output units - the phosphorus additive has been proven to be disastrous, and that engines have been ruined by continuous all-out use in just a short time." This same authority has noted that the lack of lead and the addition of phosphorus to unleaded gasoline have produced three unexpected problems in two-cycle power plants. He stated that "One is pre-ignition caused when deposits form and fire the spark plugs at the wrong time, throwing off the timing of the engine. The second is a 'dirty engine'. Outboard experts have found that lead acted as a scavenger cleaning deposits from the combustion chamber keeping such things as piston rings from sticking. And, finally, a lack of lubrication. No one realized just how much lubricating a little lead did for an engine"[28].

Compounds Emitted During Operation

In addition to the gases (water vapor, the oxides of carbon, nitrogen, sulfur, and others) from the combustion chamber, the hydrocarbons and lead compounds in the unburned fuel mixture, complexed particulate lead compounds, hydrocarbons derived from rearrangement (cracking or synthesizing reactions), and partial oxidation products can be expected to be discharged below the water surface. With the exception of the research on the percent of raw fuel passing through an engine, as previously described, a minimal amount of work has been done on qualifying and quantifying the substances in outboard motor exhausted (OME) water. Considerable achievement has been made in the identification of materials emitted from four-cycle engines and it is expected that some of these same compounds are present in OME-water.

Hydrocarbon Compounds

Various investigators have reported values for the volatile and non-volatile fractions of oil, phenols, lead, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) in OME-water and their findings appear in Table 6. A BOD value for the main component of outboard motor fuels (gasoline) was found to be of 0.078 grams per gallon[33]. Mention of the various hydrocarbons in gasoline included normal and branched alkanes, cycloalkanes and alkylbenzenes[5,23,24]. Zajic et al[34] examined specific hydrocarbons (several found in gasoline) for 5-day BOD values and found that n-hexane and n-heptane gave a 5-day BOD of zero ppm. As the length of the paraffinic hydrocarbon chain increased, the BOD increased up to the longest-chained hydrocarbon compound tested by the researchers, n-heptadecane, whose 5-day BOD was 60 ppm.

In addition to the COD values reported[19,29,30] for OME-water, the engine condensates for some engines used by the military have a reported COD value of 900 to 2000 ppm[35]. It should be noted that all these COD values presented are not a true representation of all the hydrocarbon compounds present because the aromatic and straight chained aliphatic compounds in gasoline, OME-water, and engine condensates are not oxidized in the standard COD test[36].

Table 6. Various Compounds Found in Outboard Motor Exhausts[19,29-32].

Author	Oil/Gasoline Ratio	Hours of Operation	Compound (g/l of Fuel Consumed)					
			Non-volatile Oil	Volatile Oil	Lead	Phenol	BOD	COD
Kempf, et al[29]	1:25 1:50 1:100	- - -	5 to 7 2.5 to 3.5 2 to 3	- 2 to 3 -	- 0.03 to 0.05 -	- 0.16 to 0.2 -	- - -	110 60 60
English, et al[30]	1:16	-	28	15.0	0.14	0.16	42*	114
Vogel[31]	1:20 and 1:25	- -	8 to 10	-	-	-	-	-
Eberan-Eberhorst[32]	1:24 1:50	- -	9 to 23 4 to 11	- -	- -	- -	- -	- -
Environmental Engineering, Incorporated[19]	1:50 1:50 1:50	1 4 8	- - -	- - -	- - -	- - -	1.05** 4.20** 9.00	2.50 11.5 19.00

*Ultimate BOD - seed is settled river water.

**Seed unknown - (assumed as 5-day BOD results).

Of the one billion gallons of gasoline consumed annually by outboard motors it has been estimated that 100 to 160 million gallons of fuel are wasted into receiving waters[1]. In a recent reconnaissance study by Shuster[17] it was reported that if one takes a discharge of 400 ml of exhaust products per 30 minutes of outboard motor operation as typical of an average day operation, this may be transformed into a wastewater burden in terms of population equivalent. Assuming that the products contain 85 percent biodegradable carbon, the discharge based on one engine-day would be equivalent to a population of 400 people. *Both of these figures for fuel wasted annually and the 24 hour* organic carbon population equivalent have been questioned as to validity[37].

Many organic compounds have been reported in automobile (four-stroke engine) exhaust gases. Since these compounds could be found in outboard motor exhausts (because of the similarity in two-stroke and four-stroke engine fuels) some mention will be made of them. The separation and identification of hydrocarbons in automobile exhaust gases has been accomplished by numerous investigators[38-45]. Their findings indicate that literally a hundred or more hydrocarbon compounds can be emitted in the exhausts of internal combustion engines. Many of these will not persist for a long period of time in water due to their immiscibility volatility, biodegradability, and the effects of weathering; but on the other hand, others may persist for extended periods of time.

Of all the possible oxidation products that could be formed from the partial oxidation of gasoline in both two-stroke and four-stroke engines, perhaps the phenolic family has been the most troublesome from the pollution standpoint[46-48]. English, et al[30] and Kempf et al[29] were able to measure in

OME-water 0.16 and 0.16 to 0.2 grams of phenol per liter of fuel consumed, respectively. In addition to phenols other compounds found in the partial oxidation products in automotive exhausts include alcohols, aldehydes, esters, ketones, and acid derivatives[46]. DesRosiers reported[35] concentrations of 10 to 15 milligrams per liter of formaldehyde in the condensates from military engines.

Preliminary investigations on the identification of hydrocarbons in OME-water are being conducted at the University of Massachusetts[50]. To date this work has been confined to the gas chromatographic separation and mass spectrometer analysis of samples such as a raw fuel mixture (50 parts gasoline to 1 part of lubricating oil), a standard mixture of known hydrocarbons, extracts of OME-water, and extracts of raw (non-OME) water. Numerous separate hydrocarbon peaks have become evident in the raw fuel mixture and the OME-water extract gas chromatograms. Tentative identification of these hydrocarbons has been accomplished and present work includes the confirmation of these various identifications with mass spectrometer data, supplemented with gas chromatographic retention time data.

Lead Compounds

Manufacturers of outboard motors recommend the use of leaded gasolines because the phosphorus additives in unleaded gasolines may cause problems of piston failure[51]. English et al[30] and Kempf et al[29] were able to measure in OME-water, 0.14 and 0.03 to 0.05 grams of lead per liter of fuel consumed respectively. This figure of 0.14 grams of lead as measured by English et al[30] in their laboratory experiments was only 22 percent of the lead originally present in the fuel mixture. The quantity of particulates (most significant fraction of these are lead compounds[25,49]) that are emitted in automotive exhausts varied between 0.22 and 3.2 mg/gm of gasoline burned with an average value of 0.78 mg/gm[49]. Research conducted on automobile exhausts indicates that approximately 70-80 percent of lead burned in the engine is exhausted to the atmosphere, while 20-30 percent remained in the lubricating oil and exhaust system[49].

II. GENERAL CONCLUSIONS

Two-stroke outboard motors have been shown to discharge a variety of compounds into receiving waters. The most notable of these is raw fuel (gasoline/oil mixture). Other compounds measured in OME-water include non-volatile oil, volatile oil, lead and phenols and the ranges of these materials in grams per liter of fuel consumed was from 2 to 28, 2 to 15, 0.03 to 0.14, and 0.16 to 0.20, respectively[19,29-32].

These compounds may enter receiving waters in either or both of two ways; one is the passage of fuel across the cylinder during the intake and exhaust stroke, and the other is the drainage of the liquid pool in the crankcase into the exhaust manifold. The major portion of the compounds derived in OME-water is attributed to the drainage of crankcase liquids.

The quantity of compounds emitted into receiving waters is not a constant for all engines as shown by previous researchers findings[4,15-18]. These findings indicate that up to 55 percent of the original fuel can be discharged into receiving waters. An average value for this quantity has been estimated at between 10 to 20 percent[4]. The wide range in engine efficiencies can be attributed to a number of factors which include: size of motor, intake and exhaust design, size of crankcase, speed of operation, tuning of engine, and recycling of crankcase drainage. Deflector designs may also influence the quantity of compounds in OME-water; however, no data has been published to relate various designs. The age of the engines manufactured prior to 1968, apparently has no bearing on the quantity of emitted compounds. However, some engines manufactured during and after 1968 incorporate recycling devices and these would reduce the quantity of compounds ejected into receiving waters.

In 1970 an estimated 100 to 160 million gallons of raw fuel was discharged into our nation's waterways and this loss of fuel has been estimated to represent over a 50 million dollar loss to the boating public[1]. It is anticipated that current outboard manufacturer plans for incorporating recycling devices on all new 1972 engines[1] will reduce the quantity of substances that the newer engines will eject into receiving waters but it does not appear to solve the problem of the older engines in operation. Despite this effort, in 1972, there may be over 7 million older outboards in operation that do not practice the recycling of crankcase drainage. It is these motors and their emissions that may pose a threat to the aquatic environment.

Although recycling may eliminate crankcase drainage from entering a waterway, raw fuel may still pass through the cylinders during the combined intake and exhaust stroke of two-stroke outboard engines. Data available on the percent reduction of compounds discharged by recycling devices is rather limited and perhaps these devices should be researched further before establishing the conclusive merits (from both the financial and pollutional standpoints) of recycling devices.

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SECTION TWO

ABSTRACT

The effects of the compounds associated with outboard motor subsurface exhausts on water quality and aquatic biota are reviewed. The problems affiliated with water quality may include the formation of undesirable tastes and odors and the appearance of oily substances. It has been demonstrated that outboard motor exhaust water can exhibit a toxic effect in sufficiently high concentrations to fathead minnows and bluegills, taints the flesh of various fish, and may affect the reproduction of fish.

A discussion of the current research related to the effects of outboard motors on the aquatic environment is presented. Recommendations are given for future research to broaden the understanding of the interaction of outboard motors with the aquatic environment.

The Effects of the Interaction of Outboard Motors with the Aquatic Environment - A Review

by Thomas P. Jackivicz, Jr. and Lawrence N. Kuzminski

I. GENERAL CONSIDERATIONS

A previous paper[1] on the use of outboard motors on waters has reviewed various operating conditions through which outboard motors discharge a variety of compounds into receiving waters. The major emittant is raw unburned fuel (gasoline/oil mixture). Other compounds measured in outboard motor exhausted water (OME-water) are non-volatile oil, volatile oil, lead and phenols. This particular review will restrict itself in scope to the stress placed on recipient water quality and associated aquatic biota by subsurface outboard motor exhausts. The reviewers feel that several questions still remain unanswered with regards to the use and effects of outboard motors on receiving waters and discussion is addressed to these points in the GENERAL CONCLUSIONS section of this review.

II. ENVIRONMENTAL PROBLEMS

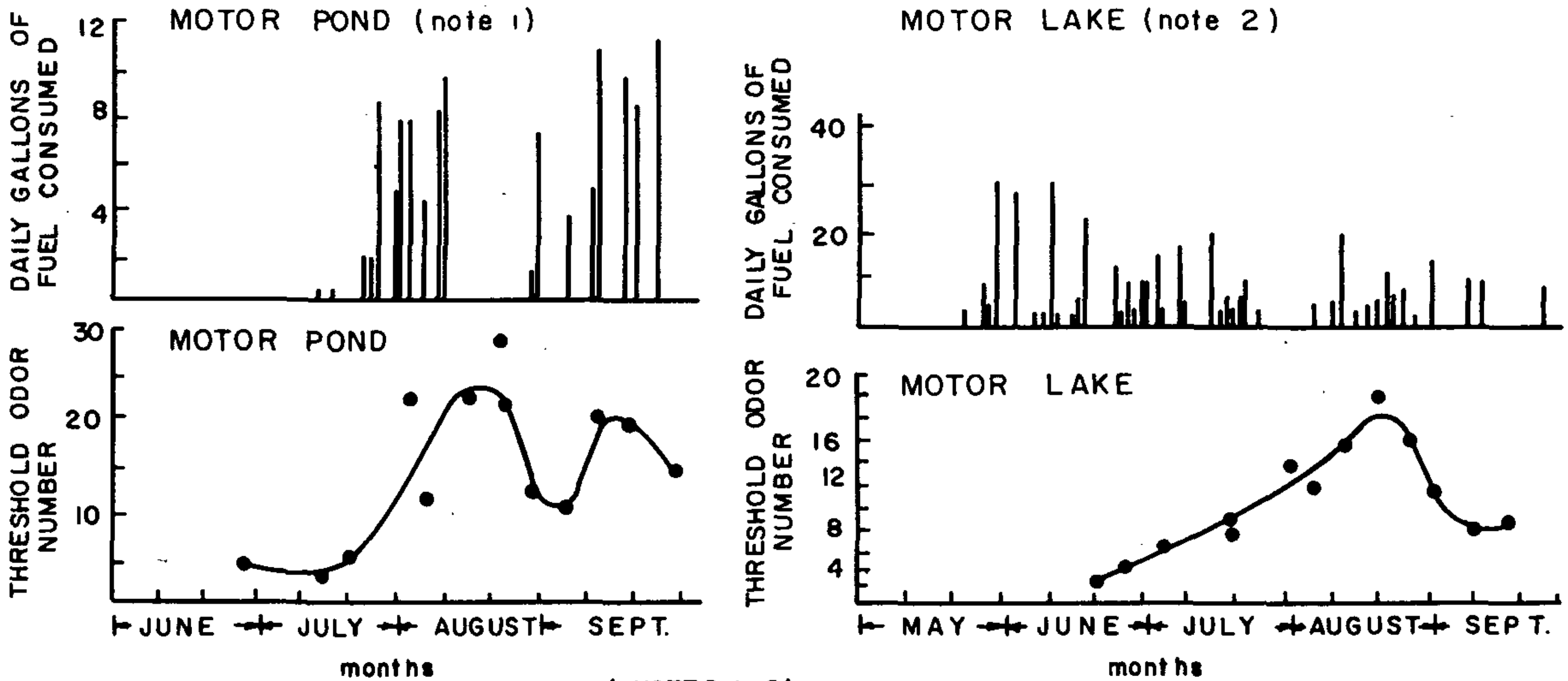
Effects on Water Quality

English *et al*[2,3] have conducted preliminary work on treatment of waters displaying OME derived tastes and odors. The treatment of water containing OME-compounds will not be dealt with in this review.

Tastes and Odors

Dietrich[4] mentions that oil derived from two-stroke outboard motor operation in Lake Constance could cause pollution of the shore floor and the shore vegetation, thereby affecting the biological processes of self-purification, the wetability of soil particles, and the filtration property of bacteria due to the disturbance in the development of ground fauna and flora. This, he states, could render the groundwater unpalatable, odorwise and tastewise.

Stewart and Howard[5] estimated that at the current rate of discharge of unburned fuel (40,000 gallons/year) into Lake George, New York, the smell of gasoline and oil will be noticeable in fish and water supplies and the lake water will have a semi-permanent fuel odor within eight years. Studies by English *et al*[2] revealed that 1.3 million gallons of odor free dilution water per gallon of fuel consumed by outboard motors would be required to obtain a threshold odor number of one. Field studies have shown that the threshold odors of an outboard motor pond and motor lake increased during heavy outboard motor operations but decreased when operation halted[3]. The relationships between threshold odor number for untreated water samples from a motor lake and motor pond and the daily fuel consumption on each are shown in Figure 1. Odors were described as musty, moldy, earthy, and wet vegetation with musty and earthy being used most often as a description for outboard motor derived odors.



(NOTES 1+2)

WATER BODY CHARACTERISTICS AND OUTBORD MOTOR USE DATA					
WATER BODY	AREA (ACRES)	VOLUME (MIL. GAL)	AVERAGE DEPTH (FT)	NO. MOTOR OPERATED	HORSEPOWER OF MOTORS
MOTOR LAKE	6.89	24.4	11	6	30 to 75
MOTOR POND	0.96	1.7	5.4	4	5.4 to 18

FIGURE 1 DAILY FUEL CONSUMPTION, THRESHOLD ODOR NUMBERS, AND WATER BODY CHARACTERISTICS FOR A MOTOR POND AND MOTOR LAKE[3]

Oily Substances

It has been reported that oil placed on a clean water surface may spread to a thickness of one molecule. The iridescence of water containing only small traces of oil are sometimes caused by such films. The visibility of oil films is shown in Table 1.

Table 1. Iridescence of Oil Films[6]

Approximate Thickness of film (inches)	Appearance	Approximate gallons of fuel to form one sq. mi. of film
0.0000015	Barely visible under most favorable light conditions	25
0.0000030	Visible as silver shean on surface of water	50
0.0000060	First trace of color may be observed	100
0.0000120	Bright bands of color are visible	200
0.0000400	Colors begin to turn dull	666
0.0000800	Colors are much darker	1332

Since the outboard motor derived substances are ejected underwater with the exhaust gases and in the subsurface mixing zone of the propellor, it is often difficult to visually detect any of these substances except at low speeds of operation. This practice allows the discharged gasoline/oil mixture from the cylinder and crankcase to be mixed into a large quantity of dilution water. Due to their specific gravities some of the fractions of the emitted substances will rise to the water's surface where they may become visible. Eberan-Ebershorst's experiments[7] showed that 50 percent of the lubricating oil present in water due to outboard motor operation rose to the surface in 3.5 days and this increased to 90 percent after 5 weeks. This suggests that an emulsion of oil in water is formed and consequent separation of these two liquids does not progress rapidly. Several investigators have reported on the visible slicks caused by outboard motor derived compounds[8,9]. At a boat speed of 20 miles per hour, the exhaust products surface approximately 50 feet astern. However, at lower speeds some pollution can be detected because of its odor, taste, and visibility[8]. Lake X investigators report visual evidence of an oil rainbow in bottom samples collected in the boat harbor area[10]. Another investigator[11] found in his laboratory test pools that outboard motor exhaust products rapidly separated and accumulated in pools on the surface. Very little exhaust material was retained in the water below the top few inches; however, because of extensive splashing, the standard propellers on the test engines were replaced with test propellers provided by the engine manufacturers. These results appear to contradict the earlier findings of Eberan-Ebershorst[7].

Effects on Aquatic Biota

As early as 1950, studies were run on outboard motors in relation to fish behavior, fish production, and angling success. The experiments of Lagler et al[12] encompassed many interrelationships between aquatic biota and outboard motors and for this reason their findings will be reviewed in depth. During the course of a summer the effects of outboard motor usage were evaluated on the following:

1. Bluegill production in experimental ponds.
2. Largemouth black bass production in experimental ponds.
3. Environmental factors affecting fish production in experimental ponds.
4. Location of nests by fishes.
5. Guarding behavior of male centrarchids.
6. Mortality of eggs and sac fry of sunfishes in natural waters.
7. Survival of advanced fry of largemouth black bass in experimental ponds.
8. Angling success.

Over a two and one-half month period outboard engines with a rating of between 5.0 to 5.5 horsepower were operated on a motor pond and a total of 194 motor hours were logged. The motor pond had a volume of approximately 4.5 million gallons of water. The total volume of fuel used and the type of fuel used (leaded or non-leaded) was not presented. Various aspects of bluegills (number of breeders, number of young, average size of breeders and young, total pounds of young; number of young per acre, etc.) in a control pond (4.2 million gallons), where no outboard motor usage occurred, were used to compare with the same aspects of bluegills from a motor pond. In comparing the numbers of young bluegills recovered from the two ponds at the close of this phase of the experiments the authors were led to the conclusion that motor use had no significant effect on production of bluegills.

Largemouth black bass production yield was somewhat higher per unit of area in the non-motor pond. The observed difference of about 3,000 fish per acre was, however, attributed by the authors to several factors other than the single controlled variable of motor use. The control pond was characterized as having a "fundamentally greater biological potential" than the motor pond. It had a greater average depth, a greater shore-line development, and a more stable water level. Vegetative differences were also cited as possibly directly enhancing the survival of young. For these reasons, no conclusions on largemouth black bass production were drawn and there was an expressed desire by the investigators to repeat the experiment.

Environmental factors studied by Lagler, et al[12] include turbulence, aquatic vegetation, turbidity, oil, plankton production, bottom organisms, and water chemistry for an outboard motor running at 3/4 speed. Turbulence from propeller action was not observed to have any gross effects directly on fish; that is, no dead fish were found in any of the experimental ponds during the course of the experiments. In water less than 30 inches deep a considerable amount of bottom materials was moved by the outboard motors. When one of the motor ponds was drained, the motor usage could be seen to have made a swath about 5 feet wide through the shallows. Rooted aquatic vegetation did not develop in the motor paths where these paths brought the propeller within 12 inches or less of the bottom. It was also evident that turbulence effects of propeller wash were minimized by beds of aquatic plants in the motor ponds.

Turbidity was not measurably increased by the motors. It was recognized, however, that turbidity caused by outboard motor operation and subsequent effects on the biology of the waters might be greater where bottom soils are dominantly clay.

No visible signs of oil from outboard motors appeared on marginal or aquatic vegetation, on the many clear pine tests strips set in the water near the shore, or on the concrete structures used to controlpond levels, and therefore, its effects on these entities could not be studied.

In order to evaluate whether motor use affected the production of free-swimming microorganisms, plankton samples were collected from the bass control pond and from the bass motor use pond and compared on a volume basis after concentration by centrifugation. The authors concluded that "although the plankton samples are few and have limitations because of the method of collection, it is evident that outboard motor use did not prohibit plankton development, and probably did not even inhibit it in any way."

The numbers and volumes of bottom organisms in the outboard's path in shallow water were substantially reduced by prolonged operation of the outboard. The authors noted that the organisms which presumably populated the bottom area corresponding to the path of travel of the boat at the start of the experiment were not necessarily destroyed by the engine and may have been washed off to the sides or tossed up into the water and consumed by the bass present. Table 2 shows the bottom fauna populations in the control and motor use ponds. Differences in dominant species and species numbers between the control and motor ponds are possibly evident from the data. Differences in volume of total organisms per square foot of sampling area between the control pond, the motor pond, and the motor path in the motor pond also seem evident but a statistical evaluation of these differences is not available.

Selected characteristics of water chemistry in these series of experiments (such as pH, hardness, alkalinity, and dissolved oxygen) were not affected by motor use. These workers concluded that outboard motors have little or no effect on similar dissolved substances in natural waters under comparable conditions. The average values of the specific characteristics for 3 motor use and 3 control ponds are given in Table 3[12].

Table 2. Comparison of Bottom Fauna in Control and Motor Use Ponds, July 1949[12]

Item of Comparison		Control Pond 19	Motor Pond 22 (exclusive of motor path)		Motor path in Pond 22	
Number of samples................		20	20		6	
Area per sample, in square feet...		.84	.84		.84	
Total area sampled, in square feet		16.80	16.80		5.04	
Organisms	Number	Vol.cc	Number	Vol. cc.	Number	Vol.cc.
Oligochaeta	212	1.75	700	3.20	32	0.20
Hirudinea	83	9.90	2	0.10	--	--
Gastropoda	416	5.65	80	0.90	3	0.05
Pelecypoda	25	1.55	1	0.50	--	--
Amphipoda	478	1.30	3	Trace	--	--
Hydracarcina	94	0.25	58	0.20	7	0.05
Ephemeroptera	703	2.50	158	2.60	9	0.20
Anisoptera	42	1.30	29	0.25	13	0.10
Zygoptera	8	1.50	4	0.90	1	0.05
Neuroptera	3	0.10	5	0.05	--	--
Trichoptera	111	0.90	58	0.60	9	0.10
Coleoptera	2	0.50	2	0.05	--	--
Corethra	146	0.35	250	0.80	14	0.05
Chironomidae	3,155	13.35	863	2.40	174	1.40
Other Diptera	69	1.15	4	1.50	37	0.30
TOTALS	5,547	41.60	2,260	13.60	309	2.55
Number per square foot	330		135		61	
Volume per square foot		2.48		.81		.50

Table 3. Average Data on Water Chemistry in Three Control and in Three Motor Use Ponds[12].

Pond	pH	Phenolphthalein alkalinity, ppm	Total (methyl orange) alkalinity, ppm	Dissolved Oxygen cc/liter
Control	7.3	14.33	129	5.17
Motor Use	7.4	16.00	120	5.27

Observations were made on nesting sites of rock bass, bluegills, pumpkinseeds, and largemouth black bass for the experimental ponds and also various lakes and channels in Michigan. From these observations it was concluded that sunfish and bass were not barred by ordinary outboard motorboat use from locating their nests in any part of natural waters except in extremely rare instances. In another portion of this study[12] it was found that once the nests were located and formed, the guardian males of the bluegill, pumpkinseed and largemouth bass would: (1) leave their nests when disturbed by motor boats or other agents; (2) return promptly after the disturbance had passed; (3) ordinarily deserted their nests permanently only if the nests were more or less obliterated. Continued agitation would possibly result in nest desertion but it was felt that such a condition was not commonly attained by outboard motor use in natural waters.

Among the factors felt important in the relationships between outboard motors and the fate of eggs and early fry in sunfish nests were speed of motor operation, depth of water, amount of wash, nature of bottom materials, and promptness with which the guardian male returned to the nest after being disturbed. It had been previously found in this series of studies that failure of the mate to return to the nest was a negligible factor and the wash and direct action of high speed operation were also ruled out as causing any detriment to survival in nests. To analyze the other relationships 10 nests were employed for each assay - 5 for experimental purposes and 5 for control. The nests of both bluegill and pumpkinseed were spotted on different types of bottom and at various depths. The experimental nests were exposed to different types of motor action. Using mortality as an effect criterion, it was concluded that the practical effects of outboard motor use on increased mortality of pumpkinseed and bluegill eggs and fry were negligible, since, in all the experiments, the maximum increase in fry mortality for motor use was only 1.5 percent.

Tests on the effect of outboard motors on the survival of advanced fry of largemouth black bass proved inconclusive. The motor pond in this case showed a marked increase in the survival rate of fry over the control pond which was contrary to expected results. Various factors such as loss of fingerlings to draining, cannibalism, and more aquatic vegetation in the control pond than in the test pond were cited as reasons for the irregular results and again there was an expressed desire by the authors to repeat the experiment.

Perhaps the longest and most interesting experiment carried out by this group of investigators[12] was on the effect of outboard motor use on angling success in Fish Lake, Livingston County, southern Michigan. This lake was a 36-acre private body of water with a previous history of no outboard motor usage. Besides the fish caught during the experiment which are listed in Table 4, there were also bullheads, ciscoes, northern pike and additional species of minnows present in the lake. Bait used to catch the fish consisted of medium size earthworms for still fishing and two popular plugs and a spoon for plug casting. Data on the fish caught during motor and nonmotor days are presented in Table 4. At the conclusion of this phase of the study the consensus of opinion of the anglers was that no differences in angling results were observed between motor and nonmotor days. When the data was analyzed statistically there was no evidence that there was a significant difference between the catch on motor days when compared with that on nonmotor days.

The reviewers were not able to ascribe any investigations or studies pertaining to outboard motor derived emissions in the period between the study by Lagler _et al_[12] and that by English _et al_[2]. In the early 1960's English _et al_[2] designed preliminary laboratory studies to measure: 1. quantities of oil, lead, and phenol in OME-water and, 2. effects of waste products from outboard motors on (a) quality of water for domestic use and on interference with water treatment processes, and (b) the toxicity to fish and tainting of fish flesh. The effects of OME-water on fish will be discussed in this section.

Two low-horsepowered outboard motors were used by English, _et al_[2] in their laboratory studies: a 5.4 horsepower - 10 year old engine and a new 10 horsepower engine. The fuel consisted of a mixture of a leaded gasoline

Table 4. Catches by Still Fishing and Sizes of Fish Taken on Motor Days and Nonmotor Days[12].

Species	First 22 Days of Fishing		Second 22 Days of Fishing		Third 22 Days of Fishing		Total Catch for 66 Days of Fishing		Medium Size and Range of Fish (in inches)	
	A*	B*	A*	B*	A*	B*	A*	B*	Motor Days	Nonmotor Days
Bluegill	222	252	209	233	203	203	634	688	5.1 (9.0-3.0)	5.3 (9.5-3.2)
Largemouth black bass	6	18	3	4	15	13	24	35	9.8 (14.6-3.9)	9.5 (16.2-3.9)
Rock bass	3	5	0	0	5	9	8	14	7.3 (8.0-4.1)	7.5 (8.1-2.6)
Black crappie	5	12	0	0	9	1	14	13	7.4 (9.7-6.0)	8.5 (10.0-7.1)
Pumpkinseed	7	7	11	11	21	12	39	30	5.5 (6.8-3.5)	5.0 (7.0-3.1)
Yellow Perch	2	4	1	2	11	11	14	17	4.6 (8.0-3.7)	4.6 (11.5-3.9)
Green Sunfish	0	3	0	0	16	10	16	13	4.6 (5.7-2.8)	4.6 (6.4-3.)0
Bowfin	0	1	0	0	0	0	0	1	--	--
Golden Shiner	0	0	0	0	1	0	1	0	--	--
TOTAL	245	302	224	250	281	259	750	811	--	--
Catch per man-hour	2.02	2.47	1.45	1.62	1.42	1.31	1.58**	1.71**	--	--

A* = *number of fish caught on motor days*
B* = number of fish caught on nonmotor days
** This represents a difference of about 1 fish for every 10 hours of effort.

and an outboard motor lubricating oil in a ratio of 16 to 1, respectively. The 5.4 horsepower motor was operated at full throttle during all tests and the 10 horsepower motor, because of extreme splashing of the test tank contents at full throttle, was operated at half to three-fourths throttle.

Bioassays were conducted by these researchers[2] to determine:

1. Acute or short-term toxicity (static bioassay) of the OME-water on two species of fish:
   a. fathead minnows, averaging 2-1/2 inches in length and 1-1/2 grams in weight and
   b. bluegills, averaging 2-1/4 inches in length and 2 grams in weight.
2. Toxicity of OME-water aged for specified periods of time.
3. Chronic or accumulative effect of OME-water on fish using continuous-flow bioassays.

In conducting the fish toxicity experiment, the researchers placed 5 test fish in each exposure jar which contained dilution water with the following characteristics: DO, 8 mg/l; pH, 7.4; alkalinity ($CaCO_3$), 18 mg/l; hardness ($CaCO_3$), 20 mg/l; and temperature, 25°C. The data for the dilution at which half the fish died in three sets of experiments are presented in Table 5. The test data indicated that both bluegills and fathead minnows were of equal sensitivity and that relatively strong solutions of OME-water were necessary for 50 percent kills. These experiments also pointed out a decrease in toxicity of OME-water upon aging and that there were few chronic or accumulative effects on fish after an exposure period of 15 days.

Laboratory and field experiments were also conducted by English _et al_[2,3] to determine whether the flesh of fish exposed to OME-water would acquire objectionable flavors. In the laboratory studies[2] adult bluegills and white crappies

Table 5. Toxicity of OME-Water to Fathead Minnows and Bluegills[2]

Exposure Time	Dilution at Which Half the Fish Die (Gal. Water/Gal Fuel Consumed)										
	Acute Toxicity of OME-Water					Decrease in Acute Toxicity of OME-Water Upon Aging				Acute and Chronic Toxicity of OME-Water	
	Sample					Age Water (Days)				Type of Test	
	1		2		3						
	A*	B**	A*	B**	A*	Fresh	1	2	4	Static	Continuous
24 hr	1,700	1,300	1,700	1,600	1,900	1,700	1,600	1,200	***	1,900	1,900
48 hr	1,700	1,600	1,800	2,500	1,900	1,800	1,600	1,200	***	1,900	1,900
72 hr	1,700	1,600	1,800	2,500	1,900	1,800	1,600	1,200	***	---	---
96 hr	1,700	1,600	1,800	2,500	1,900	1,800	1,600	1,200	***	1,900	2,200
5 day	---	---	---	---	---	---	---	---	---	---	2,400
10 day	---	---	---	---	---	---	---	---	---	---	2,400
15 day	---	---	---	---	---	---	---	---	---	---	2,500

A* = Fathead Minnows used as test species.

B** = Bluegills used as test species.

*** = No fish mortality.

6-7 inches long and weighing approximately 0.2 pounds each, were exposed to a continously renewed solution of OME-water diluted with tap water free of any taste, odor, and chlorine. After exposure the fish were removed from the test tanks and prepared for panel taste tests. Each fish was scaled, head and entrails were removed, and then wrapped in aluminum foil and baked at 350°F for 20 minutes. The fish were then divided in half and the bones and fins were removed. These fish along with control fish were kept warm and subjected to a taste panel, consisting of 12 members who were asked to record taste and odor reactions. Results of these panel tests on laboratory fish exposed to OME-water can be found in Table 6. These experiments indicated that a definite tainting of fish flesh occurred with large quantities of dilution water per gallon of fuel consumed. There was an apparent loss of taste producing compounds with exposure time which was attributed to volatilization, precipitation, or chemical and bacterial breakdown. An estimate of the dilution corresponding to detection of an unpalatable taste by half of the observers was based on graphic extrapolation of the results in Table 6 by methods applicable to odor in water. This value was placed at 300,000 gallons of water per gallon of fuel consumed.

In field experiments English et al[3] used liveboxes which were lowered 4 feet below the water surface of a motor lake, motor pond, and control pond and contained bluegills, 6 to 7 inches in length and weighing approximately 0.2 pounds. The motors used on the motor pond in this study varied from a 5.4 horsepower-10 year old engine to an 18 horsepower-new engine. Six brands of leaded gasoline were used and the fuel to oil ratio was 17 to 1. Special test propellers were used to enable achievement of optimum operating conditions under full load (4100 to 4200 rpm) while the boat moved at very slow surface speeds. The motor lake was a privately owned lake where outboards were operated primarily for water skiers on weekends and holidays. For the two bodies of water exposed to outboard motor usage, records were maintained on the date and quantity of fuel consumed, quantity of oil per gallon of gasoline used (averaged to a ratio of 23 parts of gasoline to 1 part of oil), leaded characteristics, the engine horsepower, and the duration of motor operation. Fish from the control pond were compared against those from the motor pond and motor lake. The average water temperature in all ponds during the study was 25^{0}C. In addition to the liveboxes in the motor lake, an additional tank containing 75 fish in 500 gallons of water was located on a dock near the lake through which lake water was pumped at a rate of between 10 to 20 gallons per minute. Fish injury in the liveboxes submerged in the lake necessitated this tank.

The fish were removed from these test areas and prepared in a manner as previously described[2]. In addition to baking, the fish were fried in vegetable oil and cracker meal at 370^{0}F. Once again a 12 member taste panel was chosen to assess the flavors in the fish. Data derived by the taste panel for the experimental motor pond and motor lake is tabulated in Tables 7 and 8. A greater occurrence of off-flavor in the fish from the motor pond and motor lake was observed when total observations were considered. For the fish in the 500 gallon test tank, however, the differences were not so

Table 7. Fish Flesh Tainting Observations in the Motor Pond[3].

Source	Days Exposure	Fuel (gal/mil. gal. of Water)*	Type of Cooking	No. Observations in Each Category of Off-Flavoring: None	Slight	Strong	Percent Positive (Slight and Strong)
Pond boxes	20	18.2	Fried	3	3	6	75
Control	63	--	Fried	8	4	0	33
Pond wild	34	37.5	Fried	8	7	8	65
Control	77	--	Fried	12	0	0	00
Pond wild	40	37.5	Fried	6	3	3	50
Pond wild	40	37.5	Baked	2	6	4	83
Control	83	--	Fried	10	2	0	17
Control	83	--	Baked	8	4	0	33
Pond boxes	35	60.4	Fried	4	3	5	67
Pond boxes	35	60.4	Baked	2	3	5	80
Control	111	--	Fried	9	3	0	25
Control	111	--	Baked	9	2	1	25
Pond boxes	44	72.1	Fried	6	2	4	50
Pond boxes	44	72.1	Baked	1	1	10	92
Control	120	--	Fried	8	0	0	00
Control	120	--	Baked	8	4	0	33

*Equivalent to cu m/mil cu m.

Table 8. Fish Flesh Tainting Observations in the Motor Lake[3]

Source	Days Exposure	Fuel (gal/mil. gal. of Water)*	Type of Cooking	No. Observations in Each Category of Off-Flavoring: None	Slight	Strong	Percent Positive (Slight and Strong)
Lake	26	6.8	Fried	34	2	0	06
Control	26	--	Fried	12	0	0	00
Lake	47	10.8	Fried	18	13	5	50
Control	47	--	Fried	9	3	0	25
Lake	68	12.4	Fried	14	8	2	42
Lake Tank	27	12.4	Fried	7	4	1	42
Control	68	--	Fried	6	6	0	50
Lake	83	14.0	Fried	12	8	4	50
Lake	83	14.0	Baked	1	2	9	92
Lake Tank	42	14.0	Fried	5	5	2	58
Control	83	--	Fried	10	2	0	17
Control	83	--	Baked	8	4	0	33
Lake	99	15.8	Fried	7	4	1	42
Lake	99	15.8	Baked	3	5	4	75
Lake Tank	58	15.8	Fried	9	3	0	25
Lake Tank	58	15.8	Baked	7	2	3	42
Control	99	--	Fried	11	1	0	08
Control	99	--	Baked	8	2	2	33
Lake	111	16.6	Fried	9	2	1	25
Lake	111	16.6	Baked	4	5	3	67
lake Tank	70	16.6	Fried	9	3	0	25
Lake Tank	70	16.6	Baked	5	5	2	58
Control	111	--	Fried	9	3	0	25
Control	111	--	Baked	9	2	1	25

*Equivalent to cu m/mil cu m.

pronounced, possibly due to the fact that the exposure time in the test tank was considerably less than that in the live boxes. Based on graphical interpretation of the data "tainting of fish flesh was demonstrated, and a threshold of occurrence was estimated at a combined fuel-use level of 8 gallons per million gallons of water and a daily fuel use ratio of 0.17 gallon per million gallons of water"[3].

Fish toxicity studies were conducted by Environmental Engineering Incorporated of Florida[9] on Lake X and Cat Lake, Florida, using a 4 horsepower motor running at an engine speed of 1000 rpm. The motor was suspended in a 50 gallon drum containing dilution water and nonleaded gasoline and oil (in a ratio of 50/1) was burned for 1 hr, 4 hrs, and 8 hrs. The fuel consumed during these time periods corresponded to 1 hr-730 milliliters, 4 hrs-5 pounds, and 8 hrs-8 pounds and 10 ounces, respectively. The resulting OME-water was diluted with Lake X water and a series of static bioassays were conducted on bluegills (10 fish per dilution). No fish mortalities were observed for the dilutions used on the OME-water for the 1 hr and 4 hr runs. For the 8-hour run the 10 fish in the 20 percent and 30 percent diluted waste indicated stress within one hour and death occurred between 4 and 8 hours. No additional deaths occurred in the lower dilutions, after 24 hours of exposure to the 8-hour exposed OME-water. From all the fish survival data obtained (Table 9), no Medium Tolerance Limits (TL_m) were established, however, the authors concluded that a minimum lethal dose was suggested.

Table 9. Bluegill Survival Data from the Lake X Study[9].

Percent of OME-Water	Test #1-730 ml oF Fuel Consumed	Test #2-5 lbs of Fuel Consumed	Test #3-8 lbs- 10 oz. of Fuel Consumed
	No. of Deaths	No. of Deaths	No. of Deaths
0	0	0	0
1.2	0	0	-
2.5	0	0	0
5.0	0	0	0
10.0	0	0	0
15.0	-	-	6*
20.0	0	0	10*
30.0	-	-	10*

*All deaths occurred before 24 hours of exposure.

In another aspect of these experiments benthic invertebrates were observed in grab samples taken from Lake X. The authors[9] note that the biological populations of sediments is a constantly changing one; samples, therefore, should be obtained from a variety of locations during all the seasons of the year. Yet the authors were able to draw conclusions for 5 out of 6 grab samples. The one sample excluded was in the area of heaviest outboard motor usage (old boat channel) and was excluded due to an absence of organisms which was presumed due to possible toxicity from fuel spills. It was concluded from the limited number of samples that Lake X water quality was not seriously degraded. However, the authors also sermized that the low numbers of organisms found in Lake X indicated a possible suppression of the benthic community. This was attributed to the possibility of the recent emergence of adult insects and a seasonal sampling program was suggested but not carried out.

Static bioassays conducted by Kempf et al[13] revealed that the lethal OME dose for the usual foreign domestic fish (i.e., carp, trout) was quite variable. At a concentration of 1:2000 (spent fuel to dilution volume) carp were affected after a detention period of 2 hours and were killed within 26 hours. At this same concentration trout showed sensitivity and some damage after 20 minutes with death occurring after 50 minutes. These investigators also conducted experiments in an open control pond. From this control pond carp were found to be unaffected at an OME-water concentration of 1:3000. This lower value for field results was attributed to evaporation and dispersion of toxic compounds such as carbon monoxide and carbon dioxide.

Taste tests were also run by Kempf et al[13] on fish exposed to OME-water derived from an initial fuel mixture ratio of gasoline to oil of 50:1 and it was found that initial effects on the fish flesh occurred at approximately 1:100,000 (spent fuel to dilution water). In comparing these similar results to the data of English et al[2] (taste influence at 1:300,000) which was obtained at a fuel mixture ratio of 1:17, it was calculated that a numerical proportion of 1:294,000 was obtained when the difference in fuel mixtures was considered. In another aspect of this same study carp were exposed to a concentration of 1:2000 (spent fuel to dilution water) OME-water for seven days. At daily intervals, some were removed from the OME-water and prepared for taste tests. After seven days the remaining fish were transferred to fresh water and then prepared daily for taste tests. The results of this experiment appear in Figure 2 and showed an increase in objectionable tastes with continuing exposure to OME-water, then a loss of taste when the fish were transferred out of the OME-water.

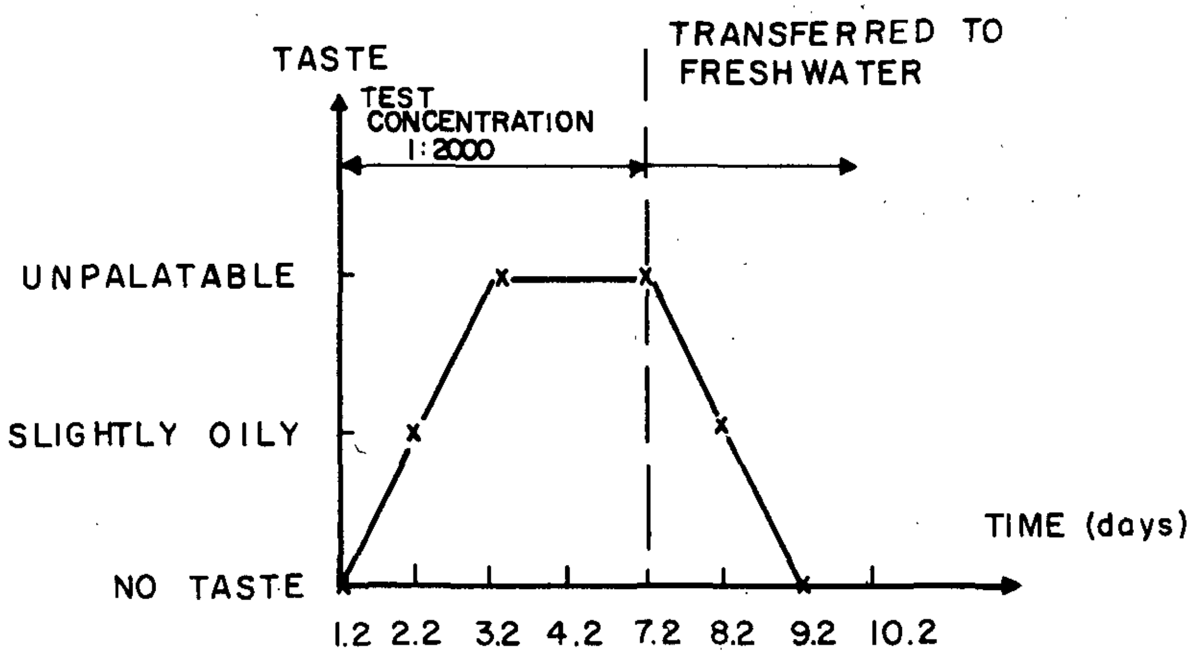


FIGURE 2 FISH FLESH TASTES DEVELOPED UPON EXPOSURE TO OME - WATER[13]

Preliminary work by Schenck and Weber[14] on the effects of outboard motors on selected animals (fathead minnows, snails and daphnids) seems inconclusive. After limited work with daphnids and snails, the authors noted, that these test species, based on visual inspection, appeared to live and reproduce equally well in OME-water from both leaded and nonleaded gasolines. Despite unresolved losses of fish in all test tanks the investigators concluded from the data presented in Table 10, that probably at some concentrations higher than 1 gallon of fuel consumed per 10,000 gallons of dilution water a noticeable effect on reproduction would be found. These tests were conducted for both leaded and nonleaded gasoline using 1-1/2 horsepower Johnson motors. Johnson lubricating motor oil was mixed with the various gasolines at a ratio of 1:50.

These same researchers are currently continuing these continuous flow bioassays and have entered into a combined study with other research groups[15] involving both field and laboratory studies on the effects of an outboard motor exhausts on the ecology of natural fresh water systems (in both southern and northern climates). Another portion of their investigation is aimed toward the identification and quantification of the major chemical components of OME-water.

Preliminary studies of the effects of OME-water on various aspects of the aquatic environment which are funded by the Massachusetts Water Resources Commission[16] are currently in progress at the University of Massachusetts. These studies have as their objectives the following:

1. To determine the effects of outboard motor exhausts on the chemical quality of recipient water.

Table 10. Summary of Data for Continuous Flow Bioassays on Fat-Head Minnows[14]

	Test Chamber (1)	Concentration of OME-water (2)	Apparent Male/Female Ratio (3)	Number of Spawnings (4)	Apparent Spawnings Per Female (5)	Average No. of Eggs per Spawning (6)	Percent Hatching Success (7)	Percent Fly Survival (8)
NONLEADED FUEL	1A	1/10,000	1/4	6	1.5	164	84	62
	1B	1/10,000	1/6	28	4.7	214	96	62
	2A	1/40,000	1/6	5	0.8	75	95	
	2B	1/40,000	2/11	4	0.4	122	75	58
	3A	1/160,000	2/1	6	6.0	114	97	89
	3B	1/160,000	1/9	0				
	4A	1/640,000	1/2	11	5.5	85	100	66
	4B	1/640,000	3/7	0				
	5A	1/2,560,000	0/0					
	5B	1/2,560,000	3/5	0				
CONTROLS	6A	0	2/2	2	1.0	15		
	6B	0	2/4	0				
	Stock	0	?	(10)	?	254	83	57
	7A	0	2/3	0				
	7B	0	0/8	0				
LEADED FUEL	8A	1/2,560,000	0/0					
	8B	1/2,560,000	1/7	9	1.3	220	42	
	9A	1/640,000	1/3	28	9.3	145	95	91
	9B	1/640,000	0/8	0				
	10A	1/160,000	2/2	28	13.0	106	93	71
	10B	1/160,000	0/8	0				
	11A	1/40,000	0/4	0				
	11B	1/40,000	1/9	0				
	12A	1/10,000	0/0					
	12B	1/10,000	3/6	1	0.2	90		

2. To determine the toxic effects of OME-water on benthic invertebrate and fish life.
3. To investigate the effects of outboard motor exhausts on the organoleptic properties of recipient water.

The chemical analysis of OME-water includes the identification of the major hydrocarbon compounds (and lead compounds) present after outboard motor operation. Static and continuous-flow bioassays will serve to evaluate the acute and chronic toxic effects of OME-water to bluegills, fathead minnows, scuds, dragonfly nymphs and damselfly nymphs. The least-detectable concentration of OME-constituents in water based on tastes and odors is to be evaluated by a panel of judges. Once this threshold value has been established, the effects of this concentration upon fish will be determined as to the degree of flesh tainting. These objectives are to be evaluated in the laboratory, then verified by field studies on selected lakes in Massachusetts.

In a report[17] from these studies, Kuzminski and Ghan studied the toxic effects of OME-water on fathead minnows and bluegills. The OME-water used in these bioassays was generated by combusting a fuel mixture (50 parts of leaded gasoline to 1 part of commercial outboard motor oil) in a 1970-7 1/2 horsepower engine and exhausting the products into a dilution water with the following characteristics: chlorine, 0 mg/l; copper, undetectable by atomic absorption spectroscopy; hardness, 14.5 to 30 mg/l as $CaCO_3$; and, alkalinity, 4.5 to 50 mg/l as $CaCO_3$.

These acute toxicity bioassays were performed according to Standard Methods (1971)[18] at a temperature of $20 \pm 1^{o}C$. These workers concluded that:

1. The average 24, 48 and 96-hour TL_{50} values based on static bioassays conducted for the spring and summer collected fathead minnows were 2150/1, 2640, and 3130/1 (gallons of dilution water to gallons of fuel consumed) or 0.047, 0.038, and 0.032 percent concentration of OME-recipient water, respectively.

2. The average 24, 48 and 96-hour TL_{50} values based on static bioassays conducted for bluegills with length ranging from 3/4" - 1" and length ranging from 2" - 2 1/2" were all 2260/1 (or 0.044 percent concentration) of OME-recipient water.

III. GENERAL CONCLUSIONS

OME-water can exhibit, in high concentrations, toxic effects on various species of fish[2,3,13]. Although data on the effects of OME-water on fish reproduction are not conclusive, it has been stated[14] that reproduction may not be hindered under conditions of normal outboard motor usage. However, further research in this direction seems called for.

It has also been demonstrated that OME-water will produce undesirable flavors in fish flesh[2,3,13]. Dilution water required to avoid such tastes has been set by various authors[2,13] at 1 gallon of fuel consumed to approximately 300,000 gallons of dilution water. It is not within the scope of this report to assess if conditions such as these actually exist or are approximated by these figures on lakes throughout the country. It may be valuable to determine fuel usage figures on selected heavily used lakes to determine if actual conditions are in fact more concentrated than the suggested dilution water values.

Various conditions created by outboard motor usage in several lakes in Western Massachusetts (Congamond Lakes and Lake Arcadia) have been the subject of complaints to local pollution control agencies. The density of boat users (water skiing, boat racing, fishing, etc.) on the Congamond Lakes has in past times warranted the necessity of a Coast Guard patrol for safety reasons. Nearby residents of these lakes have complained of visible slicks on the surface of the water and the smell of exhaust gases which were attributed to outboard motor operation.

It becomes evident that very little conclusive data exists on the direct effect of outboard motors in the field. Most work to date has been laboratory oriented; however, little effort has been made to simulate 'actual' field conditions in the laboratory. Currently the Environmental Protection Agency and the Boating Industry of America[15] are jointly sponsoring research that will be both laboratory and field oriented. This research is intended to encompass water quality changes, long-term fish effects, invertebrate and plankton responses and other associated problems in northern and southern lakes within the nation. These studies parallel in scope research sponsored by the Massachusetts Division of Natural Resources[16] which is being conducted by the Environmental Engineering Program of the University of Massachusetts at Amherst. As these studies progress, care should be taken to include the important factors involved in the determination of the effect of OME derived substances on the aquatic environment.

Several important factors have been partially evaluated while others have not been included in previous studies and may prove to be very important when the entire scope of outboard motor emitted substances and their effects on the aquatic environment are considered. A clarification of the contradicting data on the quantity of pollutants emitted for various outboard engine horsepower ratings may be beneficial. In order to evaluate if outboard derived emissions are truely a problem to the aquatic environment, many of the following questions may have to be answered:

1. What exactly do the variables of speed of operation, horsepower rating, engine condition, crankcase size, and manufacturer's brand have on the quantity of substances released to the receiving waters by outboard motors?
2. What bearing does outboard motor have on the long term effects of the biotic food-chain (plankton, invertebrates, fish, etc.)?
3. What is the mechanism of a fish kill caused by outboard motor derived emissions?
4. What are the specific agent or agents of toxicity in outboard motor materials and can fuel components be altered such that the combustion products will not exhibit this toxic effect?
5. What outboard motor derived substances cause off-odor and off-flavor in fish flesh? How long do these substances persist in natural water?
6. Can a mass balance be run on the raw fuel and outboard motor by-products (in water, air adsorbed, etc.)?

7. What is the fate of outboard motor emitted hydrocarbons (do they accumulate, evaporate, biodegrade, age, etc.)? Do they adsorb onto benthic deposits, plants, etc.? Are they carcinogenic to aquatic life on a long term basis?
8. What is the fate of lead compounds derived from the lead in the gasoline? Is lead accumulated in a passive manner by selected aquatic species wherein it can be chemically altered to yield a more toxic derivative?
9. What density of outboard motor operation can be allowed before visible slicks develop?
10. Do the exhaust gases that are not readily soluble in water have any physical effect on boaters under certain meteorological conditions in areas of high motor density?
11. At what ratio of fuel consumed to dilution water do tastes and odors in drinking water become objectionable? Does the chemistry of the receiving water have a bearing on this ratio? What physical or chemical water treatment processes are most effective in removing these OME derived tastes and odors?
12. Will incorporation of recycling devices in older models be needed to insure against any adverse effects to the aquatic environment? How effectively can the reduction of emitted substances be accomplished by recycling devices? How will enforcement of their attachment to other model outboard engines be accomplished?

Initial work has shown that problems of fish flesh tainting and water quality changes can occur under conditions of high outboard motor usage. Current research is intended to supply additional information on water quality changes and long-term aquatic biotic effects. It is apparent that much of this research will prove beneficial but may fall short of explaining the fate of outboard motor derived substances due to breadth of the scope of research needed to answer the questions presented above. Field data is needed to verify the laboratory data that has been collected to date. It is apparent from the field data obtained by early investigators that little correlation may exist between laboratory data, predicted field results and actual field results.

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