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The Physical Effects of Entrainment Current Research at ORNL

J. S. Suffern

Environmental Sciences Division
Publication No. 1073

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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CURRENT RESEARCH AT ORNL

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ABSTRACT

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An experimental program to evaluate the effects of entrainment on aquatic organisms is being conducted at ORNL. The damage to fish eggs and larvae during entrainment through condenser cooling water systems is one of the major environmental impacts of electric power plants. Studies at operating power plants have indicated that mortality rates can be excessive. These rates may vary among species and between plants. In order to assess the mortality associated with each component of the cooling system, a power plant simulator has been designed and is now under construction. The design of the apparatus is such that the internal hydraulics of an operating power plant condenser cooling system will be effectively reproduced. Experiments will be conducted using fresh water and marine fish species according to the experimental designs described herein. Rearing and holding facilities have been designed and assembled to assure a supply of specimens and allow assessment of delayed mortality. The identification of the factors which cause mortality during entrainment will provide a rational foundation for redesign of the components in cooling systems to minimize environmental impacts.

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INTRODUCTION

Entrainment, the passage of non-screenable organisms through condenser cooling systems, is an environmental issue of some concern at the present time. Available evidence¹ suggests that many fragile fish eggs and larvae are physically damaged during entrainment through power station cooling circuits and that this damage either kills the organism directly, or greatly reduces later survival. In some power plant licensing cases,^{2,3,4} this prospect has caused delay in the licensing procedures and alterations in siting and mode of operation. The mechanisms of biological damage have not been investigated carefully and the engineering criteria for minimizing or avoiding damage have not been obtained. The objective of entrainment research at ORNL is to define the biological and engineering parameters which cause mechanical damage to aquatic organisms entrained in power plant condenser cooling water, and the effects of these damages on organism survival, in order that cooling systems can be redesigned to minimize such damages.

Past entrainment research at ORNL has been carried out as a cooperative effort between the Engineering Technology and Environmental Sciences Divisions. As a result of this unique combination of engineering and biological knowledge, those studies^{5,6} dealt with the problem of entrainment in a particularly penetrating way, examining the biological and the engineering aspects of the phenomenon, both to develop accurate definition of the mortality associated with parts of the entrainment process.

Entrainment research began at ORNL in 1973. At that time, an apparatus originally part of a nuclear reactor technology development program was modified to examine the effects of shear forces on small fish. It consisted initially of a pump, about 12 m of 5.08 cm diameter glass pipe and collecting gear, through which fish and water could be passed at a variety of flow rates. During these preliminary tests, pressure remained positive; vacuum conditions were not experienced by the fish. High speed motion pictures (11,000 frames per second) were

used to examine the torsion experienced by young fish under these conditions. Those photographs showed the fish experiencing extreme torsion, some being bent double by fluid forces. Carp subjected to these test conditions were found to be lethargic and unresponsive, although mortalities were low. It should be emphasized that although the water recirculated in the system, organisms did not pass through the pump. They were introduced into the loop downstream of the pump, and recovered upstream.

At the end of these preliminary experiments, the experimental loop was modified to include 12 m of 22 mm OD tubing. This size and length of tubing was typical of that found in Tennessee Valley Authority power plants, and made the loop a closer simulation of extant power plant conditions. Again, tests were run on carp larvae, using condenser-tube velocities of 2.1 and 4.6 m/sec. As with the preliminary experiments, mortalities were low, and lethargy was observed in entrained fish. Despite this obvious lethargy, they were not selectively eaten by bluegill (Lepomis macrochirus) predators. Additional experiments were run using tadpoles of the bullfrog, Rana catesbiana, the cladoceran, Daphnia magna, and juvenile silversides, Labidesthes sicculus at condenser tube velocities up to 6 m/sec. It was found that copper, used in the 22 mm tubing, poisoned the cladocerans, and the loop was refabricated to contain only glass, stainless steel and minor amounts of plastic. The conclusion reached as a result of these preliminary experiments was that shear forces associated with turbulent flow were probably not the cause of mortalities seen at power plants.⁷

The loop was then modified to allow partial vacuum ($\sim 1/2$ atm) in the central portion of the condenser tubing. This configuration of the loop is shown schematically in Figure 1. Vacuum conditions were generated by the geometry of the system, (the U-shaped heat exchanger tube was mounted vertically) and partial vacuum was developed near the top of the inverted U. At a condenser tube velocity of 2.1 m/sec, about 0.5 atm vacuum was developed, (Figure 2) while at 5.8 m/sec, the pressure at the tube inlet was great enough to swamp out vacuum conditions.

NOTES:

1. ALL LOOP MATERIALS ARE EITHER GLASS OR STAINLESS STEEL.
BELLOWS, GASKETS AND VALVE SEALS ARE PLASTIC.
2. PUMP IS WESTINGHOUSE 150 A CANNED MOTOR PUMP.
3. LOOP IS GENERALLY CONSTRUCTED FROM 2 in. GLASS AND STAINLESS STEEL PIPES, EXCEPT FOR TUBE WHICH IS AS SHOWN.

Fig. 1. Schematic diagram of test loop. All loop materials are either glass or stainless steel. Bellows, gaskets, and valve seals are plastic, and a canned-motor pump is used (Kedl and Coutant, 1976).

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Fig. 2. Pressure in tube relative to atmosphere (m H₂O) (Kedl and Coutant, 1976).

Tests with bluegill and mosquitofish (Gambusia affinis) suggested that pressure changes might cause increased mortality and that fluid, pressure, and thermal stresses might act synergistically.^{7,8} With the loop in a configuration that allowed examination of multiple stresses, more sophisticated experiments were begun.

From 90 to 95% of the fish were recovered from the loop in the experiments; computations of mortality were based on the number of fish recovered. Organisms were maintained at $\sim 20^{\circ}\text{C}$ after the tests to observe latent mortalities.

With bluegill, there were no immediate mortalities (within 1 hr) after passage through the condenser at either test velocity. assessment of latent mortality was obviated, however, by massive dieoffs attributed to inadequacy of the holding facilities.

The striped bass, (Morone saxatilis), when passed through the loop at 2.1 and 5.6 m/sec at nonlethal temperatures suffered less than 5% mortality within 1 hour. Both experimental and control fish died off at about the same rate (Figure 3) over the ensuing days, suggesting that delayed mortality associated with entrainment was of minimal consequence. When entrainment temperature was above tolerance thresholds, results were quite different. There was an initial substantial mortality, with subsequent dieoff rates which were similar in control and entrainment samples (Figure 4). While high control mortalities made precise analysis of the data difficult, these experiments lend strength to the hypothesis that condenser tube passage along is not a major source of entrainment mortality.

Other factors need examination: cavitation by the pump, vacuum conditions (the vacuum conditions developed in the simulator were shorter and less extreme than is often the case in power plants) and the pump itself. Synergisms between factors are largely unknown, and may be important. These considerations led to the second major phase of entrainment research at ORNL, and the construction of a much more versatile experimental apparatus.

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Fig. 3. Percent mortality of larval striped bass tested at a nonlethal temperature. (a) Loop velocity, 2.1 m/sec, low ΔT . o—o, tests 2 and 4. Δ -- Δ , barrel control samples 3 and 5. (b) Loop velocity, 5.6 m/sec, low ΔT . o—o, tests 6 and 8. Δ -- Δ , barrel control samples 7 and 9. (c) Absolute control samples 1, 2, and 3 (Kedl and Coutant, 1976).

NOTE:

- "Barrel Controls" - Include handling stresses. Fish were added to the collecting barrel from a height of about 6" and were recovered with the plankton net.
- "Absolute Controls" - The fish were transferred gently from a transport bucket into a beaker of loop water. The only stresses to which these fish were subjected were those involved in living in a laboratory rather than their natural environment.

ORNL-DWG 77-12235

Fig. 4. Percent mortality of larval striped bass tested at a lethal temperature and a loop velocity of 5.8 m/sec. (a) Loop temperature, 31.0°C. o—o, tests 8 and 10, high ΔT . Δ -- Δ , barrel control samples 9 and 11, high ΔT . ●—●, absolute control samples 12 and 13, no ΔT . (b) Loop temperature, 31.9°C. o—o, tests 3 and 7, high ΔT . Δ -- Δ , barrel control samples 4 and 6, high ΔT . ●—●, absolute control sample 5, no ΔT .

NOTE:

- "Barrel Controls" - Include handling stresses. Fish were added to the collecting barrel from a height of about 6" and were recovered with the plankton net.
- "Absolute Controls" - The fish were transferred gently from a transport bucket into a beaker of loop water. The only stresses to which these fish were subjected were those involved in living in a laboratory rather than their natural environment.

CURRENT ENTRAINMENT RESEARCH AT ORNL

Current research on entrainment is based on experience gained in the work described above. Planned experimental programs are based on the use of a new and more sophisticated cooling system simulator which more thoroughly models the internal hydraulics of operating power plant cooling systems. Previous work at ORNL suggested that condenser tube passage may not be the major source of mortality during entrainment. Accordingly, the new simulator was designed to allow examination of the stresses associated with pumps (cavitation, intense turbulence sudden changes in pressure, mechanical abrasion against the impeller blades), vacuum conditions, thermal effects and condenser tubing. Several objectives were delineated as the basis for the new work. Among these were: (1) To estimate, through engineering evaluation, the mechanical and hydraulic characteristics of contemporary power stations that apparently contribute most to damage of fish eggs and larvae. This was necessary to provide an engineering basis for the design of the experimental apparatus, and was conducted at ORNL using design specifications from manufacturers and operating or planned TVA power stations (2) To provide an experimental system capable of exposing test fish to chosen stresses. The new experimental system was considered necessary because sampling difficulties and lack of experimental versatility at operating power stations make their use unacceptable (3) To obtain, spawn and rear sufficient fish for conduct of experiments, allowing large enough sample sizes for high statistical confidence in the results (4) To determine short and long term survival of fish eggs and larvae of several species after passage through a variety of hydraulically defined and controlled stresses in the test apparatus.

The scope of the project was broadened, to include determination of the impact of condenser passage on important plankton species at off-shore power stations. One of the greatest potential sources of cooling water for power plants is in the marine coastal areas. Since these areas are highly productive and serve as nursery grounds for many economically and ecologically important species of fish and shellfish,

mortality due to entrainment of various life stage of these organisms is of great concern. With minor design changes the test apparatus was modified to quantify mortality of entrained marine organisms.

The Cooling System Simulator

A highly simplified schematic drawing of the new simulator is shown in Figure 5. The apparatus is a closed loop, like the previous simulator built at ORNL.^{9,10} Experimental organisms can be introduced into the system on either side of the pump, allowing evaluation of stresses associated solely with the pump. The adjustable elevation of the return piping will allow control of the vacuum to which the larval fish are exposed. The main tank is fabricated of 1/4" type 316 stainless steel. This particular alloy was chosen because it has very good resistance to saltwater corrosion. All the metal components of the simulator proper with the exception of the pump housing and impeller have been fabricated of #316 stainless steel. Thus, it can be used to examine entrainment effects on both marine and freshwater organisms.

The pump is an Ingersoll-Rand model 10 BPM (Figure 6) equipped with a Reeves Vari-Drive. A comparison of the hydraulic parameters of a typical power plant circulating water pump and the Ingersoll-Rand 10-BPM pump is shown in Table 1. Some explanation of the terms in Table 1 is in order that an evaluation of the 10-BPM pump as a simulation of power plant circulating pumps can be made. The less obvious parameters are listed below, with definitions.

- a. Head. A measure of the pressure developed by a pump. Technically, it is the height of a vertical discharge above the pump at which design flow will be delivered. Twenty feet of head is equivalent to 8.7 psi.
- b. Tip Speed. The velocity of an impeller blade tip at design RPM.
- c. NPSH. Net positive suction head. This term refers to the decrease in pressure at the pump intake, which is the height above the surface of source water that the pump can run at design conditions without cavitation. (Cavitation is localized boiling caused by localized vacuum conditions).

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Fig. 5. Schematic drawing of the cooling system simulator

Fig. 6. The Ingersoll-Rand 10 BPM Pump.

Table 1. Hydraulic parameter comparison between a typical power plant circulating water pump and the Ingersoll-Rand 10 BPM

Parameter	Typical circulating water pump (Bull Run Steam Plant)*	Ingersoll-Rand 10-BPM
Capacity	139,000 GPM	2000 GPM
Head	20 ft	22 ft
Tip speed	95 ft/sec	61 ft/sec
NPSH - Required	13 ft	13 ft
Maximum sphere size	Large	2 in
Specific speed	94600	5150
Impeller	Mixed-axial	Mixed
Suction	Wet Pit	Flanged Pipe
RPM	235	1170
Diffuser type	Axial diffuser vanes	Volute
Efficiency	90.5%	72%

*The values listed as typical for power plant pumps are those for the units at TVA's Bull Run steamplant, and are comparable to those for 8 other TVA plants examined as a basis for this comparison.

- d. Maximum Sphere Size. The size of a sphere that will just pass between adjacent impeller blades.
- e. Specific Speed. This parameter is defined verbally as the speed in rpm at which a geometrically similar impeller would run if it were of a size to have 1-GPM capacity against a 1-ft head. Mathematically, it can be defined as:

$$N_s = \frac{\text{rpm} \sqrt{\text{gpm}}}{H^{3/4}},$$

where N_s is the specific speed and H is the head in feet for which the pump was designed, corresponding to its gpm capacity. Specific speed is a fundamental parameter in pump design and an index to the impeller type, with centrifugal pumps having specific speed values from 900 to around 3000, mixed flow pumps ranging from 3000 - 9500, and axial pumps having values above 9500. A discussion of the various impeller designs¹¹ and a detailed treatment of specific speed¹² are available.

- f. Suction. The type of intake structure.
- g. Diffuser type. The hydraulic component used to convert kinetic to potential energy and straighten out the flow.
- h. Efficiency. Measures the conversion of energy by the pump. Inefficiency in pumps ends up as fluid turbulence and ultimately, as heat.

It is worthwhile to consider several of the parameters in detail. The head (20 ft) found in the TVA (see Table 1) pumps is closely approximated by the simulator pump. Occasionally, pumps with much greater head are installed in power stations. However, it was felt that a head value typical of the plants examined (19-27 ft) would be the most useful in the simulator.

The specific speeds of the pumps indicate that they are of mixed-flow design. Although the power plant circulating water pumps are at the upper end of that design class, the shape and geometry of

the impellers are very similar. This similarity in impeller design is felt to be an important factor in the interaction of the pump with entrained organisms, and is one of the principal reasons for the selection of the 10 BPM pump.

The diffuser type is of considerable interest. In the power plant circulating water pump, axial diffuser vanes (see Fig. 7) are used to convert kinetic to potential energy and straighten out flow, while in the simulator pump (see Figs. 8, 9) a curved volute is used to accomplish the same end.

Pump efficiency is much higher (90.5%) in the CW pump than in the simulator pump (72%). This is primarily due to design factors. The CW pump is custom-designed for its specific application, while the BPM pump is an off-the-shelf model, which contains several design compromises necessary to broadening its range of possible uses. Since the simulator pump is less efficient, and pump inefficiency is expressed initially as turbulence and ultimately as heat, the simulator will represent a worst case situation. This consideration coupled with the NPSH value for the unit (13 ft) and the Reeves vari-drive will allow examination of off-design (inefficient) pump operation. This is opportune, as it is felt at this time that pump efficiency may be strongly correlated with entrainment mortality.

The small sphere size of the simulator pump could be a problem if experimental organisms are large in comparison. However, with small test animals (length:1-2 cm), the problem will be minimized.

In selecting the pump for the power plant simulator, the parameters judged to be of prime importance are head and specific speed (impeller type). Other parameters were chosen as follows. Capacity should be as low as possible. It was recognized that it would be in the thousand GPM range. Maximum sphere size should be as large as possible, suction configuration was judged not to be of primary importance. In addition, it was judged that a piped suction would result in a cheaper and easier to operate loop. Diffuser design, while possibly important, was a factor over which we had little control. Tip speed and RPM were judged to be unimportant. Finally, the pump had to be commercially available and

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Fig. 7. Section view of a power plant circulation water pump.

ORNL-DWG 77-7623

Fig. 8. End view of a BPM pump.

Fig. 9. Cross section of a BPM pump.

based on an existing design. In this framework then, the 10 BPM pump represents an effective simulation of a typical power plant circulating water pump.

The piping in the loop is fabricated of polyvinyl chloride (PVC). This material will allow easier adjustments in dimensions than would iron pipe. In addition, PVC is unaffected by salt water, an important consideration, since seawater will be used in experiments on marine organisms. Valves will be made of stainless steel to minimize corrosion problems.

The condenser was purchased from Manning and Lewis Engineering Company. Made of #316 stainless steel, it was designed to produce flow velocities typical of operating condensers. At design flow rates 126.2 liters/sec ($\approx$ 2000 gpm) condenser tube velocities will be 146.3 meters/min (8 fps). The device is made of seventy-three 3.18 cm (1 1/4") OD tubes with water boxes at each end. About 10 feet of head is lost across the condenser, again typical of the pressure changes in operating stations.

As shown in Figure 5 the height of the loop is adjustable. This is accomplished by using spool pieces in the vertical runs of pipe; adding and removing them to produce desired conditions in the top horizontal run of pipe. The main reason for this feature is to allow development of up to one atmosphere of vacuum. Vacuum conditions are often found in once-through cooling systems and merit a good deal of investigation. Sudden decompression in static test chambers has been examined and found it to be a significant mortality factor.¹³ We suspect that vacuum may be one of the more critical components of the entrainment process and plan to look at several degrees of vacuum exposure.

At the discharge end of the loop, a diffuser has been installed to lower water velocity. This has been done to ensure survival of the test organisms during retrieval. Work at power plants has repeatedly shown that larval fish suffer heavy net mortality at velocities greater than 3 fps. The retrieval system in the loop is designed to yield through-the-net velocities of around .25 fps, making net mortalities a minor consideration in experimental design. The retrieval net was

fabricated by Wildlife Supply Co. to our specifications. It is 2 m in diameter, with 500 micrometer mesh and stainless steel fittings. The main tank is externally equipped with Heat Sheets which are supplied with hot and cold water as well as steam. This heating/cooling system will allow experimental temperatures from 4°C to about 40°C $\pm$ 0.1°C.

Support Facilities

In order to maintain experimental organisms before and after tests, maintenance facilities have been built (Figure 10). One hundred forty-four 5.5 litre aquaria have been fitted onto temperature controlled (4-40 C) water supply manifolds. Each aquarium has an independently controlled flow-through rate, and all are connected to a common drain system. The facility will allow maintenance of several experimental and control groups at the same time.

To allow experimentation with marine organisms, a sea water support system has been designed as an adjunct to the power plant simulator. Consisting of a 8000 gallon reserve tank, a biofilter and associated piping, it will permit experimentation and associated maintenance of several different species at the same time.

WORKSHOP

Prior to the construction of the cooling system simulator, a workshop was held at ORNL. Specific goals of the meeting were to evaluate the design of the apparatus and to assess the useability of ORNL's proposed research program.

Workshop attendees included representatives from pump and condenser manufacturers (Ingersoll-Rand Corp.), architect-engineering firms (Burns and Roe), the Tennessee Valley Authority, Southern California Edison Co., New York University, and New York State ERDA. A brief summary of the conclusions reached by the participants can be made as follows. The basic design of the simulator was judged to be sound. Several minor modifications were suggested, changes that would add

Fig. 10. Test organism maintenance facility.

flexibility to the experimental program and increase the accuracy of sampling. These suggestions have been incorporated into the design. It was felt that there is a high probability of our experimental results being used for redesign by the electric power industry and that the most effective avenue of communication between the research effort and industry was via the regulatory agencies. One rather surprising conclusion reached by industry representatives was that the projected budget for the ORNL project (\$500,000) was too low; they encouraged a search for broader funding.

Planned Experiments

Test Species

In order to maximize the utility of experiments run on the simulator, careful selection of target species has been made. Entrained species have been identified from environmental monitoring programs during the early years of power plant operation. The most commonly entrained species were identified from data on two nuclear power plants, Surrey (an estuarine situation) and Peach Bottom (a freshwater situation). In addition, the Tennessee Valley Authority provided entrainment information from several plants in the Southeast. From these sources, a list of potential experimental organisms was developed for freshwater situations. The gizzard shad, Dorosoma cepedianum, threadfin shad, Dorosoma petenense, channel catfish, Ictalurus punctatus, the catostomids, Cyprinus carpio, Carpoides sp., and Catostomus commersoni, along with the bluegill, Lepomis macrochirus, Yellow perch, Perca flavescens, and freshwater drum, Aplodinotus grunniens will be used in initial experiments. The striped bass, Morone saxatilis will be used in both fresh and salt water experiments. Other salt water test organisms will be the menhaden Brevoortia tyrannus, the spot, Leiostomus xanthurus the anchovy, Anchoa mitchilli and the naked goby, Gobiosoma basci. In addition to fish

species, zooplankton, mostly cladocerans and copepods, will be used. Other organisms will be used when obtainable.

Experimental Sequence

The basic experimental approach will be to first examine pump-related mortality, as this factor is the least understood of all the components of the entrainment process. The effects of vacuum conditions will be evaluated next, as there is reason to believe this may be a significant mortality factor. The effects of these two stresses in combination will be examined, to see if there is any synergy between them. Upon completion of these basic studies, the effects of temperature and biocides in conjunction with other stresses will be evaluated. Experimentation will begin in June, 1977. It is anticipated that 3-5 years of experimentation will be necessary to fully utilize the potential of this system.

Experimental Design

The basic design of the experiments is straightforward. A stock of larval fish will be divided into two groups, one of which will be used as a control, the other as a test. Treatment of control groups will be uniform. They will be handled in exactly the same manner as test groups, (i.e., poured into containers, moved about the laboratory, placed in maintenance aquaria,) but will not go through the simulator. In order to assess mortality associated with recovery from the system, a preliminary series of experiments will be performed with each species.

It is anticipated that mortality rates, even in controls, will be quite high, necessitating a rather sophisticated analytical procedure. This high mortality is common to many larval fishes.¹⁴ Present plans are to use a categorical linear model (a categorical analog of analysis of covariance.)^{15,16} This analysis will compare control and test conditions by using a categorical covariance program LINCAT.¹⁵

Delayed mortality will be evaluated over a five-day period, a long enough interval to allow delayed mortality factors to manifest

themselves. Tests also will be carried out to evaluate possible variations in susceptibility to predation that might be associated with entrainment. In these experiments, larval fish from both experimental and control groups will be subjected to predation by blue-gill predators, using experimental techniques developed by the author.¹⁷ Experiment will also be carried out to examine the relationship between feeding ability (prey selection and feeding efficiency), providing a broad scale trophic examination of the effects of entrainment.

MODEL DEVELOPMENT

In order to provide a basis for assessment of pump-related mortality, members of ORNL's Computer Sciences Division were asked to develop a model to assess the probability of larval fish being killed by an impeller blade of a pump in a power plant intake. The following assumptions were given as the basis of the problem:

1. The velocity of the water is such that the fish can be considered as floating in the stream, not swimming; and turbulence is so great that the spatial orientation of the fish can be assumed to be random.

2. The density of the fish is assumed to be the same as that of water; the distribution of the fish can, therefore, be considered random.

Using the basic arguments of Buffon's needle problem (where a needle of unit length is thrown at random onto a plane partitioned into strips of parallel unit width) Ebey and Beauchamp¹⁸ developed two solutions; one where the pump blade was considered to be a line of no thickness, and a second, where the pump blade was considered to have a finite thickness.

The first of these formulations is

$$P = 4 nL/\pi^3 (R + R_0), \text{ where}$$

P is the approximate probability of a fish dying on the cutting edge of the impeller.

n is the number of impeller blades.

L is length of the larval fish.

R is the radius of the intake tube.

R_0 is the radius of the impeller hub.

The second formulation defining the probability of a fish being killed by the pump assumes the killing region is a band the width of an impeller blade, and uses a new parameter, D which is the width of the blade. The formulation is

$$P' = n (4L + D \frac{2}{\pi}) / \pi^3 (R + R_0)$$

Assuming a length of 1 cm for larval fish, and using the dimensions of the 10 BPM pump (intake radius: 10.25 cm, 4 blades of 4 mm leading edge thickness, impeller hub radius: 4.5 cm, equation (1) becomes

$$P' = 4 \quad 4(1) + .4(3.948) \quad / 31.006 (10.25 + 4.5)$$

which yields

$$P' = 0.07$$

This figure, then represents the minimum mortality expected from physical contact with the impeller blade, and provides a basis for examination of pump-related mortality.

It is expected that as data becomes available from the experimental program, similar modeling efforts will be feasible for other components of the entrainment process, making a general mathematical treatment of entrainment mortality feasible.

SUMMARY

An experimental program to evaluate the effects of entrainment on aquatic organisms is underway. In order to measure the mortality associated with each component of the cooling system, a power plant cooling system simulator has been designed and is now under construction. The design of the apparatus is such that the internal hydraulics of operating power plant cooling circuits will be effectively reproduced. Experiments will be conducted using fresh water and marine fish and zooplankton species. Rearing and holding facilities have been designed and constructed to assure a supply of specimens and to allow assessment of delayed mortality. The identification of the factors which cause mortality during entrainment should provide a rational foundation for the redesign of the components in cooling systems such that the environmental impacts of power plants will be minimized.

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