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A REVIEW OF WATER INTAKE SCREENING OPTIONS FOR COASTAL WATER USERS WITH RECOMMENDATIONS FOR OCEAN THERMAL ENERGY CONVERSION (OTEC) PLANTS

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SOLAR ENERGY

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ABSTRACT

The large volumes of water withdrawn at both the warm and cold water intakes of an OTEC plant must be screened to remove organisms and debris which could clog the heat exchangers. This paper reviews the recent literature on screening technology. In addition, various screen manufacturers and coastal facilities which use large volumes of seawater were visited to determine the operating experience with present screen technology. Static screens (particularly the Johnson Division, UOP profile wire screen and the Royce Equipment Company carrousel screen) have the potential advantage for OTEC of operating in a completely submerged state and of being cheaper to operate and maintain than traveling screens. However, there is no operational history with these static screens for large intake systems. The most promising traveling screen options for OTEC are the dual flow screens. They offer more screening surface and less head loss than through flow screens of similar size. They also have been operated in seawater for large intake systems. More detailed designs of potential OTEC plants, particularly screen wells, conduit and surge tank construction and head losses need to be determined before the best alternative intake screen can be selected.

I. INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) plants will require large volumes of water to generate electrical power. The projected water demand for OTEC-1 (a 1-MWe test unit) is 4,290 liters/sec or 68,000 gpm (gallons per minute) for the condenser and 3,785 liters/sec (60,000 gpm) for the evaporator. A Lockheed design for a 92-MWe module requires 384,858 liters/sec (6.1 million gpm) for the condenser and 410,094 liters/sec (6.5 million gpm) for the evaporator. Warm seawater (26.7-29.4 C) for the evaporator will be extracted at a depth of 6.1 to 30.5 m (20 to 100 ft); cold seawater (3.3-4.4 C) for the condenser will be taken at approximately 974 m (3,200 ft; Gilbert/Commonwealth[1]).

The large volumes of water withdrawn at both the warm and cold water intakes of an OTEC plant must be screened to remove materials which could clog the heat exchangers. The screens should also be designed to minimize the impact to marine organisms which may collect on the screens (impingement) or pass through the plant (entrainment). Both entrainment and impingement are a function of the screen mesh size, volume of water withdrawn and intake location although impingement is also a function of intake water velocity.

Most coastal electric generating stations employ vertical traveling screens, which use wire mesh of 9.5 mm (3/8 inch) openings. They are usually operated on an intermittent basis. Fish and debris frequently are collected on site and then disposed of off site.

Recent environmental regulations including the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) require cooling water intake structures to reflect the best technology available for minimizing adverse environmental impact. Section 316(b) of this act outlines requirements for a document to be submitted to the Environmental Protection Agency (EPA) which discusses the extent and significance of losses due to entrainment and impingement by an industrial water user. These regulations have prompted industry to retrofit some conventional screens with fish baskets and to incorporate a "fish trough" for returning organisms to the environment (White and Brehmer)[18]. In addition, entrainment losses at some power plants have recently led investigators to consider fine mesh screening (usually 1-3 mm open area) for larval fish protection (Tomljanovich, Heuer, and Voightlander)[2]. New screening techniques may have to be developed or older systems improved to provide environmental protection and good operational performance in new generating stations. This is also true for OTEC plants which require much larger water volumes than conventional generating stations.

This paper includes information on static and traveling water intake screen technology. Reviews of present screening options for power plants were presented by Riesbol and Gear[3]; Sonnichsen et al.[4]; Hanson, White, and Li[5]; Richards[6]; O'Keefe[7]; and Mussalli, Taft, and Hofmann[8]. A survey of fish impingement at estuarine and coastal power plants in the United States was made by Stupka and Sharma[9]. Proceedings of recent workshops concerning entrainment and impingement at electric generating stations were included in Jensen.[10-12]

The recent literature on screening technology as related to OTEC was also reviewed and included papers by Thomas and Bason[13]; Gilbert/Commonwealth[1]; Nath et al.[14]; and Hansen[15]. Thomas and Bason[13] reviewed static screen options for water intakes and their applicability to OTEC. Nath et al.[14] and Hansen[15] presented an overview of projected biological problems at potential OTEC sites, reviewed various screening systems and made cost estimates for some. In addition to the literature review, various screen manufactures and coastal facilities which use large volumes of seawater were visited to determine present available screen technology and actual operating experience. Information from the above sources was used to discuss potential options for OTEC test modules and a commercial plant.

II. STATIC SCREEN OPTIONS FOR WATER INTAKES

Static screen options for water intakes were discussed by Thomas and Bason[13] and included fixed wire-mesh screens, perforated pipes and plates, various filtering systems such as the radial well intake, Johnson Division, UOP profile wire screens, and the Royce Equipment Company carrousel screen.

Static screens have the potential advantage for OTEC of operating in a completely submerged state and of being cheaper to operate and maintain than traveling screens. They have the disadvantage of being difficult to service while submerged and the potential for collapse if they cannot be effectively backwashed and cleaned of organisms and debris. They also do not have an operating history with large volumes of seawater.

A problem with all screen systems is that larvae of macrofouling organisms pass through the mesh and then settle on the intake conduit and elsewhere in the water system. With static screens the screen surface also becomes fouled and the inner surface of the screen may be particularly difficult to clean.

Fixed wire-mesh screens are used at some electric generating stations. They require periodic removal for manual cleaning and maintenance, and most impinged organisms are killed. When removed, material and organisms in the water can enter the plant and potentially clog the condensers. Ansuini et al.[16] discussed the use of fouling resistant copper screens for OTEC, based on technology and components previously developed for aquaculture containment systems.

The perforated pipe intake consists of a submerged pipe with numerous small holes or slots through which water is drawn. One drawback is that the more openings or the greater the area of openings in the pipe, the weaker the pipe becomes structurally.

The Johnson profile wire screen is fabricated in cylindrical form by helically winding and welding V-shaped profile wire to evenly spaced support rods (Fig. 1, Appendix I). This construction results in a smooth external screen surface with a continuous slot which enlarges inwardly (Thomas and Bason)[13]. Hanson et al.[17] have demonstrated that this smooth, curved external surface allows debris and small organisms to be washed off the surface by ambient currents (Fig. 2). Heavy macrofouling growth must be mechanically removed from both the outside and inside screen surface to prevent clogging.

Loosely impinged material is cleaned off by backflushing with air or water. Air backflushing can be accomplished by the release of compressed air into the screen. Both this system and backflushing with water may require that the pumps be shut down or the water flow reversed. If the MAN brushes are used for cleaning of the condenser tubes then flow reversal could be used to clean both the condensers and the intake screens. Recent research has and is being conducted on Johnson screens and they are being considered for a number of electric generating stations.

The Royce carrousel screen represents another static screen option. This screen is also circular and the wire mesh is "Smooth-Tex", a woven mesh which has a smooth external surface to facilitate removal of fish and debris (Appendix I). Vanes within the screen and a bypass system where water is pumped past the screens will create a current vector along the wire mesh surface which should remove organisms and debris. This screen is still in the development stage and research with it is just beginning.

The Johnson profile screen is considered the most promising of the static screen options (Thomas and Bason)[13]. It is potentially the most environmentally sound screening system. However, both this screen and the carrousel screen need testing with relatively large volumes of intake water before they could be recommended in a commercial OTEC plant.

III. TRAVELING WATER SCREEN OPTIONS FOR WATER INTAKES

A. VERTICAL TRAVELING SCREENS

Four traveling screen manufacturers were visited (Appendix I): Envirex, FMC Link Belt, Royce Equipment Company, and Passavant Corporation. All make screens for electric utilities, chemical plants, waste treatment facilities (micro-screens and filtration systems), paper mills, and other water users. Passavant is a European company which has expanded into the U.S. The others are U.S. companies which have expanded to some extent overseas. Envirex and FMC are the oldest and largest U.S. manufacturers of traveling screens.

Most manufacturers provide primarily the conventional (through-flow) traveling screens (Fig. 3). These screens are perpendicular to the water flow and water passes through both the ascending and descending screen panels. Fish and debris are lifted from the water on the ascending side and are washed into one or two troughs on either the front or back side of the screen.

These manufacturers also provide dual flow (double entry, single exit) traveling screens, particularly for the overseas market (Fig. 4). These screens are placed parallel to the screen well walls and to the incoming water (similar to the Passavant screens). However, water flows inward through both the ascending and descending screen panels toward the center of the screen and then out the rear to the pumps. A modification to this screen system is FMC's No-Well screen (Fig. 5).

This screen is suspended in the water from a platform, and is free on the sides and bottom.

Passavant provides a single entry, double exit, screen (center-flow screen) (Fig. 6). Water enters the center of the screen and then exits through both the ascending and descending screens. This system has the baskets parallel to the walls of the screen well and to the incoming water flow.

B. MATERIALS AND CONSTRUCTION CONSIDERATIONS FOR TRAVELING SCREENS

The above manufacturers use a variety of screen materials. Most use a screen mesh material of 304 or 316 stainless steel of 9.5 mm (3/8 inch) diameter opening; monel wire is used extensively in salt water. Passavant has used primarily a polyester, nylon, or nytex weave of 0.5 to 1 mm (0.02 to 0.04 inch) mesh opening. Other materials used include copper-nickel and PVC.

The screen frames are made of materials including mild steel, stainless steels, and aluminum-bronze. In salt water many exposed metal surfaces are covered with a coal tar epoxy coating. Sacrificial anodes are used on many screen panels, and some plants use induced current for corrosion protection.

Screen size is variable and depends on the particular needs of each plant. A standard through-flow screen might be 2.4-3.05 m (8-10 ft) in width and 6.1-12.2 m (20-40 ft) deep. Screens are available up to 4.3 m (14 ft) in width but problems due to the screen weight plus detrital loading have occurred with this size

screen. Most manufacturers prefer their screens to be 3.05 m (10 ft) or less in width. Depth is less important and some screens over 30.5 m (100 ft) deep have been manufactured. These are usually made for riverine locations where water depth is highly variable.

A clean screen will normally have a head loss of only 5.1-7.6 m (2-3 inches). Most screens are designed to withstand a head differential of 1.5-3.05 m (5-10 ft). The recent trend is toward bigger, wider, and stronger screens. Some screens now are designed for a head differential of up to 4.6 m (15 ft) and require that the whole screen be reinforced and have heavy duty parts. As with many other features of screens, there is a wide latitude in design.

Traveling screens may run intermittently (either on a timer or when the head differential across the screen reaches a certain level) or continuously. Continuous operation is usually used when debris loading is heavy or with some fish protection systems (see pages 13 to 16). Most screens have a dual drive mechanism and will operate at either low, 0.6-1.5 m/min (2-5 ft/min), or high 3.05-9.1 m/min (10-30 ft/min), speeds.

Traveling screens are cleaned by water sprays. Those screens with a fish protection system usually have a light 13.8-69 kN/m^2 (kilometer per square meter; 2-10 psi) spray for fish and a heavy (413.8-758.6 kN/m^2; 60-110 psi) spray for debris. The through-flow screens have the spray header on the inside (Fig. 3) and wash debris either to the front or to the rear. The Passavant screen system has the header above the screen and washes materials into a trough which runs down the center of the screen (Fig. 6).

The volume of water withdrawn through an individual screen varies greatly. One of the largest flows per individual screen is with the Passavant system at a generating station in Europe: 20,820 liter/sec (330,000 gpm) through a screen with 62 panels. A typical through-flow screen at a large coastal facility might draw approximately 6309 liters/sec (100,000 gpm) per screen.

The number of screens used and the volume of water withdrawn per screen depends, in part, on the intake velocity. Most plants have intake velocities which range between 0.15 and 0.6 mps (meters per sec; 0.5 and 2.0 fps). In Europe, screens are designed for 0.9 to 1.2 mps (3 to 4 fps) velocities. In recent years, the EPA has recommended intake velocities of about 0.15 mps (0.5 fps) for fish protection, but in many situations velocities of 0.3 to 0.5 mps (1.0 to 1.5 fps) have proved adequate for fish protection. Velocities at a power plant intake usually vary widely between screens and over the surface of each screen.

The cost and delivery schedule for various screen systems depend on variables including screen size (width and depth which is dependent in part on low water depth), number of screens, screen materials, and intake volume and velocity. Screen selection procedures are discussed in brochure material provided by Envirex and FMC (Appendix I).

IV. OPERATIONAL EXPERIENCE WITH TRAVELING SCREENS AT COASTAL WATER INTAKE SYSTEMS

Coastal facilities visited during this study included the Redondo Beach Generating Station in Southern California; the Dow Chemical Plant and the B. F. Robinson and Cedar Bayou generating stations on the Gulf of Mexico near Houston, Texas; the Barney M. Davis Power Station near Corpus Christi, Texas; and the Big Bend Generating Station near Tampa, Florida. The first four utilized through-flow traveling water screens (primarily those of Envirex and FMC); the B. M. Davis Station used Passavant screens; and the Big Bend plant had FMC "No-Well" screens.

The Redondo Beach plant differs from the others in that it has an offshore intake. Water goes from the intake through a large diameter pipe to the screen well where it passes through trash bars and vertical traveling screens. A similar system is utilized at the San Onofre Nuclear Generating Station (Stupka and Sharma)[9]. Because impingement of organisms (many of them quite large) was a problem with the open, offshore intake, a velocity cap was added. The cap made the incoming current more horizontal than vertical and fishes and other motile aquatic organisms were better able to avoid this type of current. This intake system is somewhat analogous to a proposed OTEC system which would utilize an external inlet and internal sump for screening. One problem with this system is to find an adequate way to return impinged organisms back to the environment alive.

The other three plants visited which used through-flow traveling

screens are located on estuarine waters adjacent to the Gulf of Mexico. They are large water users (over 63,091 liter/sec or 1 million gpm) and have numerous screens to filter water. Dow Chemical has about 80 separate screens; many are small and only 1.5 to 2.1 m (5 to 7 ft) wide.

All three plants have had their screens clog due to jellyfish, ctenophores, or fishes (particularly large schools of the Gulf menhaden, Brevoortia patronus). In one instance, an estimated 49,900 kg (55 tons) of menhaden were impinged in a 24-hr period; 53 screen panels had to be replaced. At one plant the water spray was not strong enough to remove large jellyfish which then had to be removed by hand.

These traveling screens were designed to run intermittently, either automatically by pressure differential or manually once an 8-hr shift. Steel portions of the screens were generally protected by coal tar epoxy paint. Sacrificial anodes were used to protect the screen mesh and other metal surfaces exposed to saltwater. The greatest biofouling problem at one plant was with colonial hydroids which at times grew so thick on the trash bars that the bars had to be mechanically cleaned once a week.

The B. M. Davis Power Station near Corpus Christi, Texas uses Passavant center flow screens. Each of the two, 325 MW units have two screens which pass a total of 21,451 to 22,713 liter/sec (340,000 to 360,000 gpm). Each screen has 53 panels. The screen mesh material originally was 0.5 mm (0.02 inch) polyester dacron but was recently converted to 1 mm (0.04 inch) nylon or nytex material.

The screens rotate continuously at 4.3 to 8.5 mpm (meters per minute, 14 to 28 fpm) depending on debris loading.

This plant is located on high salinity water (30-55 ppt salinity) and exposed metal is protected cathodically. Some fouling occurred on the screen frames but in general biofouling has not been a problem. The major problem has been clogging of the screens by marine grasses. The prime reason that this fine mesh screening was used at this station was to prevent these grasses from clogging the condenser tubes. The fine mesh screens remove these fine grasses and have an additional advantage because survival of impinged organisms is high.

The Big Bend station near Tampa, Florida uses the FMC No-Well screen. Each screen and pump provides 7571 liter/sec (120,000 gpm) of water. Two screens and two pumps are located on a single platform above the water and provide circulating water for each unit's condenser. The screens are about 2.1 m (7 ft) wide and 5.3 m (17.5 ft) deep. The pump is very close to the screens and is connected to the screen well by a few feet of suction pipe. The intake velocity averages about 0.3 mps (1 fps) but is highest near the bottom of the screen at the depth of the intake pipe to the pump.

The screen mesh is stainless steel and the lip of the screen panels is carbon steel. The system is cathodically protected. Occasional problems exist with heavy barnacle growth on the lip of the screen panels and with oysters which either grow or somehow pass to the inside of the screens. In addition, marine grasses and jellyfish have clogged the screens. The screens are run intermittently either once or twice during an 8-hr shift. Only minimal maintenance

of the screens has been necessary although the screens are removed once a year for maintenance.

It is difficult to generalize from the operational experience at one industrial water user to what might be expected at another. The location of intakes, water quality, biofouling, detritus and nekton loadings on the screens, and frequency of rotation and maintenance vary from one plant to another. In many cases where a screen system has failed it is often due to its location in the water body or to improper maintenance. Most large coastal water users expend considerable man-hours each year maintaining their intake screening system. At times of heavy detrital or nekton loading on the screen, this may be a full-time job for a number of plant personnel.

V. FISH PROTECTION SYSTEMS

A. MODIFICATIONS TO STANDARD TRAVELING SCREENS

Most traveling screens are designed to protect the plant of the industrial water user but not fish and other aquatic organisms. The screens are generally run intermittently sometimes only once or twice a day. Fish that are impinged on the screens may suffocate or they may fall off the screens and become reimpinged. Those which remain on the screens are usually removed by a high pressure (690 to 828 kN/m^2 or 100 to 120 psi) spray and along with debris are either collected for disposal or returned to the environment. Even with a fish return system, many organisms are killed by the screen operation

described above or die shortly thereafter due to latent effects.

Important environmental modifications to the standard vertical traveling screen and its operation were made at the Virginia Electric and Power Company Surry Power Station in May 1974 (White and Brehmer)[18]. These modified screens, made by Envirex are known as the Ristroph traveling fish screens. Each screen had 47 screen panels which were each 4.27 m (14 ft) wide by 0.6 m (2 ft) high. To the base of each panel was attached a trough which was 50.8 mm (2 inches) deep by 139.7 mm (5.5 inches) wide. This trough held water as the screen rotated upward and carried impinged organisms. The screen was run continuously usually at 3.05 m/min (10 ft/min). As the screen panels rotated over the top of the screen two low pressure sprays, 103 to 138 kN/m^2 (15 to 20 psi), one inside and another located outside the rotating screen, washed organisms into the collection trough. This trough contained water and returned the organisms to the water away from the intake. A high pressure spray can be incorporated below the fish trough to wash all the remaining materials into a debris trough. Materials from this trough may then be collected and dumped or they may be returned to the environment.

The advantages of these modifications to impinged organisms are many. Because the screens rotate continuously, organisms are impinged for minutes rather than hours. The troughs on the screen panels keep the organisms in water as the screen ascends and help prevent organisms from falling off the screen and becoming reimpinged. The low pressure sprays gently remove the organisms from the screens

into the fish trough. At the Surrey Power Station, the average survival of all species of fish for the first 18 months of operation was 93.3% (White and Brehmer)[18].

Additional modifications have been made to the system described above. Lighter screen panels are used to reduce wear caused by continuous rotation. The speed of rotation has been reduced in some cases. For new installations, Envirex advises that the screens be tilted to the rear and that just one outside spray be used to wash fishes into the return trough.

FMC also has a dual spray and trough system for segregating fish and debris. In their system, however, fish are washed off the front of the screen by a low pressure spray located outside of the screen. This spray completely flushes the fish tray and organisms are washed into a fish return trough.

In the Passavant Screen system, the lower portion of each screen basket may be sealed off so that it holds water. Organisms are held in place until the screen rotates over the top. A spray above the screen washes organisms into a fish return trough which runs down the center of the screen assembly. Both fish and debris empty into one trough although two troughs could be incorporated into the system.

The Passavant screen often has a fine mesh, 0.5-1 mm (0.02-0.04 inch), so that relatively small organisms are removed. This can reduce overall mortality if entrainment mortality through the plant is high. Some conventional screen systems are now being backfitted

with fine mesh screens to remove small organisms, particularly fish larvae, before they are entrained (Tomljanovich et al.)[2].

At some stations, detrital loads are heavy and organisms may become impinged in the debris and not be removed by the low pressure spray. In these cases, 50% or more of the impinged organisms may be removed by the high pressure spray and many will be damaged or killed by the spray. King et al.[19] stated that there was no difference in mortality of young-of-the-year white perch and striped bass at some Hudson River power plants after they were washed off the screens with a spray of either 69-138 kN/m^2 (10-20 psi) or 207-345 kN/m^2 (30-50 psi). However there was significantly better survival of fish at a plant that used sprays of 355 kN/m^2 (50 psi) as opposed to 690 kN/m^2 (100 psi). Thus, there may be a range of spray pressures that will effectively remove impinged organisms without killing them. It is important that most fish and large macroinvertebrates be removed in the fish return trough. Because detrital material often contains numerous small organisms, it is also important that this material be returned to the environment. Additional modifications have and will continue to be made on existing screen systems to reduce mortalities to impinged organisms. In most cases, each industrial water user will have to make modifications unique to their situation.

B. FISH GUIDANCE AND DIVERSION

Presently, most screens designed for fish guidance and diversion are experimental. However, they may have application in the warm water intake for OTEC. Important variables for fish guidance and

diversion include screen or louver angle to flow; ambient, intake, and bypass velocities; and turbulence in front of the screens.

1. Horizontal Traveling Screen

The horizontal traveling screen can be described as a conveyor belt set on edge. It is similar to a vertical traveling screen in that it is an endless belt of screen panels, but it travels in a horizontal direction across the flow (Riesbol and Gear)[3]. Early developmental work on the horizontal traveling screen was conducted by Bates[20]; Bates and Van Derwalker[21]; Bates, Murphey, and Prentice[22]; National Marine Fisheries Service[23]; Farr and Prentice[24]; and Prentice and Ossiander[25]. A test model was built by Rex Screen Company and tested near Troy, Oregon. The screen is normally operational in areas where the water level is fairly constant and where the screen does not exceed about 3 m (10 ft) in depth. It is effective in bypassing fish but has not been put into large scale commercial operation.

2. Angled Louvers

Louvers, consisting of fixed steel vanes assembled much like venetian blinds, were tested in Southern California by Schuler and Larson[26]. Optimum guidance of marine fishes into a bypass canal occurred with a frame angle of 20° to flow. These louver systems are usually backed by a mesh screen of about 9.5 mm (3/8 inch). One system is being constructed at a new power plant on the West Coast (Mussalli et al.)[8]. Skinner[27] described a large louver system at the

California Delta Fish Protective Facility. This system had a capacity of 170 m^3/sec (2.7 million gpm). Although this system passes large volumes of water it was not designed with the finer screening necessary to protect power plant condensers from materials which could clog them.

3. Angled Screens

These screens were described by Taft and Mussalli[28] and Mussalli et al.[8]. They are traveling screens which are angled to the flow so that fish are guided to a bypass canal. An angle of 25° was effective in guiding alewifes. The angled screen is operated intermittently to remove debris (Mussalli et al.)[8]. These screens are being constructed at power plants on Lake Ontario. Both the angled screen and louver system often require that fish in the bypass be collected and returned to the environment, either by gravity feed or through jet pumps (Mussalli et al.)[8].

C. FISH DETERRENT SYSTEMS

Numerous methods have been employed to deter fishes from entering cooling water intake systems (Sonnichsen et al.[4], Sonnichsen, Farr and Riesbol[29], Mussalli et al.[8]). These include the use of an air bubble curtain (Smith[30]; Bibko, Wirtenan, and Kueser[31]; Alevras[32]); water and air jets (Bates and Van Derwalker[33]); electricity (Edwards and Higgins[34], Saila and Mowbray[35]); and hanging rods or chains, loud sounds, and lights (Brett and MacKinnon[36]). Mussalli et al.[8] reported that hanging chains, air bubble curtains, and water jet curtains have had moderate success. However, most deterrents have produced

inconsistent results and in some cases have aggravated impingement.

VI. DESIGN AND OPERATIONAL CONSIDERATIONS FOR OTEC

A general overview of the OTEC concept and various proposed plant configurations is given by Griffin[37] and Avery[38]. Because detailed designs are lacking for the various OTEC plant configurations, it is difficult to make specific recommendations on the intake screening system. Hansen[15] stated that details of the screen well, conduit and surge tank construction, and head loss would need to be determined before the best intake screen could be selected.

The OTEC concept provides unique water-intake screening problems. The floating plant will have large submerged intakes that require large volumes of water. Most conventional power plants with large water requirements use vertical traveling screens at their intakes. The tops of these screens are out of the water where they can be serviced and cleaned. Those power plants and ships which use submerged intakes usually require relatively small volumes of water with low intake velocities. In the latter cases, a perforated pipe or fixed bar screen are usually adequate.

At present, the Department of Energy proposes to use sumps in the OTEC plant which will be located between both the warm and cold water inlets and the heat exchangers. These sumps would provide an air-water interface where conventional screening could be used. Hansen[15] recommended that an air-water surface be incorporated within the path of flow of both the cold and warm water systems so that state-of-the-art traveling screens could be used. He concluded that a coarse bar

screen (trash rack) of 0.15-m (0.5-ft) openings would be needed at each intake and that either a through-flow or dual-flow vertical traveling screen of 9.5-mm (3/8-inch) mesh size, a through screen velocity of 0.46 m/sec (1.5 ft/sec), and water depth of 15.2 to 30.5 (50 to 100 ft) be used in the sumps. A fish collection and return system would be needed for the warm water screen system to attempt to return impinged organisms alive to the environment. Most organisms in the cold-water system will be dead because of rapid pressure changes encountered in their transit up the pipe and their subsequent impingement on the screens.

Hansen[15] made annual cost computations for each screen arrangement (principally through-flow and dual-flow vertical traveling screens and Johnson profile wire screens) based on a 100-MWe OTEC plant with warm and cold water flows of 7075 m^3/sec (15,000 ft^3/s) each. At all intake depths the principal components of the total cost were the initial cost, head loss, and operational maintenance costs. For traveling screens, the most economical screen width was 3.05 m (10 ft) and total cost was optimized at an intake velocity of 0.46 m/sec (1.5 ft/sec). Many assumptions (i.e. pump sizes, head losses, impingement rates) were made to arrive at these costs and as more detailed designs become available, revised cost estimates should be made. The space requirements and cost estimates for very large sumps or surge tanks will have to be calculated along with the added weight of standing water and traveling screens internal to the plant.

State-of-the-art traveling screens were recommended for OTEC plants by Hansen[15]. He stated that there was little operational data on dual-flow screens. However, his dual-flow screens were No-Well screens; he did not discuss the Passavant center flow screen (single entry, double exit screen) which has an extensive operational history in Europe. Because head losses may be critical in cost considerations for OTEC, a dual-flow screen may be the most practical traveling screen to use.

Thomas and Bason[13] discussed static screen options for OTEC. They stated that the Johnson profile wire screens offered the best option among static screening alternatives for OTEC. If these screens are effective at the external inlets to the warm and/or cold water intakes they would eliminate the need for trash racks, internal sumps, traveling screens, and a fish and debris return system. They would also provide the most environmentally acceptable screening system by eliminating entrainment and impingement of most nektonic organisms.

The OTEC-1 barge will require 3786 and 4290 liter/sec (60,000 and 68,000 gpm) for the warm and cold water system, respectively. For the proposed OTEC Seacoast Test Facility, about 606 and 404 liter/sec (9600 and 6400 gpm) would be required for the warm and cold water systems, respectively. It would not be worthwhile testing various traveling screens for these low volumes of water as all are presently being used in salt water for much larger flows. Static screen options, such as the Johnson profile wire screen and

Royce carrousel screen should be tested because they could provide substantial cost savings over the life of an OTEC plant and would be environmentally acceptable.

VII. SUMMARY AND CONCLUSIONS

The large volumes of water withdrawn at both the warm and cold intakes of an OTEC plant must be screened to remove materials which could clog the heat exchangers. The screens should also be designed to minimize the impact to marine organisms which may collect on the screens (impingement) or pass through the plant (entrainment). New screening techniques may have to be developed or older systems improved to provide environmental protection and good operational performance in new generating stations such as OTEC.

Present screening options for water intake systems include a variety of static and traveling screens which were discussed in the paper. Static screens have the potential advantage for OTEC of operating in a completely submerged state and of being cheaper to operate and maintain than traveling screens. However, they do not have an operating history with large volumes of seawater.

Of the static screen options the Johnson Division UOP profile wire screen and the Royce Equipment Company carrousel screen have the best potential for OTEC. Recent research has and is being conducted on Johnson screens and they are being considered for a number of electric generating stations. The Royce carrousel

screen is still in the development stage and research with it is just beginning.

The most promising of the traveling screen options for OTEC are the dual flow screens, particularly the Passavant Corp. traveling band screen and the FMC "No-Well" screen. Both offer more screening surface and less head loss than through-flow screens of similar size. They have also been operated in seawater for large intake systems.

Construction considerations for traveling screens and their operational experience at coastal water intake systems are discussed. A variety of screen sizes and materials are provided by screen manufacturers to meet a particular customers needs. Biofouling and corrosion cause some problems at coastal power plants. However, the greatest problem seems to be from the heavy loading of the screens by detrital material and aquatic organisms. Occasionally screen systems have collapsed in these situations.

Because water intake systems must reflect the best technology available for minimizing environmental damage various fish protection systems must be considered. If traveling screens are used a system should be incorporated which will return organisms impinged on the screens to the environment. The advantage of some of the static screen options is that if they are properly designed they may almost eliminate the impingement of organisms and can also reduce entrainment.

It is recommended that for OTEC-1 and the Seacoast Test Facility one or more of the static screen options be used. Because these

screens offer potential cost savings over the life of an OTEC plant and are environmentally acceptable they should be tested to determine their potential suitability for a commercial OTEC plant. The various traveling water screen options are presently used at large coastal facilities and most have an extensive operational history. Little additional information would be gained by testing them for relatively small water intake systems.

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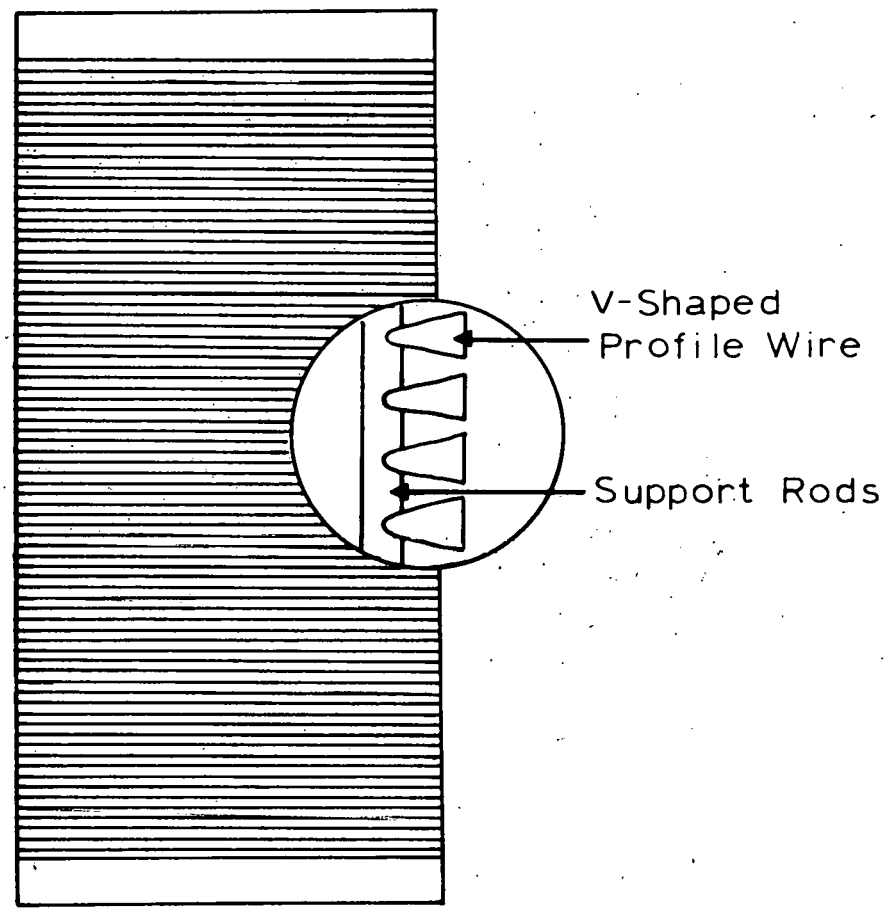
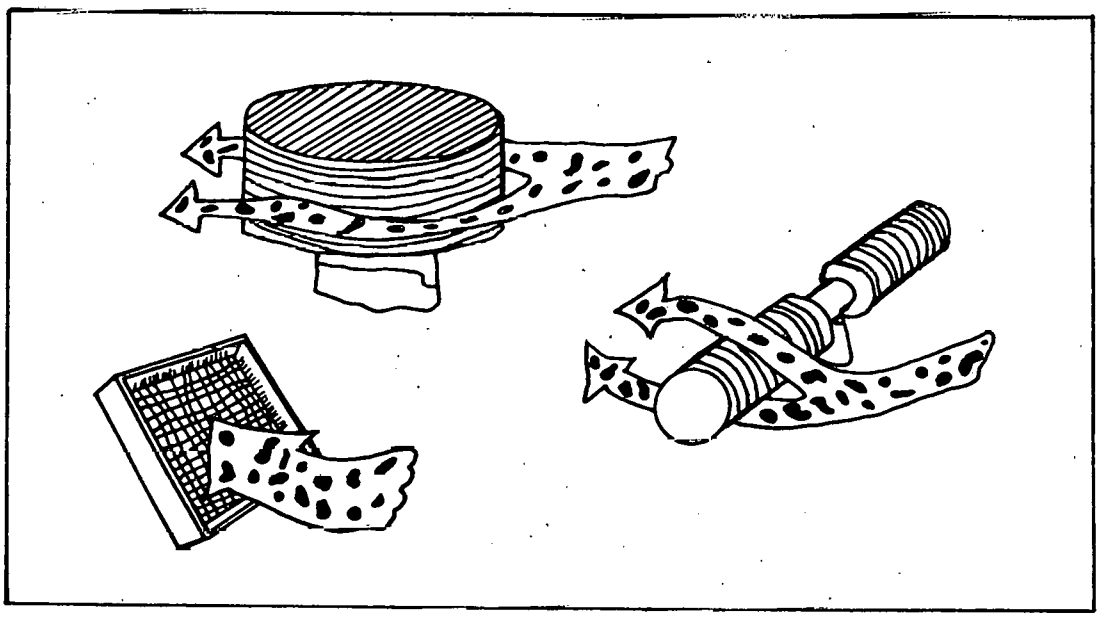
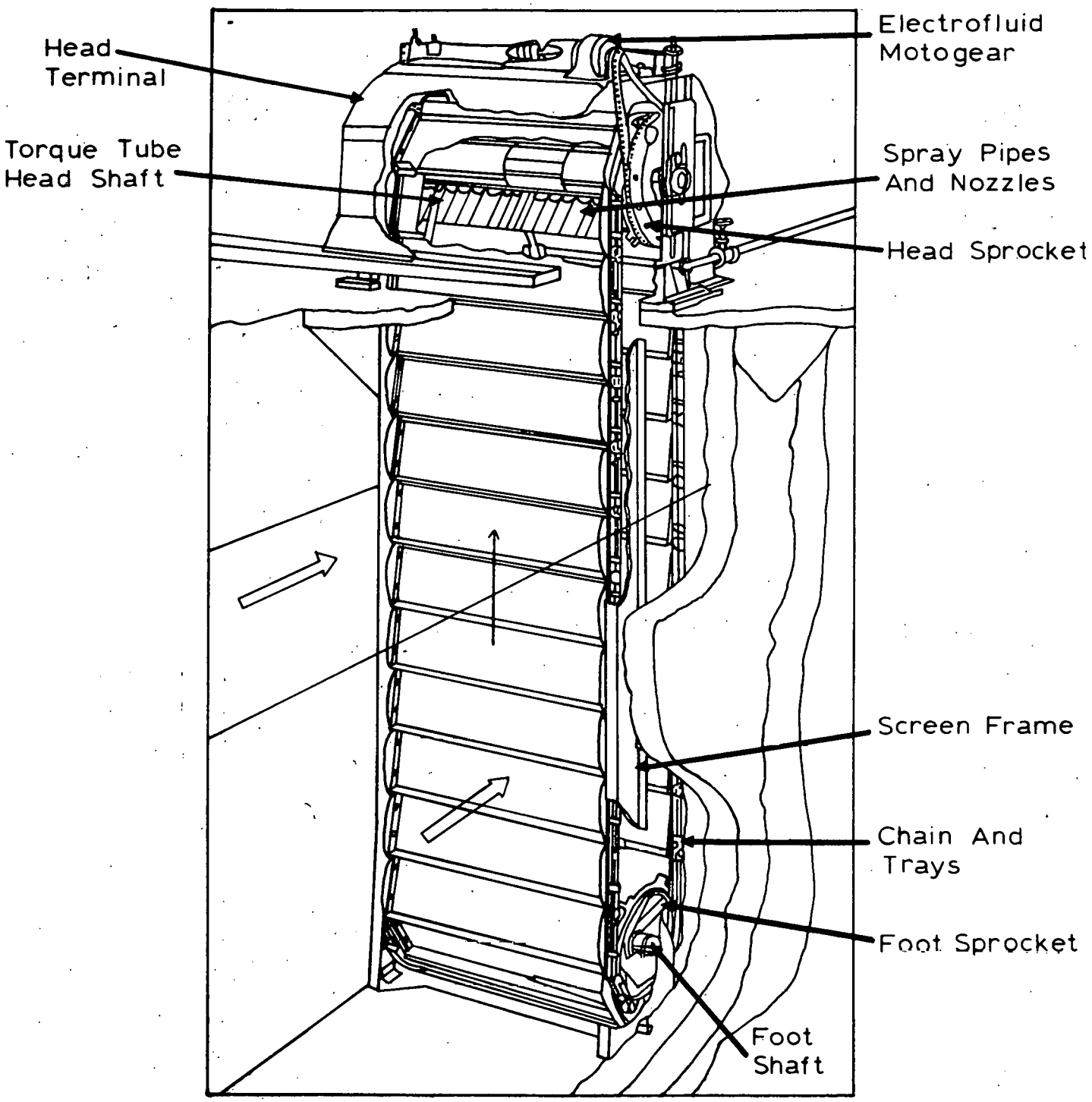


Cylindrical Johnson Profile-Wire Screen
(Hanson et al. 1978)
FIGURE 1.



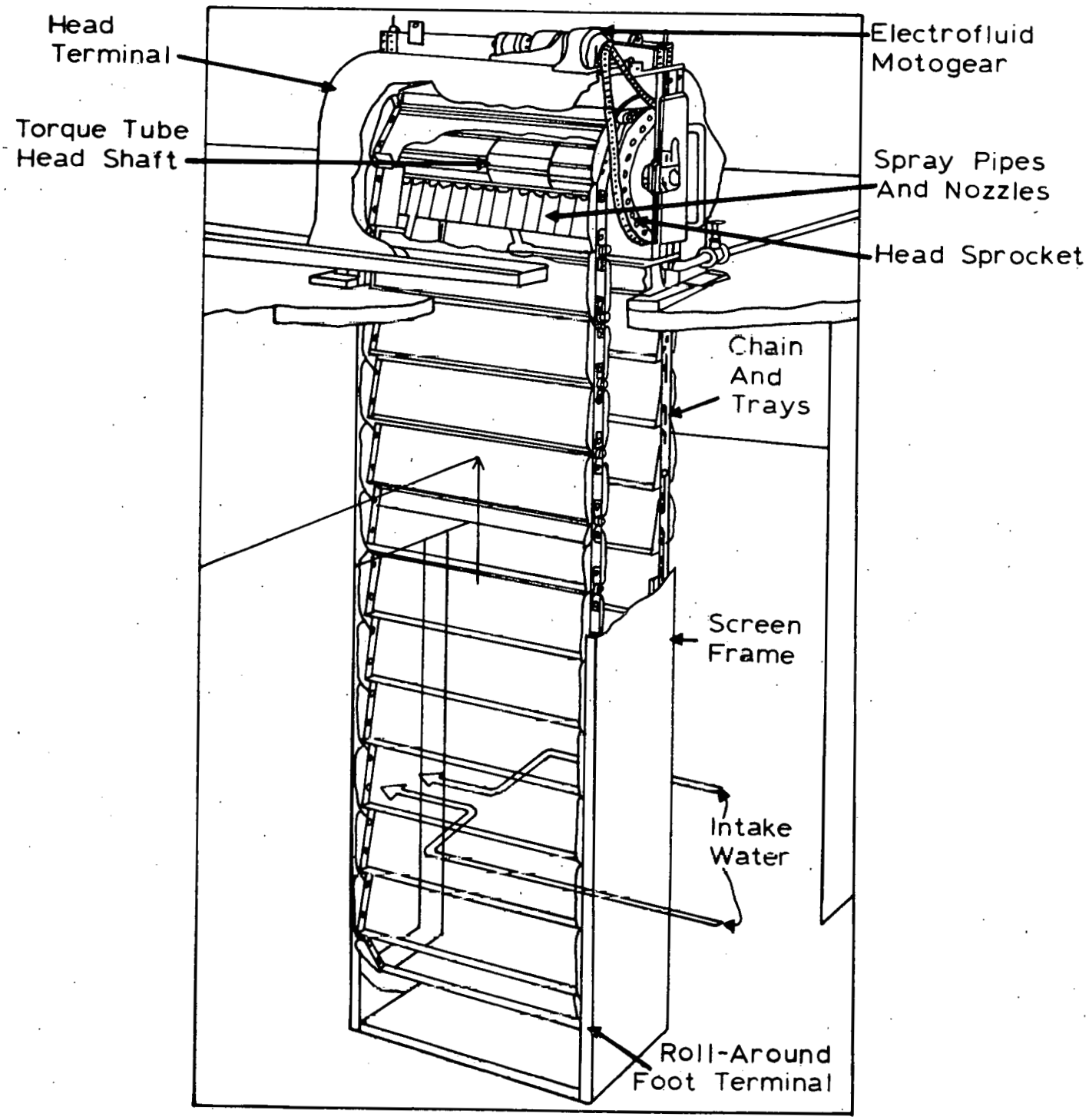
Johnson Intake Screens
(Johnson Div., UOP Inc.)
FIGURE 2.



Thru Flow Traveling Screen

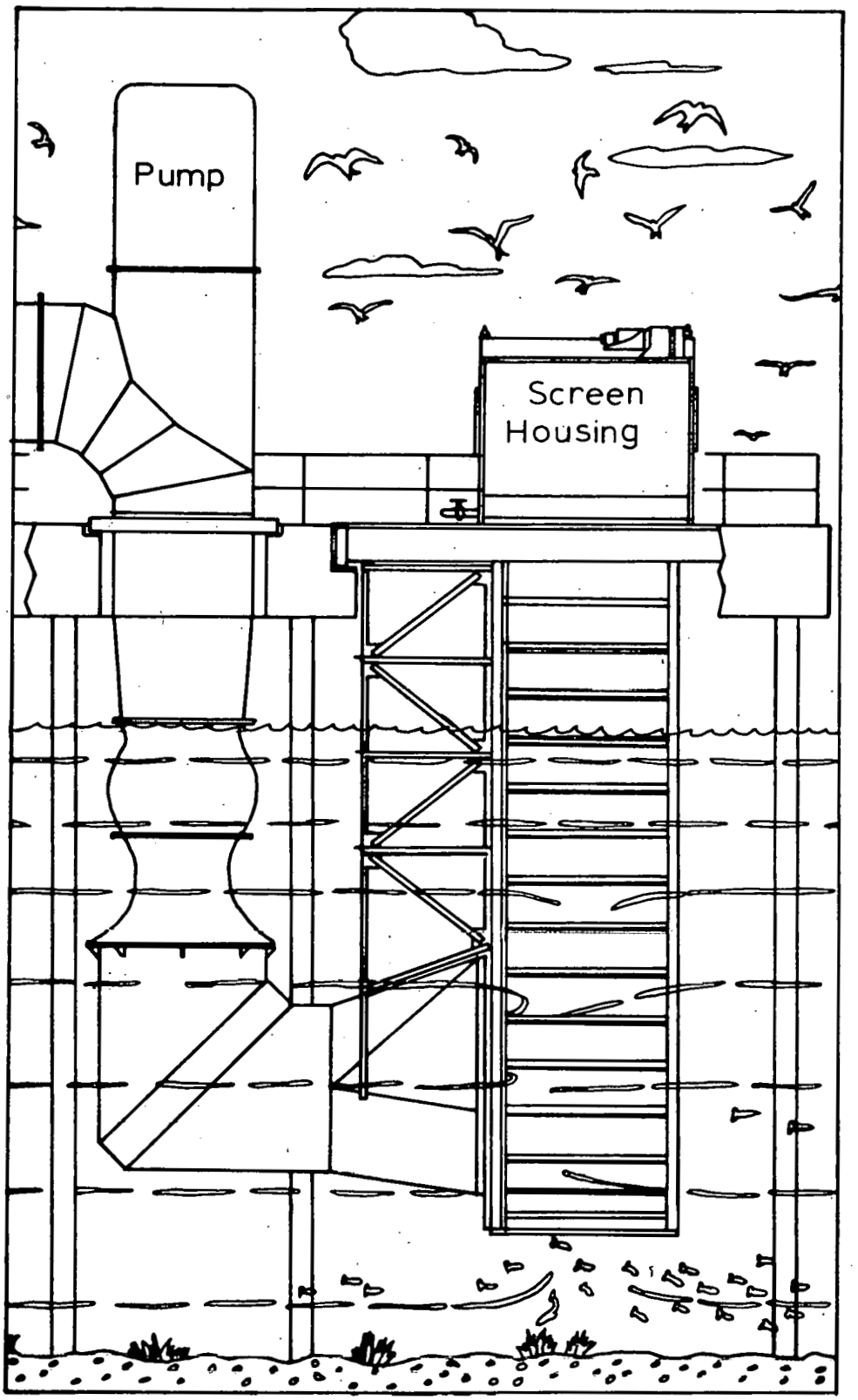
(FMC Corp.)

FIGURE 3.



Dual-Flow Traveling Screen
(FMC Corp.)

FIGURE 4.



FMC No-Well Screen

FIGURE 5.

APPENDIX I

Screen Manufacturers and Their Available Brochure Material

1. Johnson Division, UOP Inc.
   P.O. Box 43118
   St. Paul, MN 55164

   a. Johnson Screens for Surface Water Intake Systems

2. Envirex, a Rexnord Company
   Water Quality Control Division
   1901 South Prairie Street
   Waukesha, WI 53186

   a. Rex Water Screening Equipment

3. FMC Corporation
   3400 Walnut Street
   Colmar, PA 18915

   a. Traveling Water Screens
   b. Traveling Water Screen, Model 45 A, Thru-Flow
   c. Traveling Water Screens, Fish Protection System
   d. Field Notes, Spray Wash Fish to Safety from Traveling Screens
   e. System Protects Fish From Water Intake Structure
   g. Low-Cost Intake Structure Saves on Upkeep

4. Royce Equipment Company
   P.O. Box 34543
   Houston, Texas 77034

   a. Woven Slot Fine Mesh Screening

5. Passavant Corporation
   P.O. Box 2503
   Birmingham, AL 35201

   a. Traveling Band Screen
   b. Intake Technology Moves Ahead
   c. Survival of Dominant Estuarine Organisms Impinged on Fine Mesh Traveling Screens at the Barney M. Davis Power Station.

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