Design of Recirculating
BLUE CRAB SHEDDING SYSTEMS

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LOUISIANA SEA GRANT COLLEGE PROGRAM

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by

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CHAPTER 1

INTRODUCTION

1.1 Overview

The blue crab (Callinectes sapidus), like all crustaceans, derives its body shape from a shell (exoskeleton) which completely encases and protects the vital organs and muscle tissues. Periodically, immature crabs must undergo the process of ecdysis (or molting) in which the old shell is replaced. During this growth process, the crab expands the new inner shell, while dissolving and cracking the old shell until it can work itself free. The old shell is finally shed and a new larger shell emerges. For a few hours after ecdysis, the new exoskeleton is soft. Crabs captured with their shells in this condition are commonly known as "soft-shelled" or "soft" crabs.

Although each crab must shed its shell over 20 times during its life span, the time spent in the soft stage is brief. Commercial production of this seafood delicacy depends on capturing crabs that approach ecdysis (premolts), keeping these animals healthy until they molt, and harvesting the soft crabs before their shell has had time to harden. The commercial production of soft crabs is complex, involving a series of critical steps: capture, sorting, transport, shedding, processing, and sale. A brief description of the steps is given in Table 1.1. This manual focuses on the shedding aspect of commercial production with specific emphasis on using recirculating shedding systems to hold premolt crabs until they molt.

Table 1.1 Critical steps in the commercial production of soft crabs.

Step	Function
Capture	Capture of undamaged crabs from wild stock
Sorting	Identification and separation of premolt crabs
Transport	Minimizing stress and damage to premolt crabs while transporting to shedding system
Shedding	Maintaining crabs in an environment suitable for ecdysis
Processing	Sizing, wrapping, and freezing soft crabs
Sale	Development of markets for product

1.2 Evolution of Criteria

A research program was initiated in the fall of 1982 to assist the soft crab industry by developing practical design criteria for recirculating shedding systems. The successful commercial system operated by Mr. Cultus Pearson of LaCombe, Louisiana, was used as a benchmark for this research effort (Manthe et al. 1983). This system was based, in part, on design guidelines presented by Ms. Harriet Perry of the Gulf Coast Research Laboratory (Perry et al. 1982). The research team worked with Mr. Pearson to examine and refine the design of his commercial system while simultaneously testing a smaller prototype unit in the laboratory to examine the system's limits.

In the early years of the research, nitrite was identified as the principal toxic compound causing crab mortalities in recirculating systems (Manthe et al. 1984). High nitrite levels occurred when the oxygen supply was limited in the biological filter (Manthe et al. 1985). These findings permitted the research team to develop simplified design criteria for recirculating shedding systems employing low-rate biological filters (submerged rock filters) as the sole source of water purification.

In the spring of 1983, interim design criteria were released for commercial application. A large number of operators have used these criteria, demonstrating their effectiveness under commercial conditions. Often, more than 95 percent of the crabs placed in systems based on these designs shed successfully. Limitations with these designs, however, centered on the submerged rock filters used for maintaining adequate water quality. The low number of crabs that a submerged rock filter can support results from the filter's tendency to clog or its failure to maintain pH levels during peak loadings.

In 1985, research efforts were shifted toward developing smaller, more efficient filtration systems for crab shedding systems. The research team selected two types of filters for testing: fluidized bed and upflow sand filters. The fluidized bed filter was vastly superior to the submerged rock filter in its ability to remove the toxic compound nitrite (Malone and Burden, 1987). The second type, the upflow sand filter, displayed excellent ability to capture solid wastes in the system, providing the perfect complement to the fluidized bed. Laboratory findings and initial commercial applications indicate that recirculating systems using this technology are even more reliable than the proven submerged rock filter.

1.3 Objectives

This manual has two objectives. First, it presents final design recommendations for the submerged rock filtration system. Recirculating systems using submerged rock filters have been widely adopted both locally and nationally. In addition, extensive theoretical analyses and laboratory experiments have been conducted to increase our understanding of the submerged rock filter's abilities and limitations. Final design recommendations and a typical system configuration for this highly successful filtration approach are presented in Sections 4.2 and 5.1, respectively.

As a second objective, interim design recommendations for the newer, more powerful fluidized bed and upflow sand filtration systems are introduced. Commercial operators adopting this new technology (even as laboratory research was conducted) have indicated the need for more detailed design information. Interim design recommendations and system configurations that the research team believes will benefit commercial applications are presented in Section 5.2. These recommendations are termed "interim recommendations" because they are subject to revision as the research team receives more complete evaluations from the few commercial operators currently testing this technology.

CHAPTER 2

RECIRCULATING SYSTEMS

2.1 Historic Development

Currently there are three fundamental types of systems that are used to commercially produce soft crabs. These include float, flow-through, and recirculating systems (Table 2.1). Historically, the most common type was the in-lake float system. These systems employed floating holding tanks placed in the natural water body from which crabs were captured. Holes drilled in the bottoms of the tanks provided water circulation and dilution of the wastes produced by the crabs. Such float systems are still commonly used in parts of the country where protected waters of suitable quality are available (Oesterling, 1984). Small floating systems are sometimes attached to docks to provide convenient access.

The need for convenient access to the shedding trays to remove soft crabs 24 hours a day undoubtedly led to the establishment of land-based open flow-through shedding systems. Pumps were used to circulate water from a natural waterbody, through tanks which could be housed in a lighted shed. Normally, no attempts were made to treat the natural water prior to its introduction to the shedding system or before it was returned to the natural waterbody even though the circulated water contained wastes produced by the crabs. Both flow-through systems and floats depend on access to natural waters of consistently high quality. Increased recreational demands for prime shoreline property and declining water quality in many of our estuary systems have severely limited the use of this technology. In some areas of the country such as Louisiana, these factors contributed to the almost complete demise of the soft crab shedding industry.

Recirculating systems eliminate the need for access to natural water by reusing synthetically mixed seawater. A recirculating system consists of five distinct functional elements: holding trays, a biological filter, a reservoir, a sump, and a pump (Figure 2.1, Table 2.2). The holding trays are used to hold the peeler crabs through the shedding process. The filter and reservoir work to maintain suitable water quality in the system while the sump and pump provide circulation and reaeration of the system's water. Aside from the periodic addition of fresh water to compensate for evaporation or to replace water from self-cleaning filters, no water is added or discharged from the system. Commercial facilities using submerged rock filters may reuse synthetic seawater for an entire shedding season without replacement.

The advantages of a recirculating system stem from reusing the water (see Table 2.1). The dependency on access to natural water of good quality is virtually eliminated. Shedding facilities can be placed inland, away from expensive shoreline areas in a setting conducive to commercial development. Water quality in the recirculating system depends only on proper system management and, thus, is not subject to the effects of man-made pollution or storms that adversely affect all but the best placed float or open flow-through system. Furthermore, the recirculating system does not contribute to the pollution problem in our near-shore areas since all the crab-produced wastes are completely degraded within the system. Because of this feature, recirculating systems are not normally subject to environmental regulations governing discharge permits.

The principal advantage of the recirculating system arises from the fact that the operator completely controls the system. An established recirculating system will process peelers in a dependable manner, an important consideration in areas where the peeler supply is limited. The operator can readily test innovative approaches to enhance molting such as

Table 2.1 Advantages and disadvantages of the major soft crab shedding systems types.

Description	Advantages	Disadvantages
Floats		
Holding trays are suspended in the bay waters	Low capital cost No waste problem	Hard to manage Storm damage Vandalism Labor intensive Predation Sensitive to changes in bay water quality
Flow-Through System		
Natural water is pumped from bay into a land-based shedding system with wastewater discharge back to bay	Moderate capital cost High crab density Reduced labor costs	High land costs Biological fouling Discharge permit may be required Sensitive to changes in bay water quality
Recirculating System		
Synthetic seawater is filtered and reused with periodic replacement of water and salt	No discharge Reliable water quality Reduced labor costs Convenient facility location	High initial capital costs Moderate crab densities Management expertise required

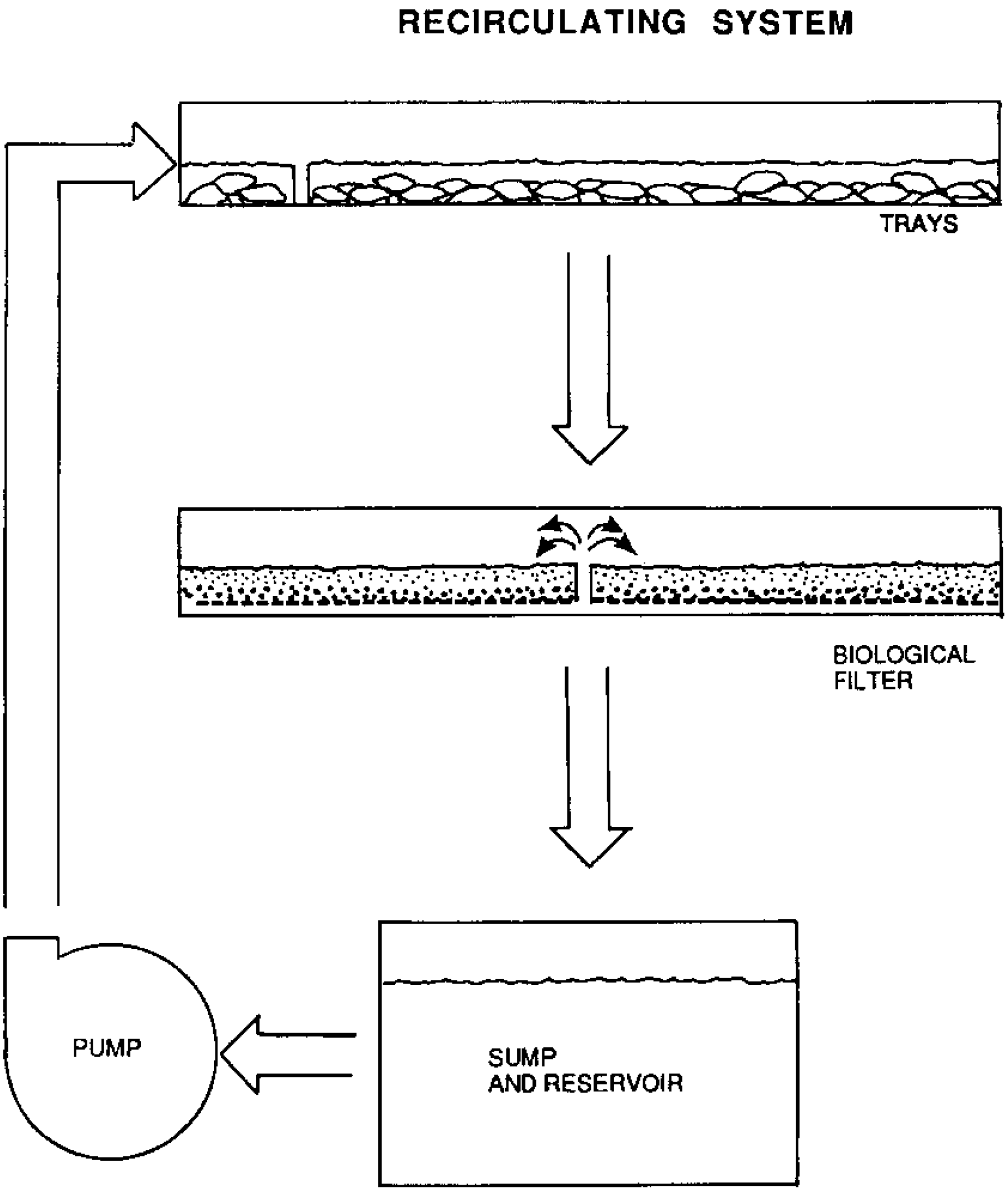

Figure 2.1 The basic components of a blue crab recirculating shedding system.

Table 2.2 Major components of a recirculating shedding system.

Function	Design Factors
Holding trays	
Provides easily reached space for holding and molting of animals	Tank surface area, aeration rates water circulation, lighting, access
Biological Filters	
Capture solids, degrade dissolved wastes, and control pH	Volume, media composition, media surface area, aeration, water flowrates
Reservoir	
Provides dilution volume to stabilize the system	Volume, circulation rates
Sump	
Provides water for pump intake and controls system water levels	Volume, turbulence, circulation rates
Pump	
Provides water circulation and aeration of system waters	Pump type, flowrate, pressure

controlling calcium levels or manipulating temperature. These advantages tend to outweigh the principal disadvantages of the recirculating systems which include the need to limit the number of crabs held in the system and to train management personnel in the area of water quality.

2.2 Carrying Capacity

The concept of a "carrying capacity" is fundamental when designing and operating a recirculating shedding system. Simply stated, the carrying capacity is the maximum number of crabs that the system can safely support for an extended period of time. The number of crabs in the system must be balanced by the capability of the system's filtration components to process wastes produced by the animals. So long as the number of crabs in the system is less than the designed carrying capacity, mortality problems caused by over-crowding or water quality deterioration should not exist. By exceeding the carrying capacity, detrimental water quality conditions result and molting success rapidly decreases.

The design criteria presented here are based on the concept of carrying capacity expressed as the number of unfed medium crabs a system can safely support. Generally, the operator will find that systems are relatively insensitive to crab size. However, for purposes of clarification, a medium crab is defined as a blue crab with a carapace width (point to point) of 4 to 4.5 inches (100 to 115 mm) and a "wet weight" of about 1/4 pound (115 grams). Design calculations are commonly based on poundage of animals; therefore, recommendations can be corrected by weight ratios if necessary.

The design criteria must be used in their entirety. Each component in a recirculating system has a specific function. For example, pumping requirements for the holding trays are controlled by the need to supply oxygen to the crabs. All components are sized to support approximately the same number of animals. This approach assures that the system's carrying capacity can be obtained without inducing failure in a specific component.

Feeding crabs in a recirculating system significantly increases the waste production rate of the crabs. The design criteria in this manual are specifically intended for the traditional shedding system in which premolt crabs are not fed. Feeding will induce system failure below the designated carrying capacity indicated by the design criteria. Experience has demonstrated that the submerged rock filter systems do not perform well when crabs are fed. The newer, more sophisticated sand filters can readily support a system in which intermolt crabs are fed, but not with the design capacities indicated in this document.

CHAPTER 3

CRITICAL WATER QUALITY PARAMETERS

The following sections briefly discuss important water quality parameters. Many of the parameters are interrelated and, therefore, complex in their interactions. The reader is directed to the suggested materials listed in the appendices for more in-depth information on the chemistry of recirculated waters. Methods used for monitoring these parameters are presented in Chapter 6.

3.1 Dissolved Oxygen

Dissolved oxygen (D.O.) is defined as the amount of oxygen dissolved in water. Dissolved oxygen concentrations are very important since the crabs and the beneficial bacteria living in the biological filter need it to live. Oxygen (O_2) concentrations are measured in units of oxygen weight (in milligrams) per volume of water (in liters). Thus, water with 5 mg-O_2/l contains 5 milligrams of dissolved oxygen in every liter of water.

The maximum amount of oxygen that water can hold is called the "saturation level." The saturation level changes with temperature and salinity (Table 3.1). As the salinity or the temperature increases, the saturation level of the water decreases. Water that contains oxygen at its saturation level contains sufficient amounts of oxygen to support aquatic life, but this available oxygen can be rapidly consumed when crabs are placed at high densities in a shedding system. In addition to crab consumption, oxygen is also consumed in large quantities by the bacteria in the biological filters. Low oxygen levels weaken the crabs and can prevent bacteria from converting crab-excreted wastes. Table 3.2 presents the effects of oxygen levels on the operation of a blue crab shedding system.

Crabs suffering from oxygen deficiencies are characterized by their inactivity. During the molting process, crabs are unable to breathe for a brief period. Crabs must, therefore, be exposed to reasonably high oxygen levels prior to molting if they are to survive the stress of shedding their shells. Molting crabs in holding tanks without sufficient oxygen are often observed clustering near aeration heads. When exposed to low oxygen levels, molting crabs often die after the backs of their shells have opened and they struggle to free their legs and claws.

Because the biological filters are submerged, the oxygen source for the bacteria is only available in the water flowing through the filters. If this oxygen supply is exhausted before the bacteria consume the crab-excreted wastes, the water purification processes cease and wastes accumulate in the system. Although oxygen deficiency in the filters does not directly affect the crabs in the holding tanks, it eventually becomes critical to the crabs when wastes accumulating in the system reach toxic levels.

3.2 Nitrogen

Nitrogen dissolved in a recirculating system is found in five major forms: nitrogen gas, organic nitrogen, ammonia, nitrite, and nitrate (Table 3.3). Dissolved nitrogen gas (N_2) continually diffuses in and out of a recirculating system. Nitrogen behaves like oxygen except that there is no demand for the gas in a typical recirculating system; thus, the system's waters are almost always at saturation. Nitrogen gas is almost totally inert and of no consequence to a normal shedding operation. The principal forms of concern are

Table 3.1 Oxygen holding capacity of water at various temperatures and salinities (in mg-O_2/l).

Temperature (°C)	Temperature (°F)	Salinity (ppt) 0	5	10	15	20	25	30	35
16	60.8	9.86	9.56	9.28	9.00	8.73	8.47	8.21	7.97
18	64.4	9.45	9.17	8.90	8.64	8.39	8.14	7.90	7.66
20	68.0	9.08	8.81	8.56	8.31	8.07	7.83	7.60	7.38
22	71.6	8.73	8.48	8.23	8.00	7.77	7.55	7.33	7.12
24	75.2	8.40	8.16	7.93	7.71	7.49	7.28	7.07	6.87
26	78.8	8.09	7.87	7.65	7.44	7.23	7.03	6.83	6.64
28	82.4	7.81	7.59	7.39	7.18	6.98	6.79	6.61	6.42
30	86.0	7.54	7.34	7.14	6.94	6.76	6.57	6.39	6.22
32	89.6	7.29	7.09	6.90	6.72	6.54	6.36	6.19	6.03

Table 3.2 The effects of various oxygen concentrations on a blue crab shedding system.

Oxygen Concentration[1] (mg-O_2/l)	Impact
> 5.0	Oxygen levels safely support all system operations
4.0-5.0	Molting crabs may begin to show signs of stress Premolt crabs not affected Bacteria in filters not affected
3.0-4.0	Significant molting mortalities in shedding trays Premolt crabs display signs of stress Bacteria in filters not affected
2.0-3.0	Few crabs will survive the molting process Premolt crabs appear listless, mortality rate increases Bacteria in filters slow down
1.0-2.0	No successful molting Premolt crabs inactive, high mortality Bacteria shut down, nitrite rapidly accumulates

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[1] Oxygen measured in holding tray for crabs, coming out of the biological filter for bacteria

Table 3.3 The major forms of nitrogen in a recirculating system.

Nitrogen Form	Abbreviation	Importance
Nitrogen Gas	N_2	Inert gas, no significance
Organic Nitrogen	Org-N	Decays to release ammonia
Un-ionized Ammonia	NH_3	Highly toxic form of ammonia; predominates at high pH values
Ammonium Ion	NH_4^+	Moderately toxic form of ammonia; predominates at low pH values
Total Ammonia	NH_3+NH_4	Sum of un-ionized ammonia and ammonium ion found in water; decays to nitrite; typically measured in the ammonia test procedure
Nitrite	NO_2^-	Highly toxic nitrogen form; decays to nitrate
Nitrate	NO_3^-	Stable nontoxic form of nitrogen

organic nitrogen, ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). The term organic nitrogen refers to the amount of nitrogen in organic matter found dissolved or suspended in the system. All plants and animals contain organic nitrogen, so solid wastes in recirculating systems contain large amounts of organic nitrogen. Ammonia, nitrite, and nitrate are chemicals produced by organisms and bacteria as they biologically process organic nitrogen. Ammonia and nitrite are considered highly toxic forms of nitrogen, while nitrate is considered safe. Concentrations of all dissolved nitrogen forms are expressed in terms of the weight of nitrogen (in milligrams) found in the compound per unit volume (liters). Thus 3.0 mg NO_3-N/l, indicates that the nitrate level is equivalent to 3.0 milligrams of nitrogen per liter.

Crabs excrete large amounts of dissolved ammonia directly into the system's water. Crabs also excrete solid wastes (feces) which contain organic nitrogen. Figure 3.1 illustrates how the bacteria in the filter use these nitrogen wastes as a food source and in the process convert the nitrogen from one form to another. Organic wastes containing nitrogen are decomposed by a wide variety of bacteria that produce ammonia as a byproduct. The ammonia produced by the decomposing processes, plus that directly excreted by the crabs, is utilized by one of highly specialized bacteria of the Nitrosomonas genus as an energy source. The Nitrosomonas bacteria convert ammonia to nitrite which, in turn is converted to nitrate by a second group of specialized bacteria of the Nitrobacter genus.

The two groups of specialized bacteria responsible for the conversion of ammonia and nitrite to nitrate are collectively called "nitrifying bacteria" and the conversion process is referred to as "nitrification." The nitrification process is important because a successful shedding operation depends on avoiding the accumulation of the toxic nitrogen forms, ammonia and nitrite. In an improperly designed or mismanaged system, the rate at which ammonia or nitrite is produced can exceed the rate of conversion by the nitrifying bacteria, causing accumulation of these toxins in the system. Under most conditions, high concentrations of ammonia or nitrite result in crab mortalities.

3.3 Ammonia Toxicity

Ammonia actually exists in water in the chemical form of un-ionized ammonia (NH_3) or as the ammonium ion (NH_4^+). The only difference between these two forms is a single hydrogen ion (H^+). Yet, NH_3 is highly toxic to aquatic organisms, including crabs, while NH_4^+ is only moderately toxic. The ammonia form depends entirely on the concentrations of hydrogen ions present in the water (pH). Waters with low pH have high concentrations of hydrogen ions and, thus, NH_4^+ dominates. Conversely, at higher pH values (pH>8), very few hydrogen ions are found in solution. Therefore, NH_3, the most toxic form of ammonia, dominates. Thus, systems with high pH values are more prone to ammonia toxicity problems. Shedding operations tend to have pH values in the range of 7.0 to 8.0 which appear to protect the crabs from total ammonia concentrations as high as 10 mg NH_3+NH_4-N/l.

3.4 Nitrite Toxicity

High nitrite concentrations decrease the ability of the crab's blood to transport oxygen. Crabs suffering from nitrite toxicity essentially suffocate. Table 3.4 presents toxicity levels derived from the observation of both commercial and experimental systems. Molting crabs are adversely affected by nitrite levels as low as 0.5 mg-N/l. Molting crabs are particularly sensitive to nitrite because they require an increased supply of oxygen to molt successfully.

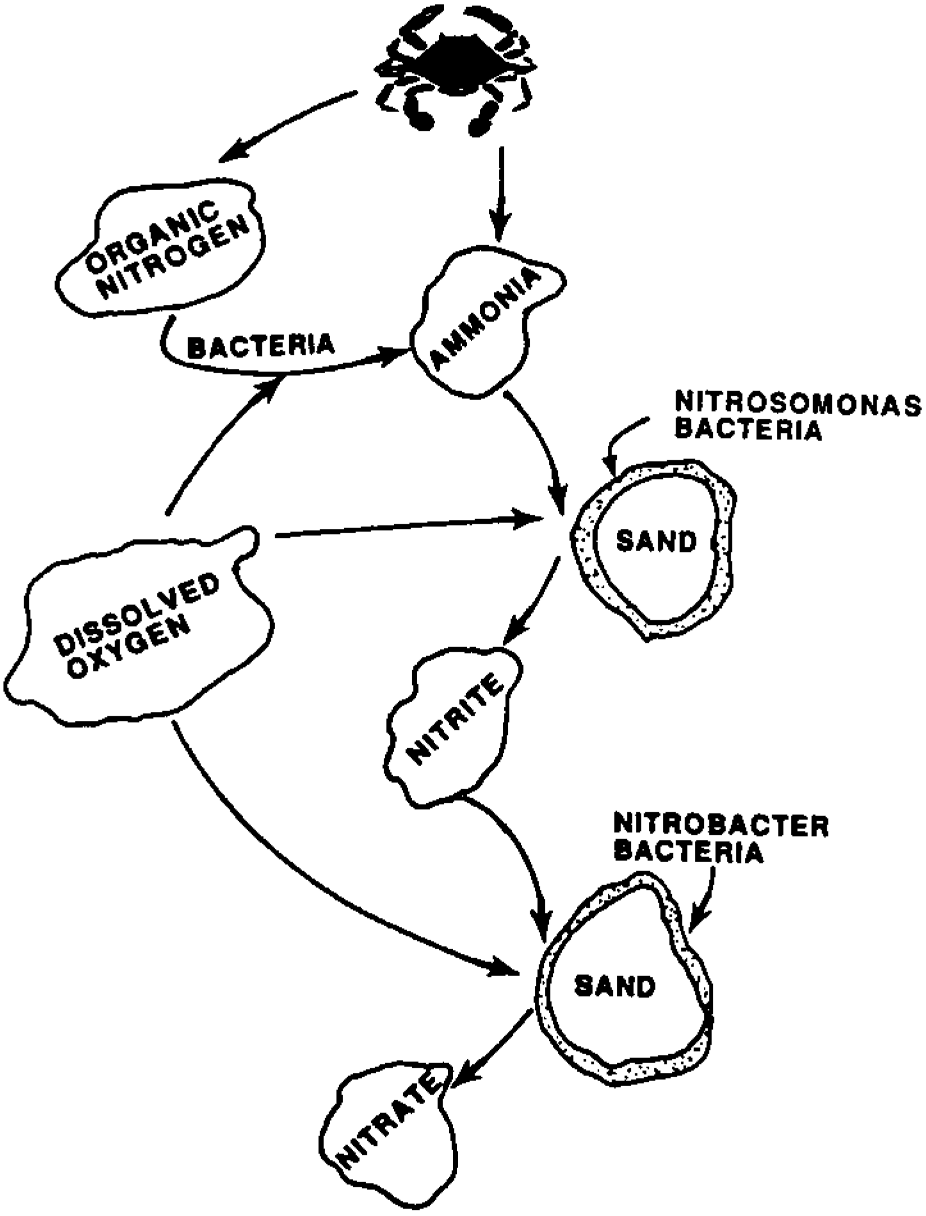


Figure 3.1 Principal pathways of nitrogen decay in a recirculating system are controlled by specialized groups of bacteria that grow in thin layers on rocks or sand grains.

Table 3.4 The impact of nitrite concentrations on the shedding operation.

Nitrite Concentration Range (mg/l)	Shedding System Impact
0.0-0.5	Safe operational range
0.5-3.0	Marginal operational range, moderate molting mortalities
3.0-10.0	Chronic mortality in molts, moderate premolt losses
> 10.0	Acute mortality, few successful molts, massive loss of premolts

If toxic nitrite concentrations are present during molting, crabs often die halfway out of their old shells, as they do when oxygen levels are low. Loss of molting crabs is one of the first indications of nitrite toxicity, which occurs if nitrite concentrations exceed 0.5 mg-N/l. Adverse impacts on intermolt crabs arise when nitrite concentrations exceed 3 mg-N/l. Intermolt crabs suffering from nitrite toxicity lose coordination and often roll over on their backs with their legs shaking uncontrollably. Nitrite concentrations above 10 mg-N/l can cause massive mortalities of all crabs.

3.5 Nitrate

Nitrate is the stable end product of the decompositional and nitrifying processes in a recirculating system. Virtually all nitrogen, except the inert nitrogen gas, added to the system, ends up as nitrate. As long as the biological filter remains well aerated, nitrate just accumulates in the recirculating system. Large concentrations of nitrate do not appear to have a toxic effect on aquatic organisms (Colt and Armstrong, 1979; Spotte, 1979).

3.6 Water Temperature

The water temperature in most recirculating shedding systems is controlled by ambient air temperatures. The shallowness of the crab holding tanks and the rapid circulation of water promote the transfer of heat into or out of the system's waters. Thus, the system's water temperature is typically within 2°F of the air temperature.

Water temperature is an important factor in the recirculating system because it controls the metabolic rate of all organisms in the system and the maximum amount of dissolved gases, such as oxygen, that the water can hold (Table 3.1). As temperature increases, the amount of oxygen contained in the water decreases while the rate that oxygen is consumed by the crabs and the bacteria increases. Thus, as temperature goes up, the dissolved oxygen levels in a system typically go down.

The optimum temperature for molting crabs in Louisiana appears to be about 77°F (25°C). At this temperature, the crabs molt rapidly with a high degree of success because the temperature is near their metabolic optimum while being cool enough to insure adequate oxygen. Below this temperature, the rate of molting slows, the crabs remain in the system longer, and the economic profitability of the system declines. Above this temperature, the crabs molt more rapidly but molting success declines as the temperature rises above their metabolic optimum. Also the crabs' shells harden faster, requiring that the shedding tanks be checked more frequently.

Although the optimum temperature for each shedding system may differ slightly because of differences in the temperatures of harvesting waters, temperature is a major factor when controlling the success and profitability of a shedding system. Commercial operators in Louisiana are concerned with maintaining cooler temperatures in the summer. Thus, systems are typically sheltered from direct sunlight and sumps are buried belowground to maintain a cool source of circulation water.

3.7 pH

pH is the measure of the concentration of hydrogen ion (H^+) in water. The pH scale ranges from 1 to 14. A pH of 7.0 is considered neutral while water with a pH below 7.0 is considered acidic. Alkaline waters have pH values above 7.0. Table 3.5 identifies the significance of various pH ranges. Natural seawater tends to be slightly alkaline with a pH of about 8.0. Brackish estuaries frequently have pH values less than 8.0, reflecting the influence of fresh water and the decay of organic matter in marshes. Thus, pH values of harvesting waters can vary significantly from location to location.

Marine organisms are usually adapted to a narrow pH range, though crabs are not particularly sensitive to pH variations between 6.5 and 8.0. Low pH values in a recirculating shedding system have an adverse impact on the bacteria in the biological filter. Low pH values can also increase the potential for increasing the dissolved metals level in a recirculating system. Even moderate levels of dissolved metals in the water can influence the taste of the soft crabs produced in the system.

The water purifying processes and respiration of animals in a recirculating system always tend to cause a decline in pH below the 8.0 normal for seawater. To prevent adverse impact from low pH values, recirculating systems should be designed and managed to maintain pH values above 7.0 and below 8.0. Above a pH of 8.0, moderate accumulations of un-ionized ammonia (NH_3) can cause problems with shedding crabs. Below a pH of 7.0, nitrifying bacteria in the biological filters can be inhibited and metal solubility from gravel in the biological filters or from pump impellers can pose potential problems.

3.8 Alkalinity

Alkalinity measures the ability of water to resist a drop in pH as a result of acid addition (Sawyer and McCarty, 1978). Alkalinity is determined by the amount of acid needed to reduce the pH of a water sample to 4.5. If large amounts of acid must be added, the alkalinity is high. Conversely, if the pH drops rapidly upon the addition of a small amount of acid, then the sample's alkalinity is low. A wide variety of chemicals in water can contribute to its alkalinity; therefore, alkalinity is expressed as equivalents of calcium carbonate ($CaCO_3$). Thus, a sample with an alkalinity of 150 mg-$CaCO_3$/l can resist a pH change as well as 150 milligrams of calcium carbonate per liter.

The principal chemical contributing to the alkalinity of a recirculating system with a maximum pH range between 6.0 and 8.3 is normally the bicarbonate ion (HCO_3^-). The bicarbonate ion interacts with dissolved carbon dioxide (CO_2) and carbonate ions (CO_3^-) through the carbonate alkalinity system to control the pH (Sawyer and McCarty, 1978). The carbonate ions dominate when the pH is high (>9.5), but in the presence of acid, carbonate ions absorb free hydrogen ions (H^+) to form the bicarbonate ion. The removal of these hydrogen ions controls the pH. Similarly, the bicarbonate ion can absorb a hydrogen ion when the pH drops below 8.0, as it is converted to dissolved carbon dioxide gas. The pH can be controlled by manipulating the levels of carbonate ions, bicarbonate ions, and carbon dioxide gas in a recirculating system.

Alkalinity control is commonly performed by using calcareous gravel in the biological filters, a method employed in submerged rock filter systems. The clam shell and dolomitic limestone recommended for these filters are composed of calcium carbonate. These media dissolve when the pH drops below 7.3 releasing carbonate ions which are rapidly converted to bicarbonate, thus stabilizing the pH. Systems with calcareous media rarely fall below pH 7.0. At this pH, the crabs are well protected from ammonia toxicity, but 7.0 to 7.3 is below the optimum pH for the nitrifying bacteria. This method of pH control also leads to long-term accumulations of calcium ions (Ca^{++}) in the water which is suspected of accelerating the hardening of soft crabs (Freeman et al. 1986).

Table 3.5 The relationship between pH and aquatic systems.

pH Range	Comment
9.0-10.0	Associated with algae blooms in natural water Un-ionized ammonia predominates; ammonia is acutely toxic Nitrifying bacteria inhibited Calcium bicarbonates and metals precipitate
8.0-9.0	Normal range for ocean water Ammonia toxicity can be a problem Optimum range for nitrifying bacteria
7.0-8.0	Normal range for marsh and estuary systems Optimum range for recirculating system operation Ammonium ion ($NH4^+$) predominates, ammonia toxicity rare Nitrification process mildly inhibited
6.0-7.0	Associated with marsh backwater areas Ammonium ion ($NH4^+$) predominates, ammonia toxicity rare Nitrifying bacteria severely inhibited Nitrite toxicity common Calcareous gravel and metals dissolve

pH control is also achieved by adding sodium bicarbonate ($NaHCO_3$) to the system. More commonly known as baking soda, sodium bicarbonate can be used to raise the pH. The baking soda adds bicarbonate ions to the water leaving only sodium (Na^+) as a cation residual, thus avoiding potential problems with calcium accumulation. This method of pH control may be required with the new sand filters since they typically contain noncalcareous sands as media.

The accumulation of dissolved carbon dioxide (CO_2) gas tends to lower the pH of a recirculating system, particularly if the alkalinity is low. In many cases, significant increases in pH can be achieved by simply increasing aeration rates in the system. The depression of pH by CO_2 accumulation occurs when a system is heavily loaded since both the crabs and bacteria release carbon dioxide into the water when they respire. The removal of the carbon dioxide from the water by aeration permits the bicarbonate ions to react more readily with the hydrogen ions in the system, thus raising the pH.

3.9 Salinity

Salinity is the measure of the amount of dissolved salts in water. Salinity is measured in parts per thousand, or "ppt" which indicates the ratio of the weight of salts in a sample against the weight of a unit volume of water. A water sample with a salinity of 5 ppt has five grams of salt in each liter of water (a liter of water weighs 1000 grams). A reading of 33 to 36 parts per thousand (ppt) is the normal value for seawater. Most recirculating crab systems have a lower salinity than seawater. The inland marshes along the Gulf Coast typically display salinities as low as 5 ppt, while crab systems associated with the bays tend to have salinities over 20 ppt.

Salinity in a recirculating system should be adjusted to that of the harvesting water, though an exact match is not necessary. Crabs do not appear sensitive to salinity differences of less than about 5 ppt between the harvesting water and the shedding system. A commercial marine salt mixture should be used to adjust salinity. Table 3.6 estimates the amount of salt that must be added to fresh water to obtain desired salinity levels. The principal salt in seawater is sodium chloride (NaCl), common table salt. However, synthetic sea salt mixtures contain a wide variety of other salts (Table 3.7) which can be important to marine organisms such as the crab. Table salt or rock salt does not contain all of these critical minerals and should not be used in these systems.

Evaporation of water from a recirculating system tends to slowly increase the salinity. However, if the sump and reservoir water levels are maintained by adding fresh water, the salinity will also remain constant. The addition of fresh water to compensate for water lost as a result of evaporation, spillage, or periodic filter cleaning will lower the salinity. Salinity must be periodically increased if these conditions exist.

Problems with salinity generally stem from one of two sources. The first is leakage within the shedding system, which removes dissolved salts that must be replaced. The addition of fresh water will decrease salinity unless additional salts are added at the same time. Thus, to minimize salt costs, recirculating systems must be watertight. The second problem stems from unexpected changes in the salinity of the harvesting water. Estuary systems typically show substantial increases in salinity in late summer and fall. Springtime salinity measurements of the harvesting area taken during system setup may be entirely inappropriate for late summer conditions.

Table 3.6 Sea salt quantities (in pounds) needed to adjust fresh water to the desired salinity level in a recirculating system.

System Volume (gallons)	Desired Salinity (ppt) 5	10	15	20	25	30	35
100	4	8	13	17	21	25	29
200	8	17	25	33	42	50	58
300	13	25	38	50	63	75	88
400	17	33	50	67	83	100	117
500	21	42	63	83	104	125	146
600	25	50	75	100	125	150	175
700	29	58	88	117	146	175	204
800	33	67	100	133	167	200	233
900	38	75	113	150	188	225	263
1000	42	83	125	167	208	250	292
1100	46	92	138	183	229	275	321
1200	50	100	150	200	250	300	350
1300	54	108	163	217	271	325	379
1400	58	117	175	233	292	350	409
1500	63	125	188	250	313	375	438
1600	67	133	200	267	333	400	467
1700	71	142	213	283	354	425	496
1800	75	150	225	300	375	450	525
1900	79	158	238	317	396	475	554
2000	83	167	250	333	417	500	584

Table 3.7 The major chemical components found in a typical synthetic sea salt (taken from King, 1972).

Compound	Symbol	Concentration (mg/l)
Chloride	Cl	18,400
Sodium	Na	10,200
Sulfate	SO_4^{-2}	2500
Magnesium	Mg	1200
Potassium	K	370
Calcium	Ca	370
Bicarbonate	HCO_3^-	140
Boric Acid	H_3BO_3	25
Bromide	Br	20
Strontium	Sr	8
Silicate	SiO_3	3
Phosphate	PO_4^{-3}	1
Manganese	Mn	1

3.10 Ion Balances

Like nitrate, other chemicals accumulate in a recirculating system over time. This gradual accumulation will change the salt balance in the system and can cause problems for a system operating in a closed recirculating format for extended periods. Crabs do not appear sensitive to minor changes in ion composition; however, there is little doubt that eventually changes in ion composition would adversely impact a shedding system operation. For example, toxic concentrations of heavy metals cause a number of harmful effects on aquatic organisms (Spotte, 1979). Using construction materials which contain heavy metals such as zinc, copper, or lead no doubt will eventually lead to a buildup of metal concentrations which can become toxic within a system.

Calcium levels in a recirculating system may be important to the crab, since the principal mineral in a crab's shell is calcium carbonate. High calcium levels may accelerate the rate at which a soft crab hardens its shell (Freeman et al. 1986) and substantial increases may interfere with the molting process itself. Calcium ion levels in a recirculating system with a submerged rock filter increase as the dolomitic limestone or shell in the biological filter dissolves. As noted earlier, the pH of a recirculating system tends to drop as the processes contributing to water purification produce hydrogen ions. When the pH drops to about 7.0, the hydrogen ions begin to react with the calcium carbonate. As the limestone dissolves, the hydrogen ions are removed and calcium ions are released into the water. This dissolution process protects the crabs from rapid drops in pH but releases calcium.

There have been no documented cases of difficulties attributed to shifts in ion composition or more specifically to calcium accumulation. But few, if any, reports from commercial operations of rapid shell hardening have been investigated. No problems with ion shifts have been observed in experimental or commercial systems monitored by the authors. Problems are avoided if the system water is replaced annually and proper materials are used for constructing a system.

3.11 Water Quality Guidelines

Table 3.8 presents safe operational ranges for selected water quality parameters used to monitor the basic operation of a recirculating system. These parameters were developed from the observation of both experimental and commercial operations over a five-year period. If all the parameters are within the specified ranges, the system will operate properly and there should be no difficulty in shedding crabs. Systems with water quality parameters falling outside the safe operational ranges may still operate successfully. The values presented in Table 3.8 merely reflect a safe range for conditions of actual operation.

If problems persist even though all the water quality parameters in Table 3.8 are within the specified limits, then the problems cannot be attributed to the basic operation of the recirculating system. Mishandling the crabs prior to their introduction to the system, for example, is unrelated to water quality, yet will cause poor molting success. Problems may also be caused by failure to observe a water quality parameter not discussed here. For example, inexperienced operators often fail to properly flush freshly fiberglassed components prior to use. Chemicals released as fiberglass cures are highly toxic to crabs. Even residual amounts of these chemicals cause molting losses. If the water quality parameters are within range, look elsewhere for the problem.

Table 3.8 Water quality guidelines for a recirculating system when used for a crab shedding operation.

Parameter	Recommended Range
Dissolved Oxygen	Above 5.0 mg O_2/l in holding trays Above 6.0 mg O_2/l in sump Waters leaving filters must contain above 2.0 mg-O_2/l
Total Ammonia	Below 1.0 mg (NH_3+NH_4)-N/l in holding trays
Nitrite	Below 0.5 mg NO_2-N/l in holding trays
Nitrate	Below 500 mg NO_3-N/l in sump
Temperature	75-80°F (24-27°C) in holding trays
pH	Hold between 7.0 and 8.0 for normal operation Hold between 7.5 and 8.0 during peak loading
Alkalinity	Above 100 mg $CaCO_3$/l at all times
Salinity	Match salinity of harvesting waters within 5 ppt

CHAPTER 4

MAJOR COMPONENTS OF A RECIRCULATING SYSTEM

The major components required for a closed recirculating system include holding trays, filters, a sump, a reservoir, screen boxes, and pumps. This section identifies each component, discusses the rationale used for designing these components, and presents a variety of ways to configure a successful recirculating system.

4.1 Holding Trays

The holding trays are designed to meet three objectives: (1) to hold a large number of crabs, (2) to prevent escape of the crabs, and (3) to provide easy access and viewing for the operator. The specific tray dimensions are not critical so long as these criteria are met.

The overall dimensions of a typical holding tray are 3 x 8 feet (Figure 4.1). This tray holds up to 150 crabs and is a size commonly used in the commercial industry. The 3-foot width permits the operator to reach easily across the tray and remove crabs. Trays should be placed at a convenient height for working and should also be well lighted to facilitate identification of molting crabs. If space is limited, a double-stacked system can be used with walkways between stacks for access to the upper trays. The tank sidewalls should be smooth and at least 12 inches high to prevent the escape of crabs. Molded fiberglass trays appear to be the most durable. Fiberglass-coated wood trays are relatively inexpensive to construct and can be used for several years before requiring replacement.

Rapid aeration of the trays, required to maintain a sufficient dissolved oxygen supply for the crabs, is accomplished by continually discharging water into the tray through a spray head at a 45-degree angle (Figure 4.2). Placing the spray head off center on the tank's drain end assures that the discharge will induce a moderate circulation pattern. A flowrate of 2.25 gpm (0.015 gpm/crab) through the spray head illustrated in Figure 4.2 will provide aeration and flushing of wastes for 150 crabs in a 3 x 8-foot tray (6.25 crabs/square foot). Experienced operators often place two spray heads in the tank, operating the second spray head during periods of peak loading or in hot weather to minimize dissolved oxygen deficiencies. The tray corners are removed or blocked off, as these areas create "dead zones" in the circulation pattern. Corners typically exhibit depleted dissolved oxygen supplies and can eventually cause mortalities if crabs are held in large numbers.

The tank drainage system consists of a 5 x 1.5-inch (inside diameter) PVC stand pipe. A 1/4-inch hole, drilled 3/4 inch from the bottom of the standpipe, induces automatic drainage of the tray should a power failure occur. Without the circulating flow, the crabs must be provided access to atmospheric air or they will suffocate. The standpipe can be removed to facilitate tray drainage during the off-season. A PVC female fitting cast directly into the tank bottom may be used to support the 1.5-inch standpipe, or threaded PVC couples may be fitted to existing tanks (Figure 4.3). The standpipe may be surrounded by a 4-inch collar with a slotted lower lip. This collar protects the overflow from being clogged by solids.

4.2 Biological Filters

This section presents three types of biological filters (submerged rock, upflow sand, and fluidized bed) that may be used to process wastes in the recirculating system. All three

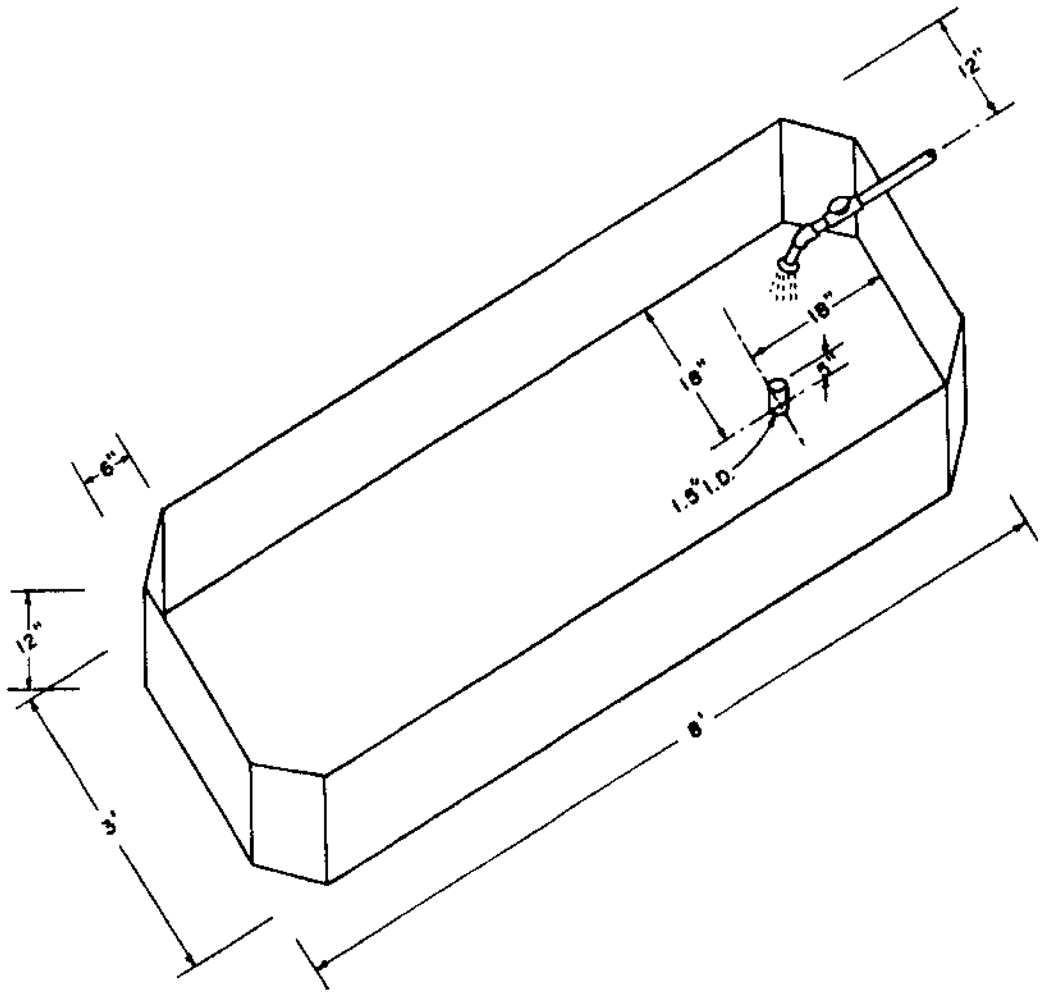


Figure 4.1 Typical configuration for a blue crab shedding tray capable of holding 150 crabs.

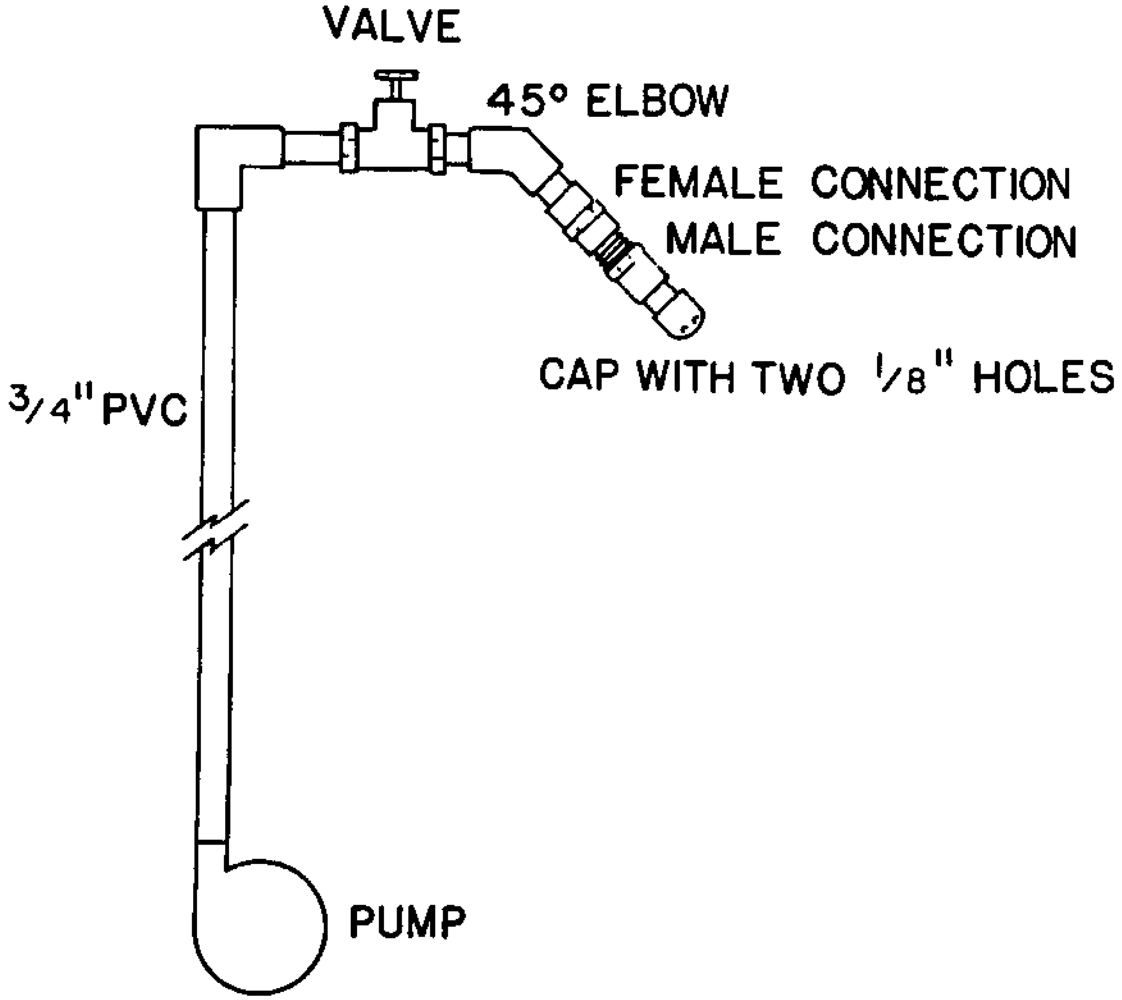


Figure 4.2 A spray head which provides aeration to a shedding tray so that the crabs will have adequate oxygen.

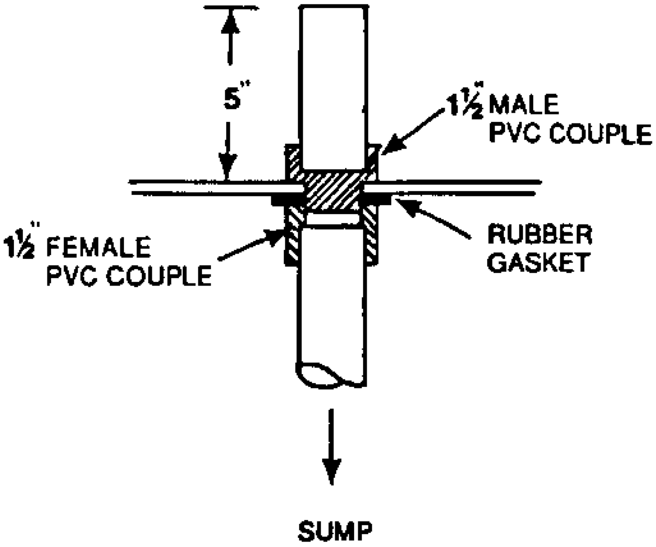


Figure 4.3 Detailed illustration of a standpipe used to drain a shedding tray.

filters are designed to cultivate populations of waste-consuming bacteria on the surface of the gravel or sand grains (Figure 4.4). Since the bacteria remain attached or "fixed" on the substrate surface, these filters are technically known as "fixed film" biological filters. Bacteria living in the thin film draw dissolved wastes, oxygen, and other required nutrients from the passing water. The rate at which bacteria consume waste is controlled by a wide variety of factors (Table 4.1). Filters are designed and managed to encourage the growth of a bacterial film which continually purifies the recirculating water. This bacterial film contains hundreds of bacterial types. The nitrifying bacteria require special attention since they remove (or oxidize) the toxic forms of nitrogen.

The importance of nitrogen in recirculating systems was previously discussed in Section 3.2 and illustrated in Figure 3.1. Two specific types (or genera) of bacteria required to process nitrogen through its toxic decay stages are Nitrosomonas and Nitrobacter. The Nitrosomonas bacteria live by converting toxic ammonia to toxic nitrite while the Nitrobacter bacteria live by converting toxic nitrite to nontoxic nitrate. Both genera of bacteria prefer to live in a fixed-film mode (attached to a substrate) removing ammonia and nitrite from the water as it passes through the filter. The bacteria are strict "aerobes," meaning they must have oxygen present to function. Furthermore, the bacteria are sensitive to both pH and temperature (Table 4.2).

Nitrifying bacteria have a slow growth rate. Consequently, about 30 to 40 days are required to establish a population of nitrifying bacteria in a biological filter. When a sudden increase in crab population (typically 25 percent or greater) occurs within the system, an additional two or three days are necessary for the established bacterial population to expand and accommodate the increase in waste load. Fortunately, once the nitrifying bacteria are established, they prove durable, occasionally slowing down when abused, but rapidly recovering when the adverse conditions are corrected.

The biological filter designs presented in the following sections provide a physical environment that favors growth of nitrifying bacteria. Proper system management (Section 6.0) is required if the bacterial populations within the filters are to remain healthy. A well maintained biological filter will purify the water so that the water quality does not interfere with the sensitive molting crabs.

4.3 Submerged Rock Filters

The submerged rock filter has been used successfully for maintaining water quality in recirculating shedding systems for several years. A typical filter consists simply of a calcareous stone or shell bed through which water circulates (Figure 4.5). The beneficial nitrifying bacteria coat the gravel, processing the wastes as the system water flows through the filter bed. Solid wastes settle into the spaces between the gravel and gradually decay. Dissolution of the calcium carbonate medium holds the pH at or above 7.0.

Carrying Capacity. The volume of the medium found in the filter bed and the amount of oxygen supplied by the water flowing through the filter bed control the carrying capacity of a submerged rock filter. Experimental studies and commercial observations have shown that 1 cubic foot of medium supports approximately 33 crabs. This volume contains sufficient surface area to support the bacterial films and contains enough void space between the gravel to store accumulated solids for an entire shedding season. The shape or depth of the bed is not critical so long as the water passes evenly through the bed. Most beds, however, are between 1 and 2 feet deep.

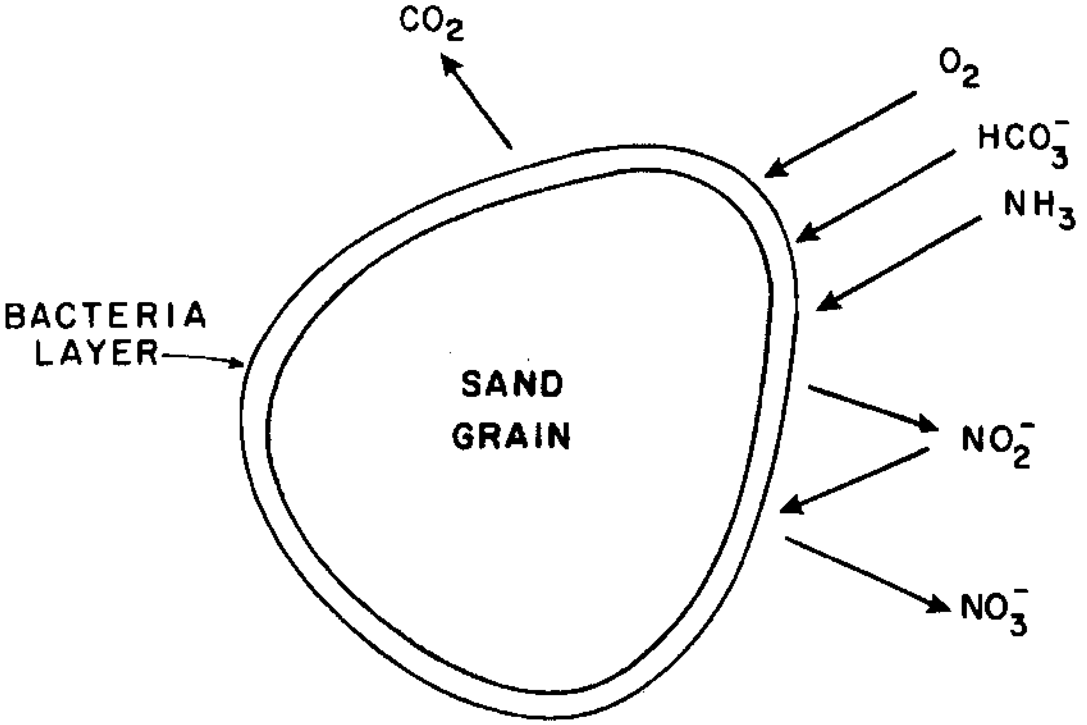


Figure 4.4 The bacterial film, coating the sand grain, actively removes and releases a variety of nitrogen forms from the recirculating water.

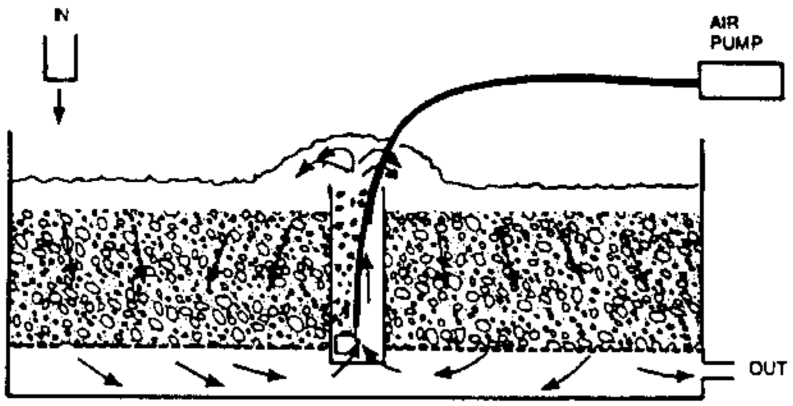
Table 4.1 Factors affecting the rate of waste consumption by fixed-film biological filters.

Factor	Importance
Waste Concentration	Higher waste levels permit rapid uptake of wastes into the film layer
Dissolved Oxygen Concentration	The bacteria require oxygen to function; waste degradation is reduced if dissolved oxygen levels fall below 2.0 mg-O_2/l
pH	Bacterial action is inhibited by low pH; sensitive populations are adversely affected by pH values below below 8.0; general inhibition occurs below 7.0
Flowrate	Wastes must be continually transported to the bacterial film; rapid flowrates provide for transport of wastes, assure good waste distribution within the filter bed, and induce turbulence that accelerates the uptake process
Media Size	Smaller substrates like sand have more surface area to support bacterial films
Temperature	Bacterial activity increases with temperature increases

Table 4.2 The effect of various water quality parameters on nitrifying bacteria.

Factor	Importance
Temperature	Optimum temperature is 25-30°C, growth slows at lower temperatures, inhibited by temperature below 20°C (Wild et al. 1971)
pH	Optimum pH at 8.3; severely inhibited by pH values below 7.0
Salinity	Not sensitive to salinity
Dissolved Oxygen	Maximum efficiency reported for dissolved oxygen concentrations above 3.0 mg-O_2/l, severe inhibition when concentrations fall below 2.0 mg-O_2/l
Alkalinity	Inhibition has been demonstrated when bicarbonate alkalinity falls below 80 mg-$CaCO_3$/l (Paz, 1984)
Miscellaneous	Sensitive to a wide variety of antibiotics and metal ions

AIRLIFT AERATION



RECYCLE AERATION

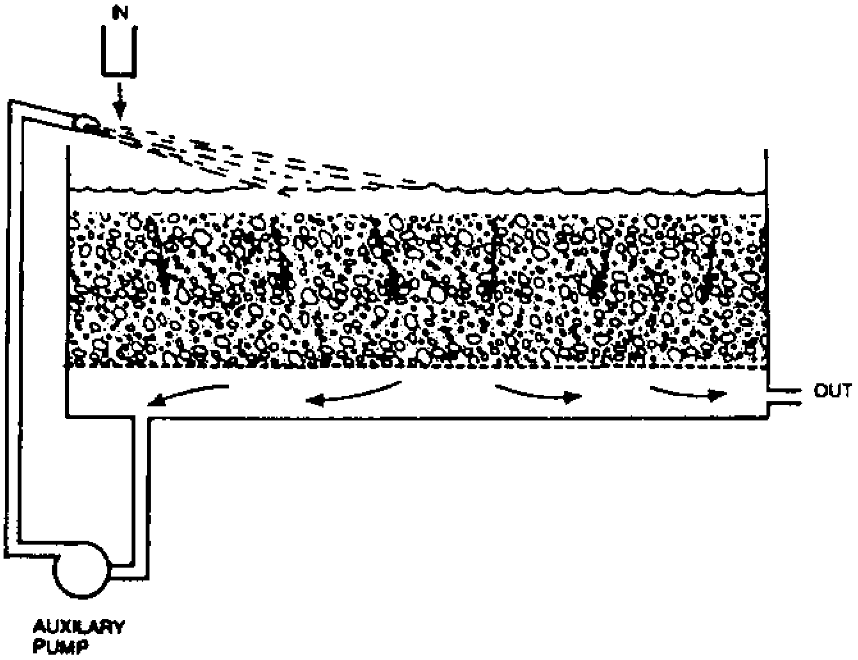


Figure 4.5 Submerged rock filters consist of a gravel or shell bed through which system water circulates. Performance is improved by increasing the oxygen supply with an airlift or recirculation line.

Dissolved Oxygen. Poor oxygen supplies caused failure of submerged biological beds in the early recirculating blue crab shedding systems (Manthe et al. 1984). Later research concluded that increasing the flowrate of well aerated waters through the filter bed would alleviate the problem (Manthe et al. 1985). Consequently, airlift tubes or reaeration spray heads (Figure 4.5) are now widely used in the industry. Either method is capable of completely eliminating oxygen deficiencies in the biological beds. Based on how much oxygen the nitrifying bacteria require for processing wastes from a single crab, calculations reveal that the minimum flowrate required for a submerged rock filter equals 0.02 gpm/crab. This design flowrate assumes that the water flowing into the filter (influent) contains at least 6 mg-O_2/l. Whether the flow comes directly from the trays, the sump, a recirculation line, or a combination of sources makes no difference. Experienced operators supply flow rates in excess of this minimum and periodically check the water leaving the filter (effluent) to assure a minimum dissolved oxygen concentration of 2.0 mg-O_2/l. This minimum concentration assures that the nitrifying bacteria's ability to convert the toxic crab wastes will not be inhibited.

Gravel Size. Designing a submerged rock filter requires selection of the medium. The two recommended media are a graded gray limestone (#67 or #57 grade) or small clam shells. In either case, the size of the gravel (or shell) should be between about 0.5 and 1.5 inches. A smaller medium tends to clog quickly as the solids accumulate while a larger medium lacks the surface area needed to support a large population of nitrifying bacteria. Full sized oyster shells are also commonly used, but are not recommended with the design guidelines presented here. An oyster shell bed is very resistant to clogging, capturing solids effectively, but has inadequate surface area to support the bacteria.

pH. As previously mentioned, the dissolution of the calcareous gravel or shell in the filter bed controls the pH in a submerged rock filter system. The pH level (7.0) maintained by this dissolution process is significantly below the optimum for the nitrifying bacteria. The design guidelines, however, compensate for this lower than optimum performance. If a noncalcareous media is used, then the pH must be controlled by other means. However, nitrification performance can be enhanced during periods of peak loading by raising the pH above 7.5 by adding sodium bicarbonate and/or through supplemental aeration to remove carbon dioxide.

Filter Design. Submerged rock filter systems are commonly designed for closed recirculation systems. That is, they are designed to run an entire season without discharging water. Fresh water must be added periodically to compensate for evaporation or spillage but, otherwise, the same water is reused for months. Sea salts are mixed at the beginning of the season to obtain the desired salinity. Only minor adjustments may be required during the course of a season.

Table 4.3 summarizes the relationship between filter volume, flowrates, and crab carrying capacity for a variety of system sizes utilizing a submerged rock filter. The required filter volume is easily calculated for any system based on the following relationship:

$$V = 0.03 * N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

where,

V = the volume of gravel or shell in the filter bed (ft^3), and
N = the number of crabs in the system (the carrying capacity).

Table 4.3 Submerged rock filter medium volumes and flows for a variety of soft crab shedding systems.

Trays[1]	Carrying Capacity (crabs)	Filter Volume (ft^3)	Flowrate (gpm)
1	150	4.5	3.0
2	300	9.0	6.0
3	450	13.5	9.0
4	600	18.0	12.0
5	750	22.5	15.0
6	900	27.0	18.0
7	1050	31.5	21.0
8	1200	36.0	24.0
9	1350	40.5	27.0
10	1500	45.0	30.0
11	1650	49.5	33.0
12	1800	54.0	36.0

[1] assumes 3 x 8-foot trays.

Similarly, the required flowrate through the filter can be calculated by Equation 4.2:

$$Q = 0.02 * N \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

where,

Q = the minimum flowrate through the submerged rock filter (gpm).

The actual dimensions (bed depth, length, and width) of the filter are not critical. Submerged rock filters employing #67 gray limestone or clam shells that are sized with Equation 4.1 and supplied the aerated flow designated by Equation 4.2 will be sufficient to purify wastes regardless of their actual shape. Figure 4.6 illustrates a submerged rock filter which has been placed in a spherical 1000-gallon sump. At least 18 cubic feet of the medium were placed over the underdrain to produce a filter/sump combination capable of supporting approximately 600 crabs. This can be modified and scaled down to a "trash-can" filter (Figure 4.7). These small filters are popular with individuals interested in molting crabs for private consumption. A 32-gallon plastic trash can filter equipped with a PVC underdrain system can provide treatment for approximately 75 crabs. These filters can be connected in series to support a greater number of crabs.

4.4 Upflow Sand Filters

The upflow sand filter consists of a coarse sand bed through which water passes upward at a slow rate. Compared with the submerged rock filter, the sand grains have a greater surface area for supporting the nitrifying bacteria and are very effective at capturing suspended solids entering the filter. However, these sand beds contain little void space for the storage of solids and must be periodically cleaned by expanding the bed to release the solids or the sand bed will clog.

Operation. Figure 4.8 illustrates a pressurized upflow sand filter constructed from 4-inch (interior diameter) clear acrylic pipe and common PVC fittings. Water flows into the bottom of the column, up through the underdrain, a 3-inch support bed of gravel, and a bed of sand. The rate at which the water is forced up through the sand bed controls the filter's operation. The sand bed remains packed, resting on the gravel bed, during normal low flow operation. Solids entering the bed are captured and dissolved wastes are consumed by the bacteria attached to the sand grains. The water leaving the filter surface is clear, free of suspended solids, and contains low concentrations of dissolved waste. This clean water is discharged into the sump for recirculation through the holding trays.

As the filter operates, solids accumulate within the sand bed and the bacterial film thickens, gradually restricting flow through sections of the bed. This flow restriction causes a pressure buildup under the bed. Eventually, this pressure increase results in sand boil formations which occur within a small section of the bed, allowing the water to rapidly bypass the sand, thereby ending the filter's effective mode of operation. To re-establish normal operation, the accumulation of waste solids and excess bacterial films must be removed. This removal of wastes is accomplished by expanding the filter bed.

During the expansion operation, the flowrate is increased through the bed so the individual sand particles are lifted and suspended in the water column by the high water velocity. Precise setting of the expansion flowrate will lift the sand bed without washing the sand out of the column. The abrasive action of the sand particles hitting each other as the sand expands shears the excessively thick bacterial films and leads to the release of the

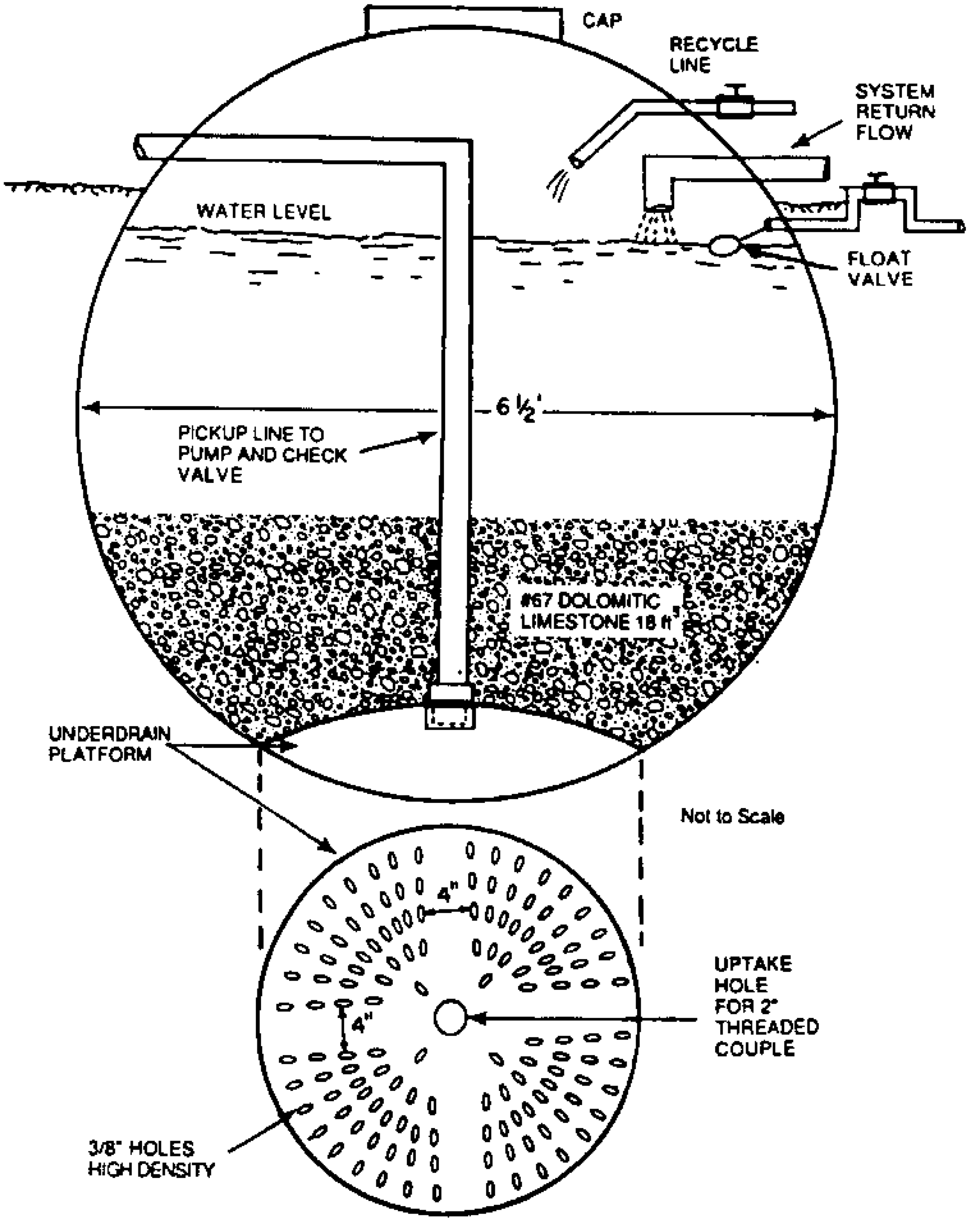


Figure 4.6 A globe-shaped sump/submerged rock filter combination designed to provide dilution volume and filtration for approximately 600 crabs.

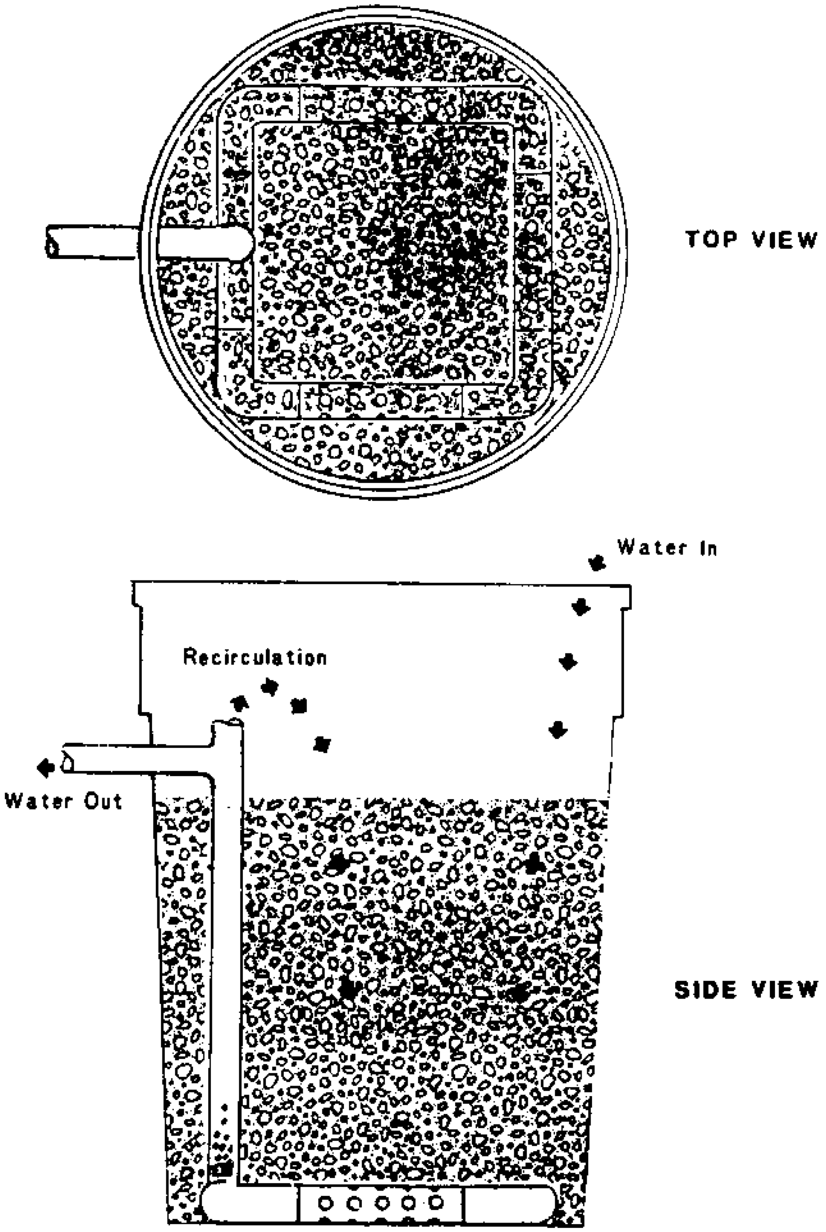


Figure 4.7 A submerged rock filter that has been designed to fit into a 32 gallon trash can with filtration capacity to support 75 crabs.

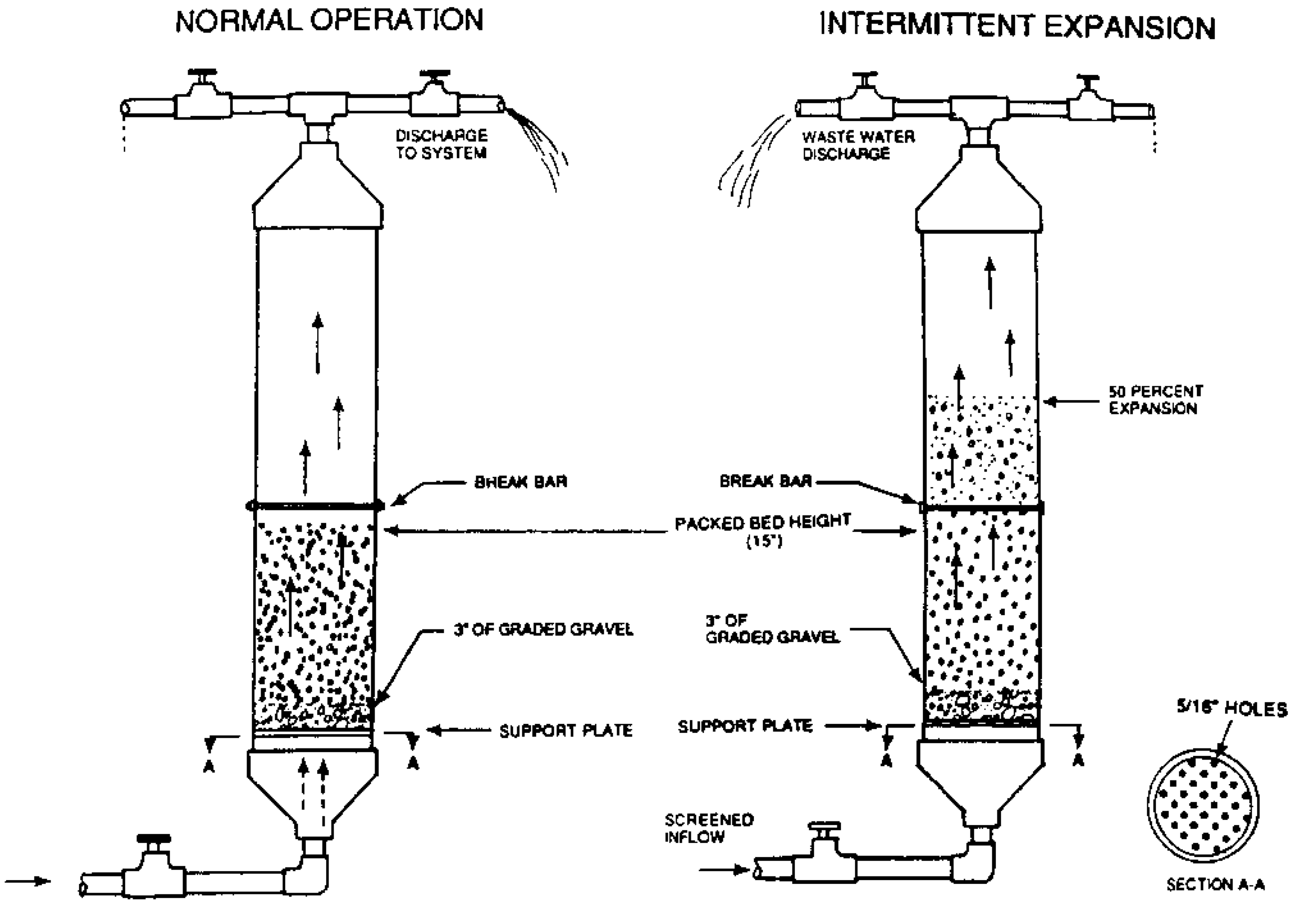


Figure 4.8 The two modes of operation for a pressurized upflow sand filter constructed from common PVC pipe and fittings.

accumulated solid wastes. The abraded bacterial biomass and solid wastes have a lower density than the sand and are washed out of the filter. The water leaving the filter during expansion is very dirty, with a high solids content. These waters are directed away from the sump to prevent reentry of these wastes to the recirculation system.

The physical capture of solids and their removal with the upflow expansion wash eliminates over 50 percent of the wastes produced in the recirculating system. In addition, the upflow sand filter serves as an effective biological filter supporting a large population of nitrifying bacteria. The filter's efficiency is limited only by the frequency of expansion and the rate at which wastes (and oxygen) are transported into the filter bed. The filter design guidelines presented here are intended to maximize the upflow sand filter's effectiveness.

Filter Design. Designing an upflow sand filter requires knowledge of the expansion characteristics of the sand used in the filter bed. Flowrates for expansion studies are called "fluxrates" and are expressed as gallons of flow per unit area of filter surface area (gpm/ft^2). Thus, a fluxrate of 3 gpm/ft^2 is equivalent to a flow of 3 gallons per minute through a square filter that has sides of 1 foot (height is not considered).

At lower fluxrates, the sand's weight exceeds the ability of the water to lift the bed, thus the filter sand remains packed. As the fluxrate increases, the water lifts the sand particles causing expansion of the filter bed. The amount of bed expansion is expressed as a percent of the original bed height. Thus, a 12-inch sand bed at 50 percent expansion has increased in height to 18 inches.

Table 4.4 presents the relationship between fluxrates and expansion for three commercially available sands. Several factors affect the relationship between fluxrates and percent expansion (Table 4.5). Fluxrates must be determined experimentally for each type of sand. Coarse sands are recommended for use in upflow sand filters since they tolerate higher fluxrates than fine sands without expanding. These higher fluxrates allow a higher rate of solids removal and increase the filter's maximum nitrification capacity by increasing the oxygen supply. However, the coarse sands also demand a greater fluxrate for expansion purposes, increasing the pumping requirements.

The design of upflow sand filters requires a quantitative appreciation of the hydraulic behavior of sands subject to expansion and biological film development. Although upflow sand filters can be configured in a wide variety of shapes with a wide variety of sands, the individual operator cannot anticipate the problems that can occur with an innovative configuration. Operators who wish to utilize these filters for commercial production are advised to follow the design recommendations in this manual precisely, copy a working upflow sand filter, or obtain a commercially produced upflow sand filter. Changes that appear small can severely affect the operational behavior of an upflow sand filter.

Figure 4.9 presents a generic design for an upflow sand filter compatible with the requirements of small commercial operators. Filters in this configuration have been subject to commercial testing by the authors and seem to function quite well. This filter box has a dual diffuser system on the bottom. A 2-inch input line feeds water into a diffuser pipe of similar size (perforated on the bottom side only), which forces inflowing water toward the filter bottom. This design prevents the momentum of the inflowing water from creating a zone of high pressure on the wall opposite the input line. Secondly, the support plate (Figure 4.9, Section A-A) contains equally spaced holes to assure even distribution of the upflowing water through the sand bed.

Table 4.4 The relationship between fluxrates and percent expansion for three commercially available sand grades for clean, washed, 15-inch deep filter beds.

	Fluxrate (gpm/ft²)		
Percent Expansion	Medium Filter Sand[1]	Coarse Filter Sand[2]	Crushed Dolomite[3]
0[4]	9	14	25
25	34	44	75
50	49	65	99
75	62	79	119
100	78	96	133

[1] 0.84-1.68 mm filter sand graded to pass a #12 mesh and retain on a #40 mesh screen, often used for sand blasting.

[2] 1.19-2.38 mm filter sand, graded to pass a #8 mesh and retain on a #16 mesh screen, often used for sand blasting.

[3] 4.76-7.93 mm crushed dolomitic limestone, graded to pass a 5/16 inch mesh and retain on a #4 mesh screen, often used for gravel in salt water aquariums.

[4] Maximum flow without bed expansion.

Table 4.5 Factors affecting the relationship between flux rate and percent expansion of sand beds.

Factor	Impact
Grain Size	Fluxrates required to expand beds decrease with decreasing sand size
Shape	Rounded sands expand more readily than crushed angular sands
Density	Sands of heavier minerals require higher fluxrates to expand than those of lighter minerals
Bed Depth	Deeper beds require less flux but higher pressures to achieve expansion
Bacterial Growth	Growth of bacterial films on sand particles increases their effective size without increasing their weight and thus they expand more readily

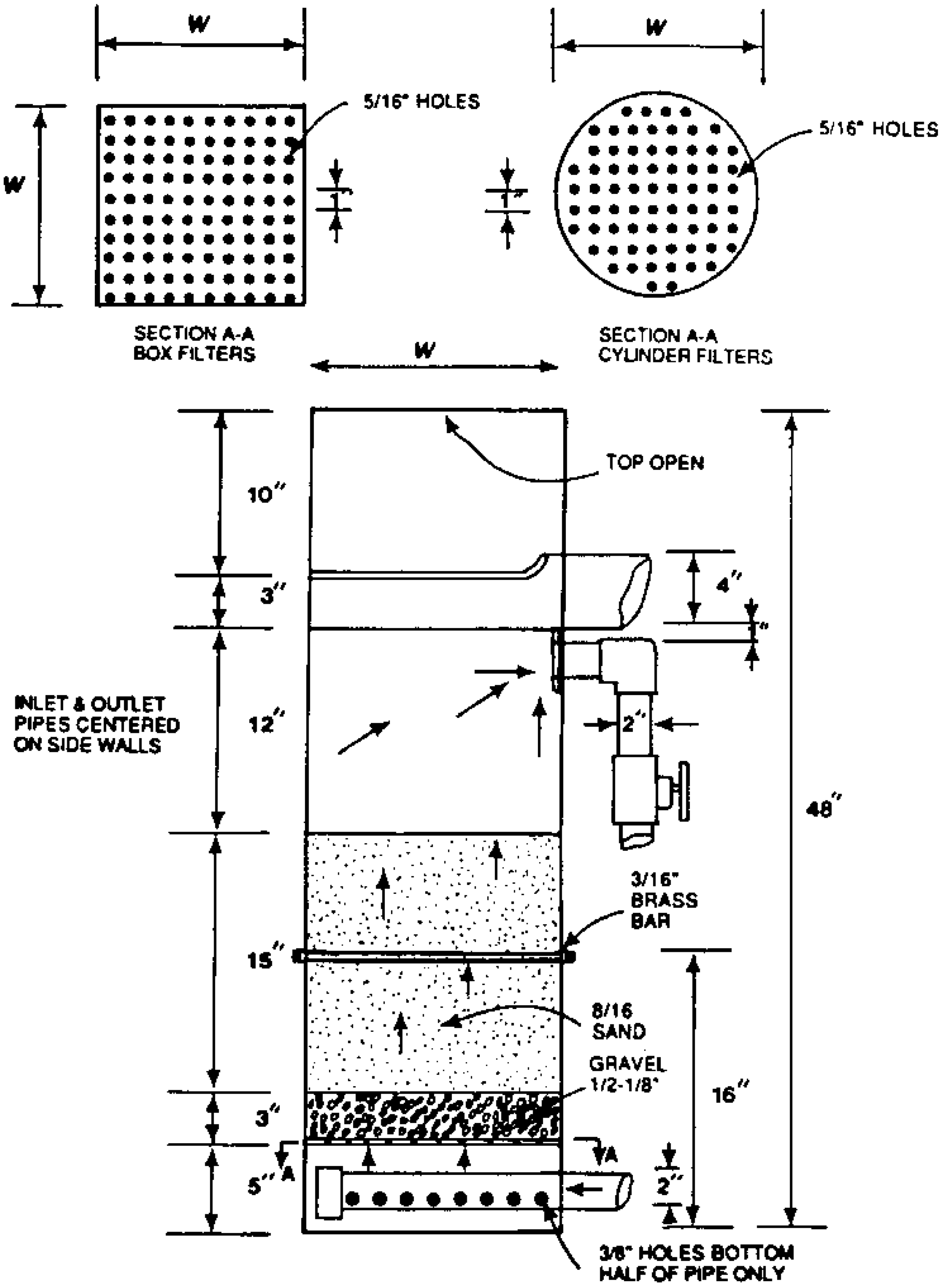


Figure 4.9 Generalized diagram of an open-top upflow sand filter for widths, W, ranging from 10 to 20 inches.

A 3-inch gravel bed placed over the support plate prevents the sand from falling through the holes when the flow is stopped. The gravel bed should contain a mixture of gravel ranging from 1/2 to 1/8 inch in diameter. A 15-inch bed of coarse (8/16) filter sand rests on the gravel bed surface. During normal operation, the valve on the 2-inch discharge line is left open. Waters passing through the sand bed and through this discharge line are directed back to the reservoir or sump. During the expansion cycle the valve on the 2-inch discharge line must be closed and the fluxrate through the bed increased to induce a 50 percent expansion of the bed.

The sand grains in the filter bed have a tendency to stick together during the initial stages of expansion. A brass "break" bar, installed in the filter column, assures that the lower bed section breaks up so it will not be forced in a piston-like manner into the overdrain pipe. All wash water is discharged through the 4-inch overflow pipe out of the system for further treatment or discharge. The 4-inch overflow pipe, extending across the filter, has the top inch sliced off, forming a weir to assure even flow distribution during expansion. The filter top is generally left open, providing the operator with access to the sand bed. Expansion can be verified visually or by probing the bed with a pole. The frequency and duration of expansion can be determined by checking for sand boils and by directly observing the solids content of the wash water.

The upflow sand filter can be constructed as a square box or a cylinder without altering the specified dimensions. The carrying capacity and flow requirements, however, do vary. Table 4.6 and Table 4.7 present the critical operational parameters for the square and cylindrical filters, respectively. Experimental estimates indicate that an upflow sand filter with a bed of coarse (8/16) filter sand will support approximately 750 crabs per cubic foot of sand. Thus, the carrying capacity is based on the volume of sand held in each filter.

Design flowrates for upflow sand filters must consider the bacterial film which will develop and grow on the sand media. Experimental observations, based on the coarse (8/16) filter sand, indicate that these flowrates are approximately two-thirds that observed with a clean sand. Thus, the normal required flowrate is computed as 67 percent of the maximum fluxrate without expansion (Table 4.4) times the surface area of support plate. The flowrate required for 50 percent expansion is computed without correction since biological film development does not significantly affect the expansion characteristics of the coarse (8/16) filter sand once the bed has been expanded.

The coarse (8/16) filter sand was selected for design purposes in this manual because the sand permits a relatively high fluxrate without expansion (14 gpm/ft^2) and effectively abrades biological film accumulations during cleaning. The fluxrate required to achieve the recommended 50 percent expansion (65 gpm/ft^2) can be matched with the pumping requirements for the balance of the recirculation system. The sizing of inflow pipes and discharge lines, as well as the space provided for expansion in the generic upflow filter design, were specifically selected for this sand. Using filter sands other than 8/16 in size will alter the hydraulic requirements for normal operation and expansion, thereby invalidating the design assumptions. Thus, the dimensions presented in Figure 4.9 are recommended only for use with the specified 8/16 filter sand.

4.5 Fluidized Bed Filters

<u>Operation</u>. The fluidized bed filter (Figure 4.10) consists of a sand bed which is continuously expanded (fluidized) by a constant upflow of water. Typically, fluidized bed filters are maintained between 25 and 100 percent expansion. The turbulent environment

Table 4.6 Carrying capacities and operational flows for box-shaped upflow sand filters using 8/16 filter sand in the configuration illustrated in Figure 4.9.

Filter Diameter (in)	Sand Volume (ft^3)	Carrying Capacity (crabs)	Normal Flow (gpm)	Expansion Flow (gpm)
10	0.86	650	7	45
11	1.1	790	8	55
12	1.3	940	9	65
13	1.5	1100	11	76
14	1.7	1280	13	88
15	2.0	1470	15	102
16	2.2	1670	17	116
17	2.5	1880	19	130
18	2.8	2110	21	146
19	3.1	2350	24	163
20	3.5	2600	26	181

Table 4.7 Carrying capacities and operational flows for cylindrical upflow sand filters using 8/16 filter sand in the configuration illustrated in illustrated in Figure 4.9.

Filter Diameter (in)	Sand Volume (ft^3)	Carrying Capacity (crabs)	Normal Flow (gpm)	Expansion Flow (gpm)
10	0.7	510	5	35
11	0.8	620	6	43
12	1.0	740	7	51
13	1.2	860	9	60
14	1.3	1000	10	69
15	1.5	1150	12	80
16	1.7	1310	13	91
17	2.0	1480	15	102
18	2.2	1660	17	115
19	2.5	1850	18	128
20	2.7	2050	20	142

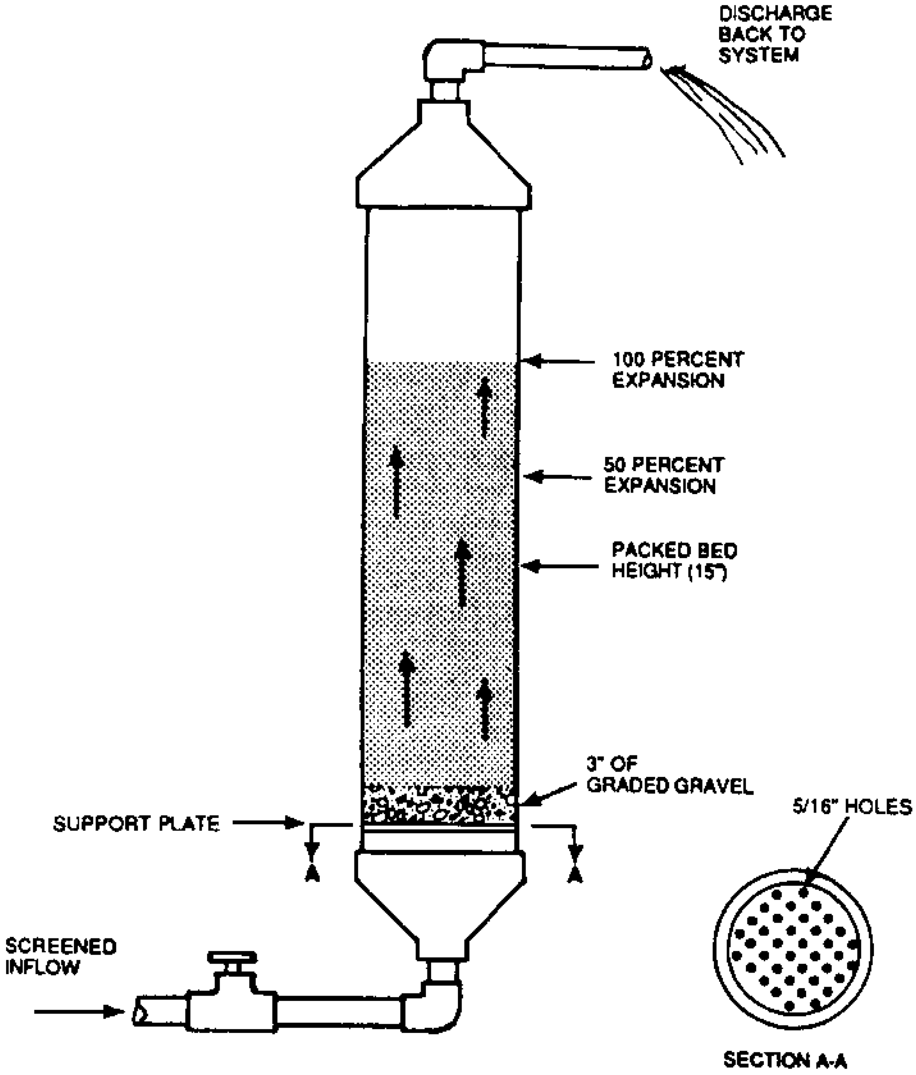


Figure 4.10 A fluidized bed is continously operated at 50 to 100 percent expansion to assure suspension of the entire sand bed.

and rapid transport of oxygen and dissolved wastes through the filter favor bacterial growth. Waste conversion rates and bacterial growth are very rapid. The sand particles increase in diameter as the bacterial layer around the sand particles thickens. The dynamic rolling of the sands assures full utilization of the bed. During expansion, the particles bounce around in the bed continuously striking the filter walls or other sand particles. This mildly abrasive environment continuously wears off the bacterial slime layer around the sand particles, thereby eliminating any clogging problems. The fluidized bed cannot hold solids finer or lighter than the sand particles, so sheared biomass and solids from the shedding system pass out of the filter. The bed is self-cleaning and requires no routine maintenance.

Because the fluidized bed operates in a turbulent environment, the filter has no capacity to remove suspended solids from the recirculating system. In fact, solids are continually generated since the growing bacterial biomass eventually passes through the filter bed as a result of abrasive action. Consequently, the fluidized bed must be complemented by a filter capable of capturing and/or removing solids in recirculating systems. Thus, in most applications, the fluidized bed is accompanied by an upflow sand filter to assure complete water treatment. The bed can also be used to upgrade the nitrification capabilities of an existing treatment system.

Filter Design. Figure 4.11 presents a generic drawing for the design of an unpressurized fluidized bed. An unpressurized (or open) fluidized bed closely resembles the design of an upflow sand filter (Figure 4.9). The fluidized beds, however, use only the expanded mode of operation and require only one large drain line. A brass "break" bar placed at the bed's surface alleviates packing in the event of a pump shutdown. The carrying capacity of a fluidized bed exceeds (1000 crabs/ft^3) that of an upflow sand filter of the same size, but the expansion flows for the fluidized beds in both square (Table 4.8) and cylindrical (Table 4.9) shapes are substantially higher than the corresponding upflow sand filters.

Although the open, unpressurized configuration presents the operator with the advantages of easy access to the sand bed, pumping costs associated with keeping a large bed expanded continuously are high. Recognizing that only a small pressure drop occurs across a bed, pressurized fluidized beds (Figure 4.12) can be placed in series with the distribution manifold for the spray heads in the holding trays (see Figure 5.5). This configuration substantially reduces the overall flow requirements for the recirculating system.

Pressurized filters must be designed to withstand the maximum (or shut off) pressure that can be produced by the recirculating system's pump. By using a pressure relief valve on the distribution manifold (which feeds the fluidized sand filter) this maximum pressure can be limited. The generic filter series presented in Figure 4.12 should be fabricated from PVC, clear PVC, or acrylic piping with known pressure ratings. The translucent or clear piping allows the operator to easily set flowrates and observe the degree of biological film development within the filters. Table 4.10 presents the carrying capacity for a variety of cylindrical filters. Square box filters are not recommended since this configuration does not resist pressurization forces.

4.6 Biological Filter Selection

Submerged Rock Filter. The most commonly employed filter in the Gulf region is the submerged rock filter. Original designs (Perry et al. 1982) have been greatly uncomplicated to the point that this filter consists simply of a bed of small calcareous rocks

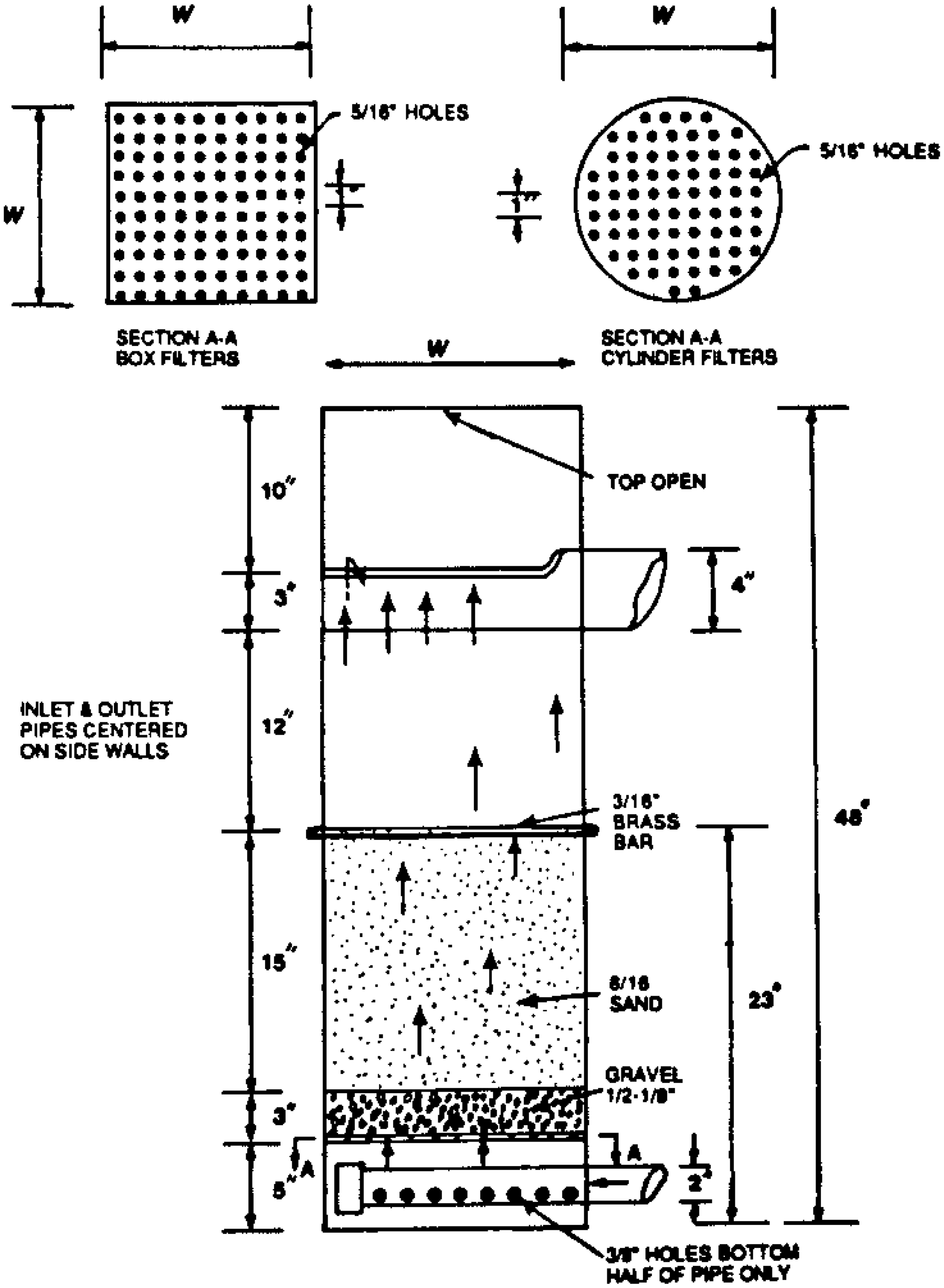


Figure 4.11 Generalized diagram of an open-top fluidized bed that can be used when pressurization of the filter is not required.

Table 4.8 Carrying capacities and operational flows for box-shaped fluidized bed filters using 8/16 filter sand in the configuration illustrated in Figure 4.11.

Filter Width (in)	Sand Volume (ft^3)	Carrying Capacity (crabs)	Expansion Flow (gpm)
10	0.9	900	45
11	1.1	1100	55
12	1.3	1300	65
13	1.5	1500	76
14	1.7	1700	88
15	2.0	2000	102
16	2.2	2200	116
17	2.5	2500	130
18	2.8	2800	146
19	3.1	3100	163
20	3.5	3500	181

Table 4.9 Carrying capacities and operational flows for cylindrical fluidized bed filters using 8/16 filter sand in the configuration illustrated in Figure 4.11.

Filter Diameter (in)	Sand Volume (ft^3)	Carrying Capacity (crabs)	Expansion Flow (gpm)
10	0.7	700	35
11	0.8	800	43
12	1.0	1000	51
13	1.2	1200	60
14	1.3	1300	69
15	1.5	1500	80
16	1.7	1700	91
17	2.0	2000	102
18	2.2	2200	115
19	2.5	2500	128
20	2.7	2700	142

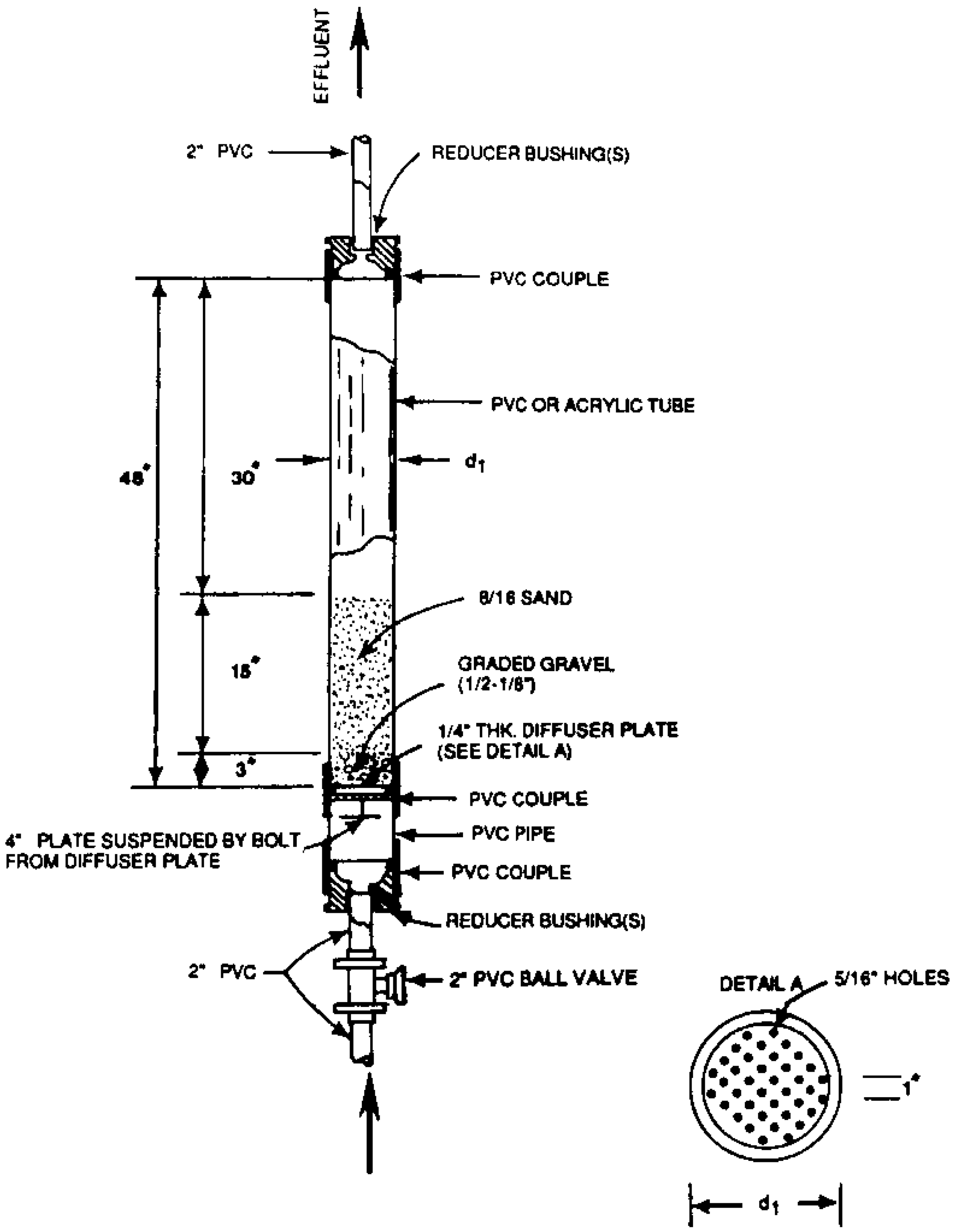


Figure 4.12 Pressurized fluidized beds are operated in series with the aeration heads in the trays to minimize the size of the circulation pumps.

Table 4.10 Carrying capacities and operational flows for cylindrical pressurized fluidized bed filters using 8/16 filter sand with the configuration illustrated in Figure 4.12.

Filter Diameter (in)	Sand Volume (ft^3)	Carrying Capacity (crabs)	Expansion Flow (gpm)
4	0.11	110	6
6	0.25	250	13
8	0.44	440	23
10	0.68	680	36
12	1.0	1000	51

or shells through which water rapidly circulates. The large amounts of dissolved oxygen required by the bacteria in a submerged rock filter result from the decay of captured solids, the oxidation of dissolved wastes, and the degradation of the bacterial biomass that grows in the filter. Thus, the most popular submerged rock filter designs employ a recirculating line which assures oxygen supply during peak loading.

Studies have determined that the maximum carrying capacity of a submerged rock filter is controlled by filter clogging or by the filter's inability to maintain the system pH at a level for efficient nitrification (Manthe et al. 1985). Under experimental conditions, the submerged rock filters have been successfully loaded with capacities of 50 crabs per cubic foot of rock. Generally, however, a volumetric loading capacity of 33 crabs per cubic foot of filter medium has been used as a design criterion, providing the operator with some margin of safety.

The principal advantage of the submerged rock filter lies in its passive nature. The processes of solids capture and reduction, nitrification, and pH control are balanced. Consequently, the filter can be operated for an entire shedding season without maintenance assuming that no clogging takes place. The materials required for constructing a submerged rock filter are readily available to the commercial fisherman. The pumping requirements are compatible with those required for maintaining adequate oxygen levels in the tanks holding the crabs.

The submerged rock filter is limited by its low volumetric carrying capacity. The filters are very bulky. Thus, for larger shedding facilities, the required size of a submerged rock filter can become prohibitive. This disadvantage is partially mitigated by placing the rock filters in the sump or reservoir. Annual maintenance requires that the filter be dug up once a year to wash the medium and remove accumulated solids.

Upflow Sand Filter. The upflow sand filter is the best general purpose filter tested by the authors in over five years of research on recirculating systems. The filter is robust, rapidly adjusting to changes in loading, while water clarity remains consistently superb. The recommended carrying capacity for an upflow sand filter exceeds that of the submerged rock filter by over 20 times. The nitrification power of the upflow sand filter reflects two major factors. First, the intermittent removal of bacteria and trapped solids from the filter bed significantly reduces the amount of decaying material in the recirculating system. Second, the oxygen demand in the upflow sand filter is only one-third that of the submerged rock filter. This means that two-thirds of the wastes, either excreted by the crabs as solids or created by bacterial growth, are physically removed from the system. Wastes flushed from the system place no demands on the system. Consequently, aeration requirements per crab for the filter are significantly reduced. Likewise, competition among bacterial populations for substrate space is lessened. Finally, the buildup of dissolved waste products (nitrate) is significantly slowed.

The major disadvantage of the upflow sand filter is the requirement for active management. The filter must be cleaned (expanded) at least once a day to prevent the bed from caking as the bacterial slime layers from different sand particles tend to grow together. Management operations also include pH monitoring and the addition of sodium bicarbonate. Failure to perform these routine operations quickly leads to filter failure. The design of upflow sand filters is more complicated than that of the submerged rock filters. Flowrates, both for normal operation and cleaning, must be compatible with the sand selected for the filter bed. In addition, filter dimensions must be carefully selected to assure that oxygen demands are met under normal operation and to guarantee that the required flowrates are compatible with the recirculation pump.

Fluidized Bed Filter. The fluidized sand filter is compact, easy to construct, and virtually maintenance free. The filter provides excellent control of nitrite and ammonia in a recirculating system and rapidly responds to shock loadings. The filter's ability to reduce nitrite levels exceeds that of both the submerged rock filter and the upflow sand filter. The recommended carrying capacity for the fluidized bed (1000 crabs/ft^3) is greater than that of the upflow sand filter and over 30 times that of the submerged rock filter. The filter's condition can be easily determined since the sand increases in size and turns light brown with a bacterial increase.

Fluidized sand beds perform reliably up to the point of failure. Failure points are very predictable since the operator can observe the filter as it "gels up" or clogs under excessive loading. Fluidized beds are self-cleaning and can even recover within a few days after reaching a failure point. Filters are not particularly sensitive to the selection of sand size or flowrates. Filters operating at 50 percent expansion function, as well as fully expanded beds, provided maximum loadings are not approached.

Three main disadvantages occur when using the fluidized bed filter in a recirculating system. The first involves the filter's inability to capture solids. The fluidized bed is a specialty filter, meaning that the filter is best used when complementing a filter that can remove solids. The filter does not have the "stand alone" capabilities of the submerged rock filter. The second disadvantage involves the filter's inability to maintain adequate pH levels. Fluidized sand beds require the addition of sodium bicarbonate to assure that bicarbonate and pH levels are compatible with the needs of the nitrifying bacteria. And, finally, the fluidized bed filter requires high flowrates to maintain its continuous mode of operation. For example, the fluidized bed requires five times as much flow as an upflow sand filter to support an equivalent number of crabs.

A very effective filtration system can be configured if an upflow sand filter (for solids removal) and a fluidized sand filter (for nitrification) are combined. The authors believe this combination will replace the submerged rock filter as the preferred treatment method in Louisiana's recirculating soft crab shedding industry. The most apparent advantage of utilizing these new filters is their small size which has become an apparent need for most operators. More importantly, the combination of fluidized bed and upflow sand filter will out-perform a properly designed submerged rock filter. Shock loading has less impact on these systems, and peak nitrite levels associated with such disturbances are greatly reduced. Submerged rock filters will, however, remain popular for smaller systems that do not warrant the increased management demands of the two sand filters.

The fluidized bed and upflow sand filters also appear ideal for nitrification control in calcium-free systems that have been proposed (Freeman et al. 1986) to extend the hardening time for soft crabs. If a noncalcareous sand is used as a medium, the sand filters will not contribute or consume calcium. Calcium levels in the system can then be precisely controlled through chemical addition.

4.7 Sumps and Reservoirs

Sumps and reservoirs hold the bulk of the water in a recirculating shedding system. Operators should understand the conceptual functions of sumps and reservoirs even though many systems employ a single tank to perform both functions.

Sumps. The sump (Figure 4.13) serves as a collection point for water returning from the holding trays and filters and provides a source of water for the pump intake. The sump

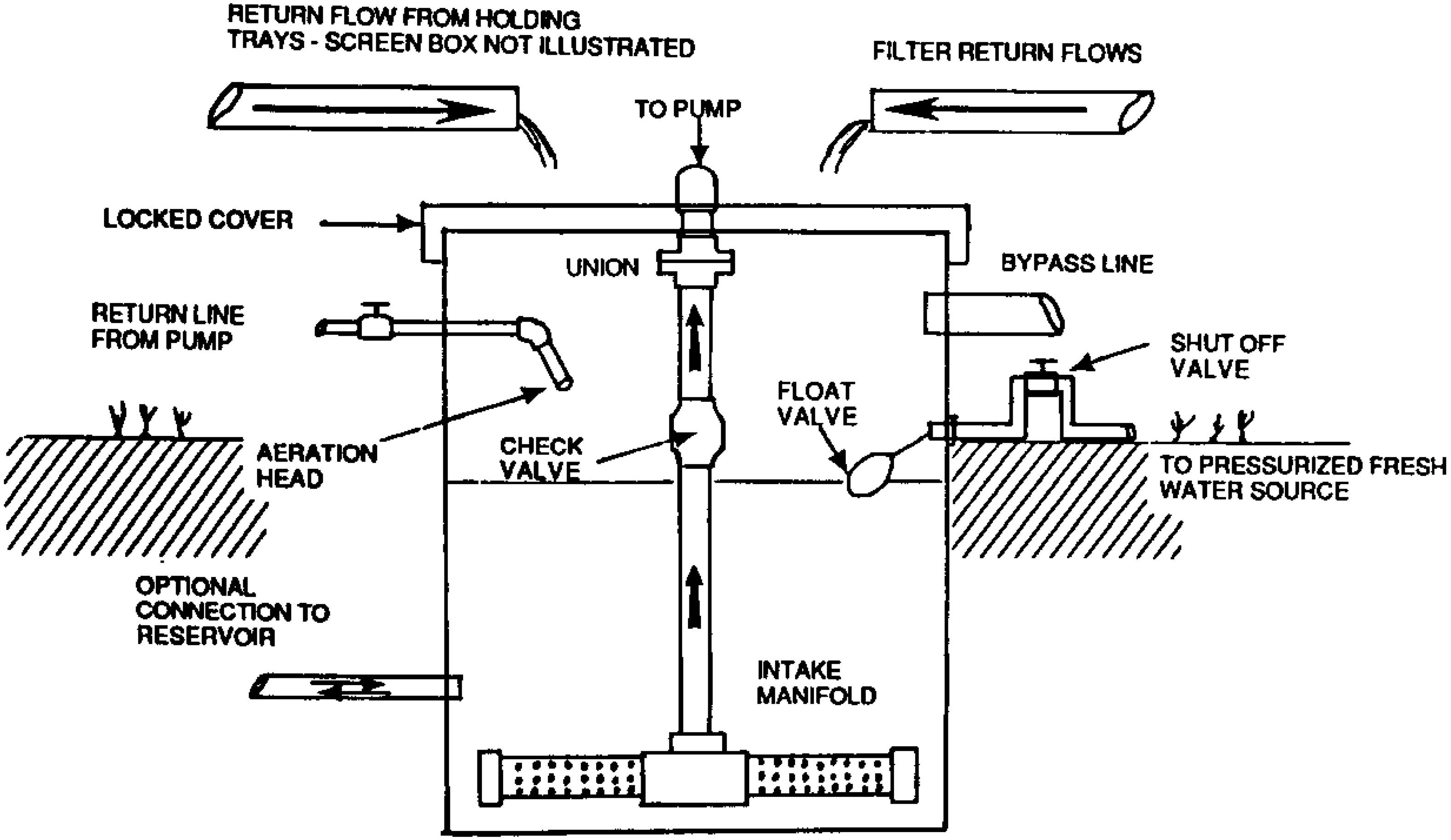


Figure 4.13 The typical components found in a recirculating system sump.

must be sized to permit water fluctuations associated with daily operation of the facility without allowing the pump to run dry. The sump should have a sufficient volume to permit pump operation for about five minutes without any return flow. The sumps used with the sand filters must be properly sized to assure that turbulence from the return and reaeration lines prevents solids from settling. The sump should be only partially filled during normal operation to permit short-term storage of water drained from the system.

Water levels are best controlled by a float valve connected to a pressurized freshwater source. This float valve will release water slowly to compensate for evaporation in the recirculating system. In most cases, the float valve is simply connected to the nearest tap, which can be conveniently closed when draining the system. Since fresh water enters the system slowly, chlorine is neutralized in the system before it can adversely affect the animals. Most systems can absorb a 20 percent addition of chlorinated tap water within a day without any adverse impact.

The sump should be equipped with a bypass pipe unless the sump design, in combination with the reservoir, permits complete drainage of the holding trays and filters in the recirculating system. This bypass pipe should direct excess water to an external ditch or drain to avoid water damage during power failures.

The intake manifold for the recirculating pump is a critical component of the system. Besides the obvious need for intake water, the manifold must exclude debris that could clog spray heads or underdrain plates within the recirculating system. The performance of a centrifugal pump, typically used with recirculating systems, is adversely affected by constrictions on the intake line. Thus, the intake line must be protected without causing a significant head loss. In a typical sump, the intake line (2-inch PVC) is connected to a perforated manifold (4-inch PVC) near the bottom of the sump. The perforations (1/4-3/8 inch) in the manifold are often protected by a loose wrap of screening material. The intake manifold should also include a check valve that will prevent water backflow when the pump is turned off. The check valve will aid in pump priming and prevent the backflow of sand particles in systems using the upflow sand or fluidized bed filters in the event of system shutdown. Finally, the entire manifold unit should be connected to the pump with a removable union, permitting periodic cleaning of the manifold.

Sumps placed outside should be buried so that the water level is below the ground level. Since soil is an effective insulator, burying the sump will help stabilize temperatures in the recirculating system. Outdoor sumps should be covered to prevent foreign matter, particularly leaves, from falling in the system. Covers should be locked and the sump fenced, if necessary, to prevent entry of children and animals.

Reservoirs. The reservoir functions to stabilize water quality in the recirculating system. The design of recirculating systems is based on the concept of balancing the bacterial population with the crab population in the shedding system. When this balance is achieved, the wastes are removed or consumed by the bacteria as quickly as they are produced and the water remains free of ammonia and nitrite. In a commercial setting, however, the supply of crabs fluctuates from day to day, and the bacteria respond slowly to these population changes. Thus, a dynamic imbalance exists. For example, the bacteria take a day or two to adjust to an increase in the number crabs. During this period of adjustment, the rate of waste production exceeds the rate of consumption by the bacteria, leading to a short term accumulation of ammonia and nitrite in the system. The reservoir provides additional water to dilute these wastes so that concentrations will remain below toxic levels.

As a secondary and optional function, the reservoir provides for storage of the recirculating water when the system is drained. This becomes a virtual requirement in areas that are subject to periodic power failures. If the reservoir/sump combination does not provide sufficient volume, saltwater will be lost from the bypass line during pump shutdown, requiring the addition of water and salt when operation resumes. The capital costs of constructing and installing a large reservoir must be balanced against the frequency and cost associated with periodic power failures.

The submerged rock systems operate well when total system volume is held above two gallons per crab. When this volume ratio is maintained, the system can absorb sudden population increases in excess of 20 percent without adverse impact. If a "no discharge" draindown capability is desired, the sump and reservoir together must hold at least two gallons of water for each crab in the system at the carrying capacity. Thus, a 1,000-crab system must hold at least 2,000 gallons of water. If complete draindown capability is not warranted, the amount of water held in the trays may be deducted (about 0.5 gallons per crab) and the required total sump/reservoir volume is only 1,500 gallons. However, 500 gallons of water will be lost each time the system is drained.

The authors anticipate that systems using upflow sand and fluidized bed filters can operate at a lower volume ratio. The upflow sand filters remove solids in the washing cycle that account for over 50 percent of the total waste load to the system. The removal mechanism, solids entrapment, is purely physical and thus responds instantaneously to increases in crab population. Since the upflow sand filter reduces the rate of waste accumulation during the imbalance period, the required volume of dilution water is also reduced. The interim recommendation for minimum water volume for systems using upflow sand filters is one gallon per crab. Thus a 1,000-crab system with draindown compatibility requires a sump/reservoir combination of only 1,000 gallons. If power interruptions are not anticipated then the sump/reservoir requirements are reduced to 500 gallons.

Reservoirs are normally buried in the ground at the same level as the sump. The reservoirs should be covered, locked, and fenced to assure that small children or animals cannot become trapped. Interconnections between the reservoir and sump should be below the operational water level in the sump. A small reaeration line or upflow filter discharge line should feed water into the reservoir to assure a slow mixing of water.

Reservoir/Sump Combinations. Many operators place the submerged rock filters in a single tank that serves both as a sump and a reservoir (as illustrated in Figure 4.6). This reservoir/sump combination works very well in recirculating shedding systems treated with submerged rock filters. Solids settling is not a concern with the submerged rock filters since all the solid wastes produced by the crabs are either captured or degraded. The underdrain system for the submerged rock filter also serves as an intake manifold, the gravel or shell bed effectively prefiltering the water. When designing the reservoir/sump combination, the water displaced by the filter medium is normally neglected.

Submerged rock filters can also be placed in tanks that serve as reservoirs which are connected in series with a sump (see Figure 5.2). In this case, aeration heads should be placed in each reservoir to help boost the dissolved oxygen levels in the water flowing through the submerged rock filter. Each filter requires a bypass line since flow restriction through the submerged rock filters is an inherent possibility.

Using a single tank as a sump/reservoir may be acceptable for the sand filter systems. Some attention, however, must be given to maintaining a turbulent environment to prevent solids from settling. System designs based on using two separate tanks, one configured as a sump and the other configured as a reservoir, inherently minimize solids settling in the reservoir.

4.8 Screen Boxes

Screen boxes are used to prevent debris from entering the distribution system where it might clog openings in the spray heads and underdrain plates. The screens also remove solid wastes from the system. Screen boxes are considered optional with the submerged rock filter systems since the rock beds effectively protect the distribution system; however, the sand filters do not provide protection and their underdrains are sometimes subject to clogging. Thus, systems employing sand filters must have the intake waters filtered through at least one screen. Failure to provide screening for the recirculation system will eventually lead to clogging problems with aeration heads and failure of the sand filters.

Figure 4.14 illustrates the placement and configuration of a screening box arrangement. These two boxes are placed such that all return flows from the holding trays must pass through at least one screen. The leading (or top) screen box is designed with a notched end so that water will divert to the second screen box when the top screen clogs. The lower box is similarly notched to prohibit water loss from the system should it clog. Most screen boxes are at least 2 x 3 feet in size. Boxes should be sized so that the leading box will not clog in a 24-hour period. The leading box should be cleaned each day.

In addition to the screen boxes, many operators wrap the intake manifold loosely with screening material. Plastic 1/8-inch mesh screen, typically used for this purpose, does not clog and provides a second line of defense should both the screening boxes be bypassed. Additional protection can be provided by inline screens that, for example, are frequently used to pre-filter water in the intake line on swimming pool pumps.

4.9 Pumps

Low-head centrifugal pumps are most commonly used for water recirculation in shedding systems. Pumps for recirculating systems must be designed for continuous operation and should be constructed of corrosion-resistant materials. Impellers and housings that contact the water should be plastic, brass, or stainless steel. Cast-iron components should be avoided. The pump should be self-priming and designed to run dry for short periods of time. There are a number of swimming pool and sauna pumps that meet these criteria.

The pump output (gpm) varies with the operational pressure of the system. Each pump model has a performance curve which specifies flowrates with increasing pressure. The pump must be selected to deliver the desired flow at the normal operational pressures of a recirculation system. Observation of typical installations indicates that most recirculation systems following these criteria have operational pressures of about 30 feet (or roughly 15 psi) on the discharge end of the pump. This discharge pressure, however, depends upon the configuration of the distribution system. Generally, smaller or longer piping lines, as well as nonessential elbows and T's, increase operational pressures and consequently decrease flowrates.

Pumps that provide excessive flowrates increase the operator's flexibility to operate a shedding system. For example, aeration lines can be added at critical points within the system during periods of peak loading to enhance performance. Thus, obtaining a pump that has a flowrate capacity over the minimum rates specified generally makes good sense.

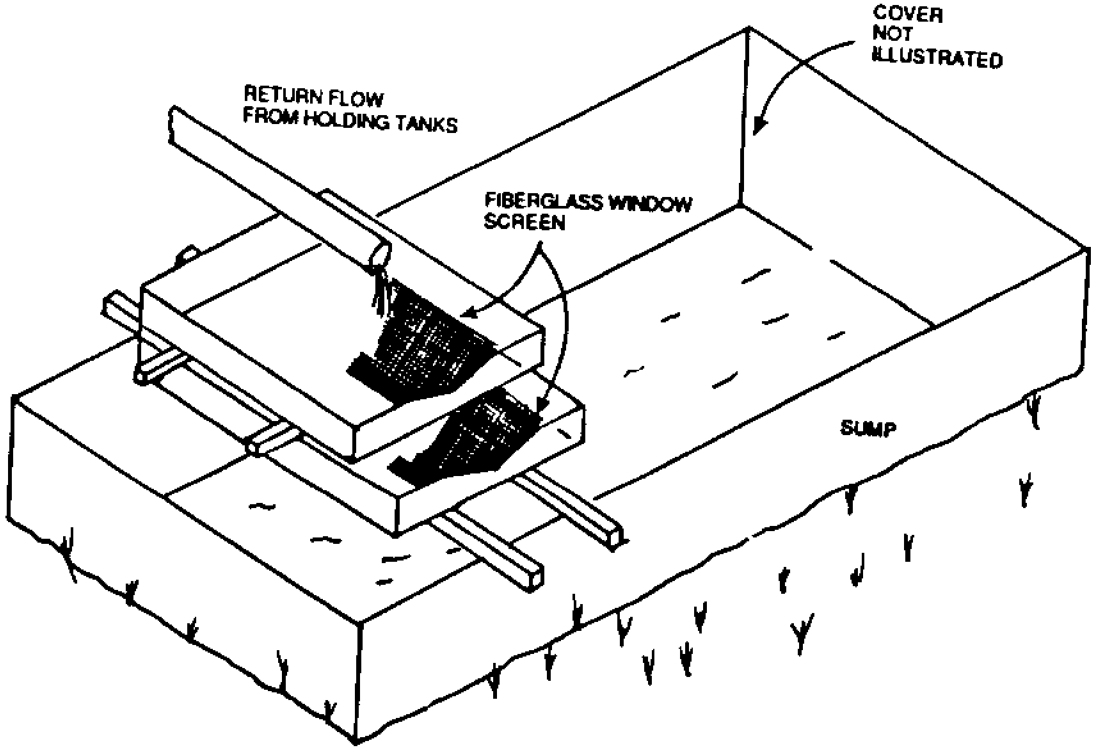


Figure 4.14 All water entering a sump should be filtered through a series of screen boxes to assure that wastes will not clog underdrains or sprayhead nozzles.

Backup pumps are recommended for commercial operations. Although the animals in a shedding system equipped with self-draining tanks can withstand a loss of circulation water for a few hours, major losses will occur if water flow is not quickly restored. Pump failures will occur. Further consideration should be given to commercial facilities located in areas where power failures are quite frequent. Operators faced with these situations can purchase portable generators for restoring power on a short-term basis.

CHAPTER 5

RECIRCULATION SHEDDING SYSTEM CONFIGURATIONS

The system elements presented in Chapter 4 can be combined in a variety of ways to form a recirculating shedding system. This section presents design criteria that should be followed to assure that these systems are capable of maintaining suitable water quality for a shedding operation. A series of configurations that have advantages, such as ease of operation or minimized pumping costs are presented to illustrate designs that can be developed under the "umbrella" of general criteria.

5.1 Submerged Rock Filtration

Table 5.1 presents design criteria for shedding systems employing submerged rock systems. The parameters represent the minumum values that yield satisfactory results. All system components must be designed to support the same number of crabs at design capacity. For most of the parameters, components are sized by multiplying the constant value by the number of crabs at design capacity. Thus, the medium volume in a submerged rock filter for a 1,000 crab system is 1,000 X 0.03, or 30 cubic feet. This volume represents the minimum recommended value. It is doubtful that increasing the amount of medium will make the filter more efficient, unless the corresponding flowrate through the filter is also increased.

The submerged rock filtration systems have been applied commercially for a number of years and a consensus design has essentially emerged from the interaction of commercial operators, marine advisory agents, and research groups. The circulation loop simply moves from component to component (Figure 5.1). This configuration combines the sump, reservoir, and rock filter into a single unit. The submerged rock filter system is simple to construct and requires no water exhange or maintenance during the course of a shedding season. Table 5.2 presents component sizing calculated from Table 5.1 for a range of system sizes.

Four Tray/600-Crab Configuration. Figure 4.6 illustrates a 1,000-gallon sump/reservoir combination that holds 18 cubic feet of #67 grade dolomitic limestone capable of supporting four trays or 600 crabs. This configuration requires a pumping capacity of 12 gpm for system operation; however, the sump is undersized. The tray water volume (300 gallons) must be maintained to meet the two gallons-per-crab total volume requirement. This design operates at near capacity; therefore, about 200 gallons of water will be lost from the system if the pump is turned off. However, because of the small volume of water lost, the system can be restarted without additional water, although salts must be added later to compensate for spillage.

Eight Tray/1200-Crab Configuration. Figure 5.2 illustrates a sump configuration that can support 1200 crabs or eight trays. The sump consists of two components to simplify construction. The leading reservoir contains the filter while the second sump stores water and supplies the pump. The two sumps hold approximately 2700 gallons, though only 2400 gallons are required. The operational levels indicated in Figure 5.2 leave space for 675 gallons of water, enough to absorb the 600-gallon tray volume during power outages. Seventy-two cubic feet of gravel (twice the minimum required) is placed in the first sump. The minimum circulation rate for this filter (from Table 5.2) is 24 gpm. A pump capable of delivering about 30 gpm at 30 feet of pressure should be selected for this system. This pump size will also provide supplemental aeration needed for excess capacity.

Table 5.1 Summary of design criteria for shedding systems employing submerged rock filtration.

Parameter	Value	Comment
Tray Area	0.16 ft^2/crab	Normal loading density for trays
Water Depth	5 inches	Recommended water depth in trays
Media Size	0.5-1.5 inches	Size of clam shell or gravel in filter bed
Media Volume	0.03 ft^3/crab	Volume of clam shell or gravel in the submerged rock filter
Total Volume	2 gallons/crab	Total of operational volume of all components
Flowrates	0.015 gpm/crab 0.020 gpm/crab	Minumum flowrate to trays Minimum flow through filter

Table 5.2 Sizing information for the popular submerged rock filter system.

	Number of Trays					
Parameter	2	4	6	8	10	12
Number of crabs	300	600	900	1200	1500	1800
Sump Volume (gallons)	600	1200	1800	2400	3000	3600
Media Volume (ft^3)	9	18	27	36	45	54
Pump Flow (gpm)	6	12	18	24	30	36

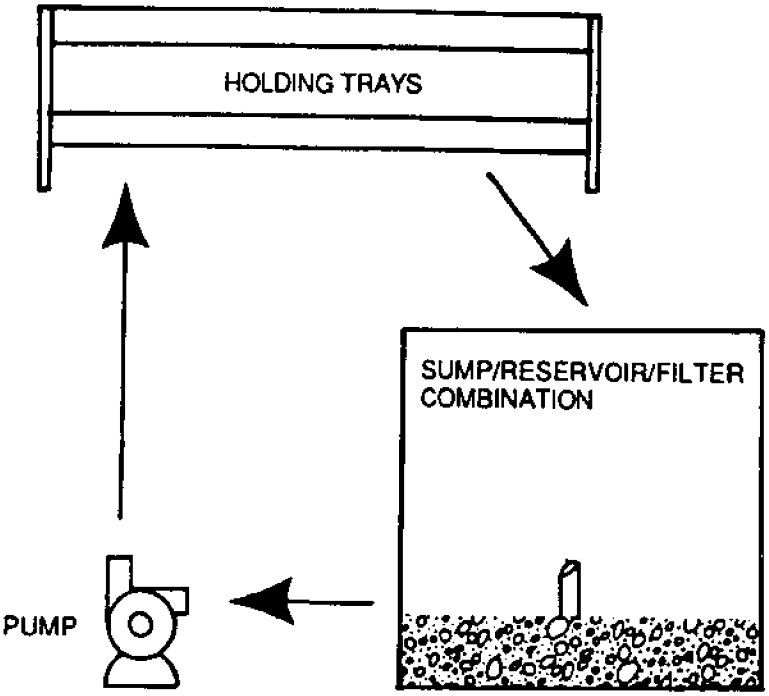


Figure 5.1 The flow diagram for a recirculating shedding system which combines the sump, reservoir, and submerged rock filter into a single tank.

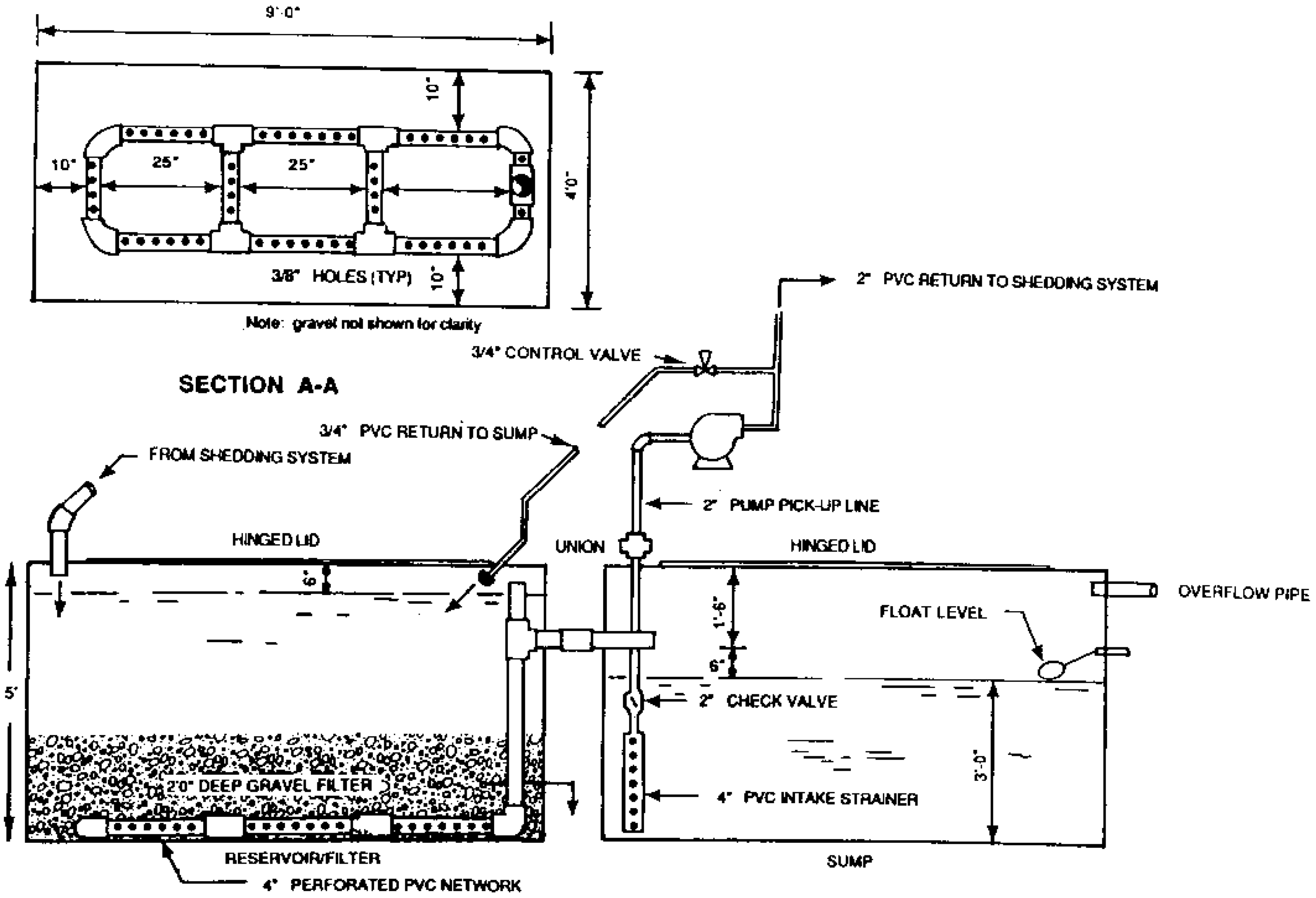


Figure 5.2 A submerged rock filter and sump combination capable of supporting 1200 crabs.

Single-Tray/75-Crab Configuration. Finally, Figure 5.3 illustrates an effective hobby-sized filtration system capable of supporting approximately 75 crabs in a single tray. The sumps are constructed from inexpensive 32-gallon plastic trash cans. Three trash cans are used to provide additional volume to the system (about 80 gallons). Combining these reservoirs with the 75 gallons in the holding tray, the system's water volume requirements are maintained. One filter filled to a 16-inch depth with rock provides the necessary filtering capacity required for 75 crabs. By adding full-sized oyster shells to the first sump to trap solids, the gravel filter is protected from clogging, the period between filter cleanings is extended, and the overall system has additional nitrification ability. A submersible pump capable of delivering between 5 and 10 gpm at an operational pressure of 20 feet (8.7 psi) is more than sufficient for this configuration.

5.2 Sand Filtration Configurations

Table 5.3 presents the general design criteria for systems that utilize sand filtration systems. These designs differ from the submerged rock criteria primarily in that they require less sand. The fluidized beds, for example, are capable of supporting 1000 crabs/ft^3 of sand in comparison with 33 crabs/ft^3 for the submerged rock filters. At least 50 percent of the sand must be allocated to the upflow sand filters to assure that solids will be removed from the system. The removal of solids reduces the total system volume to one gallon per crab, substantially lowering the cost associated with reservoirs.

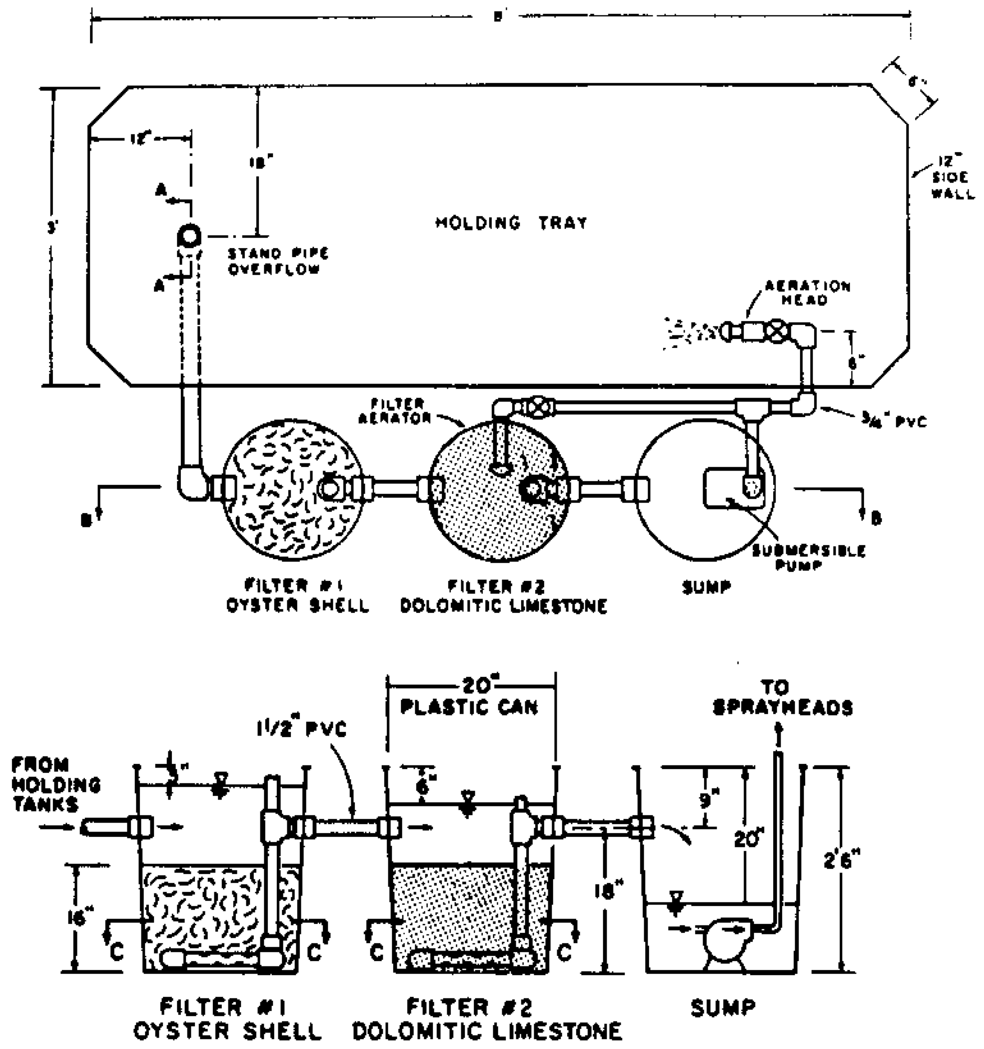
These criteria require the use of sand graded to pass a standard 8-mesh screen and to be retained on a 16-mesh screen. The 8/16 filter sand should be placed at a depth of 15 inches. The hydraulic behavior of sands in expansion or near expansion is complex. Other sand grades are not compatible with the flow values presented in this table.

Systems employing sand filters are more complex in design and operation than the submerged rock systems. All configurations must include an upflow sand filter which assures that solid wastes are removed from the system. System configurations differ primarily in their pumping requirements although all comply with the general criteria outlined in Table 5.3.

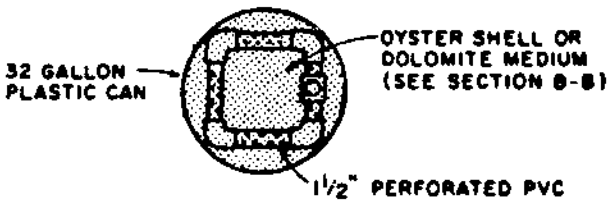
5.3 Upflow Sand Filter Only

Figure 5.4 illustrates a system flow diagram with a combined reservoir/sump and a single upflow sand filter for water treatment. This configuration consists of two parallel circulation loops: the first loop provides aeration and circulation to the trays while the second loop circulates water from the sump to the upflow sand filter and back to the sump. This design permits the use of an open-topped upflow sand filter either square (Table 5.4) or cylindrical (Table 5.5). Component sizes were derived from Tables 4.6 (box filter designs), 4.7 (cylindrical filter designs), and 5.3 (system designs).

This system is equipped with two pumps. The circulation pump provides continuous circulation through both the tray and filter loops. The second pump is switched on intermittently to expand the upflow sand filter once or twice a day. This pump also serves as a backup for the system circulation pump. A single filter and a large expansion pump facilitate the use of timing switches for the cleaning cycle. A sump/reservoir combination is recommended because this system maximizes the rate of solids removal from the system.



SECTION B-B
UNDERDRAIN ROCK FILTER SYSTEM



SECTION C-C

Figure 5.3 A series of three 32 gallon plastic trash cans used with a single tray to support 75 crabs.

Table 5.3 Summary of interim design criteria for shedding systems employing sand filtration.

Parameter	Value	Comment
Tray Area	0.16 ft^2/crab	Normal loading density for trays
Water Depth	5 inches	Recommended depth in trays
Sand Size	1.2-2.4 mm	Diameter of 8/16 filter sand
Bed Depth	15 inches	Assumed depth in sand filters
Sand Volume	0.00100 ft^3/crab	For the portion of capacity supported by fluidized bed
	0.00133 ft^3/crab	For the portion of capacity supported by upflow sand filter; at least 50 percent of sand volume must be in the upflow sand filter
Total Volume	1 gallon/crab	Total of operational volume of all components
Flowrates	0.015 gpm/crab	Minumum flowrate to trays
	65 gpm/ft^2	Normal operational fluxrate for fluidized bed
	9.4 gpm/ft^2	Normal operational fluxrate to upflow sand filter
	65 gpm/ft^2	Expansion fluxrate for upflow sand filter

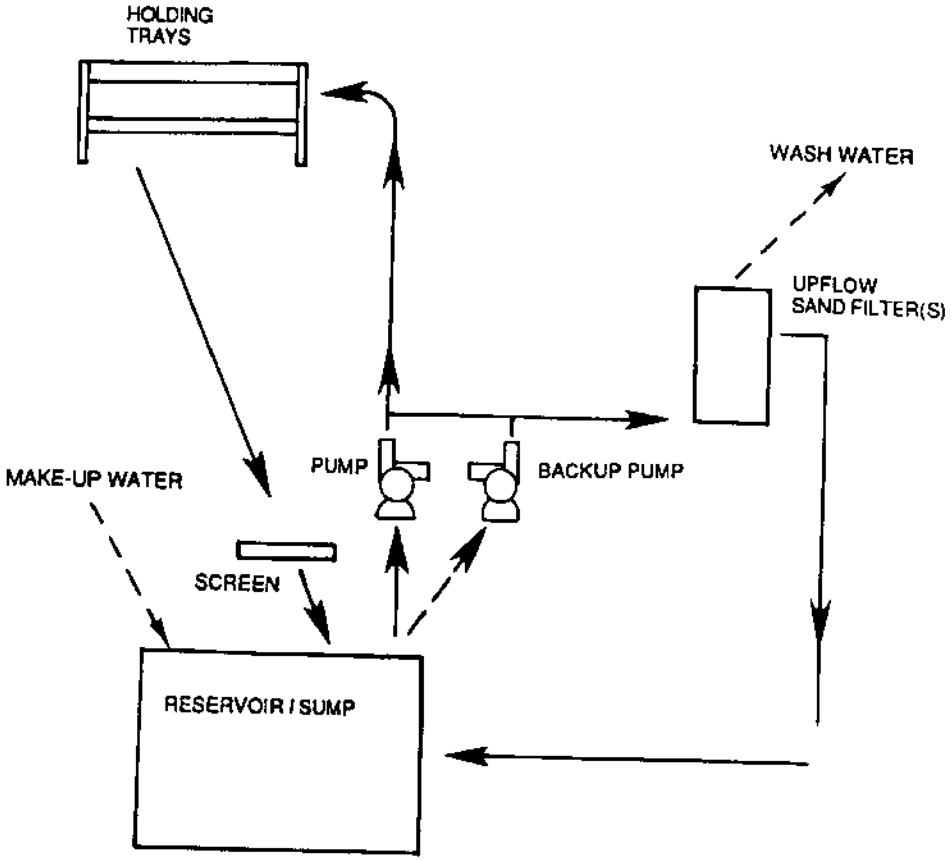


Figure 5.4 Flow diagram for a recirculating system filtered solely by an open-top upflow sand filter.

Table 5.4 System design based on a single square upflow sand filter.

	Number of Trays					
Parameter	2	4	6	8	10	12
Number of crabs	300	600	900	1200	1500	1800
Sump Volume (gallons)	300	600	900	1200	1500	1800
Filter Width (inches)	7.0	10.0	12.0	14.0	15.0	17.0
Filter Volume (ft^3)	0.4	0.9	1.3	1.7	2.0	2.5
Flow to Trays (gpm)	5	9	14	18	23	27
Upflow Sand Filter Flowrate (gpm)	3	7	9	13	15	19
Circulation Pump Flowrate (gpm)	8	16	23	31	38	46
Expansion Pump Flowrate (gpm)	22	45	65	88	102	130

Table 5.5 System design based on a single cylindrical upflow sand filter.

	Number of Trays					
Parameter	2	4	6	8	10	12
Number of crabs	300	600	900	1200	1500	1800
Sump Volume (gallons)	300	600	900	1200	1500	1800
Filter Diameter (inches)	8.0	11.0	14.0	16.0	18.0	19.0
Filter Volume (ft^3)	0.4	0.8	1.3	1.7	2.2	2.5
Flow to Trays (gpm)	5	9	14	18	23	27
Upflow Sand Filter Flowrate (gpm)	3	6	10	13	17	18
Circulation Pump Flowrate (gpm)	8	15	24	31	40	45
Expansion Pump Flowrate (gpm)	23	43	69	91	115	128

5.4 Upflow Sand and Fluidized Bed Combination

Figure 5.5 illustrates the flow diagram for a system that employs both the upflow sand and fluidized bed filters for controlling water quality. This system is designed to permit operation with a single circulation pump. Filter component designs (Table 5.6) were selected to minimize pumping requirements.

A pressurized fluidized bed, placed in series with the holding tanks in the aeration loop, takes advantage of the filter's low head loss and eliminates the pumping costs associated with maintaining bed expansion. The circulation pump permits expansion of the two upflow sand filters, thus eliminating the need for a larger expansion pump. Expansion can be accomplished by momemtarily shutting down the flow to the fluidized bed and holding tanks and diverting the flow to the upflow sand filters, one at a time. Alternatively, the backup pump (identical in size to the circulation pump) can also be used for expansion, avoiding interruptions of flow to the holding tanks.

The total water volume in the system will circulate through the two upflow sand filters only once every three hours. Therefore, the sump design (size) assures that solid wastes remain in suspension until caught by the filters. Only return flows from the upflow sand filters (free of waste solids) are permitted to enter the larger reservoir, thereby preventing solids accumulation in this large tank. The fluidized bed treats the total volume of system water every hour, providing for rapid control of ammonia and nitrite. The combination of upflow sand and fluidized bed filters provides a filtration system that is smaller, yet more powerful than the traditional submerged rock filter. This combination provides superior water quality even when subject to shock loading.

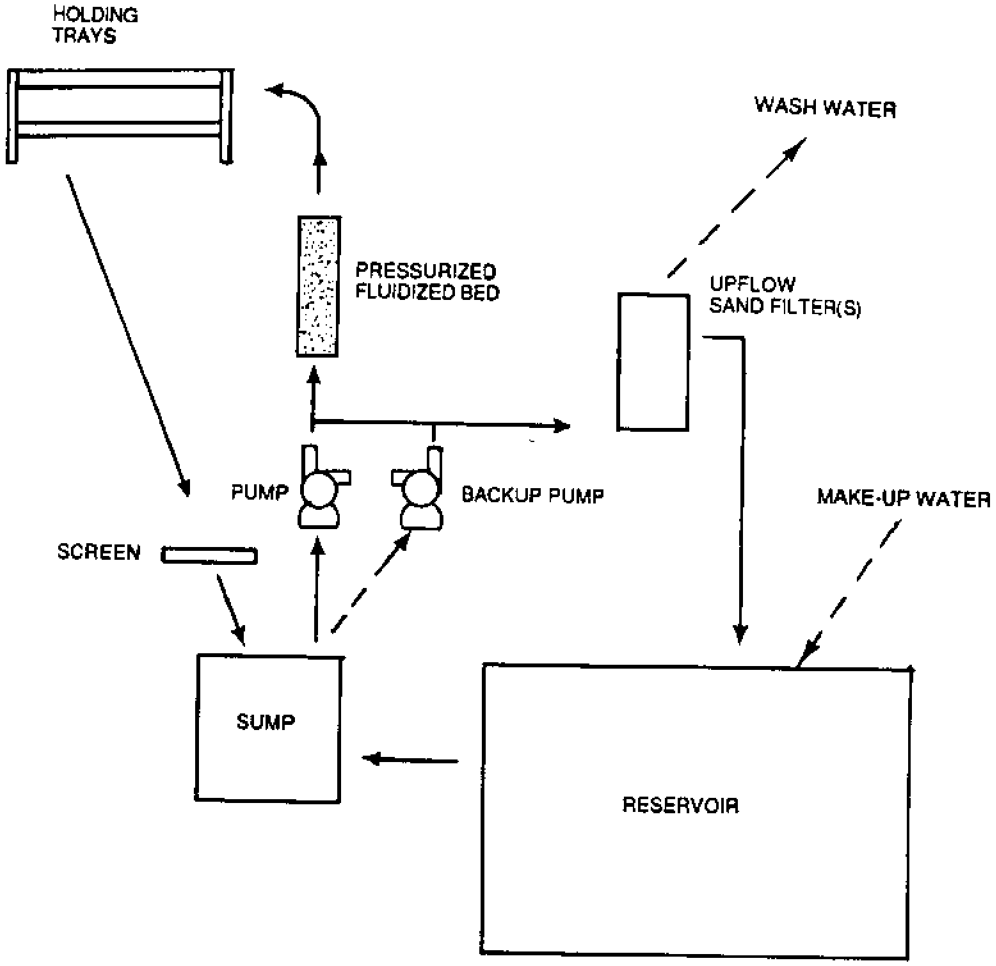


Figure 5.5 Flow diagram for a recirculating shedding system that uses a pressurized fluidized bed in combination with two upflow sand filters to minimize the required capacity of the circulating and backup pumps.

Table 5.6 System design based on a combined sand filter system to minimize pumping requirements.

Parameter	Number of Trays					
	2	4	6	8	10	12
Number of crabs	300	600	900	1200	1500	1800
Fluidized Bed Filter						
Diameter (in)	4	6	6	8	8	10
Sand Volume (ft^3)	0.11	0.25	0.25	0.44	0.44	0.68
Carrying Capacity (crabs)	110	250	250	440	440	680
Flow to Trays and Fluidized Beds (gpm)	6	13	13	23	23	35
Upflow Sand Filters						
Number	1	2	2	2	2	2
Diameter (in)	6	6	8	10	10	12
Sand Volume* (ft^3)	0.25	0.25	0.44	0.68	0.68	1.0
Carrying Capacity (crabs)*	188	184	327	511	511	750
Normal Flow (gpm)*	2	2	3	5	5	7
Expansion Flow (gpm)*	13	13	23	36	36	51
Circulation Pump (gpm)	13	17	23	36	36	51
Backup Pump (gpm)	13	17	23	36	36	51
Sump Volume (gallons)	100	200	200	300	400	400
Reservoir Volume (gallons)	200	400	700	900	1100	1400

*Values given for a single filter.

CHAPTER 6

SYSTEM MANAGEMENT

Once construction is completed, maintaining adequate water quality in a recirculating system is almost entirely under the operator's control. Understanding the behavior of the system and water quality are essential requirements for system management over an extended period of time. The following sections identify the management problems that may not be immediately apparent to the operator of a newly constructed system.

6.1 Flushing New Systems

The fiberglass used with system components (trays, filters, sumps, etc.) and the cement used to join the PVC piping system release highly toxic compounds when cured. Newly constructed systems must be flushed at least once prior to the introduction of crabs. Flushing is accomplished by filling the system with fresh water, turning on the circulation pumps, and letting the system run for about 24 hours. All this water should then be drained and replaced. If time permits, repeat the process. The process should also be undertaken when new components are added to the system. Failure to flush a newly constructed system will almost certainly lead to crab mortalities.

6.2 Filter Acclimation

The biological filters will function effectively only after a bacterial population is well established in the filter. These bacteria must be grown in the filter. Filter acclimation is the process by which the initial population is cultivated, and this is done simply by adding a small number of crabs to the system.

These crabs will excrete ammonia which encourages the establishment of Nitrosomonas bacteria in the filter. As the Nitrosomonas bacteria become established, they produce nitrite which, in turn, encourages the growth of Nitrobacter bacteria, which consume the nitrite. Depending on the temperature, this acclimation process takes about 30 to 45 days for systems using the submerged rock filters. The sand filters have been started with this method in about three weeks. The acclimation method has a distinct disadvantage since the Nitrobacter bacteria are not fed until the Nitrosomonas bacteria population becomes established. Thus, the acclimation is accomplished serially, with the Nitrosomonas population growing first and then the Nitrobacter population, lengthening the time for acclimation. Figure 6.1 illustrates the accumulation and decline of ammonia and nitrite as acclimation proceeds.

Filter acclimation can be accomplished faster by chemical addition, at a total cost under $20. Ammonium chloride ($NH_4Cl$) is added to feed the Nitrosomonas population while, simultaneously, sodium nitrite ($NaNO_2$) is added to initiate the growth of the Nitrobacter bacteria. Both populations become established simultaneously, reducing the start up time by at least 30 percent (Manthe and Malone, 1987). Using this method a submerged rock filter can be started up in about four weeks and the sand filter populations can become established in as little as three weeks. Figure 6.2 illustrates the simultaneous reduction in nitrite and ammonia from a chemically dosed system. Both the ammonium chloride and the sodium nitrite should be added at a concentration level of about 10 mg/l (about four grams for each hundred gallons of water) to initiate the acclimation process. Upon completion of

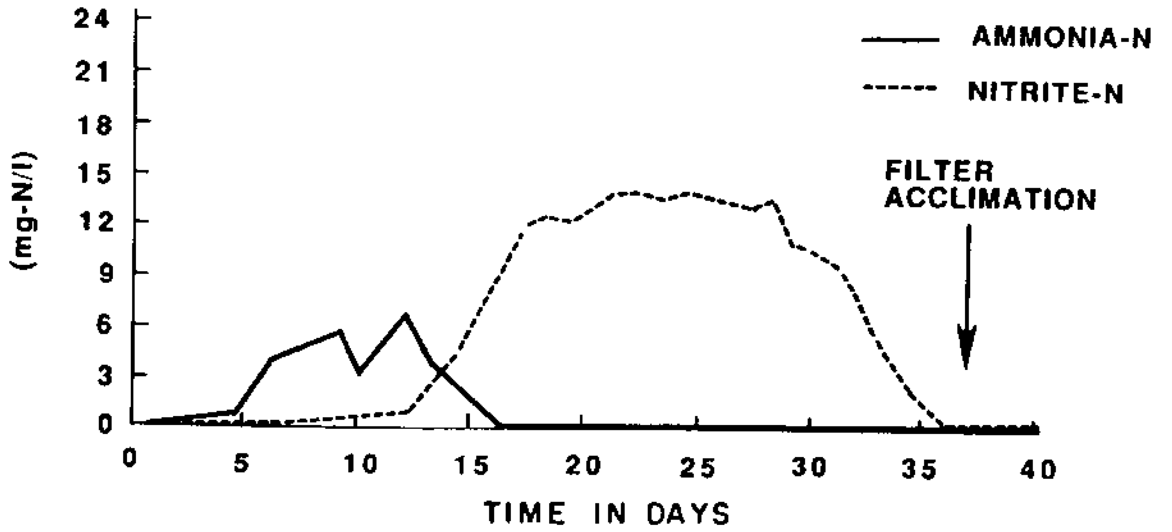


Figure 6.1 The ammonia and nitrite curves that result from acclimation of a biological filter with aquatic species.

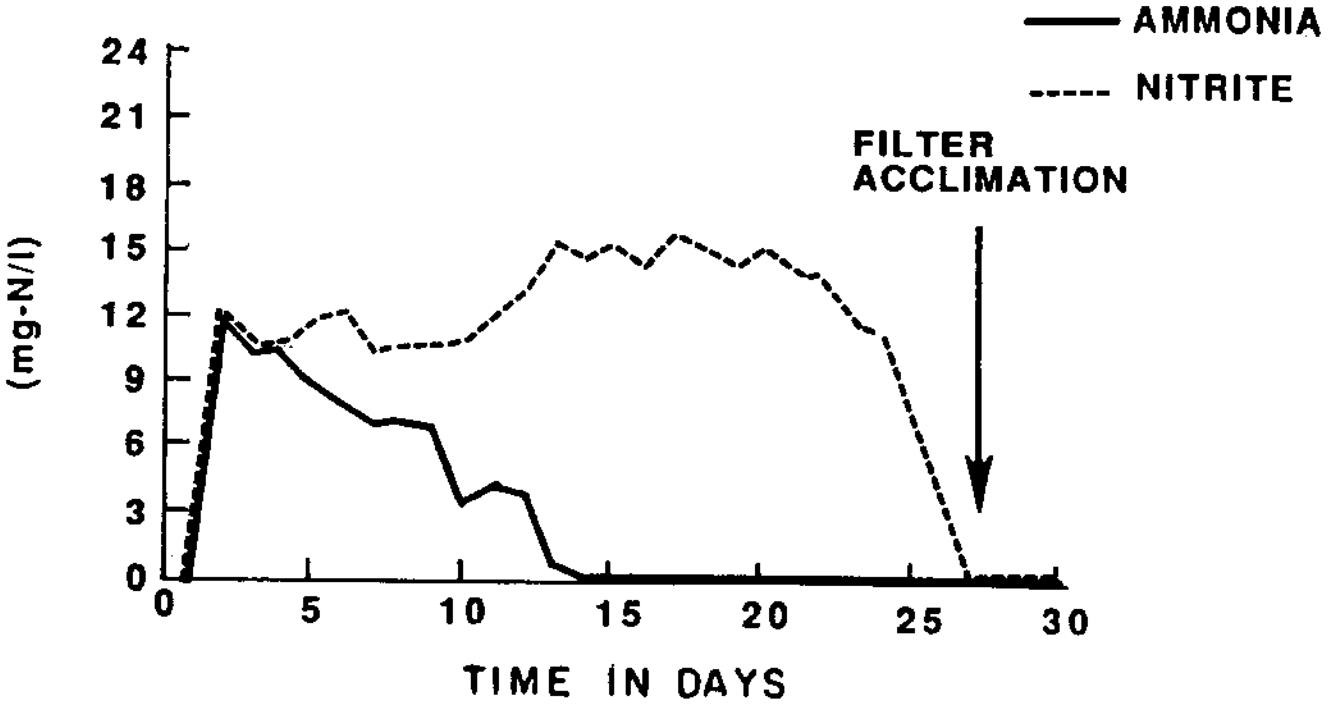


Figure 6.2 The acclimation with chemical addition is faster than acclimation with animals because nitrite is immediately available to stimulate the growth of the Nitrobacter species of bacteria.

the acclimation, only a small amount of salt (NaCl) and nitrate (NO_3^-) remain as a residuals in the system.

Acclimation of a filter will proceed faster if the bacteria are maintained under ideal conditions. Table 4.2 identifies the major factors controlling the growth rate of nitrifying bacteria. Temperature and pH are the most important controlling factors. If speed of acclimation is critical, the biological filter should be kept warm and the pH should be raised to at least 8.0.

6.3 Avoiding Shock Loading

All biological filters operate best when maintained with a constant population of crabs. Shock loading is the most common cause of minor water quality disruptions. Sudden jumps in crab numbers in a system should be avoided. A short-term increase in ammonia (followed by a short-term increase in nitrite) will occur anytime the system population increases by more than approximately 10 percent per day. These transitional peaks of ammonia and nitrite take about three days to disappear. The larger the population increase, the higher the resulting peak. The reservoirs are added to the shedding system to neutralize this shock effect, but each system has its limits. The operator must observe the effects of shock loading and then avoid excessive shocks thereafter.

6.4 pH Control

pH has a serious impact on the rate at which the bacteria in the system function. Maintaining pH in the range of 7.5 to 8.0 will assure that the bacteria operate effectively without seriously exposing the crabs to ammonia toxicity. Submerged rock filters are designed to operate in pH range of 7.0 to 7.5 and normally do not require active pH management. Systems equipped with sand filtration units are subject to rapid pH drops; thus, pH levels must be observed daily to assure maximum operational efficiency. The pH in all recirculating systems will drop, because the nitrifying bacteria produce acids as part of the nitrifying process.

pH levels in a shedding system can be increased mechanically or chemically. The first step in raising the system's pH is to check for carbon dioxide accumulation. To do this, remove a sample of water and promptly measure its pH. Next, place a small aquarium airstone in the sample and aerate the sample for about 30 minutes. Check the pH again. If the pH increases significantly, more than half a pH unit, then the system has accumulated carbon dioxide and its presence contributes to the pH decline. To raise the pH in the shedding system, the rate of aeration must be increased in the reservoir or sump. This approach is effective only if the alkalinity (or bicarbonate level) in the system remains high.

If aeration fails to raise the pH of the water, then the alkalinity probably has been exhausted and chemical addition must be implemented. Sodium bicarbonate ($NaHCO_3$ or baking soda) can be added to correct this situation. Addition of baking soda will raise the pH toward, but not over 8.3. The authors estimate that for each 100 crabs in a recirculating system, approximately 65 grams of the bicarbonate ion (HCO_3^-) are consumed by the nitrifying bacteria each week. If this alkalinity is not replaced by intermittent water additions that compensate for evaporation, spillage, and loss of expansion waters, then alkalinity must be restored by chemical addition. Most systems filtered with sand filters require the periodic addition of sodium bicarbonate to maintain alkalinity levels. Total alkalinity in a well-buffered system should be between 100 and 500 mg-$CaCO_3$/l.

6.5 Maintaining Salinity

Recirculating systems operated in a closed format may require minor adjustments in salinity levels about once a month to compensate for spillage. These adjustments are normally accomplished by the slowly adding artificial sea salt over a few days until the salinity levels are raised to normal. Suddenly raising the salinity by a single addition of salt is not necessary or desirable.

Recirculating systems operating in a semi-open format require salt additions at least once a week. Systems that employ upflow sand filters lose salt each time the filter is cleaned and the expansion waters are discharged from the system. The amount of salt lost during expansion can be roughly calculated and added each day or the salinity can be checked every third or fourth day and corrected as needed.

Periodic checks of the harvesting area should be made to make sure that these natural water has not changed in salinity. Bays and estuaries typically show their lowest salinity readings in the spring. As the summer progresses the amount of rainfall decreases and salinity levels increase. Readings taken from the harvesting area in the early spring do not indicate conditions that exist in the late summer.

6.6 Periodic Water Quality Monitoring

Since recirculating systems are dynamic in nature, periodic monitoring is required to insure adequate water quality in the shedding facility. Monitoring usually consists of testing ammonia, nitrite, pH, alkalinity, salinity, dissolved oxygen, and temperature. A guideline for water quality monitoring based on these parameters is presented in Table 6.1.

Ammonia and nitrite monitoring is virtually mandatory with any recirculating shedding system. Most operators continuously check both ammonia and nitrite levels, especially during startup periods and also during periods of shock loading. When systems are running smoothly, ammonia and nitrite levels should be monitored daily in both the holding trays and at the point that the water (commonly called the effluent) leaves the filter. Ammonia and nitrite test kits are very inexpensive and can be purchased from an aquarium shop.

pH testing equipment actually depends upon the degree of accuracy the operator wants to achieve. Simple pH monitoring can be achieved by using inexpensive litmus paper purchased from an aquarium shop. However, using litmus paper does have its disadvantages since the method is somewhat limited in accuracy. More accurate pH measuring devices include simple portable meters which operate on a 9-volt battery. These meters cost approximately $200. Monitoring for pH should be conducted on a weekly basis in the sump (or sump/reservior) and at the filter effluent.

In shedding operations that employ the new sand filter, alkalinity must be periodically checked, in addition to pH, to maintain an adequate buffering capacity in the system water. Alkalinity monitoring is not required in shedding systems that employ the submerged rock filter designs since the calcareous media provide sufficient buffering capacity. Weekly monitoring of alkalinity is usually conducted at both the sump and filter effluent locations. Alkalinity test kits, similar to the ammonia and nitrite kits, can also be purchased at a local aquarium store.

Table 6.1 Summary of essential water quality parameters to monitor in a recirculating shedding system.

Parameter	Location	Guideline	Frequency
Total Ammonia	Trays Filter Effluent	< 1.0 mg/l	Daily
Nitrite	Trays Filter Effluent	< 0.5 mg/l	Daily
pH	Trays Sump	7.0 - 8.0 7.5 - 8.0	Weekly
Alkalinity*	Sump	> 100 mg/l	Weekly
Salinity	Sump	Within 5 ppt of harvesting water salinity	Monthly; Weekly w/ sand filters
Dissolved Oxygen	Trays Sump Filter Effluent	> 5.0 mg/l > 6.0 mg/l > 2.0 mg/l	Weekly
Temperature	Trays	75 - 80°F (24 - 27°C)	Weekly

* - not required for systems using submerged rock filters.

Salinity measurements are also mandatory, particularly for systems using upflow sand filters where filter cleaning is performed on a daily basis. Salinity measurements are best made at the sump on a weekly basis for systems using the sand filters and on a monthly basis for systems using the submerged rock filter designs. Salinity measurements are made using a refractometer or conductivity meter. Hand-held refractometers usually cost between $150 and $175.

As previously mentioned, dissolved oxygen is also a critical water quality parameter. Dissolved oxygen levels are generally monitored in the trays and in the effluent water from the filters. Measurements should be made weekly or daily during periods of peak loading. Although oxygen meters are quite expensive (typically $750 to $1000), they do provide the operator with valuable information concerning water quality particularly filter performance. Operators without dissolved oxygen meters are unaware of potential problems which may exist with filters particularly during periods of heavy loading.

6.7 Annual Maintenance

Submerged rock filters should be cleaned. The media must be removed, washed, and replaced in the filter bed to assure the removal of accumulated solid wastes in the system. This cleaning process prevents filter clogging during the next season. The system water should be completely replaced.

Upflow sand filters and fluidized beds should be operated for about one week with the system empty prior to shutting the system down. This procedure allows the bacteria population to run down, decreasing the biomass in the system during shut down. The filters should be drained and left sitting damp during the off season. Cleaning the sand filters is not required.

Sumps and reservoirs should be drained and rinsed at the end of the season to eliminate any solids that may have accumulated. Tanks which have been placed belowground may have to be refilled to prevent rising groundwater from floating the tanks out of the ground or collapsing the sidewalls. Inside the shedding facility, all piping above ground should be drained to prevent freeze damage. Pumps should be inspected and serviced as required by their operational manuals.

6.8 Record Keeping

Recorded observations on water quality are an important aspect of successfully managing a shedding operation. By maintaining updated files on water quality, operators can accurately determine where problems may possibly occur within the system, given the guidelines within this manual. Recording daily observations on water quality may also give the operator insight on methods that may increase the production rate of soft crabs in the system. A typical log sheet used for recording water quality and other miscellaneous data is presented in Table 6.2.

Table 6.2 Typical log sheet for recording water quality and system data.

Date	# Crabs in System	# Premolt Mort.	# Molting Mort.	# Soft Crabs	Total Ammonia	Nitrite	O_2	pH	Temp	Salinity	Alkalinity

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