

SOLIDS REMOVAL IN A RECIRCULATING AQUACULTURE SYSTEM

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ABSTRACT

The objective of this work was to investigate the efficiency of both double drain and screen filter on solids removal in recirculating aquaculture system to improve the water quality and increase the fish growth rate. A model was developed to determine the solids removal in recirculating aquaculture system. By fitting the predictions of the model to measured settleable and suspended solids, settleable solids removal was determined that about 0.0304 to 0.0556 kg m⁻³ (30.40 to 55.60 mg l⁻¹) while it was 0.039 kg m⁻³ (39 mg l⁻¹) for the theoretical approach and suspended solids removal was determined that about 0.0123 to 0.0806 kg m⁻³ (12.30 to 80.60 mg l⁻¹) while it was from 0.0124 to 0.1425 kg m⁻³ for the theoretical approach. It was calculated that the hydrocyclone and drum filter efficiency to remove the solids from the system ranged from 27.4 to 57.79 % and 15.46 to 57.71 % respectively. It was calculated that the hydrocyclone and drum filter efficiency to remove the solids from the system ranged from 27.4 to 57.79 % and 15.46 to 57.71 % respectively. The daily average of settleable and suspended solids removed by hydrocyclone and drum filter ranged from 0.33 to 6.26 kg/day and 0.11 to 11.43 kg/day, respectively. The model results were in a reasonable agreement with the experimental ones.

Keywords: Model - Settleable solids – Suspended solids – Hydrocyclone – Drum filter

1. INTRODUCTION

Management and removal of solids is one key process in an RAS. In recirculating finfish systems the main particulate waste materials are feces, uneaten feed, decaying fish, and tank and pipes biofilm slough (Chen *et al.*, 1993; Patterson and Watts, 2003).

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Since the adverse effects of solids on recirculating systems were recognized, research on solids removal has been recommended by many investigators (**Brinker *et al.*, 2005; Summerfelt and Penne, 2005; Davidson and Summerfelt, 2005; Steicke *et al.*, 2007; Merino *et al.*, 2007; Bai, 2007; Timmons and Ebeling, 2007; Sandu *et al.*, 2008; Pfeiffer *et al.*, 2008; Couturier *et al.*, 2009; d'Orbcastel *et al.*, 2009**). Solids that are not removed from the RAS have numerous consequences for the fish in the system and system components. The presence of suspended solids in recirculating finfish aquaculture systems can cause damage to fish gills, increase biochemical oxygen demand, reduce biofilter nitrification, and increase ammonia in the system (**Chapman *et al.*, 1987; Bergheim *et al.*, 1998; Wong, 2001; Zhu and Chen, 2001**). The solids found in RAS operations vary in size and settling properties and have an effect in the design and operation of the solid removal mechanisms (**Merino *et al.*, 2007**). All recirculating aquaculture systems utilize processes to remove waste solids, oxidize ammonia and nitrite-N, and aerate and/or oxygenate the water. Methods or processes that improve solids removal also improve water quality, which can potentially enhance production and certain operating costs. However, selection of the best treatment system for a particular aquaculture operation is difficult, given the variety of processes available, and the lack of uniform methodology for evaluation of water treatment effectiveness and economic accounting and other practical considerations (**Bai, 2007 and Timmons and Ebeling, 2007**).

The effective management of solids in aquaculture is one of the major obstacles to the continued development of the aquaculture industry (**Piedrahita *et al.*, 1996**) and is often considered the most critical process to manage in aquaculture systems (**Summerfelt, 1996**).

Feed input into the system controls the production of solids and particulate matter (feces and uneaten feed). Solids and particulate matter are the major sources of carbonaceous oxygen demand and nutrient input into the water, especially if they degrade within the system. The feed portion is not assimilated by the fish excreted as an organic waste (fecal solids) and the uneaten feed consume dissolved oxygen and generate

total ammonia nitrogen (TAN) when broken down by bacteria within the system (**Timmons and Ebeling, 2007**).

The best solids removal practices remove solids from the system as soon as possible and expose the solids to least turbulence and mechanical shear (**Summerfelt, 1996**). Conventional solids removal processes generally remove solids larger than 100 μm . However, only a few processes typically used in aquaculture can remove dissolved solids or colloidal solids smaller than 20 μm (**Chen et al., 1994**).

A variety of methods are currently used for solids removal in aquaculture operations (gravitational, filtration, or screening methods). Gravitational methods may result in the removal of particles that are less dense than water (e.g., dissolved air flotation), or the particles that are more dense than water (e.g., settling basins, centrifuges, hydrocyclones). Filtration or screening methods relies on particle size and particle surface properties for removal from the culture water. There are several commercial types of these filtration mechanisms, including drum filters, disk filters, triangle filters, etc. Other types of filtration systems are based on granular media beds (**Cripps and Bergheim, 2000**).

Settling basins are the most common solids removal process used in flow through aquaculture systems. Properly designed and operated, settling basins can be effective in reducing suspended solids concentrations to low levels. But they must be managed carefully to achieve high nutrient removal rates. Micro screens and settling basins have difficulty controlling fine solids below about 40 μm which can create problems in high water reuse systems (**Libey, 1993 and Merino et al., 2007**). **Stechey and Trudell (1990)** evaluated the reduction in suspended solids and nutrient concentrations obtained from existing settling basins in Ontario. Variables of different types were determined: production and management, water chemistry and solids chemistry characteristics. They found that although the total suspended solids removal efficiency of existing aquaculture facilities was rather low, ranging from 15.5 to 31.7% depending on the type of settling basin used, properly designed and

operated settling systems could achieve solids removal efficiencies approaching 90%.

Modeling of solids removal processes in aquaculture processes in aquaculture systems has not received much attention in either the aquacultural or environmental engineering literature. Modeling of removal rates by settling is complicated in aquaculture water because of the variability in particle size and density of suspended solids. Thus, effective comparison of different types of solids removal systems requires the establishment of a uniform sampling and testing protocol **(Delos and Malone, 1996 and Pfeiffer *et al.*, 2008)**.

If flow baffles or dual-drain effluent configurations are used for continuous, hydraulic removal of settled solids **(Timmons *et al.*, 1998)**, then settled solids are routed to the designated effluent port and do not accumulate on benthic surfaces. Otherwise, accumulated settled solids are removed by periodic events, as specified by the maximum allowed solids accumulated and other management variables. When media is present in the water column, solid sedimentation is enhanced by interception and diffusion **(Chen *et al.*, 1994)**.

Rigorous quantification of solids sedimentation, whether intended or not, required consideration of (1) distributions of sizes, particle densities, and settling velocities, (2) particle interaction (e.g., flocculation), (3) water velocity profiles with a facility unit, (4) particle retention time, and (5) particle re-suspension by scouring and fish activity **(James, 1984b; Tchobanoglous and Schroeder, 1985; Chen *et al.*, 1994)**.

Within a recirculating aquaculture system (RAS), almost all waste products originates from the formulated diet provided to the cultured animal. The rapid buildup of this waste can lead to the decline in water quality, inducing stress upon the animal, therefore, the main objective of this work was to investigate the efficiency of both double drain and screen filter in solids removal from the recirculating aquaculture system to improve the water quality and increase the fish growth rate.

2. Theoretical Approach

The effectiveness of the double drain at concentrating solids within the bottom center drain discharge can be illustrated by a steady state solids balance written over the culture tank (Tommons *et al.*, 2002).

$$\{Q_{TS_{in}}\} + \{TS_P\} = \{Q_{out1} \cdot TS_{out1}\} + \{Q_{out2} \cdot TS_{out2}\} \quad (1)$$

Where:

Q is the water flow rate, m³/day

Q_{out1} is the flow rate leaving the lateral drain, m³/day

Q_{out2} is the flow rate leaving the main drain, m³/day

TS_{in} is the TS concentration entering unit, kg m⁻³

TS_{out1} is the TS concentration leaving the lateral drain, kg m⁻³

TS_{out2} is the TS concentration leaving the main drain, kg m⁻³

TS_P is the TS production rate, kg TS produced per day

TS resulted from feeding can be determined by using the following equation:

$$TS_P = A_{TS} \cdot R_{feed} \cdot \rho_{fish} \cdot V_{tank} \quad (2)$$

Where:

A_{TS} is the TS produced as a proportion of feed fed, (25% of feed fed) as according to Hopkins and Mancini (1989) and Losordo and Hobbs (2000)

R_{feed} is the feeding rate, kg feed per kg fish per day

ρ_{fish} is the density of fish in the culture tank, kg fish per m³

V_{tank} is the volume of water contained within culture tank, m³

A simplified approach to solids sedimentation is used here, where solid removal rate by sedimentation (TS_{out2}, kg m⁻³) is:

$$TS_{out2} = TS_{in} (\text{fraction removed}) (\text{exchange rate, 1/day})$$

$$TS_{out2} = TS_{in} (v_s / HLR) (Q/V) \quad (3)$$

It could be rewritten as:-

$$TS_{out2} = TS_{in} (v_s / d) \quad (4)$$

Where:

v_s is the particle mean settling velocity ($m\ h^{-1}$)

d is the water depth (m)

HLR is the hydraulic loading rate ($m^3\ m^{-2}\ h^{-1}$)

This derivation represents solid sedimentation in terms of first order, exponential decay kinetics, a simplification that has been used exponential decay kinetics, a simplification that has been used by others (**Fritz *et al.*, 1979; Fritz, 1985; James, 1984; Piedrahita and Giovannini, 1989**). The sedimentation term represents one term in the differential equation for TS_{in} , with additional sources and sink added as needed. If the water body is stratified, then solids settle from the top layer to the bottom layer and from the bottom layer and from the bottom layer to the bottom surface of the facility unit. Any upward vertical mixing of solids is considered by the use of reduced settling velocities. Typical particle settling velocity used in model is given by (**Chesness *et al.*, 1975; Chen *et al.*, 1994**) mention that solids of fish in basin designed for sedimentation 0.83 to $5\ m\ h^{-1}$ for 65 to 90% of total particulate solids.

3. Materials and Methods

The experiment was carried out at Agricultural Engineering Department, Faculty of Agriculture, Moshtohor, Benha University. During the period of March to July, 2011.

3.1. Materials

3.1.1. System Description:

Figure (1) illustrates the experimental setup. It shows the recirculating aquaculture system which consists of fish tank, hydrocyclone, screen filter, biological filter and aeration tank.

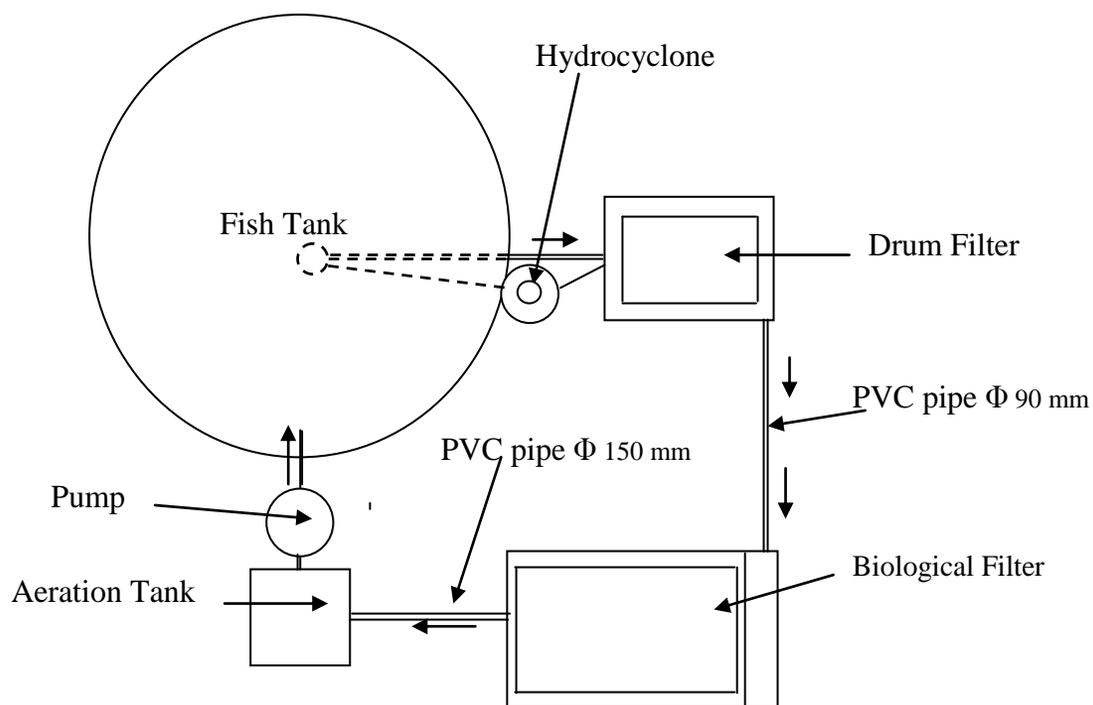


Figure (1): Recirculating aquaculture system.

Fish tank is a circular in shape and made from fiberglass has two openings for both settleable and suspended solids. Its volume is 7 m^3 and has a diameter of 3m. The first opening allows for 1-10% of the total flow, the second opening allows for 90 – 99% of the total flow.

The hydrocyclone is used to remove the settleable solids which made from stainless steel and has inlet diameter of 30 mm, overflow diameter of 50 mm, height of 350 mm, top diameter of 335 mm, underflow of 50 mm and cone angle of 68° .

The drum screen filter used in this system which has dimensions were 0.7 m in diameter and 0.8 m long. The filter was made from stainless steel at private company for steel industry. The fine mesh silk 60 micron was used as media of screening. The filter was driven by one motor of 0.5 kW power and 1500 rpm and a gearbox was used to reduce the rotation speed 500 times to give the recommended rotating speed (3 rpm).

Rotating Biological Contactor (RBC) used in this system, has 1.2 m in diameter and 1.5 m long. The filter was made from stainless steel. Used plastic sheets were used as a media. The filter was driven by one motor of 1.5 kW power and 1500 rpm and a gearbox to reduce the speed 500 times to give the recommended rotating speed (3 rpm).

Air-contact aeration system was used to transfer all gases present in atmospheric air into water. This system can only increase dissolved oxygen concentrations to saturation, and the efficiency of oxygen transfer declines as the dissolved oxygen concentration in water increase (**Boyd, 1982**). The air was pumped to the aeration tank by an air blower, under various pressures through leaky pipes of 16 mm in diameter of different lengths. The tank has a dimensions of 1 x 1x 1 m³ and was totally filled with water.

3.2. Methods

Tilapia nilotica fingerlings, which were used in the experiment, were brought from the General Authority for Fish Resources Development of A.R.E. in El-Knater El-Khiria, Kalubia, Egypt. The fish was weighed every week and the flow rate was adjusted according to the growth rate. The weekly fish weight was used to adjust both of water flow rate and length of leaky pipe and air pressure of the aerator.

The daily feed rates at different fish sizes were applied according to **Rakocy (1989)** and the feed pellet diameter was prepared according to **Jauncey and Ross (1982)**. Feeding was stopped during weighing process.

Water samples were collected daily from four locations, at the inlet and the outlet of the screen filter for measuring suspended solids, and at the inlet and the outlet of the hydrocyclone for measuring settleable solids according to **APHA (1998)**. The samples were stored in refrigeration for analysis.

Settleable solids removal and hydrocyclone efficiency were calculated as follows:

$$SSR_h = \frac{SS_{hin} - SS_{hout}}{1000} \quad (5)$$

$$\eta_h = \frac{(SS_{hin} - SS_{hout})}{SS_{hin}} \times 100 \quad (6)$$

Where:

SSR_h is the settleable solids removed, $kg\ m^{-3}$

SS_{hin} is the settleable solids at the inlet the hydrocyclone, $mg\ l^{-1}$

SS_{hout} is the settleable solids at the outlet the hydrocyclone, $mg\ l^{-1}$

η_h is the removal efficiency for settleable solids (%)

Suspended solids removal and screen filter efficiency were calculated as follows:

$$SSR_f = \frac{SS_{fin} - SS_{fout}}{1000} \quad (7)$$

$$\eta_f = \frac{(SS_{fin} - SS_{fout})}{SS_{fin}} \times 100 \quad (8)$$

Where

SSR_f is the suspended solids removed, $kg\ m^{-3}$

SS_{fin} is the suspended solids at the inlet the screen filter, $mg\ l^{-1}$

SS_{fout} is the suspended solids at the outlet the screen filter, $mg\ l^{-1}$

η_f is the screen filter efficiency for suspended solids (%)

4. RESULTS AND DISCUSSION

4.1. Settleable Solids

There are two levels of solids that to be removed from the recirculating aquaculture system (RAS), one is the settleable solids which is more dependent on the gravity rather than centrifugal force, while the second type is the suspended solids which is dependent on the centrifugal force. The hydrocyclone was used to remove the settleable solids from the

(RAS). The data was recorded daily. Fig (2) shows the predicted and measured settleable solids removal from the recirculating aquaculture system (RAS). It indicates that the average settleable solids removal from the system was $0.0429 \pm 0.0127 \text{ kg m}^{-3}$ ($42.90 \pm 12.70 \text{ mg l}^{-1}$) and it could be seen that the average daily solids removed from the system ranged from 0.33 to 6.62 kg/day experimentally while it was estimated to be from 0.34 to 4.41 kg/day theoretically fig (3).

The variations between the predicted and the measured are shown in fig (2) which shows that the predicted and the measured are in a reasonable agreement. The best fit for the relationship between the predicted and the measured values is in the following equation:

$$SSR_{hp} = 0.039 - 9.6 \times 10^{-23} SSR_{hm} \quad R^2 = 0.999 \quad (9)$$

Where:

SSR_{hp} is the predicted settleable solids removal by hydrocyclone, kg m^{-3}
 SSR_{hm} is the measured settleable solids removal by hydrocyclone, kg m^{-3}

4.2. Suspended Solids

Fig (4) shows the predicted and the measured suspended solids removal from the recirculating aquaculture system (RAS).

It could be seen that the suspended solids removed by the system increased with growth period, where it was about 0.0123 kg m^{-3} (12.30 mg l^{-1}) at the beginning and increased rapidly to reach 0.0806 kg m^{-3} (80.60 mg l^{-1}) after 3 months. Also, the results show that the average daily solids removed from the system ranged from 0.11 to 11.34 kg/day experimentally while it was from 0.11 to 15.70 kg/day for the theoretical approach fig (5).

The variations between the predicted and the measured are shown in fig (4). It shows the predicted and measured are in a reasonable agreement. The best fit for the relationship between the predicted and measured values was as follows:

$$SSR_{fp} = 1.59SSR_{fm} - 0.015 \quad R^2 = 0.915 \quad (10)$$

Where:

SSR_{fp} is the predicted suspended solids removal by filter, kg m^{-3}
 SSR_{fm} is the measured suspended solids removal by filter, kg m^{-3}

These results are in agreement with **Steicke *et al.* (2007)** whose found that the suspended solids removed from 0.0104 to 0.0400 kg m⁻³ (10.40 to 40.00 mg l⁻¹).

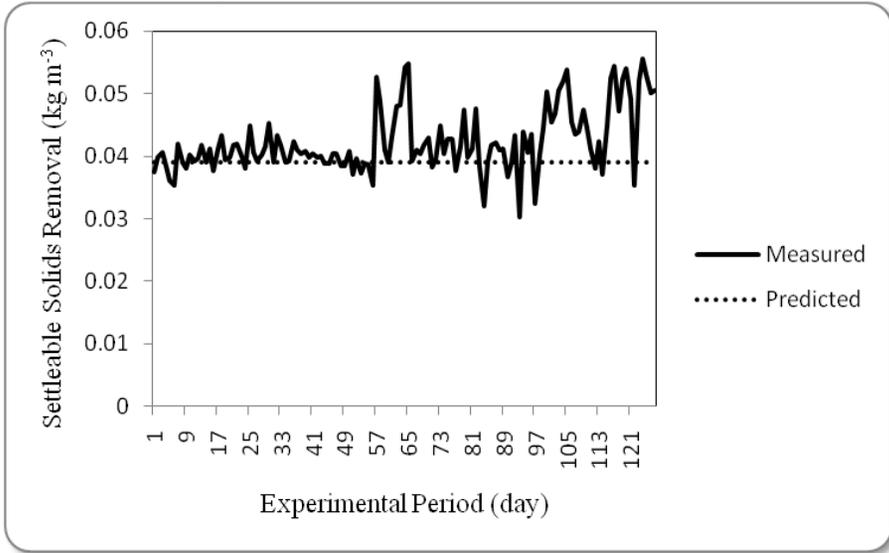


Fig. (2) The predicted and the measured settleable solids removed from the system (RAS).

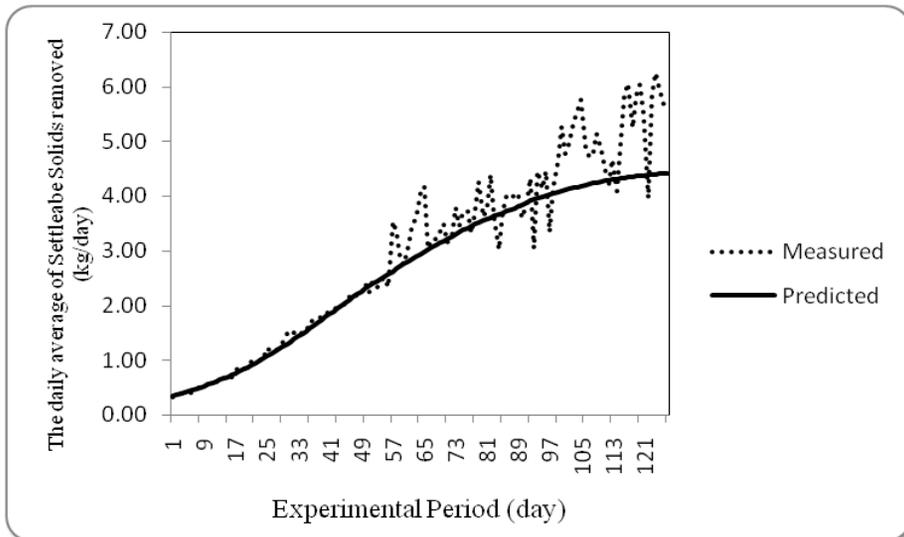


Fig. (3) The daily average of settleable solids removed by hydrocyclone (kg/day)

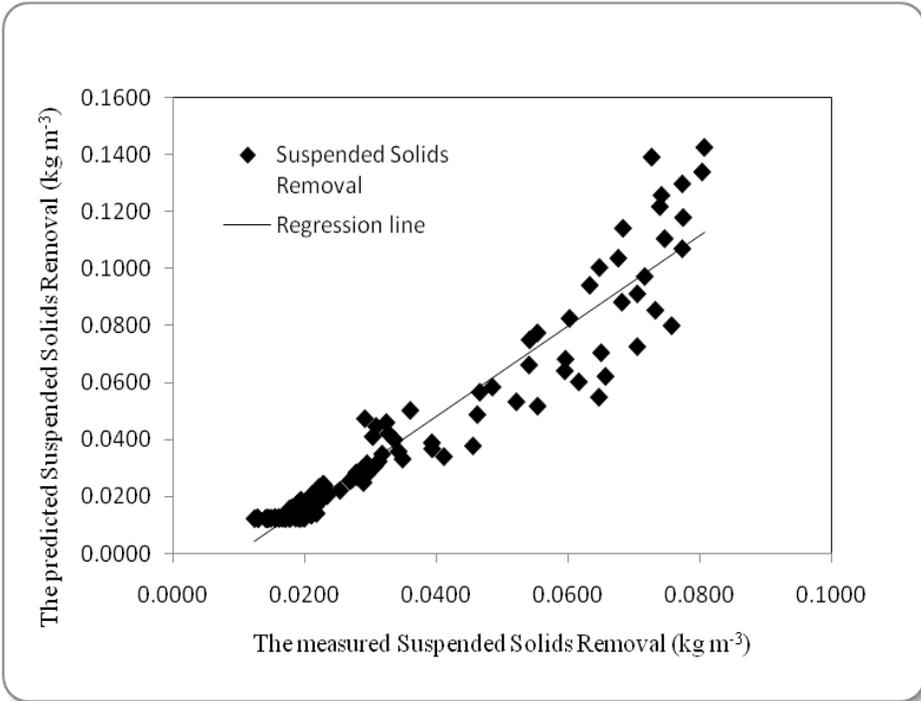


Fig. (4) The predicted and the measured suspended solids removal from the system (RAS)

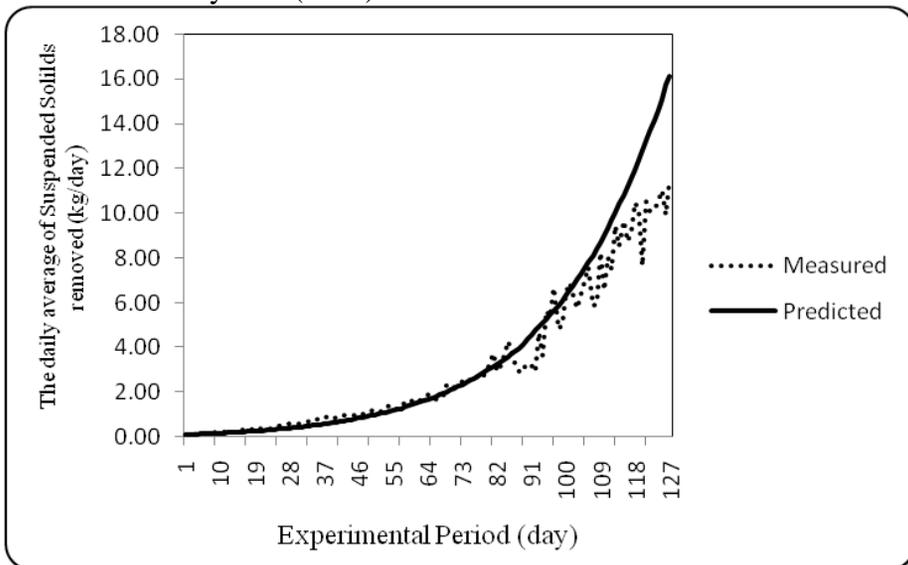


Fig. (5) The daily average of suspended solids removed by drum filter (kg/day)

4.3. The efficiency in removing solids

Hydrocyclone efficiency in removing settleable solids:

Hydrocyclone efficiency in removing settleable solids was determined by measuring the settleable solids concentration in the water entering the hydrocyclone and the settleable concentration in the water leaving the it. The data represented in Fig. (6) shows that the efficiency of the hydrocyclone for settleable solids removal from the system ranged from 27.4 to 57.79 %. These results are in agreement with those obtained by **Twarowska *et al.* (1997)**.

The drum filter efficiency:

The efficiency of the drum filter was determined by measuring the suspended solids concentration in the water entering the drum and the suspended concentration in the water leaving the drum. Since the drum was continuously rotated and the backwash water was always on, this provided a convenient means of measuring drum efficiency. The data presented in fig. (6) shows the efficiency of the drum filter for suspended solids removal from the system which ranged from 15.46 to 57.71 %. These results are in agreement with **d'Orbcastel *et al.* (2009)** whose found that the suspended solids efficiency of $40 \pm 18.5\%$.

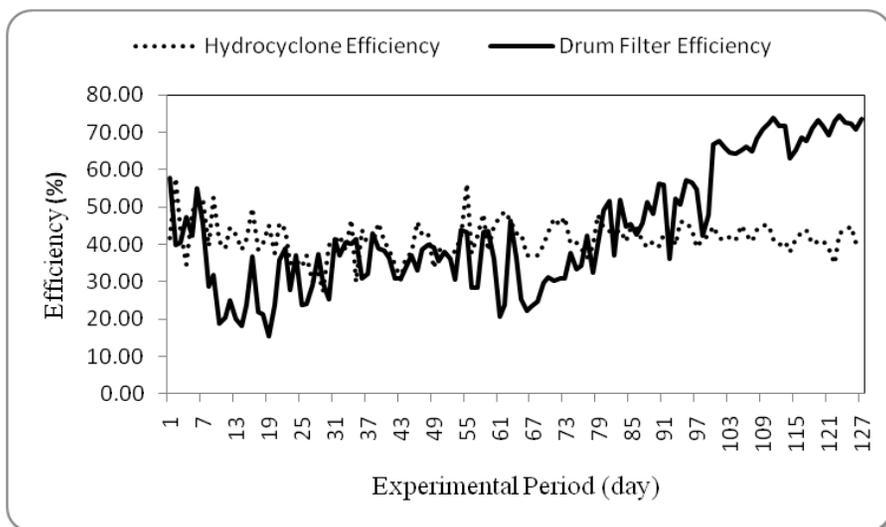


Fig. (6) The efficiency of the removal settleable and suspended solids (%)

CONCLUSIONS

An experiment to investigate the efficiency of both hydrocyclone and screen filter in removing both settleable and suspended solids was carried out successively. Statistics model was developed to predicted the settleable and suspended solids removed from the recirculating aquaculture system (RAS). The results indicated that the settleable and suspended solids removed by the recirculating aquaculture system (RAS) ranged from 0.0304 to 0.0556 kg m⁻³ and 0.0123 to 0.0806 kg m⁻³, respectively. The efficiency of the hydrocyclone and the drum filter to removed settleable and suspended solids ranged from 27.4 to 57.79 % and 15.46 to 57.71 %, respectively. The daily average of settleable and suspended solids removed by hydrocyclone and drum filter ranged from 0.33 to 6.26 kg/day and 0.11 to 11.43 kg/day, respectively. The model results were in a reasonable agreement with the experimental ones.

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الملخص العربي

إزالة المخلفات الصلبة فى نظام إعادة تدوير المياه فى الزراعة المائية

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تعتبر المخلفات الناجمة عن إخراج الأسماك وباقي الغذاء الذى لم يؤكل من أهم المشكلات فى الاستزراع المائي المكثف داخل نظام إعادة تدوير المياه نظرا لان تراكمها يؤدي إلى زيادة الحاجة إلى الأكسجين الذائب فى المياه وارتفاع نسبة غاز الأمونيا السام للأسماك وسرعة انسداد المرشحات الميكانيكية والحيوية وبالتالي فعمليات إزالة تلك المخلفات تعتبر من العوامل المهمة لتفادى المشكلات السابقة. ومن ثم كان الهدف من هذا البحث هو دراسة كفاءة كلا من مجمع المخلفات والمرشح الشبكي فى نظام إعادة تدوير المياه وذلك لتحسين جودة المياه وزيادة معدل نمو الاسماك. وقد تم تطوير نموذج رياضى لإيجاد معدل إزالة المخلفات الصلبة من نظام إعادة تدوير المياه، وكانت أهم النتائج كما يلى:

- معدل إزالة المخلفات الصلبة المترسبة الفعلية والنظرية يتراوح من ٠.٠٣٠٤ إلى ٠.٠٥٥٦ كجم م^{-٣} و ٠.٠٣٩٠ كجم م^{-٣}، على الترتيب. وكان متوسط كمية المخلفات المترسبة المزلة يوميا بواسطة مجمع المخلفات الفعلية والنظرية يتراوح من ٠.٣٣ إلى ٦.٢٦ كجم/يوم ومن ٠.٣٤ إلى ٤.٤١ كجم/يوم، على الترتيب.
- معدل إزالة المخلفات الصلبة العائمة الفعلية والنظرية يتراوح من ٠.٠١٢٣ إلى ٠.٠٨٠٦ كجم م^{-٣} ومن ٠.٠١٢٤ إلى ٠.١٤٢٥ كجم م^{-٣}، على الترتيب. وكان متوسط كمية المخلفات العائمة المزلة يوميا بواسطة المرشح الشبكي الفعلية والنظرية يتراوح من ٠.١١ إلى ١١.٣٤ كجم/يوم ومن ٠.١١ إلى ١٥.٧٠ كجم/يوم، على الترتيب.
- وكانت كفاءة مجمع المخلفات تتراوح من ٢٧.٤٠ إلى ٥٧.٧٩%.
- وكانت كفاءة المرشح الشبكي تتراوح من ١٥.٤٦ إلى ٥٧.٧١%.
- وكانت نتائج النموذج الرياضي متفقه مع النتائج التجريبية.

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