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EVALUATION OF SETTLEABLE SOLIDS REMOVAL METHODS IN RECIRCULATING AQUACULTURE SYSTEM

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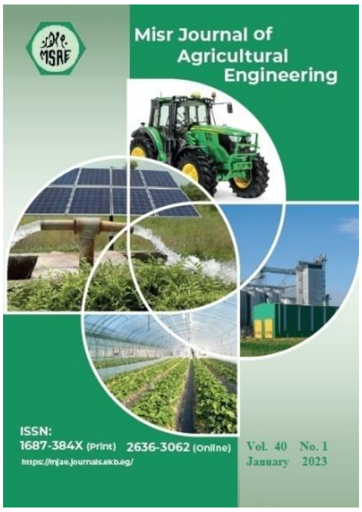

Keywords:
Settleable solids; Hydrocyclone; Settling tank; Efficiency; Flow rate.

ABSTRACT

The main aim of this work is to study the effect of using different methods of settling solids removal for recirculating aquaculture system to improve the water quality. To achieve that, the effects of water flow rates (0.05, 0.07 and 0.1 m^3 min^{-1}), inlet diameters (32, 50 and 60 mm) and outlet diameters (32, 50 and 60 mm) for hydrocyclone, also different distance at the inlet of settling tank (4.0, 8.0 12.0 and 16.0 m from the inlet) and retention times (4.0, 6.0 and 8.0 h) for settling tank on settleable solids removed and efficiency were studied. The results indicate that, the settleable solids removed by using hydrocyclone decreased from 0.133 to 0.057, 0.102 to 0.089 and 0.106 to 0.085 kg m^{-3} with increasing flow rate, inlet and outlet diameters of hydrocyclone. The settleable solids removed by using settling tank increased from 0.052 to 0.058, 0.017 to 0.041, 0.011 to 0.025 and 0.006 to 0.011 kg m^{-3} after 4, 8, 12 and 16 m at the inlet tank, respectively, when the retention time increased from 4.0 to 8.0 h. The hydrocyclone efficiency in removing solids decreased from 48.5 to 33.7, 42.1 to 37.9 and 42.1 to 38.1% with increasing flow rate, inlet diameter and outlet diameter of hydrocyclone. The settling tank efficiency decreased from 27.37 to 2.70, 30.94 to 9.68 and 32.95 to 10.89 % at 4.0, 6.0 and 8.0 h of retention time, respectively, when the distance of the inlet of settling tank increased from 4.0 to 16 m.

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 **(Patterson and Watts, 2003, Lee, 2010 and Badiola *et al.*, 2018)**.

In the aquaculture engineering field, numerous studies have focused on solids removal within culture systems. This is important because the fecal matter, uneaten feed, and feed fines can be broken rapidly into much finer particles due to water turbulence, animal motion, scouring, and pumping making it much more difficult to remove fine particulate matter than larger particles **(Summerfelt *et al.*, 2000 and Ahmed and Turchini, 2021)**. The use of clarifiers and swirl separators is an efficient method for solids removal within fish tanks. Swirl separators have already been used for different applications such as urban drainage systems, water quality control, mineral industry and wastewater treatment **(Andoh and Saul, 2003, Vinci *et al.*, 2004, Veerapen *et al.*, 2005 and Azaria and van Rijn, 2018)**.

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 filers, triangle filters, etc. Other types of filtration systems are based on granular media beds **(Cripps and Bergheim, 2000, Khater *et al.*, 2011 and Lee, 2015)**.

Accumulation of suspended and dissolved solids oriented both from uneaten and indigested feed are considered as restricting factors for more production of fish in a recirculating aquaculture system **(Rafiee and Saad, 2008)**. In order to remove the solid particles in aquaculture systems, an eco– trap recirculating system designed. In Eco-trap of cylindrical aquaculture system the solid trap efficiency, increased more in comparison with other aquaculture systems due to the flow pattern in cylindrical tanks. In this system, most of the solid particles release from central outlet and discharge to settling tank and few parts of particles that flow from lateral outlet move to drum filter to separate solid materials from liquid. The density of uneaten food and fish feces are more than water density and required for more detention time to deposit. Settlement of uneaten food and feces develop an organic condition on the bed, and decomposed by anaerobic bacteria and increases infectious condition. By altering the physical shape of the particles to finer gel particles, removal of solid makes more difficult **(Khater, 2012 and Xiao *et al.*, 2019)**.

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, Merino *et al.*, 2007 and Timmons and Ebeling, 2010)**. **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%.

Within a recirculating aquaculture system (RAS), almost all waste products originate 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 aim of this work is to study the effect of using different methods of settling solids removal for recirculating aquaculture system to improve the water quality.

2. MATERIALS AND METHODS

The main experiment was carried out in a Fish Farm unit, Faculty of Agriculture Moshtohor, Benha University, Egypt (latitude 30° 21` N and 31° 13` E). During the period of June to August, 2021 season.

2.1. Materials

2.1.1. System description

The system which consists of two units (hydrocyclone and settling tank) were used to remove the settleable solids from recirculating aquaculture system.

2.1.1.1. Hydrocyclone:

The hydrocyclone is used to remove the settleable solids which made from stainless steel and has total height of 1000 mm, top diameter of 350 mm and underflow of 50 mm as shown in figure (1). The diameter of the inlet pipe was three different pipe diameters were 30, 40 and 50 mm. Similarly, the diameter of the overflow pipe was three different pipe diameters were 50, 60 and 70 mm. the height of cone of 450 mm and cone angle of 68º.

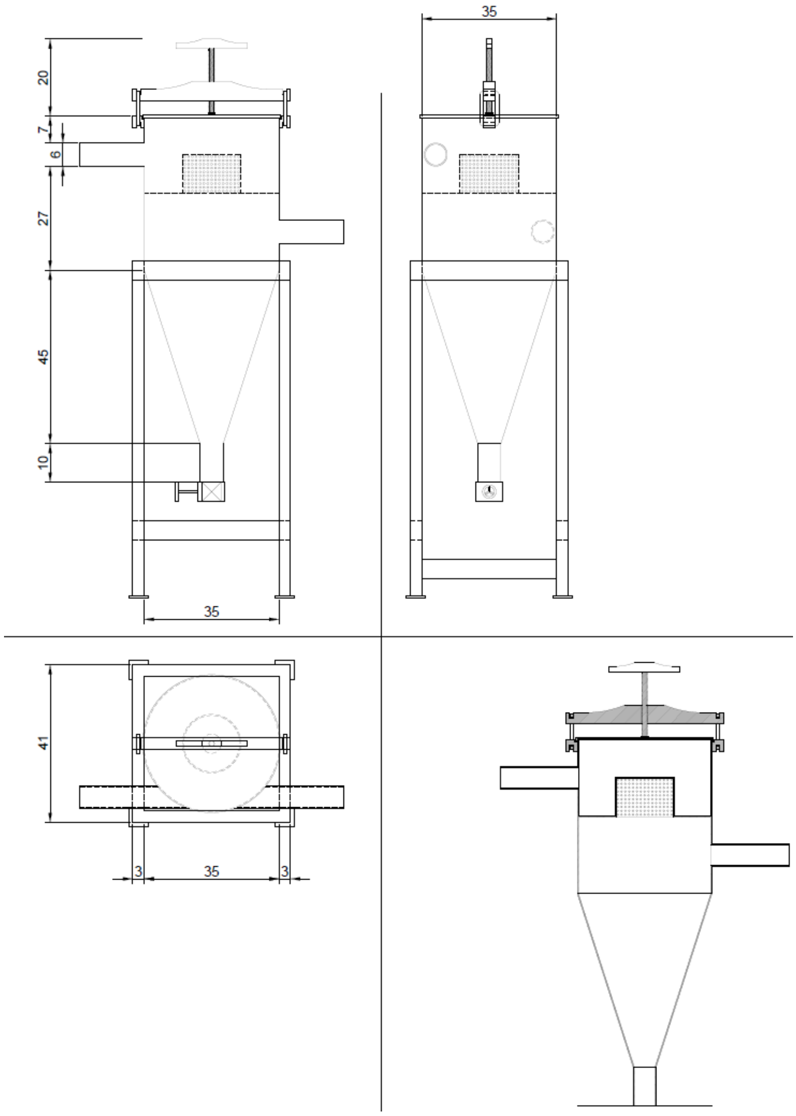

Figure (1): Hydrocyclone

Other structural modifications of the hydrocyclone involved investigating the influence of the structure of the top (overflow) outlet on separation performance. The following is a description of the various types of overflow outlet studied:

- Disc outlet (base outlet): a circular spill plate atop and channelling water into, an axial pipe.
- Central pipe outlet: the above axial pipe without disc.
- Side outlet: a circular opening on the tank sidewall as shown in figure (2a).
- Center to side outlet: an elbow pointing up, acting as an overflow weir and evacuating water via a horizontal pipe running through the tank sidewall (figure 2b).

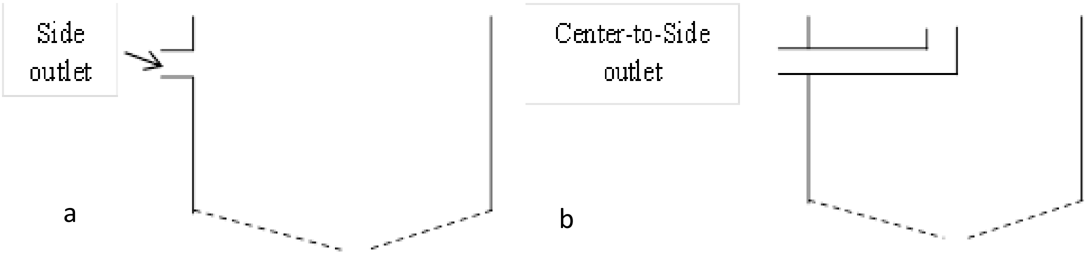

Figure (2): Side and center-to-side outlets

2.1.1.2. Settling tank:

The system consists of three rectangular concrete settling tanks covered by polyethylene sheet with 1 mm thickness that used for removal settlable solids. Dimensions of each tank are 17.5 m long, 1.2 m wide and 0.3 m high. The ground slope of tanks was 2 %. Figure (3) shows the settling tanks.

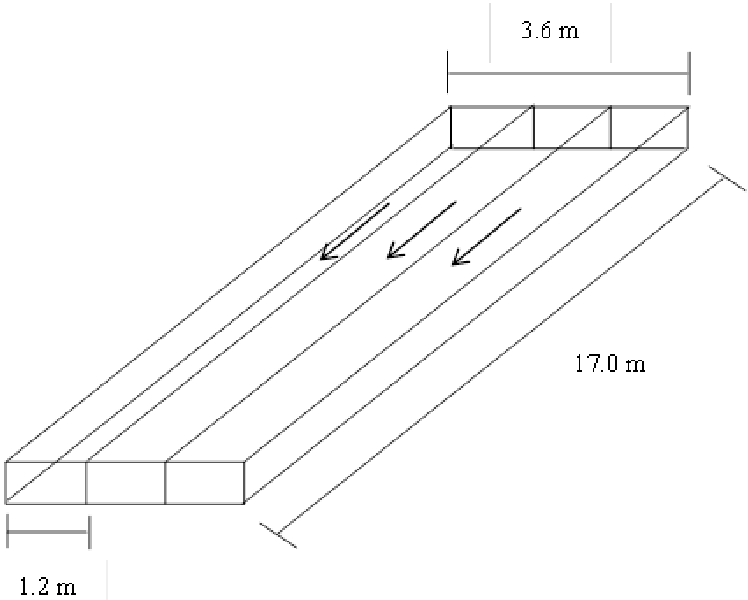

Figure (3): The settling tanks.

2.2. Methods:

2.2.1. Treatments:

The treatments include: two methods for removal solids (hydrocyclone and settling tank). The treatments for hydrocyclone were three flow rates (0.05, 0.07 and 0.1 m^3 min^{-1}), three inlet diameters (32, 50 and 60 mm) and three outlet diameters (32, 50 and 60 mm). The treatments for settling tank were five stations (0, 4.0, 8.0 12.0 and 16.0 m from the inlet) and three retention times (4.0, 6.0 and 8.0 h).

2.2.2. Measurements:

Water samples were collected at the inlet and the outlet of the hydrocyclone and settling for measuring settleable solids according to **APHA (1998)**. The samples were stored in refrigeration for analysis.

Settleable solids removal and removal efficiency were calculated as follows:

$$SSR = \frac{SS_{in} - SS_{out}}{1000} \quad (1)$$

$$\eta = \frac{SS_{in} - SS_{out}}{\mathrm{SS_{in}}} \times 100 \quad (2)$$

Where:

SSR is the settleable solids removed, kg m^{-3}

SS_{in} is the settleable solids at the inlet the hydrocyclone, mg L^{-1}

SS_{out} is the settleable solids at the outlet the hydrocyclone, mg L^{-1}

η is the removal efficiency for settleable solids (%)

3. RESULTS AND DISCUSSIONS

3.1. Settleable Solids Removed:

3.1.1. Settleable Solids Removed by using hydrocyclone:

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 centrifugal force rather than the gravity, while the second type is the settleable solids which is dependent on the gravity. The hydrocyclone was used to remove the settleable solids from the recirculating aquaculture system. Table (1) shows the effect of water flow rate, inlet diameter and outlet diameter of hydrocyclone on the settleable solids removed from recirculating aquaculture system. The results indicate that the settleable solids removed decreases with increasing water flow rate, inlet diameter and outlet diameter of hydrocyclone. It indicates that when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1}, the settleable solids removed by using hydrocyclone decreased from 0.133 to 0.057 (by 57.14%) kg m^{-3}. It also indicates that when the inlet diameter of hydrocyclone increased from 32 to 60 mm, the settleable solids removed by using hydrocyclone decreased from 0.102 to 0.089 (by 12.75%) kg m^{-3}, while the settleable solids removed by using hydrocyclone decreased from 0.106 to 0.085 (by 19.81%) kg m^{-3}, when the outlet diameter of hydrocyclone increased from 32 to 60 mm.

It could be noticed that increasing the inlet diameter of hydrocyclone, tends to decrease the settleable solids removed by using hydrocyclone from 0.140 to 0.127, 0.104 to 0.088 and 0.062 to 0.050 kg m^{-3} at 0.05, 0.07 and 0.10 m^3 min^{-1} water flow rate, respectively. The results also indicate that the settleable solids removed decreased from 0.140 to 0.062, 0.132 to 0.060 and 0.127 to 0.050 kg m^{-3} at 32, 50 and 60 mm of inlet diameter of hydrocyclone, respectively when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1} as shown in figure (4).

Table (1): Settleable solids removed at different water flow rate, inlet diameter and outlet diameter of hydrocyclone.

Inlet Diameter, mm	Outlet Diameter, mm	Flow rate, m^3 min^{-1}			Mean
		0.05	0.07	0.10	
		Settleable Solids Removed, kg m^{-3}			
32	32	0.151	0.112	0.071	0.111
	50	0.139	0.104	0.063	0.102
	60	0.131	0.096	0.053	0.093
	Mean	0.140	0.104	0.062	
50	32	0.144	0.106	0.068	0.106
	50	0.128	0.093	0.068	0.096
	60	0.123	0.088	0.043	0.085
	Mean	0.132	0.096	0.060	
60	32	0.14	0.1	0.065	0.102
	50	0.124	0.084	0.05	0.086
	60	0.118	0.081	0.035	0.078
	Mean	0.127	0.088	0.050	
Mean of flow rate	0.133	0.096	0.057		
Mean of Inlet diameter	0.102	0.096	0.089		
Mean of outlet diameter	0.106	0.095	0.085		

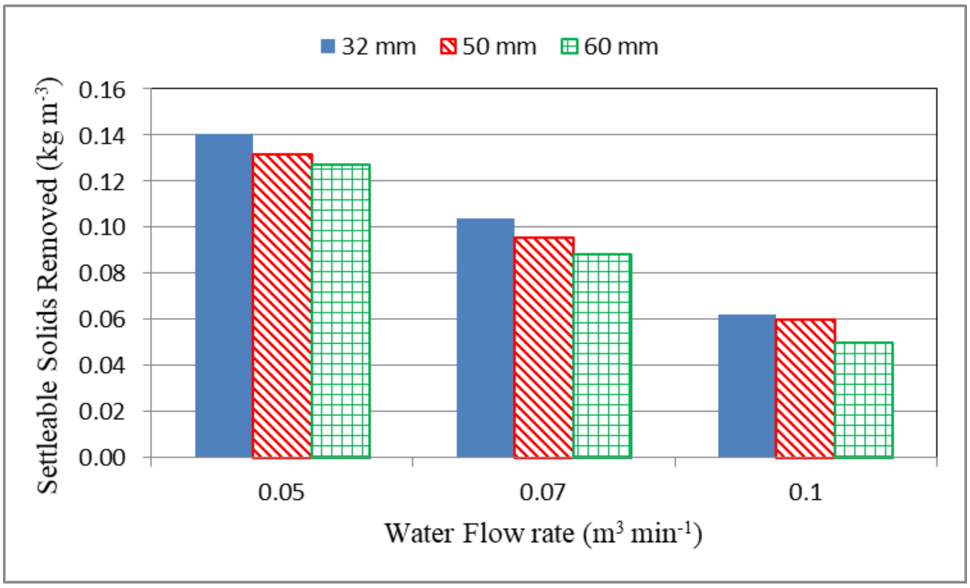

Figure (4): Settleable solids removed at different flow rates and inlet diameters of hydrocyclone.

Regarding the effect of inlet and outlet diameters of hydrocyclone, the results indicate that the settleable solids removed decreases with increasing the inlet and outlet diameters of hydrocyclone. It decreased from 0.111 to 0.102, 0.102 to 0.086 and 0.093 to 0.078 kg m^{-3} at 32, 50 and 60 mm outlet diameter hydrocyclone, respectively, when the inlet diameter of hydrocyclone increased from 32 to 60 mm. The results also indicate that the settleable solids removed decreased from 0.111 to 0.093, 0.106 to 0.085 and 0.102 to 0.078 kg m^{-3} at 32, 50 and 60 mm inlet diameter hydrocyclone, respectively, when the outlet diameter of hydrocyclone increased from 32 to 60 mm as shown in figure (5).

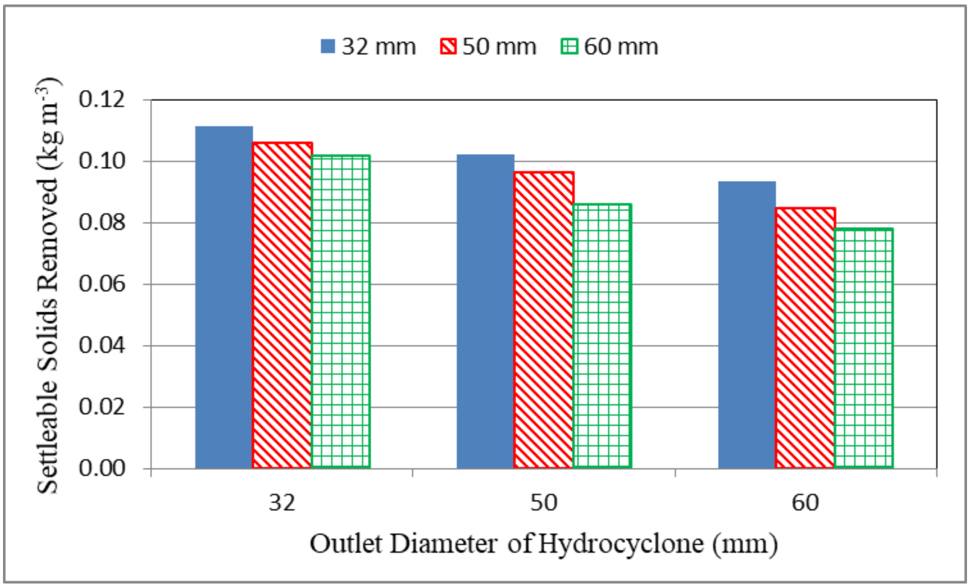

Figure (5): Settleable solids removed at different inlet and outlet diameters of hydrocyclone.

The results also indicate that the settleable solids removed decreased from 0.145 to 0.124, 0.106 to 0.088 and 0.068 to 0.044 kg m^{-3} at 32, 50 and 60 mm outlet diameter hydrocyclone, respectively, when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1}. The results also indicate that the settleable solids removed decreased from 0.145 to 0.068, 0.130 to 0.060 and 0.124 to 0.044 kg m^{-3} at 0.05, 0.07 and 0.10 m^3 min^{-1} water flow rate, respectively, when the when the outlet diameter of hydrocyclone increased from 32 to 60 mm as shown in figure (6).

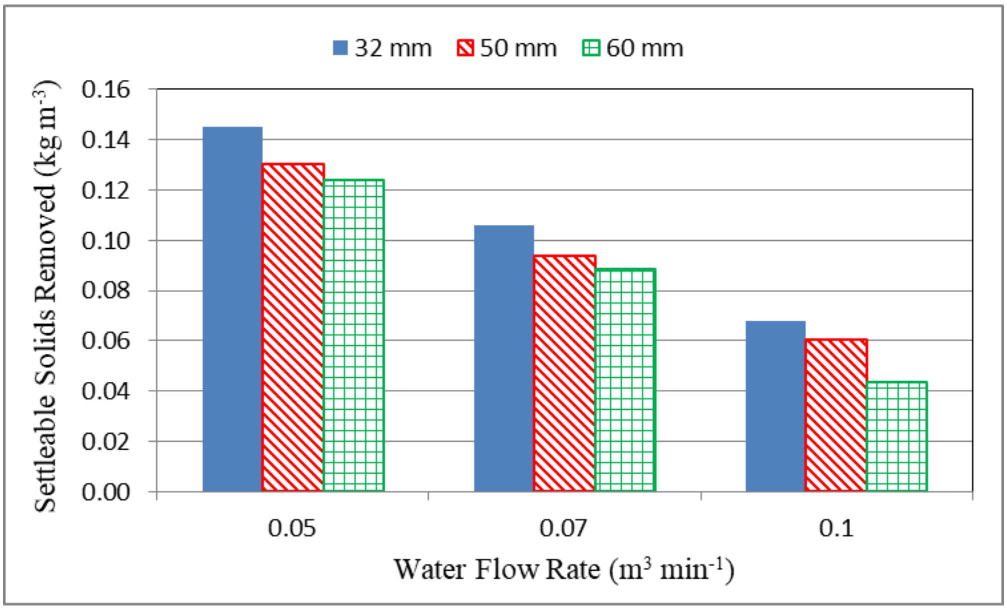

Figure (6): Settleable solids removed at different flow rates and outlet diameters of hydrocyclone.

3.1.2. Settleable Solids Removed by using settling tank:

Figure (7) shows the effect of retention time and distance after the inlet of settling tank on the settleable solids removed by using settling tank. The results indicate that the settleable solids removed increases with increasing retention time and decreases with increasing distance. It indicates that when the retention time increased from 4.0 to 8.0 h, the settleable solids removed by using settling tank increased from 0.052 to 0.058, 0.017 to 0.041, 0.011 to 0.025 and 0.006 to 0.011 kg m^{-3}, respectively, after 4, 8, 12 and 16 m at the inlet tank. The results also indicate that the settleable solids removed decreased from 0.052 to 0.006, 0.056 to 0.009 and 0.058 to 0.011 kg m^{-3} at 4.0, 6.0 and 8.0 h of retention time, respectively, when the distance of the inlet of settling tank increased from 4.0 to 16 m.

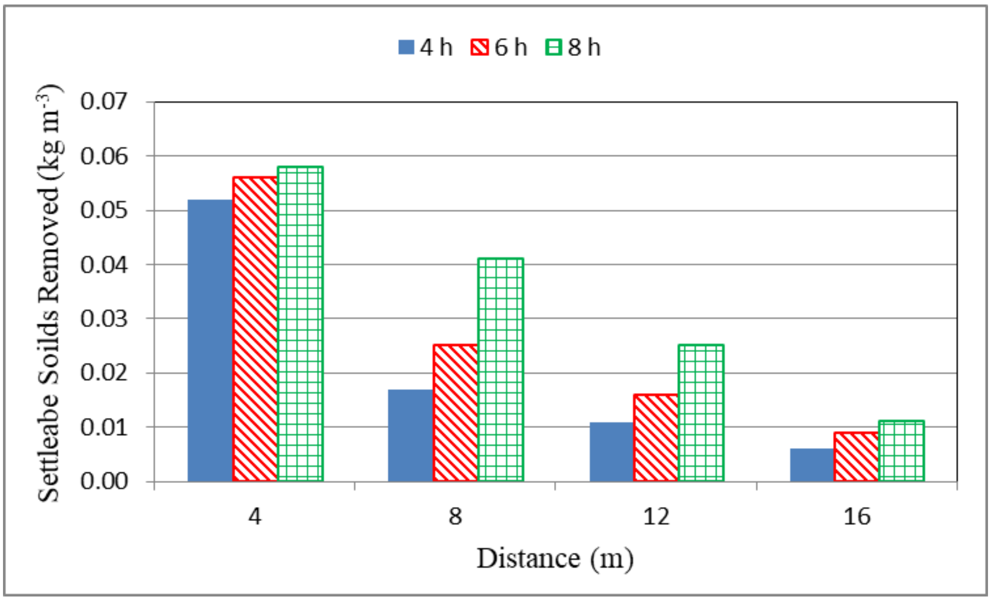

Figure (7): Settleable solids removed at different retention time and distance of settling tank.

3.2. The efficiency in removing solids:

3.2.1. Hydrocyclone efficiency:

Table (2) shows the effect of water flow rate, inlet diameter and outlet diameter of hydrocyclone efficiency in removing settleable solids from recirculating aquaculture system. The results indicate that the hydrocyclone efficiency in removing solids decreases with increasing water flow rate, inlet diameter and outlet diameter of hydrocyclone. It indicates that when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1}, the hydrocyclone efficiency in removing settleable solids decreased from 48.5 to 33.7 (by 50.52%) %. It also indicates that when the inlet diameter of hydrocyclone increased from 32 to 60 mm, the hydrocyclone efficiency in removing settleable solids decreased from 42.1 to 37.9 (by 9.98 %) %, while the hydrocyclone efficiency in removing settleable solids decreased from 42.1 to 38.1 (by 9.50%) %, when the outlet diameter of hydrocyclone increased from 32 to 60 mm. These results are in agreement with those obtained by **Twarowska *et al.* (1997) and Lee (2015)**.

It could be noticed that increasing the inlet diameter of hydrocyclone, tends to decrease the hydrocyclone efficiency in removing settleable solids from 52.7 to 44.8, 38.8 to 36.3 and 34.9 to 32.6 % at 0.05, 0.07 and 0.10 m^3 min^{-1} water flow rate, respectively. The results also indicate that the hydrocyclone efficiency in removing settleable solids decreased from 52.7 to 34.9, 48.1 to 33.6 and 44.8 to 32.6 % at 32, 50 and 60 mm of inlet diameter of hydrocyclone, respectively when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1} as shown in figure (8).

Table (2): Hydrocyclone efficiency at different water flow rate, inlet diameter and outlet diameter of hydrocyclone.

Inlet Diameter, mm	Outlet Diameter, mm	Flow rate, m^3 min^{-1} 0.05	0.07	0.10	Mean
		Hydrocyclone Efficiency, %			
32	32	54.9	40.4	37.8	44.4
	50	53.1	38.8	33.9	41.9
	60	50.2	37.1	33.1	40.1
	Mean	52.7	38.8	34.9	
50	32	51.4	38.4	35.6	41.8
	50	47.4	37.3	32.7	39.1
	60	45.6	35.6	32.6	37.9
	Mean	48.1	37.1	33.6	
60	32	48.6	37.3	34.2	40.0
	50	43.1	36.4	32.2	37.2
	60	42.6	35.2	31.3	36.4
	Mean	44.8	36.3	32.6	
Mean of flow rate		48.5	37.4	33.7	
Mean of Inlet diameter		42.1	39.6	37.9	
Mean of outlet diameter		42.1	39.4	38.1	

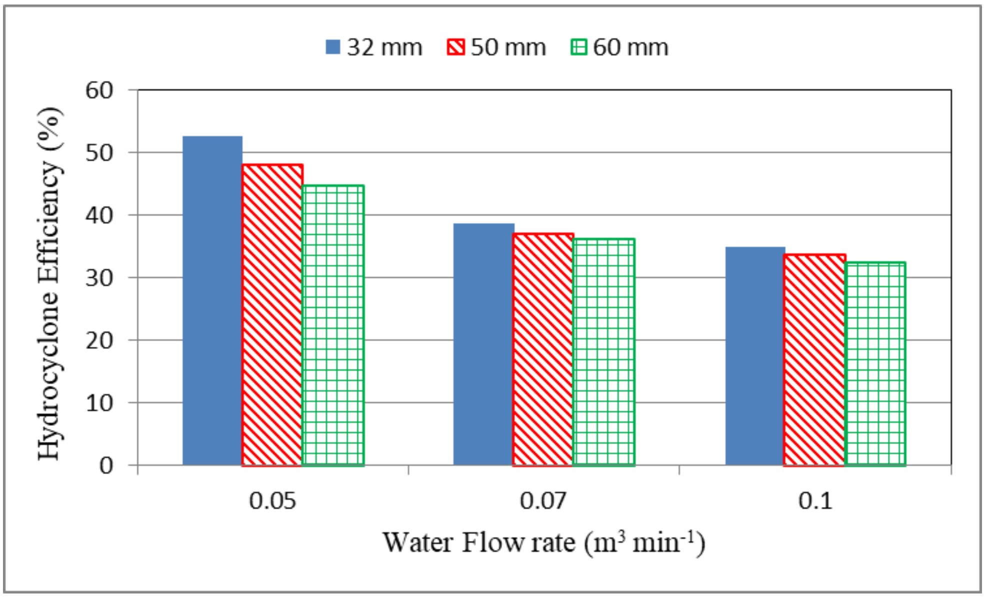

Figure (8): Hydrocyclone efficiency at different flow rates and inlet diameters of hydrocyclone.

Regarding the effect of inlet and outlet diameters of hydrocyclone, the results indicate that the hydrocyclone efficiency in removing settleable solids decreases with increasing the inlet and outlet diameters of hydrocyclone. It decreased from 44.4 to 40.0, 41.9 to 37.2 and 40.1 to 36.4 % at 32, 50 and 60 mm outlet diameter hydrocyclone, respectively, when the inlet diameter of hydrocyclone increased from 32 to 60 mm. The results also indicate that the hydrocyclone efficiency in removing settleable solids decreased from 44.4 to 40.1, 41.8 to 37.9 and 40.0 to

36.4 % at 32, 50 and 60 mm inlet diameter hydrocyclone, respectively, when the outlet diameter of hydrocyclone increased from 32 to 60 mm as shown in figure (9).

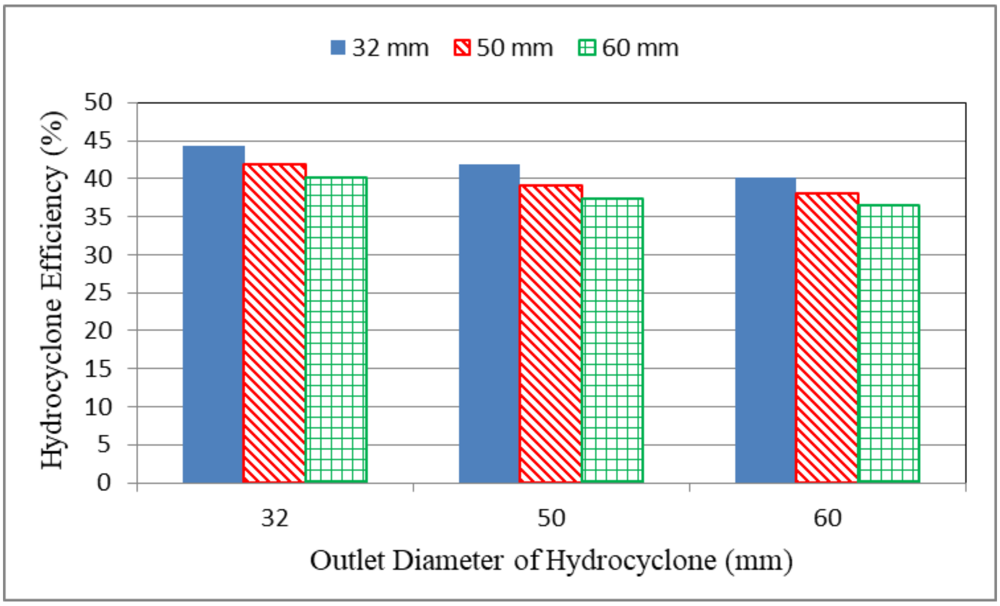

Figure (9): The hydrocyclone efficiency at different inlet and outlet diameters of hydrocyclone.

The results also indicate that the hydrocyclone efficiency in removing settleable solids decreased from 51.6 to 46.1, 38.7 to 36.0 and 35.9 to 32.3 % at 32, 50 and 60 mm outlet diameter hydrocyclone, respectively, when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1}. The results also indicate that the hydrocyclone efficiency in removing settleable solids decreased from 51.6 to 35.9, 47.9 to 32.9 and 46.1 to 32.3 at 0.05, 0.07 and 0.10 m^3 min^{-1} water flow rate, respectively, when the when the outlet diameter of hydrocyclone increased from 32 to 60 mm as shown in figure (10).

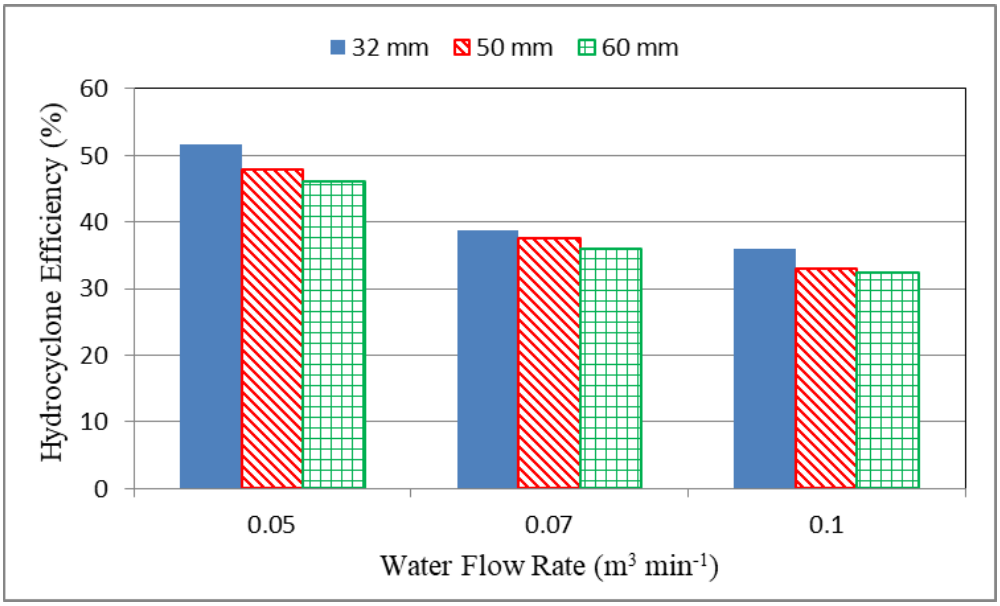

Figure (10): The hydrocyclone efficiency at different flow rates and outlet diameters of hydrocyclone.

3.2.2. Settling tank efficiency:

Figure (11) shows the effect of retention time and distance after the inlet of settling tank on the settling tank efficiency. The results indicate that the settleable solids removed increases with increasing retention time and decreases with increasing distance. It indicates that when the retention time increased from 4.0 to 8.0 h, the settling tank efficiency increased from 27.37 to 32.95, 18,32 to 30.75, 16.53 to 26.00 and 2.70 to 10.89 %, after 4, 8, 12 and 16 m at the inlet tank, respectively. The results also indicate that the settling tank efficiency decreased from 27.37 to 2.70, 30.94 to 9.68 and 32.95 to 10.89 % at 4.0, 6.0 and 8.0 h of retention time, respectively, when the distance of the inlet of settling tank increased from 4.0 to 16 m. The settling tank efficiency was decreased with increasing distance due to decreasing the concentration of settleable solids in water.

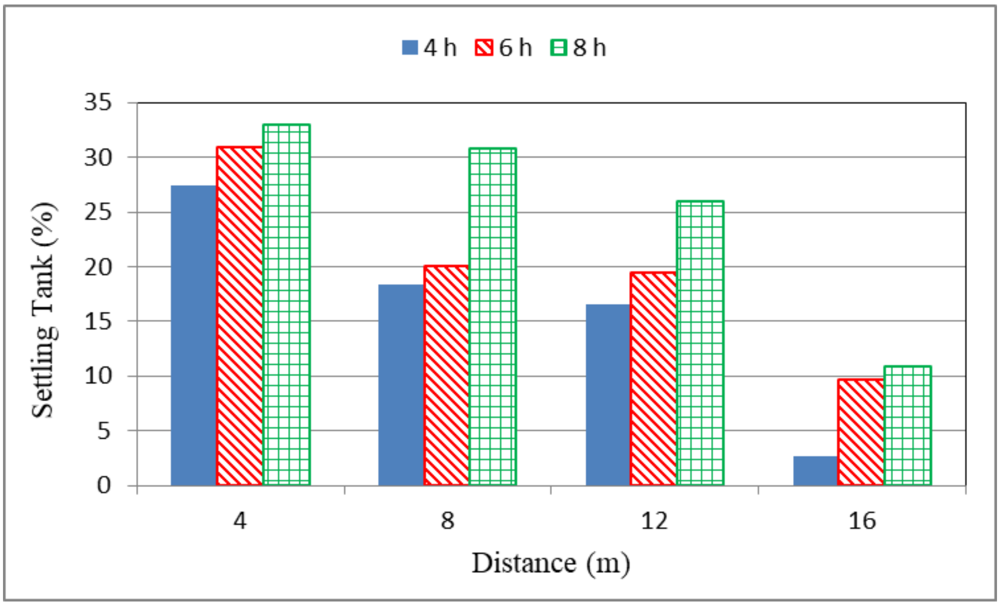

Figure (11): Settling tank efficiency at different retention time and distance of settling tank.

4. CONCLUSION

The experiment was carried out to study the effect of using different methods of settling solids removal for recirculating aquaculture system to improve the water quality. The obtained results can be summarized as follows:

- The settleable solids removed by using hydrocyclone decreased from 0.133 to 0.057 kg m^{-3}, when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1}. It decreased from 0.102 to 0.089 kg m^{-3}, when the inlet diameter of hydrocyclone increased from 32 to 60 mm, while the settleable solids removed by using hydrocyclone decreased from 0.106 to 0.085 kg m^{-3}, when the outlet diameter of hydrocyclone increased from 32 to 60 mm.
- The settleable solids removed by using settling tank increased from 0.052 to 0.058, 0.017 to 0.041, 0.011 to 0.025 and 0.006 to 0.011 kg m^{-3}, respectively, after 4, 8, 12 and 16 m at the inlet tank, when the retention time increased from 4.0 to 8.0 h.
- The hydrocyclone efficiency in removing settleable solids decreased from 48.5 to 33.7 %, when the water flow rate increased from 0.05 to 0.10 m^3 min^{-1}. It decreased from 42.1 to

37.9 %, when the inlet diameter of hydrocyclone increased from 32 to 60 mm, while the hydrocyclone efficiency decreased from 42.1 to 38.1 (by 9.50%) %, when the outlet diameter of hydrocyclone increased from 32 to 60 mm.

- The settling tank efficiency decreased from 27.37 to 2.70, 30.94 to 9.68 and 32.95 to 10.89 % at 4.0, 6.0 and 8.0 h of retention time, respectively, when the distance of the inlet of settling tank increased from 4.0 to 16 m.

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تقييم طرق التخلص من المخلفات الصلبة المترسبة فى نظام إعادة تدوير المياه

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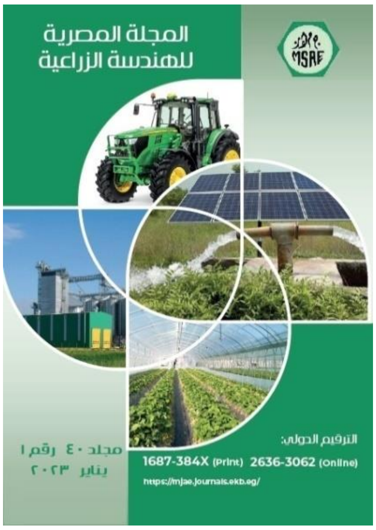

الملخص العربي

الهدف الرئيسي من هذا البحث هو دراسة تأثير استخدام طرق مختلفة لإزالة المخلفات الصلبة المترسبة فى نظام اعادة تدوير المياه لتحسين صفات وجودة المياه فى نظم الزراعات المائية المتكاملة. ولتحقيق ذلك تم دراسة تأثير معدل سريان المياه (٠,٠٥، ٠,٠٧، ٠,١٠ م^{3} دقيقة$^{-1}$) وقطر فتحة الدخول لمجمع المخلفات (٣٢، ٥٠، ٦٠ مم) وقطر فتحة الخروج لمجمع المخلفات (٣٢، ٥٠، ٦٠ مم) لمجمع المخلفات وأيضا البعد من الدخول لحوض الترسيب (٤، ٨، ١٢، ١٦ متر) وزمن بقاء (٤، ٦، ٨ ساعات) لحوض الترسيب على المخلفات الصلبة المترسبة المزالة وكفاءة مجمع المخلفات وحوض الترسيب. أشارت النتائج إلى أن معدل ازالة المخلفات الصلبة المترسبة باستخدام مجمع المخلفات انخفض من ٠,١٣٣ الى ٠,٠٥٧ ومن ٠,١٠٦ الى ٠,٠٨٥ ومن ٠,١٠٢ الى ٠,٠٨٩ كجم م$^{-3}$ بزيادة معدل سريان المياه وقطر فتحة دخول وخروج مجمع المخلفات. زاد معدل ازالة المخلفات الصلبة المترسبة باستخدام حوض الترسيب من ٠,٠٥٢ الى ٠,٠٥٨ ومن ٠,٠١٧ الى ٠,٠٤١ ومن ٠,٠١١ الى ٠,٠٢٥ ومن ٠,٠٠٦ الى ٠,٠١١ كجم م$^{-3}$ بعد ٤ و٨ و١٢ و١٦ متر من دخول حوض الترسيب على الترتيب، عند زيادة زمن البقاء من ٤ الى ٨ ساعات. انخفضت كفاءة مجمع المخلفات فى ازالة المخلفات الصلبة المترسبة من ٤٨,٥ الى ٣٣,٧ ومن ٤٢,١ الى ٣٧,٩ ومن ٤٢,١ الى ٣٨,١% بزيادة معدل سريان المياه وقطر فتحة دخول وخروج مجمع المخلفات. انخفضت كفاءة حوض الترسيب فى ازالة المخلفات الصلبة المترسبة من ٢٧,٣٧ الى ٢,٧٠ ومن ٣٠,٩٤ الى ٩,٦٨ ومن ٣٢,٩٥ الى ١٠,٨٩% عند زمن بقاء ٤ و ٦ و٨ ساعة على الترتيب، مع زيادة البعد عن فتحة الخول من ٤ الى ١٦ متر.

الكلمات المفتاحية:

المخلفات الصلبة؛ مجمع المخلفات؛ احواض الترسيب؛ الكفاءة.