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# A Test Method for Optimal Micro-screen Drum Filter Selection

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# Title

A test method for optimal micro-screen drum filter selection

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# Abstract

In order to meet increasing demand for seafood worldwide Recirculation Aquaculture Systems (RAS) are frequently used. These systems are susceptible to contamination by waste matter including faecal material in the water. It is imperative that this material is removed from the system. The maintenance of good water quality is a pre-requisite to the success of the operation. Negligence in this area will adversely affect animal growth rates and also the economic performance of the system.

Micro-screen drum filters are a popular solution for the removal of this material (Cripps, Simon J. and Bergheim, Asbjørn., 2000). These screens are nominally rated by their screen aperture size measured in microns.

A common issue with the selection of this equipment is in relation to the many variables that influence filter performance. For simplicity, vendors have rationalised selection criteria for filters to the flow capacity at each end of the potential solids loading spectrum, without any reference to a specific culture species.

This paper outlines a technique for accurate micro-screen drum filter selection for site and species specific applications using simple equipment, allowing the identification of an optimal filtration solution, in terms of cost and filtration performance. It also evaluates the potential of cake filtration for increased filter mechanical efficiency performance,

# Highlights

This paper sets out to establish;

- Optimal drum filter selection
- Particle size distribution of suspended solids in a RAS
- Feasibility and effectiveness of cake filtration in mechanical efficiency and flow rate terms.

It is envisaged that this new methodology can be adopted by aquaculturists to address the need within the aquaculture industry for documented and optimised species specific filtration solutions.

**Keywords**

Particle Size Distribution

Total Suspended Solids

Filtration

Filter cake

Recirculation

Aquaculture

**Abbreviations**

BOD – Biological Oxygen Demand

PSD – Particle Size Distribution

RAS – Recirculation Aquaculture System

RPM – Revolutions per Minute

TSS – Total Suspended Solids

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**Nomenclature and Units**

- $A_t = Area\ of\ Test\ Micro\ Screen\ (m^2)$
- $A_p = Area\ required\ for\ Process\ flow\ (m^2)$
- $Q_p = Process\ Flow\ rate\ (L/min)$
- $Q_t = Maximum\ Micro\ Screen\ Flow\ Rate\ (L/min)$

# 1.0. Introduction

As world population continues to grow, the demand for protein derived from aquatic life will also increase. Declining wild fish stocks combined with the growing popularity of seafood worldwide provides an unsustainable situation for food markets. In order to preserve wild fish stock levels and satisfy the worldwide demand in a sustainable way, the expansion and further development of RAS's is essential.

In order to ensure successful RAS operation, an optimally designed water treatment system that can continuously and effectively remove by-products of aquaculture before they can have a detrimental effect on water quality parameters in the RAS is required.

At the forefront of optimised water treatment systems, is an effective filtration solution for the removal of solid waste feeding by-products. It has been shown that high levels of TSS are detrimental to the animals health, and stress may be induced (Chapman,P.E. et al,1987),(Magor,B. G., 1988)&(Alabaster, J. S., and Lloyd, R., 1982). If left within the re-circulated waters, these solids will influence the efficiency of all the other water treatment systems, increase the biological oxygen demand (BOD) placed on the system, as well as providing a habitat that enables the proliferation of pathogens (Cripps, S.J and Liltved, H., 1999).

In an optimally configured micro-screen drum filter the micro-screen rating (µm) selected should be based on the particle size distribution of the suspended solids in the RAS waters and the desired water quality.

## 1.1.Drum Filter Description

Drum filters used in aquaculture consist of a micro-screen filter covering the entire curved surface of an open ended cylinder. The drum is placed inside a housing which is sealed along the perimeter of the open ends.

Influent water is gravity fed to the filter and enters the centre of the drum and passes radially through the filter screen. Suspended solids that are larger than the micron rating of the installed micro-screen are retained. See figure 1.

Figure 1

Caption: Mono-Filament Microscreen, Open Channel Drum Filter and Operating Principle of Drum Filter (Waste Streams Highlighted in Red)

### 1.1.1. Drum Filter Operation

As captured solids accumulate on the inside of the screen, they will blind the screen and cause an obstruction to the flow of water. The corresponding increase in resistance to water flow through the screen caused by blinding manifests itself as an increase in the level of influent water inside the drum, to a maximum level before which the filter must be backwashed to prevent water bypassing the screen (Greencorn, Nancy., 2009).

Backwashing may be continuous or intermittent in its operation. Typically, a filter operating at continuous backwash is operating at its maximum flow capacity. Continuous backwashing ensures an unblocked screen and hence maximum flow rates can be achieved. Intermittent backwashing is acceptable when there is extra flow capacity within the filter. The time duration between each backwashing event is determined by the degree of excess flow capacity. During such time intervals filter cakes may be established on the screen. Filter cakes are formed by a build-up of debris on the filter screen. This cake can also be instrumental in the filtering process, however if it is allowed to become too dense, the filtering process may be adversely affected. (This is dealt with in greater detail in section 1.3).

### 1.1.2. Flow Capacity

Whilst backwashing frequency is leading contributory factor influencing the flow capacity of a filter, the filter flow capacity also depends on other factors, (Boucher,P. L., 1947), including:

- Micron rating of the screen.
- Submerged area of the screen (or differential water level).
- TSS concentration of the water.
- Particle size distribution of suspended solids in the water

### 1.1.3. Mechanical Efficiency

Mechanical efficiency of a drum filter is important in order to quantify the performance of the unit. The mechanical efficiency is a measure of the amount of material being removed by the filter, relative to the total level of material in the influent waters.

The single most influencing factor for the mechanical efficiency of a microscreen filter is the particle size distribution of the solids in the influent water relative to the pore size of the microscreen.

### 1.1.4. Particle Size Distribution

In aquaculture facilities solids are primarily comprised of uneaten feed, faeces and biofloc (suspended bacterial colonies).These particles vary in size, and are characterised by size into the following classes:

- Settleable (> 100 µm)
- Fines (1 < µm < 100)
- Colloidal (0.001 < µm < 1)
- Dissolved (< 0.001 µm) (M.B. Timmons et al., 2002).

In relation to mechanical drum filtration, settleable solids, once entrained in the water stream are easily removed. Fine suspended solids; require greater consideration due to the profound changes seen in the flow capacity at this size range of a micro-screen, as shown in figure 4.

## 1.2. Drum Filter Economics

The capital and running costs are the remaining factors to be considered when a filter unit is to be used in a commercial environment. The hypothesis has been formed that reduced operating costs may be achieved by over specifying the filter in flow rate terms. This is done by examining the capital and running costs for a number of filters operating under similar conditions. It may then be ascertained if it is more economical to operate a smaller filter at continuous backwashing or a larger unit in intermittent backwashing mode.

To illustrate the capital and backwashing costs for each of a selection of commercially available drum filters, the data has been calculated and normalised for each filter operating at their maximum flow capacity in **Error! Reference source not found.**Table 1. It can be seen that as expected the backwashing costs for the lager filter units are greater, as are the capital costs.

The data has been normalised to ease comparison between the different sizes of drum filters analysed. Normalisation of the data also allows the sensitive cost information provided to be protected on behalf of the distributor. Normalisation of the data involve setting the lowest variable encountered to a base value of 1 and representing all other value based upon this baseline.

Assumptions made for normalised data.

- Flow capacities for each filter were provided by a local drum filter distributor
- Capital costs normalised based upon quotations from local drum filter distributor.
- Running costs normalised based upon motor and pump power ratings provided by local drum filter distributor.

Table 1

Caption: Drum Filter Maximum Flow Capacities Using a 40 Micron Microscreen

As larger units have a higher flow capacity they can run for a longer periods at 36L/s ("Filter A" max flow capacity)flow rate without the need for cleaning. As a result the backwashing frequency and associated backwashing cost will be reduced as shown below in table 2. The automatic backwashing frequency is calculated as the ratio of the flow capacity of the "Filter A" unit to the flow capacity of the unit in question.

Table 2

**Caption: Drum Filters Operating at 36 L/s Backwashing Frequency and Power Usage**

Due to the fact that larger filters do not necessarily have proportionally larger motors, a 50% reduction in backwashing frequency will not necessarily result in a 50% reduction in power usage.

The running cost payback achieved by utilising a larger filter backwashing intermittently can take a long time period until it is more economical to operate than a smaller filter operating in continuous backwashing mode, this is due to the initial higher capital purchase costs of the larger unit. This can be seen in figure 2 where the cumulative total costs of running each of the above filters per year at a flow rate of 36 l/s and a conservative electricity cost.

It is therefore advisable that when selecting a filter with medium terms cost constraints that the most economical unit will be a smaller unit operating in continuously backwashing mode.

Figure 2

Caption: 2 Normalised capital and Running Costs of Drum Filters Operating at 36 L/s

Due to the reduced running costs of the larger units for the specified flow rate, any increase in energy prices will reduce the time to achieve the break-even point. Once the break-even point has been reached, the larger unit will perform better in economic terms than the comparison "filter A" unit.

## 1.3.Cake Filtration

As a filter screen become blinded a layer or cake of accumulated material will form, it is thought that this cake of material will provide greater filtration efficiencies than the screen alone. However, the formation of a cake increases the resistance to flow and hence decreases the flowrate.

The test method of cake filtration is known as constant pressure filtration, signified by a decreasing flowrate under constant pressure. The drum filter performs cake filtration under constant rate filtration conditions which is signified by an increasing water level (pressure) at constant flowrate.

The two methods are analogous and any tests carried out in one method will have reflected data in the alternate method.

One aspect of this paper will investigate if cake filtration increases the mechanical efficiency of filtration and also if the expected decrease in flowrate is acceptable relative to the increase in mechanical efficiency.

# 2.0. Materials and Methods

## 2.1. Test Location

The filter tests were carried out in a traditional earthen pond trout fresh water culture facility in Ireland .Water samples were taken from the outlet of earthen ponds at the site. These tests were conducted to evaluate the feasibility of installing a drum filter in order to facilitate water recirculation.

## 2.2. Recommended Drum Filter Simulation Tests

Optimal RAS design should include a filter, selected for both the species being cultured and the system upon which it is to be installed. To test the suitability of filtering screens a test tube filter simulator was used as seen in figure 3

Figure 3

Caption: Test Tube Apparatus

The apparatus is supplied with 100, 60, 40, 30, 25, 18& 10 micron microscreens, these screens reflect the commercial range of drum filters available. The following are the procedures advised by drum filter manufacturers.

The device requires a minimum of 70cm of water depth in a location representative of the unfiltered RAS water (usually the culture tanks), and it replicates the function of a drum filter as follows:

- It contains a sealed micro-screen opening which is 20cm below water level to represent the normal head of water pressure across a drum filter screen.
- By immersing the tube at this depth for 10 seconds, the normal rotational speed of the drum filter of 3 RPM is simulated.

The primary characteristics of a drum filter i.e. flow capacity and filtration efficiency can be determined using the test tube by measuring the volume of filtrate collected by the test tube during the 10 second filtration test time, the flow rate (litre/second) of the micro-screen can be calculated. The flow capacity (litre/second /$m^2$) of the screen, and hence the size of drum filter required, can be easily calculated using equation 3-4 when the diameter of the submerged test screen is known.

## 2.3. Cake Filtration Method

The cake filtration method involves using the following procedure in order to evaluate the influence of cake filtration on mechanical filtration efficiency and flow rates.

1. The volume of filtrate collected by the test tube during the 10 second filtration test time is noted and the flow rate (litre/second) of the micro-screen is subsequently calculated.
2. The filtrate is collected and subsequently tested for TSS levels, this will allow the mechanical efficiency of the screen after the passage of the recorded level of filtrate has passed to be determined.
3. The steps 1 & 2 are then repeated with no cleaning of the filter being performed between tests, this simulates the effect of a filter cake build up.
4. Cake filtration tests were performed for the microscreens which allowed an acceptable volume (for TSS Testing) as a filter cake established.

# 3.0. Theory/calculation

Determination of the level of TSS in the influent and filtrate waters allow a number of values to be determined such as the mechanical efficiency of each filter screen as well as the PSD of the influent waters. TSS testing procedures are to be conducted according to standard methods (APHA, 1997),the TSS level may be calculated using equation 3-1,

$$TSS\ Concentration\ \left(\frac{mg}{L}\right) = \frac{Final\ Mass\ Filter\ Paper - Initial\ Mass\ Filter\ Paper}{Volume\ of\ sample}$$

**Equation 3-1 TSS Concentration**

## 3.1. Determination of the PSD

TSS testing results from multiple microscreens allows the mass of material above a given size as a percentage of the overall mass of material present to be calculated using equation 3-2.

$$\frac{Influent\ TSS - Filtrate\ TSS\ @\ Rating}{Influent\ TSS} * \frac{100}{1}$$

**Equation 3-2 Cumulative Mass Percentage of Particulate**

The TSS testing results with multiple microscreens also allow the mass of material between a defined size range as a percentage of the overall mass of material present to be determined using equation 3-3.

$$\frac{Filtrate\ TSS\ @\ Upper\ Rating\ - Filtrate\ TSS\ @\ Lower\ Rating}{Influent\ TSS} * \frac{100}{1}$$

**Equation 3-3 Fractional Mass Percentage of Particulate**

## 3.2. Determining the Filter Area Required & Mechanical Efficiency.

The primary variable when calculating the filter area required for a process is the flow capacity of the micro screen. The flow capacity of a micro screen is at a maximum immediately after backwashing when no material is blinding the micro screen. As screen aperture size becomes smaller the maximum flow capacity of a micro screen will decrease.

In order to calculate the area of micro screen required to handle a process flow rate the following equation 3-4 is used.

$$A_p = \frac{Q_p}{Q_t} * A_t$$

**Equation 3-4 Microscreen Area Calculation**

It should be noted that this is the minimum area required for the process flow rate. As the filter becomes blinded the flow rate through the filter will decrease or the filter water level will rise and eventually bypass the filter.

The mechanical efficiency of the micro screen may be calculated by using equation 3-5.

$$Mechanical\ Efficiency = \frac{Influent\ TSS - Filtrate\ TSS}{Influent\ TSS} * \frac{100}{1}$$

**Equation 3-5 Filter Screen Mechanical Efficiency**

The removal rate will establish the mass of material removed per second form the influent water source by a particular microscreen using the equation 3-6 shown below.

$$Removal\ Rate\ (mg/s) = Influent\ TSS(mg/L) * Flowrate(L/s) * Mechanical\ Efficiency$$

**Equation 3-6 Filter Screen Removal Rate**

# 4.0. Results

## 4.1. Maximum Microscreen Flow Capacities

Using the drum filter test tube apparatus and test method the flow capacities of each of the commercially available micro-screens were established while filtering the trout pond effluent waters, as can be seen in figure 4. It can be seen that the flow capacity of the microscreens is a direct function of their pore size. Screen flow capacity is seen to decrease with each reduction in microscreen rating. This implies that for a given flowrate, finer screens will require a greater surface area than those required for coarser screens.

Figure 4

Caption: Microscreen Maximum Flow Capacities (Screen flow capacity is based upon a test screen area of $4.4178*10^{-3}$ m^2)

## 4.2. Mechanical Efficiency Testing

In order to determine the mechanical removal efficiency for each microscreen, water samples were collected during the flow capacity tests. These samples included filtrate from each microscreen and pond water samples from where the tests were conducted. TSS levels were determined for each of these samples upon which mechanical removal efficiencies were subsequently calculated for each microscreen, as can be seen in figure 5.

Figure 5

The results show that as progressively finer microscreens are used the mechanical removal efficiency is increased. The data also indicates that the relationship is not linear, a twenty micron downward shift from a 60 micron screen to a 40 micron screen yields a 24.22% increase in efficiency whereas a downward shift of the same magnitude from a 30 micron screen to a 10 micron screen will yield only 4.07% increase in mechanical removal efficiency.

### 4.3. Particle Size Distribution Testing

Using the results of the TSS test results for each of the microscreens above, a particle size distribution of the solids in the water at the test site was calculated using equation 3-3. The results shown in figure 6, indicate that almost half of all the particulate present is greater than 100 microns in size and that a significant amount (24.24%) of the particulate is also found within the 40-60 micron range, while only a very small proportion of the material is present below 30 microns in size.

Figure 6

### 4.4. Cake Filter Simulation Tests

The results from the cake filtration tests are shown in figures 7, 8, 9 & 10. These results were limited to tests where acceptable filtrate volumes for TSS testing could collected, in this case the 30-100 micron microscreens. Sub 30 micron screens were found to blind prematurely making them unfeasible for filtrate collection for TSS testing, and hence subsequent cake filter evaluation.

Within these results it can be seen that the flowrate reduces in a linear fashion until a point is reached where the reduction in flowrate decreases, this can be seen in figures 9 & 10.

Contrary to the hypothesis that cake filtration will provide an increased mechanical removal efficiency due to particulate build up, no appreciable increase in the mechanical removal efficiency of each filter screen due to formation of a cake layer was identified in the testing conducted.

However, flowrates are seen to reduce thus indicating the presence of an additional resistance to the fluid flow caused by particulate build up. The results suggest that maximum removal rates are achieved while the filter is free of particulate. Therefore, it is advisable to operate the filter in continuous backwashing mode for optimal removal rates.

Figure 7

Caption: 100 Micron Cake Filtration Test Results

Figure 8

Caption: 60 Micron Cake Filtration Test Results

Figure 9

Caption: 40 Micron Cake Filtration Test Results

Figure 10

Caption: 30 Micron Cake Filtration Test Results

# 5.0. Discussion

There are three main considerations when selecting a microscreen drum filter for aquaculture, the system flow rate, the mechanical efficiency required and the running / purchase costs of the proposed filtration solution. Each of these factors will be addressed in turn as follows.

## 5.1. Filter Selection

In order to determine the optimal filter for an application the required flowrate must be known and the mechanical efficiency required must be specified.

The first step is to determine the correct filter size for the required application. This is done using the flow capacity table seen in table 3 coupled with the required system flowrate. The flow capacity data is generated using the maximum flow capacities measured in figure 4 and the submerged screen area of the microscreen in the drum filter. It can be seen that there is a direct linear relationship in flow capacity for each microscreen rating, between the drum filter sizes identified. It can also be seen that there is a linear increase in size between the “A,B,C & D” filter units.The maximum flow capacities do not follow a similar trend across microscreen rating for each particular filter, they do however increase with enlarged microscreen rating.

Table 3

Caption: Filter Flow Capacities

When a flowrate is specified, for example 24 L/s, it can then be determined which filter will meet this flowrate requirement as seen in table 4. In the table a value of 1 or greater indicates that the filter will accommodate the required flowrate, these values are calculated by dividing the filter flow capacity by the required flowrate of 24 L/s. Any value greater than 1 indicates the filter has excess capacity for the flowrate required, for example a value of 2.25 seen in the “Filter C” series for a 18 micron screen indicates that the filter has 125% excess capacity available.

For the table the example flowrate of 24L/s was used, as this represents the minimum flowrate required by the “Filter D” series with a 10 micron microscreen. This allows the effects across the spectrum of available filter units and microscreens to be seen.

Table 4

Caption: Drum Filter Flowrate Evaluation

It was shown earlier in figure 2 that the most cost effective filter choice in the short to medium term, is the smallest filter available for the required flow capacity, backwashing continuously. For the example flowrate of 24L/s, the smallest filter that meets the flow criteria for each microscreen rating should be selected, as shown in table 5. However, if a long term investment is feasible, a larger unit may be specified.

Table 5

Caption: Drum Filter Selected for Specified Flowrate and Micron Rating

These filter selections are valid only in terms of flowrate. However, in order to evaluate the optimal filter the required mechanical efficiency must also be considered, values for the mechanical efficiency were previously shown in figure 5. In this regard, material removal (or remaining) rates for each of the available microscreen have been calculated, using the established mechanical efficiencies and the measured influent water conditions of 17.22mg/L (n=15) and the example flowrate of 24l/s, this data may be seen in table 6.

Table 6

Caption: Microscreen Material Removal & Remaining Material Rates

From the table 6 above, it has been shown that the mechanical efficiency of the screen selected can have two possible outcomes when operating within the subject system. The first outcome being that the material removal rate will contribute to lowering the overall TSS level of the system. However the corresponding rate of material remaining beyond the filter may be excessive resulting in an increased level of difficulty to filter out fine solids. If the unfiltered material is not removed then the levels of fine solids within a system may quickly rise to unacceptable levels, consequently affecting the overall system performance.

The material remaining should be a carefully considered when selecting a filter screen. The optimal filter selection is based upon the system requirements for water quality in conjunction with economic considerations.

The optimal filter solution in terms of cost for the subject flowrate and system TSS level is found by considering both each of the proposed filters in Table 5 and their associated material removal rates for their microscreen as shown in Table 6.

This cost has been quantified for each of the proposed filter / microscreen combinations seen in Table 5 by calculating the normalised capital/running cost of each of these units on a material removal rate basis, as shown in Figure 11.

Figure 11

Caption: Normalised Costs to Achieve Removal Rates

The values in figure 11 allow a cost to be associated with the removal of material from the influent water source. It can be seen that the “Filter A” series 30 micron screen removes material at the lowest cost. However, if the amount of material remaining after this filter unit is not acceptable, a filter with a screen of a lower micron rating must be selected, this will incur additional costs as a result of the increased filter performance, as quantified in Figure 11.

## 5.2. Cake Filtration

Cake filtration is typically only an option where screens allow an appreciable level of solids to pass through when the screen is in a clean condition, i.e. if a screen is retaining 99% of material there is little additional advantage to be obtained by cake filtration.

The results from the cake filtration tests shown in figures 7-10 indicate that for the trout pond water tested, there is no significant increase in the mechanical efficiencies of the various microscreens as a filter cake is formed.

On the same graphs it is also shown that dramatic reductions in flow rate also occur as the cake establishes. This decrease in the flow rate indicates that the resistance to fluid flow is increasing over time as the filtrate volume increases, therefore confirming the creation of a filter cake.

These combined outcomes suggest that a cake filtration strategy does not offer any advantages and is therefore not an appropriate filtration solution for this site.

### 5.3. Particle Size Distribution

The tests methods outlined in this paper, in addition to identifying the optimal filtration solution also provides a simple solution for site specific information on the PSD of solids entrained in the waters at this facility to be calculated.

The PSD of the particulate within a system is the most influential factor in determining the mechanical of the various available microscreens. This mechanical efficiency data has been previously shown to provide key information in relation to establishing the most cost effective mechanical filtration solution for optimum material removal rates.

Such information is usually hard to find or is unavailable for particular species / systems, as the determination of particle size distribution often proves to be experimentally difficult (Wong, Kevin B., Piedrahita, Raul H., 2000).This is primarily due to either the labour intensity of PSD studies such as the sieving method used by (Cripps, Simon J., 1995)&(Pfeiffer et Al, 2008) or the very significant expense of high resolution laser probes used as successfully by (Brinker et al, 2005).

The simple methodology for PSD determination outlined in this paper minimises the effects of pore clogging that may be incurred when using the sieving method. Pore clogging has the potential to retain particles smaller than the screen rating utilised, potentially distorting the resulting PSD obtained (Patterson, R.N., and Watts, K.C., 2003).

## 6.0. Conclusions

Typically the selection of an optimal drum filter solution is a balance of the capital cost of the filter, the size of which is related the flow capacity of the screen, and the effectiveness of the screen rating at removing particulate matter.

The performance of a drum filter was also shown to be a function of many variables, including key variables such as the flow capacity and mechanical efficiency, which have been accounted for in the recommended economic appraisal method shown in Figure 11.

This method also recognises that it more economical in the short to medium term to select filters of various microscreen ratings backwashing continuously and discounts the principles of cake filtration, as this was shown to be not practical, for this site.

It has been shown in figures 7-10 that no appreciable increase in the mechanical removal efficiency of each filter screen was identified after the formation of a filter cake, however a decrease in the flow capacity due to the formation of a filter cake was identified.

Figure 2 shows the normalised capital/running cost of choice of filter units on a material removal rate basis. Having acquired such information aquaculturists may now select a drum filter solution which is optimised for their facility whilst recognising their individual budget constraints.

## Appendices

## Vitae

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