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Turbidity removal by centrifugal microfiltration

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Abstract

Water turbidity is an important characteristic of surface waters and wastewater treatment plant effluents as well as a key indicator of water quality. Turbidity is the lack of clarity of water caused by microalgae and other particles that attenuates light. The cost of clarifying water can be high. This is primarily due to the physical and chemical steps that must be taken to remove the extremely small entrained particles and colloidal substances that cause high turbidity, and the large amounts of water that generally must be process for such small masses of entrained materials. This paper discusses the results of a series of experiments of a potentially new method of clarifying water by incorporating microfiltration through a high throughput filter operating under a centrifugal force. The results have shown that significant reductions in turbidity can be achieved at relatively high water flux values through a commercially available filter. This indicates the potential of the technology as a water clarifying method by means of this low energy separation device.

Keywords: Centrifuge, Centrifugal force, Microfiltration, Turbidity removal, Water clarification

1. Introduction

Centrifuges are able to speed up fluid separation of unwanted compounds by dramatically increasing the force of gravity by orders of magnitude. They achieve this by spinning at very high angular velocities creating very strong centrifugal forces. They are currently being evaluated as a method for ultrafiltration and desalination of water [1-3]. The centrifuge's ability to increase the force of gravity is measured by its relative centrifugal force (RCF) which is determined as a multiplier of the gravity force, or simply as the "g-force." This is the force exerted on the contents of the centrifuge resulting from the revolutions of the rotor and is given by

$$RCF = (1.118x10^{-5})(rpm)^2(R) \quad (1)$$

Where rpm is the rotor revolutions per minute, and R is the rotor radius in centimeters.

Therefore, utilizing centrifugal forces and micro filters have the potential to change the standard water clarification process to one of a portable and high volume water purification method for applications such as turbidity removal. The standard method for clarifying water is to add a sufficient amount of coagulant, mix and allow the coagulation process to form agglomerates, and then allow the agglomerates to settle where the supernatant is pumped off, or by separating out the bottom layer of liquid containing the concentrated agglomerates. The agglomerates from this settling process will typically still be over 50% water by weight. The advantage of centrifugal microfiltration (CMF) over this standard process is that it eliminates the need for huge and expensive settling chambers, and also speeds up the process as settling is not required. In addition, all of the water can be treated as the captured solid was easily dewatered to low moisture values via the centrifugal force. The full utilization of the micro filter is easily obtained as filtration follows the conventional rules governing filtration. It also allows for higher volumes of permeate per area than the standard process which will allow for faster processing rates, and thus less energy usage and substantially less capital costs and space requirements.

Efficient filtration of solids from a liquid involves the formation of a filter cake and subsequent high efficiency removal of subsequent solids passing through the cake. Energy utilization is a function of the filter's clean water permeability (Darcy's Law) and the cake resistance formed from the filtration of the solids on the walls of the filter (usually described by the Carmen-Kozeny relationship). For the CFM process, the turbid water is introduced at the bottom of the rotating vertical filter assembly, and the cake forms initially at the bottom and works its way up the vertical sides as the cake resistance increases. Therefore CFM is a pseudo-batch process due to the fact that at some point in time the filter throughput will decrease due to the increased cake resistance. This time is governed by the characteristics of the particles, the filter area, the value of the RCF, the agglomerate concentration and the liquid flow rate. It is

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important to note that cake filtration plays a major role in obtaining high separation efficiencies. Thus, there will be a point at which higher values of the RCF for a given centrifugal configuration will result in more agglomerate penetration through the filter, and thus, lower removal efficiencies [4].

2. Materials and methods

An experimental vertical basket centrifuge was designed and constructed in order to test the possibility of using centrifugal microfiltration as a method of clarifying wastewater. The centrifuge and its dimensions are shown in Figure 1. The rotor has an internal diameter of 30.5 cm and a height of 30.5 cm and is made from perforated rolled sheet steel. The filter therefore had a nominal filtration area of ~0.29 m^2 (excluding the area of the bottom and the top of the filter). Filter is made of polypropylene with the pore size of 1 µm. The micro filter was placed inside a side-perforated cellulose acetate filter container which had a closed bottom and top, but where the top was in a doughnut configuration so that the feed water could be introduced into the opening. This was done to prevent overspray of the feed liquid from the top of the rotor. A nylon netting (1.6 mm opening size) scrim was also constructed in a similar shape such that the filters fit into the scrim. The scrim acted as a cushion between the filter and the rotating metal rotor. This assembly was then inserted into the metal rotor for testing purposes.

The centrifuge was operated at speeds of 100, 300, 600, and 900 rpm (RCF values of 1.7, 15.3, 61.4, and 138.1 respectively) powered by a 2.24 kW AC 3-phase electric motor. The motor speed was controlled via an Emerson Commander SK Model 2 variable frequency drive (VFD) controller. The water used was obtained from the effluent of wastewater treatment plant (stabilization pond). The water is algae laden and has turbidity of 30-40 NTU. Flow from a water container was fed by a pump into the bottom of the rotor where it was immediately forced to the walls of the filter by the centrifugal forces (Figure 2). Flow rates were chosen such that all the water passed through the filter and was collected in the outer drum of the centrifuge and drained by gravity. Samples were collected periodically for the purpose of analysis for turbidity. Turbidity was determined by turbidity meter (HacH 2100P, USA). Steady state flow conditions were verified by visually observing the inside of the filter to determine that there was no water buildup in the system.

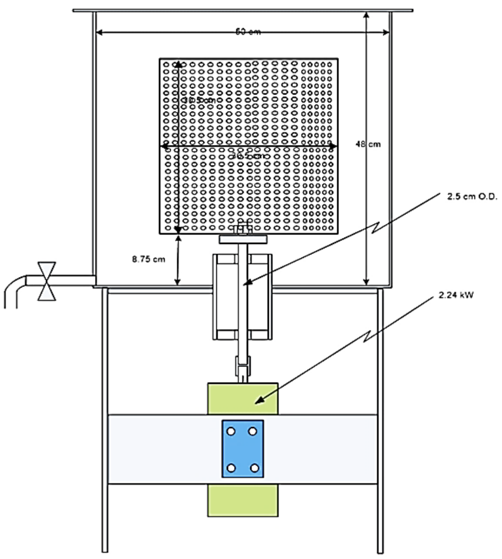

Figure 1 Schematic basket centrifuge

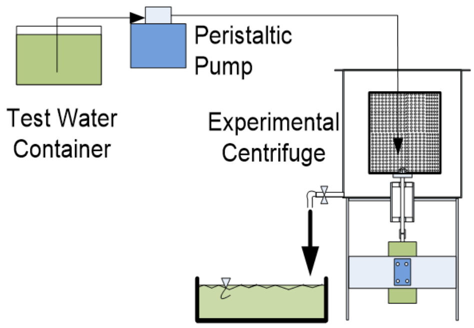

Figure 2 Experimental schematic

3. Results

It was determined that the wastewater would not permeate through the filter without the use of a centrifugal force (i.e., at 0 rpm). Therefore the value of turbidity removal efficiency at 0 rpm has been assigned a value of 0. A series of experiments for a constant filtration flux of 0.741 L/m2-min (based on the average liquid flow rate of 21.5 mL/min and the nominal filter area of 0.29 m2) were conducted at rpm values ranging from 100 – 900 (RCF values from 1.7 – 138.1) and the results are shown in Figure 3. As expected, the turbidity removal efficiency decreases as the RCF value increases indicating the effect of the increasing centrifugal force on penetration of the micro sized particles through the filter.

Figure 4 shows the effect of increasing the flow rate, and thus the filtration flux on turbidity removal efficiency. The data was taken early (after 2 minutes) during the filtration cycle in order to see the impact of flux on particle penetration. The data clearly showed an optimum for this particular particle size distribution at flux values less than 5 L/m2-min.

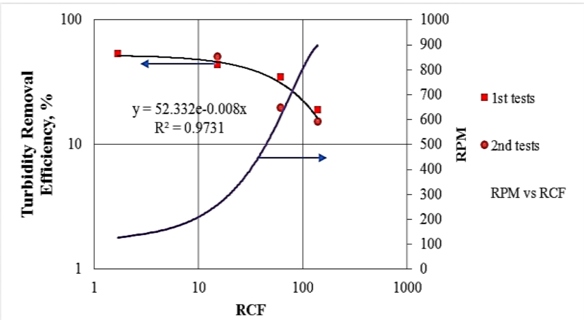

Figure 3 Experimental results for a filtration flux of 0.0741 L/m^2-min (based on the average liquid flow rate of 21.5 mL/min and the nominal filter area of 0.29 m^2)

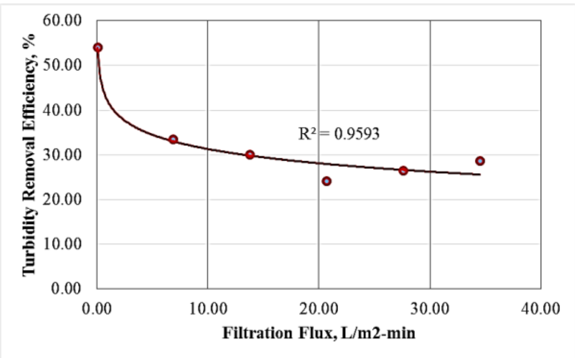

Figure 4 Turbidity Removal Efficiency vs Filtration Flux (RCF = 1.7)

Also, as shown in Figure 5, the turbidity removal efficiency versus the filtration time is shown for a value of RCF – 1.7 and a filtration flux of 6.9 L/m2-min. As expected, the removal efficiency increases as filtration time increases due to the particle cake formation and repaired mechanisms occurring over time.

4. Discussion

The results clearly show that significant removal of turbidity can be achieved at relatively low values of the relative centrifugal force (RCF) for the given characteristics of this wastewater tested. These results indicate that removal efficiency is a function of the RCF, the filtration flux, and, indirectly, the characteristics (size, shape, density, etc.) of the particles responsible for turbidity. In addition, low rpm and small footprint of the system indicates that centrifugal microfiltration may have significant energy and space requirement advantages over more conventional water clarification methods.

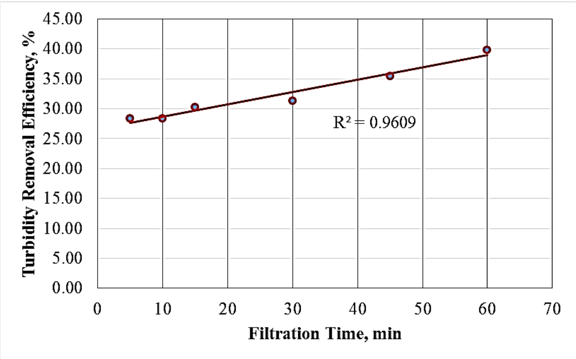

Figure 5 Turbidity removal efficiency versus filtration time

5. Conclusion

Proof-of-concept testing of centrifugal microfiltration (CFM) has been conducted using a moderate sized vertical centrifuge outfitted with a conventional filter press filter treating a typical wastewater effluent containing significant levels of turbidity. The testing has shown that the system was able to obtain reasonable levels of turbidity removal at low levels of the relative centrifugal force, and at reasonable levels of wastewater flow rates. These results indicate that significant additional testing should be conducted utilizing the CFM concept on other types of wastewater in order to understand the effect of different particle characteristics on removal, as well as filter design and centrifugal operating conditions.

6. Acknowledgement

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