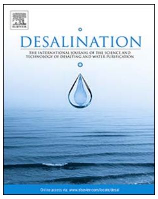
ARTICLE IN PRESS

Desalination xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal



Filtration characteristics of threaded microfiber water filters

Hilla Shemer[a,*], Abraham Sagiv[a], Marina Holenberg[b], Adva Zach Maor[b]

[a] Rabin Desalination Laboratory, Wolfson Faculty of Chemical Engineering, Technion-Israel Institute of Technology, Haifa 32000, Israel
[b] Amiad Water Systems Ltd., D.N. Galil Elyon, 1233500, Israel

ARTICLE INFO

Keywords:
Cake filtration
Mechanism
Pressure drop
Slurry
Calcium carbonate

ABSTRACT

Textile fibers are widely used for fine filtration in the disposable cartridge filter market. In this work the filtration mechanism of threaded microfiber water filters was characterized by testing the effect of filtration velocity, slurry concentration, particles size distribution (PSD) and filter pore size and porosity, on the filter performance. Constant flow rate experiments were conducted with micronized $CaCO_3$ slurry as a model substance. It was found that the predominant filtration mechanism of the studied filters is cake filtration. Very efficient filtration followed by effective automatic cleaning of the filter was obtained as indicated by complete removal of the $CaCO_3$ particles in all the conditions studied and similar clean filter resistance over repetitive cycles. Shorter filtration cycles were obtained at higher velocities, low porosity filter and narrow PSD. Correspondingly, the filter capacity declined as the filtration cycles were shorter. Yet, the filter capacity was found to be independent of the $CaCO_3$ slurry concentration. A criterion of specific consumed energy per unit filtrate volume (E_s) was developed. Analyses of the effect of the various studied parameters on E_s revealed its dependence on the slurry concentration, velocity and filtration time.

1. Introduction

Filtration is a separation process at which suspended solids are removed from liquid on the surface (cake filtration) and/or within the depth of a filter medium. Filtration efficiency depends on many factors including particles characteristics (size, shape, strength, surface chemistry and concentration); filterability characteristics of the liquids (viscosity, volatility, toxicity, corrosiveness, temperature, pH, and ionic strength); filter technology (chemical and thermal resistance), filter design (medium type, pore size and depth); and operating conditions (filtration rate and duration) [1].

In depth filtration the suspended particles are smaller than the medium pores and therefore are trapped within various depths of the filter. The mechanisms of removal include the following forces (alone or combined): hydrodynamic, gravitational, molecular, Brownian, and/or electrostatic [2]. The initial pressure drop across a depth filter is generally higher than a surface filter of equivalent efficiency. However, the pressure drop increase rate, as particles accumulates within the filter, is more gradual [3].

Cake filtration is based on retention of the solid particles on the surface of the porous medium. The driving force for cake filtration includes gravity (hydrostatic pressure), pressure, vacuum or centrifugal. The cake has a complex pore structure determined by the characteristics of the solids. The filtration performance depends on the cake permeability, pore size, particle size and compressibility [4].

From operational and energy consumption considerations any filter needs to be cleaned or replaced periodically. Depth filters are backwashed i.e., the flow through the filter is reversed to achieve fluidization. Surface filters are cleaned with high pressure water jets, backflow across the surface of the filter or replaces as in the case of most cartridge filters [5].

Laboratory scale filters testing is most often conducted under constant pressure filtration due to convenience. Nevertheless, most large scale industrial applications operate at a constant filtration rate. During constant rate filtration longer filtration cycles are obtained and the differential pressure is proportional to the filtration time [6].

The basic filtration element in threaded microfiber filter manufactured by Amiad® Water Systems Ltd. (Israel) is a “thread cassette”. Fine threads (10 µm in diameter) are wound over a rigid grooved base plate. Water flows through the thread layers into the grooves and channel the water to specially designed outlets. The rigid base plate supports the thread layers also plays a major role in the cleaning process of the media. The filters are cleaned automatically, at a pre-determined differential pressure level, by boosting highly pressurized water that pass through the thread layers. This creates a powerful spot back flush, which carries with it the trapped particles and the filter cake out of the cassettes thread layers. The performance efficiency of these filters was demonstrated in surface water dealing mainly with

---

[*] Corresponding author.
E-mail address: shilla@technion.ac.il (H. Shemer).

http://dx.doi.org/10.1016/j.desal.2017.07.009
Received 14 May 2017; Accepted 12 July 2017

Please cite this article as: Shemer, H., Desalination (2017), http://dx.doi.org/10.1016/j.desal.2017.07.009

Table 1
Filters characterization.

Filter	Pore size (μm)	Porosity- Ψ	Permeability[a] κ_0 ($\times 10^{-14}$ m^2)
A	2	0.18	5.86
B	1	0.07	5.33
C	2	0.52	1.11
D	3	0.62	8.86

[a] Measured at a velocity of 0.12 cm/s and calculated using Eq. (7).

biofouling phenomena [7–10]. Yet, the fundamentals of the filtering mechanism was not studied.

The objective of the work presented herein was to characterize the filtration mechanism of Amiad threaded microfiber filters. Effect of various parameters, including filtration velocity, slurry concentration, size distribution and filter porosity, on the filter performance and its consumed energy were investigated using micronized $CaCO_3$ slurry as model substance.

2. Experimental

A laboratory scale filtration system, equipped with 140 cm^2 thread cylinders, were obtained from Amiad® Water System Company. Characterization of the filters is displayed in Table 1. The porosities of the filters were determined using the ratio between the volumes of the filters and filtration media (Eq. (1)). The permeability was calculated using equation derived from the Darcy's theory (See Section 3.1).

$$\Psi = 1 - \frac{V_F}{V_M} \tag{1}$$

where V_F is the volume of the fibers and V_M is the volume of the filtration media.

$CaCO_3$ slurry was pumped through the filter (Fig. 1) at a constant flow rate of 0.4, 0.7 and 1.0 L/min (velocities of 0.05, 0.08 and 0.12 cm/s respectively). Initial concentrations of $CaCO_3$ slurry were 35, 47, 75 and 130 mg/L corresponding to turbidities of 50, 75, 150 and 300 NTU respectively.

The slurry was prepared in DI water using micronized $CaCO_3$ powder 1 (Socal® Solvay Chemicals International, Belgium). The slurry surface mean diameter D [3,2] was 2.2 μm (Eq. (2), [11]) with a relatively narrow particle size distribution (PSD) of 1.0 μm, as shown in Fig. 2. The width of PSD is defined as the difference between the volume and surface mean diameters (D [4,3] − D [3,2]) [11]. The effect of the size distribution was tested using a second micronized $CaCO_3$, powder 2, of D [3,2] = 4.6 μm (Fluka, Germany) with wider PSD width of 4.9 μm. Size analysis was conducted using Mastersizer 2000 (Malvern, UK).

$$D[3,2] = \frac{\sum_{i=1}^{n} D_i^3 v_i}{\sum_{i=1}^{n} D_i^2 v_i} \tag{2}$$

where D is the diameter of a particle (m) and v_i is the proportion of particle in the size fraction.

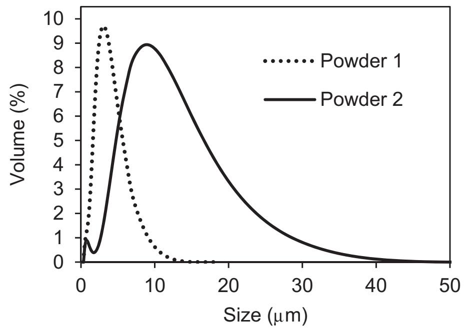


Fig. 2. Particles size distribution of micronized $CaCO_3$ powders 1 and 2.

The following parameters were monitored during the experiments: differential pressure (ΔP), inlet and outlet turbidities. ΔP was measured with a Piezoresistive Differential Pressure Transmitter (Model NP-300, NOVUS Brazil) with data acquisition system (MyPCLab v. 1.22, Novus Electronics Products, Brazil). Turbidity was measured using Hach 2100P Turbidimeter.

As the micronized $CaCO_3$ layer builds up on and in the filter, the pressure differential across the filter increased. Once the differential pressure reached a pre-determined level, a cleaning sequence was conducted using high-pressure water jets spray system. The cleaning was carried out at a flowrate of 1.6 L/min, for 1.1 min at a pressure of 8.5 bar (total of 1.9 L). The filter was used multiple times, as it did not loss its filtration efficiency after cleaning (See Section 4.1).

3. Theory and calculations

3.1. Filtration equations

Quantitative characterization of filters performance is based on Darcy's law which describes filtration through porous media [12].

$$\frac{Q}{A} = \frac{\Delta P}{\mu(R_m + R_c)} \tag{3}$$

where Q is the flow rate (m^3/s), A is the filtration area (m^2), ΔP is the pressure difference across the porous media (Pa), μ is the dynamic viscosity of the liquid (Pa s), R_m and R_c are the filter and cake resistances respectively (1/m). These resistances relate to filtration parameters according to:

$$R_m = \frac{l}{\kappa} \tag{4}$$

$$R_C = \frac{\alpha \cdot C \cdot Q \cdot t}{A} \tag{5}$$

here l is the filter thickness (m), κ is the permeability of the liquid through the filter (m^2), α is the specific cake resistance (m/kg), and C is the slurry concentration (kg/m^3).

Combining Eqs. (3), (4) and (5) yields a linear relationship between filtration pressure difference and time:

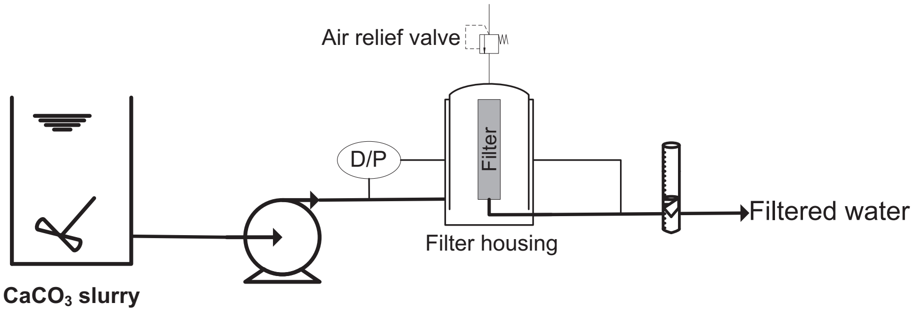


Fig. 1. Schematics of the experimental system.