입자분리를 위한 여과방식에 따른 비용-효율 분석

From Deep Bed Filter to Membrane Filtration: Process Intensification, Cost and Energy Considerations

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Abstract

The industrial development of large scale deep bed filters has been a very important step in the process of drinking water production and more recently in the tertiary treatment of wastewater. The target of deep bed filtration is the retention is the retention of small particles generally smaller than 30 microns at relatively small concentration, generally less than 30 mg/l from natural water (surface water or aquifers) or secondary treated wastewater.

The relation between the retention efficiency and the characteristics of the particles has been extensively studied experimentally and through different models of retention. During the last years the development of new technologies (fiber filter, membrane modules) lead to more intensive processes compared to conventional sand filtration. Fiber filters can combine intensification with a decrease in specific energy needed however they cannot be operated under gravity like sand filters.

Membrane filters (UF or MF) are much more intensive and efficient than sand filters. The specific energy needed is not so high (about 0.1 Kwh/M^3) but is higher than sand or fiber filter. A Life Cycle Analysis (LCA) has to be made for a complete comparison between these technologies taking in account that the efficiency of particle retention obtained by membrane filters is unique.

Key words: Deep bed filter, membrane filter, energy consumption, turbidity, removal efficiency
주제어: 심층여과, 막여과, 에너지비용, 탁도, 제거효율

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1. INTRODUCTION

The industrial development of large scale deep bed filters has been a very important step in the process of drinking water production and more recently in the tertiary treatment of wastewater.

The target of deep bed filtration is the retention is the retention of small particles generally smaller than 30 microns at relatively small concentration, generally less than 30 mg/l from natural water (surface water or aquifers) or secondary treated wastewater.

The relation between the retention efficiency and the characteristics of the particles has been extensively studied experimentally and through different models of retention.

Both coincide in showing , for the conditions of water treatment, the existence of a minimum of retention for particles which size is between 0.1 and 1 micron. This is due to the different forces predominately involved in the retention of particles: diffusion forces for submicron particles, inertia and hydrodynamic forces for larger particles (Ben Aim, R. et al., 1993).

The influence of the filtration velocity has been extensively studied too. It is evident that smaller the filtration velocity , higher the retention efficiency and smaller the initial pressure drop and its increase with time. But this would result in larger filter and so larger footprint and larger investment cost.

The typical range of filtration velocity (5 to 20 m/h) for the design of rapid sand filters is thus the result of a compromise between efficiency and cost.

The consequence of the progressive retention in the filter is the decrease of the porosity and the increase of the specific area (Chang, et al., 1995; Lu and Ju, 1989):

$$\varepsilon = \varepsilon_0 - \beta \cdot \sigma$$

where :

ε_0 = initial porosity

σ = retention (volume of particles deposited /volume of the bed)

β = correction factor for taking in account the water immobilized between the particles retained ($\beta > 1$, generally $10 < \beta < 20$)

$$\text{Specific Area: } S_g = (S_g)_0 + \Sigma n_i d_i^2 / n_i d_i^3$$

where :

$(S_g)_0$ = $6/d$ for a spherical grain

= $4/d$ for a fiber

d being the diameter of the grain or the fiber

n_i and d_i are given by the particle size distribution of the particles retained.

As a result the progressive increase of the pressure drop is given by the Kozeny equation.:

$$\Delta P = h_k \, \mu u_m \, Z \, S_g^2 \, (1 - \varepsilon)2 / \varepsilon^3$$

where:

h_k is the so called Kozeny coefficient which value is generally taken as 4.5 or 5 for granular media (but much more for fibrous media) (Song, L. et al., 1995)

μ is the dynamic viscosity

u_m is the filtration velocity

Z is the height of the bed

The porosity function included in the Kozeny equation is very sensible to the variations of the porosity. For instance a decrease from the initial value of 0.4 (typical of sand filter) to a final value of 0.25 (typical values in sand filtration) results in an increase of the pressure drop by a ratio of about 6.

So despite the small initial pressure drop due to small filtration velocity (for instance 25cm water), the final pressure may be much more (1.5 m. water: these data correspond to a filtration velocity of 10 m/h, through a filter of 1m height and a sand size of 1 mm (Kwon, et al., 1998).

From the pressure drop calculated from the Kozeny equation ,the theoretical energy consumption may be evaluated .For the filtration it is very small: about 0;5 wh/M^3. The energy needs for the backwash is 4 or 5 times larger but the frequency and the duration of backwash is

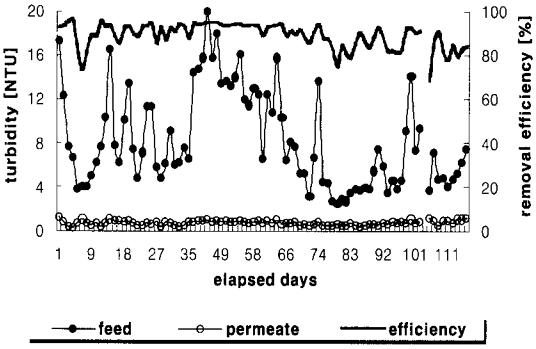

Fig. 1. Turbity variation during Long term experiment.

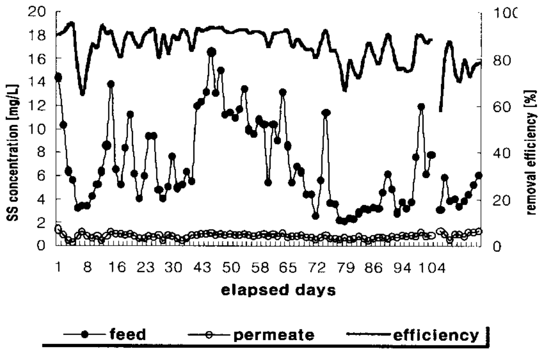

Fig. 2. SS varaiation during long term experiment.

small. However the power which has too be installed is large due to the large flowrate which can be treated.

As a conclusion the sand filter is efficient and needs small energy of operation but it needs large foot print.

2. RECENT ADVANCES IN DEEP BED FILTRATION: FROM GRANULAR TO FIBROUS MEDIA

Compared to sand traditionally used in filtration, a fibrous media has a much higher porosity(more than 0.9) and the specific area (which depends on the diameter of the fiber) is generally larger .

For instance , for a fiber of 60 microns diameter, the specific area is 66 700 M^2/M^3 compared to 6000 for a sand grain which diameter is 1 mm.

Typical results obtained with 3FM filter developed by the Company NanoEntech are presented in **Fig. 1, Fig. 2** and **Fig. 3** obtained during long term experiment of Gyeongan River water.

They show that even at very large filtration velocities the retention of micro particles is high with an intensification of the process by a ratio of about 20 compared to sand filtration.

This experiment has been realized in the conditions described below:

l Gyeongan River

l Site: Gwangju City Gyeonggi Province KOREA

l Design Condition

dimension	200 x 2,000H x 1EA
flexible fiber	61μm
packing density	80kg/M^2

l Operating Condition - filtration

flowrate	180M^3/day
filtration duration	2hours
flux	5,700M^3/M^2/day

l Operating Condition backwash

method	water+air
backwash time	2minutes 55seconds
backwash quantity	below 1% of treated water
backwash logic	

AIR(+WATER)	25 sec	25 sec	25 sec
WATER	30 sec	30 sec	40 sec

Despite a range of head loss variation which is higher

Table 1. Summarizes the comparison between a typical sand filter and the 3FM fiter (NanoEntech Company)

	Symbol (Unit)	SAND FILTER	3FM FILTER
Packing Material	-	Granular sand	Fibrous: Polyamide fibers (Nylon)
Density	(kg.dm-3)	2.5	1.1371
Specific Area (M2 of external area/M3 of bed)	S (m-1) = Sg (1-)	2000 to 4000	5000 to 20 000
Initial Porosity	0	38%	91%

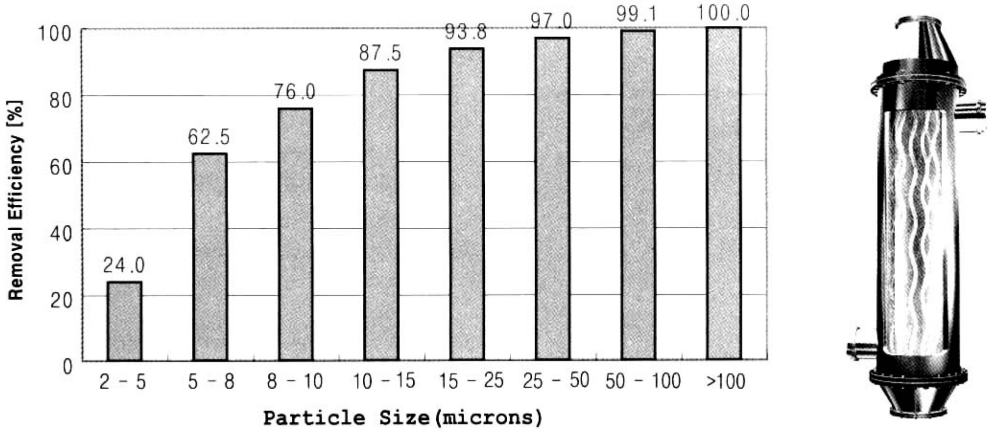

Fig. 3. Removal efficiency depending on the particle size and schematic view of the filter.

than for a sand filter (typically from 0.3 bar to 0.8 bar) the specific energy consumption (0.06 KWh/M^3) is about 10 times smaller than in sand filtration due to the very large flowrate able to be treated.

3. FROM DEEP BED FILTER TO MEMBRANE FILTRATION

During the last years , large scale water treatment plants have been installed using membrane filtration in place of deep bed filtration.

The efficiency of retention of membrane modules (MF or UF) is 100%: in fact SS are not measurable in the permeate of a membrane module when the so called "integrity" of the module has been checked. So UF and MF membranes are very efficient for particles removal including microorganisms (bacteria for MF, bacteria and viruses for UF membranes).

When applied to water treatment membranes are typically operated at flow rates of 50 to 100 l/h.M^2. Most of the commercially available membrane modules contain a membrane area of 100 M^2 or more for a module volume of about 0.1 M^3. The productivity of these modules is more than 5 M3/H for a filter volume less than 0.1 M^3.

Due to recent improvements in module design and operation conditions (use of submerged modules operated in dead en filtration with periodic backwashing and/or bubbles production), the specific energy needed for filtration considerably decreased during the last years. To day the value is about 0.1 Kwh/M^3.

4. CONCLUSION

During the last years the development of new technologies (fiber filter, membrane modules) lead to more intensive processes compared to conventional sand filtration .

Fiber filters can combine intensification with a decrease in specific energy needed however they cannot be operated under gravity like sand filters.

Membrane filters (UF or MF) are much more intensive and efficient than sand filters. The specific energy needed

Table 2. Comparison of deep bed filters and membrane filtration

	Efficiency of particle retention	Foot print	Energy consumption	Investment cost
Sand filter	Good	Large	Small	Small
Fiber Filter	Good	Small	small	Moderate
UF or MF	Excellent	Small	moderate	High

is not so high (about 0.1 Kwh/M^3) but is higher than sand or fiber filter.

A Life Cycle Analysis has to be made for a complete comparison between these technologies taking in account that the efficiency of particle retention obtained by membrane filters is unique.

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