Deep bed sand filters are used extensively in drinking water and wastewater treatment. In this study, sand and pumice were used as a filtration media under rapid filtration conditions and performance results for both were compared. Turbidity removal performance and head losses were investigated as functions of filtration rate, bed depth and particle size. Under the same experimental conditions such as 750 mm bed depth, 7.64m^3/m^2.h flow rate and, 0.5-1.0 mm grain size, turbidity removal rates for sand and pumice were found to be 85-90% and 98-99%, respectively. Furthermore, the head loss for sand and pumice were found to be 460 mm and 215 mm, respectively. The results obtained have shown that pumice has a high potential for use as a filter bed material.

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n potable water supplies and in wastewater many pollutants are particles or are associated with particulate matter, therefore the removal of particulate matter is a principal target of water and wastewater treatment. As a conventional water treatment, filtration is an essential step in the production of high quality water by depositing particulate matter within the media [1, 2]. Depth filtration (i.e. filtration in deep porous beds) is the treatment process most often used for the final separation of particles from water. Depth filtration removes particles by attaching them to the media or to previously retained particles. Sand has been used extensively as a filter medium and the slow sand filtration system is one of the earliest processes used for removing contaminants from surface waters to produce drinking water. Slow sand filters operate at very low filtration rates (0.1-0.5 m^3/m^2.h). Slow sand filters were widely employed for water treatment until the difficulties associated with high turbidities in surface waters were realized, which led to the development of rapid sand filters. Due to their lower space requirement, higher production capacity and higher flexibility in treating waters of different turbidities, rapid sand filters have gained wide acceptance for municipal applications. It is possible to reach filtration rates of 5-15 m^3/m^2.h in rapid sand filters [3].

Several approaches such as modifying pre-treatment techniques, using filter aid materials and different filter bed materials, and the application of dual or multimedia filtration have been considered to improve filter performance [4]. By using filter bed materials other than sand and changing the conventional flow direction (up-flow filters), it could be possible to extend the periods between backwashing of filters, as a result of lower head losses [2, 5, 6].

Pumice is a light, porous volcanic rock that is formed during explosive eruptions. It resembles a sponge because it consists of a network of gas bubbles fixed amidst fragile volcanic glass and minerals. All types of magma (basalt, andesite, dacite and rhyolite) will form pumice. Pumice is riddled with pores of irregular or oval shape, which are usually not connected to each other. It has long been used as an abrasive in cleaning, polishing and scouring compounds. It is also employed as a lightweight aggregate in precast masonry units, poured concrete, insulation and acoustic tiles and plaster [7]. Pumice is used as a biofilm support material in water and wastewater treatment because of its high porosity and large surface area.

Filter bed materials must be able to be supplied easily. Italy, with a share of 44%, is the biggest pumice producer in the world. Turkey is the second bigger producer, with a share of 9% [8].

The objective of the following study is to investigate the performance of pumice as a filter bed material under rapid

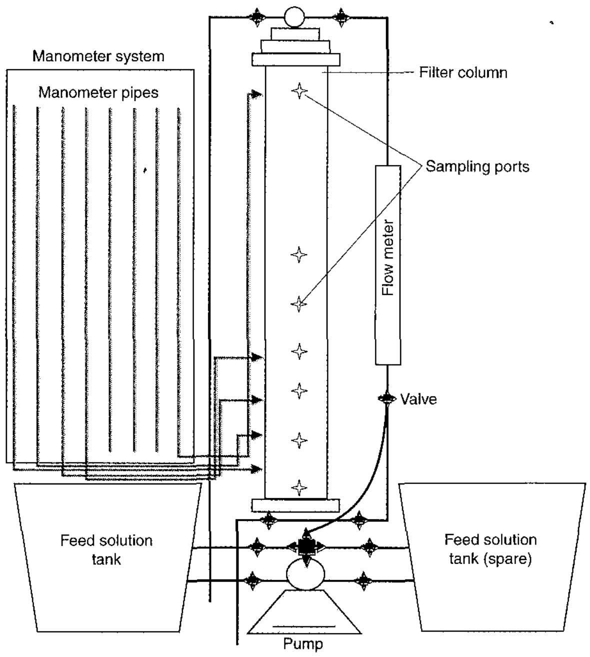

Figure 1: Schematic of experimental equipment.

Table 1: Parameter values for pumice.

Parameters	Values
Chemical composition (%):	
SiO_2	72.07
AlO_2	13.50
Fe_2O_3	1.21
Na_2O	1.60
K_2O	11.27
TiO_2	0.35
Uniformity coefficient (D_{60}/D_{10})	1.35
Effective grain size D_{10} (mm)	0.59
Porosity (%)	69.24
Density (0.5-1.0 mm grain size) (g/cm^3)	0.689

Figure 2: SEM of pumice.

filtration conditions, and compare the results with sand, a conventional filter bed material. The investigated parameters for pumice are flow rate, bed depth and particle size. Also flow rate and bed depth are investigated for sand.

The experimental system used in the filtration tests is shown in Figure 1. The main components of the system are a filter column, a flow meter, a manometer system, a feed solution tank and a spare tank. The Perspex filter column is 100 mm in diameter and 1350 mm in length, with inlet and outlet connections so that water may flow either downwards or upwards through the column. At the base of the column is a 0.35 mm gauze mesh, supported by a coarser stainless steel mesh, to retain the granular filter media. Suspension or wash water is supplied to the column from 350 l (litre) polythene tanks by a pump through a GEC-Marconi 2000 flow meter, (range 0.5-5.0 l/min). One tank acts as a standby while the other is in use. The column has 39 manometer tappings at 20 mm vertical intervals over the lower 800 mm. Each manometer tapping has a chromed valve and is connected by 10 mm diameter translucent plastic tubing to a 41-tube manometer. This set of manometer tubes is connected at the top by a manifold with an air valve for either releasing or pumping in air to adjust the water levels in the manometers. Opposite each manometer (except the one in the lower end piece) is a sampling port. Samples collected from the sampling ports were analyzed for their turbidity contents using an ORBECO turbidimeter. Meanwhile, in order to calculate the head loss values, pressure changes were read from the corresponding manometer level for each sampling port during the filtration.

The suspension used in the tests was prepared artificially by using a clay. The initial turbidity level was kept constant in all tests by adding 26 g of clay to 350 l of clean water in the feed solution tank. Prepared suspension including clay was in the range of 29-31 NTU.

The sand used in the experiments as a filtration material has a grain size of 0.5-1.0 mm and a porosity of 0.4. The pumice, which was supplied by Ercis, Turkey, was ground and prepared as three different grain sized (0.5-1.0 mm, 1.0-2.0 mm, 2.0-5.0 mm) filtration material by sieving. The chemical composition of the pumice was obtained from an Electron Probe Microscopic Analyzer (EPMA) and the results, together with some calculated parameters, are given in Table 1 and its porous structure is shown in Figure 2.

Table 2: Sieve analysis of pumice.

Sieve size (cm)	% remained (X)
0.1000	1.0
0.0840	28.0
0.0710	27.0
0.0600	19.6
0.0500	19.4
0.0425	4.0
0.0088	1.0

Initial head loss occurs when turbidity-free water passes through the clean bed. Initial head loss is a function of filtration rate, bed porosity, grain size and bed depth. There are many equations to calculate the initial head loss for sand filters (9). The Rose equation was chosen to calculate the initial head loss.

$$H_L = \frac{1.067.L.Va^2.}{\phi.g.\varepsilon^4} \sum \frac{C_D.X}{d} \qquad (1)$$

where H_L = initial head loss (mm), C_D = drag coefficient, Va = filtration velocity (mm/min), ε = porosity (%), d = particle diameter (mm), X : remained (%), ϕ = shape factor (0.85) and g = gravitational constant (mm/min^2)

In order to calculate the X values in the Rose equation, a sieve analysis was performed and the results are shown in Table 2.

When water with clay passes through the filter bed, particulate materials are deposited inside the pores of the bed, which leads to a reduction in pore size. Since the resistance of the bed to the flow is reversely proportional to the exponential function of porosity (flow resistance $\alpha\ \varepsilon^{-4}$), decreasing pore size increases the filter bed resistance to the flow. This phenomenon can be seen through the increase in corresponding manometer

Table 3: Experimental and calculated initial head loss values (0.5-1.0 mm grain size & 15.28 m³/m².h inflow rate).

Bed depth (mm)	Initial head loss	
	Experimental	Calculated
470	225	238
750	355	387
1000	545	520

levels. Head loss developments with time were calculated using Equation 2:

$$H_t=H_2-H_1+H_0 \qquad (2)$$

where H_t = head loss (mm), H_0 = initial head loss (head loss measured for clean bed, mm), H_1 = first manometer level (mm) and H_2 = second manometer level (mm)

Tap water was used for backwashing purposes for the sand and pumice beds. Backwashing operation was applied by introducing the water at the lower end of the column. During the backwashing operation, for both pumice and sand, the filter bed material was expanded to the level of an extra 10% of the height of the bed.

By using Equation 1, initial head loss values were calculated. In Table 3 calculated and experimental initial head loss values are shown. As can be seen, there is a good agreement between experimental and computed values of initial head loss.

Some experiments in which pumice was used as a filter bed material were carried out in order to show the effect of flow rate on head loss and suspended solids removal rate. Applied flow rates, for 750 mm of bed depth and 0.5-1.0 mm sieve ranged pumice were 7.64, 15.28 & 22.91 $m^3/m^2.h$, respectively. The changes of measured head loss values with time for these flow rates are shown in Figure 3.

As expected, head losses increase with time during the operation of a filter. As the filtration process progresses, particulate matter retained in the pores leads to a size decrease in the pores. The resistance of bed to the water flow will increase due to the size reduction of the pores. Increasing resistance with time increases the head losses. Furthermore, head losses increase proportionally with the square of the flow rate.

The changes in the particulate matter removal rate of pumice with time for 750 mm of bed depth and various flow rates are shown in Figure 4. For the 7.64 $m^3/m^2.h$ flow rate, removal rates changed within the range of 97-99.5%. But for greater flow rates, removal rates dropped to 74%. Depositing particles in the pores

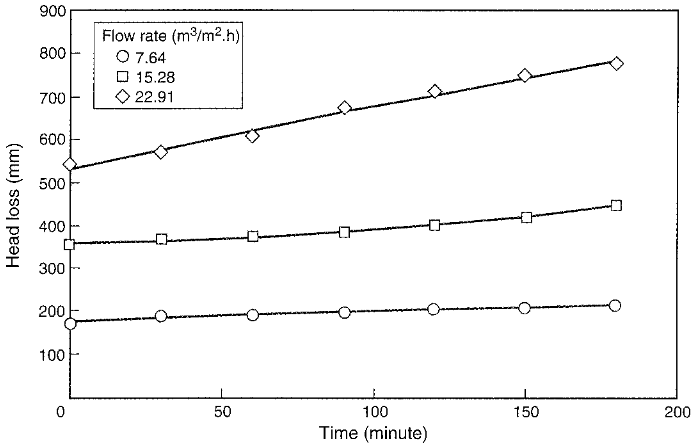

Figure 3: The change of measured head loss values with time for the pumice bed under the various flow rates (750 mm bed depth, 0.5-1.0 mm grain size).

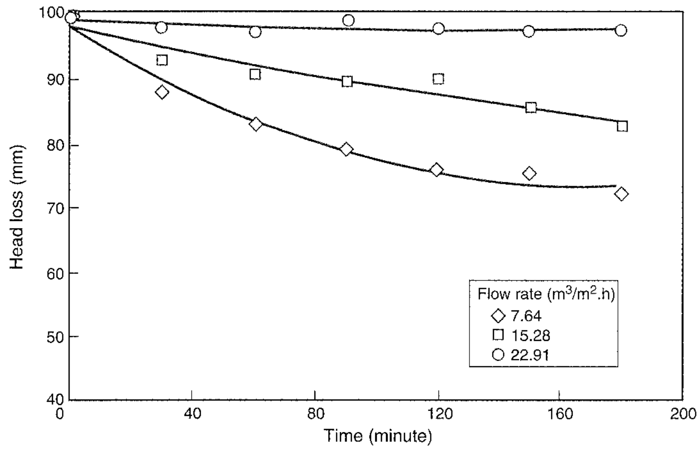

Figure 4: The change of particulate matter removal ratio with time for the pumice bed under the various flow rates (750 mm bed depth, 0.5-1.0 mm grain size).

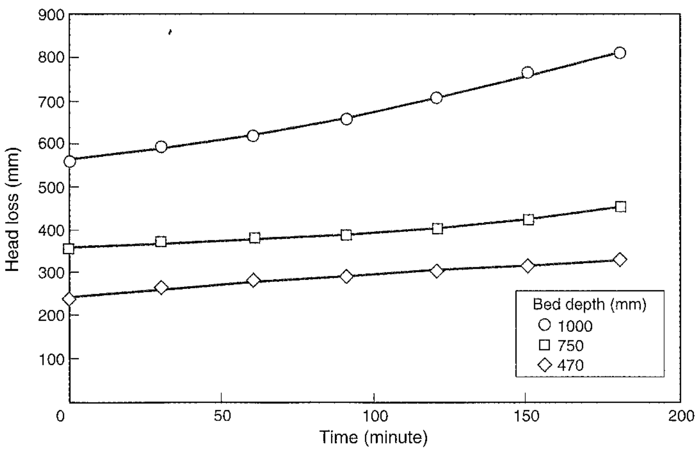

Figure 5: The change of head loss values with time for the pumice bed under the various bed depths (15.28 m³/m².h flow rate, 0.5-1.0 mm grain size).

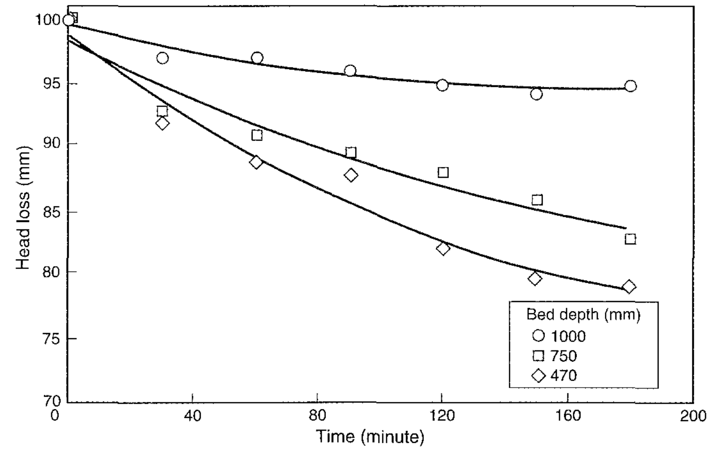

Figure 6: The change of suspended solids removal ratio with time for the pumice bed under the various bed depths (15.28 m^3/m^2.h flow rate, 0.5-1.0 mm grain size).

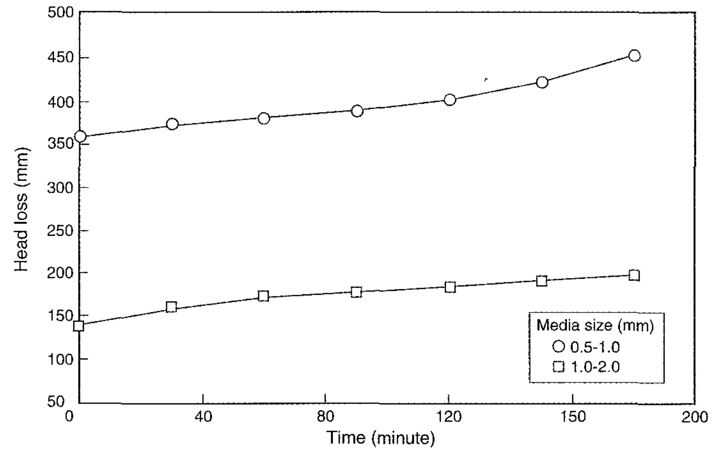

Figure 7: The change of head loss values with time for pumice bed under the different grain sizes (15.28 m^3/m^2.h flow rate, 750 mm bed depth).

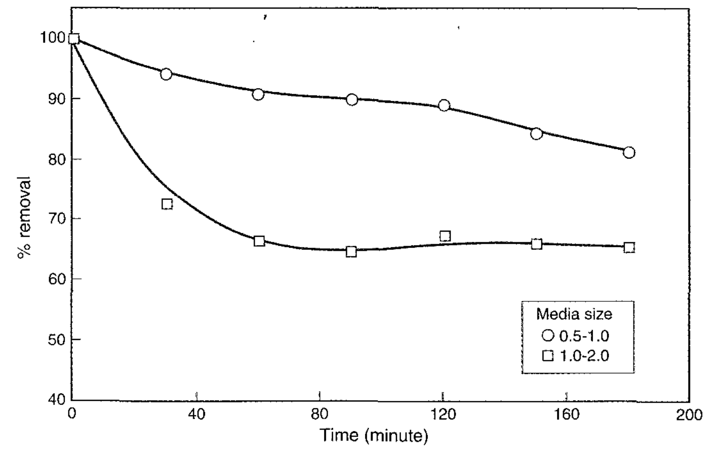

Figure 8: The change of turbidity removal ratio with time for the pumice bed under the different grain sizes (15.28 m^3/m^2.h flow rate, 750 mm bed depth).

lead to a size reduction of pores, and therefore rises in local liquid velocity. The increasing velocity drags previously deposited particles from the filter bed, which then appear in the effluent. Furthermore, increasing flow rate increases the driving force, and this leads to higher amounts of particulate matter being dragged to the effluent.

In this part of the study, by keeping constant the filtration rate (15.28 m^3/m^2.h) and the pumice size in the filter bed (0.5-1.0 mm) the effect of filter bed depth on suspended solids removal rate and head loss were investigated. Increasing the bed depth leads to an increase in friction force of the bed because of increasing surface area, and this causes an increase in head loss values (Figure 5).

The change of suspended solids removal rate with time for 1000 mm, 750 mm and 470 mm of bed depths is shown in Figure 6. Increasing bed depth increases the available surface area for the capture of particulate matter. Thus, more particulate matter can be retained in the filtration bed, so the removal rate of the particulate matter is improved by increasing the bed depth.

In order to investigate the effect of filter media size, the filtration rate and bed depth were kept constant (15.28 m^3/m^2.h) and 750 mm, respectively), while the media size was changed. The used filter media size was in the range of 0.5-1.0 mm and 1.0-2.0 mm. Development of head loss with time for these media sizes is depicted in Figure 7. Since head loss is reversely proportional to material size, increasing material size decreases head loss.

The change in suspended solids removal rate with time for 0.5-1 mm and 1-2 mm of media sizes is shown in Figure 8. It can be seen that increasing the media size decreases the turbidity removal rate because of the higher inter-grain spacing.

Due to the high porosity of pumice, a filter bed consisting of pumice retains more suspended solids than a sand filter bed (head loss α ε-4). Thus, the clogging observed in the pumice bed is smaller than a sand filter bed with a similar grain size. The increase in head loss over time for pumice progresses more slowly than with sand media (Figure 9).

Sand is not a porous material and particulate material can only be retained in the spaces between the grains in the filter bed, so smaller particulate matter can more easily drain through the sand media and escape in the effluent water (Figure 10).

When pumice is used as filter bed material it is possible to distinguish between two levels of porosity, one of the pumice itself and the other of the filter bed. Thus, while bigger particles are retained in the filter bed, smaller particles are retained inside the pores of the pumice. Consequently, in a pumice bed clogging progresses more slowly, and the volume of the bed is used more efficiently than in a sand bed. Smaller particles retained inside the pores of pumice are shown in Figure 11 as a SEM photography, with a dense accumulation of particulate matter

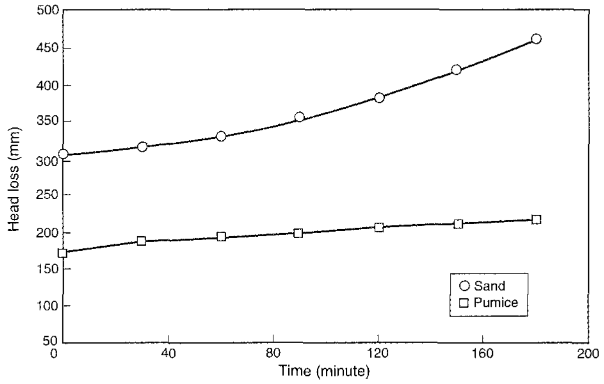

Figure 9: The comparison of head loss values with time for the sand and pumice bed (750 mm bed depth, 7.64 m^3/m^2.h flow rate & 0.5-1.0 mm grain size).

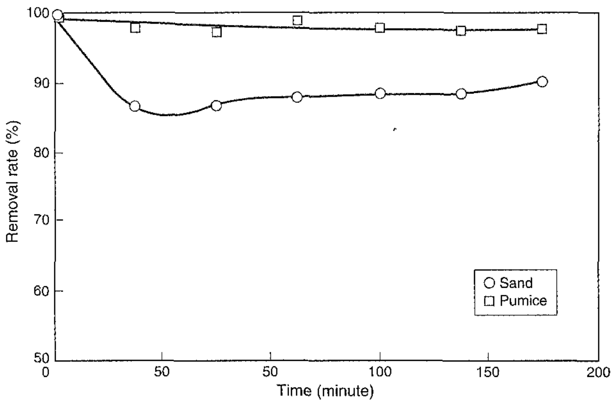

Figure 10: The comparison of turbidity removal ratios with time for the pumice and sand bed (750 mm bed depth, 7.64 m^3/m^2.h flow rate & 0.5-1.0 mm grain size).

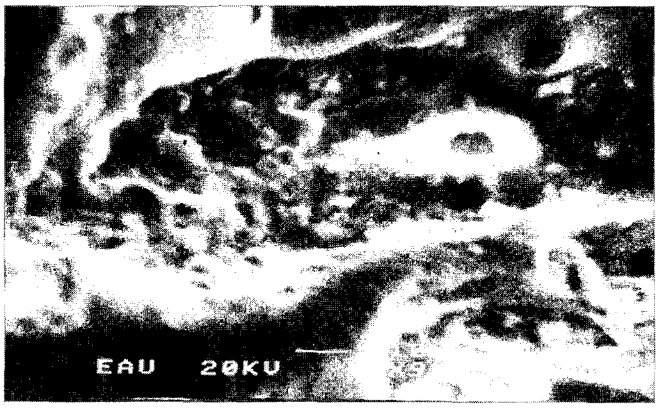

Figure 11: SEM of pumice after filtration.

inside the pores.As can be seen from Figure 12, backwashing effectively cleans the pumice.

The results obtained lead to the following conclusions:

- For a pumice bed, smaller head loss and greater turbidity removal efficiency was observed in comparison to a sand bed under the same experimental conditions.

Figure 12: SEM of pumice after the backwashing process.

- A pumice bed has a greater porosity, so it has a greater capacity for the accumulation of particulate matter. As smaller particulate material is deposited inside the pores of pumice grains, the filtration bed can be used more efficiently.
- A pumice bed has a greater porosity and higher deposition capacity of particulate compared to sand bed, so pumice bed filters have longer periods between backwashes.
- Pumice is resistant to acid and base solutions. No deformation because of the water was observed during the study.
- Pumice is a fragile matter and it may crumble during the filtration compared to sand, but no deformation was observed during the investigation.

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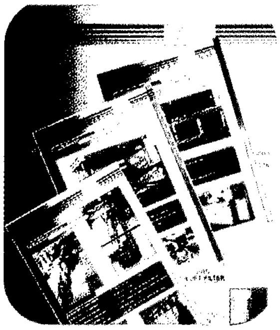

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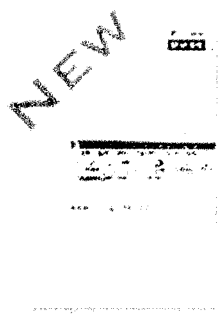

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