INITIAL COLLECTION EFFICIENCY FOR GLASS FILTER MEDIA

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ABSTRACT

This study investigated the ability of using crushed glass solid wastes in water filtration by using a pilot plant, constructed in Al-Wathba water treatment plant in Baghdad. Different depths and different grain sizes of crushed glass were used as mono and dual media with sand and porcelaniate in the filtration process. The mathematical model by Tufenkji and Elimelech was used to evaluate the initial collection efficiency η of these filters. The results indicated that the collection efficiency varied inversely with the filtration rate. For the mono media filters the theoretical ηth values were more than the practical values ηprac calculated from the experimental work. In the glass filter ηprac was obtained by multiplying ηth by a factor 0.945 where this factor was 0.714 for the sand filter. All the dual filters showed that ηth was less than ηprac. Whereas the dual filter 35cm porcelanite and 35cm glass showed the highest collection efficiency. To obtain ηprac in the dual filter glass and sand, ηth is multiplied by **1.374**, as for the dual filters porcelanite and glass the factor was **1.168** and **1.204**.

الخلاصه:

تضمن البحث دراسة امكانية استخدام النفايات الصلبه مثل الزجاج المطحون كماده مرشحه في محطات تصفية مياه الشرب وذلك عن طريق بناء منظومة ريادية في مشروع ماء الوثبه في مدينة بغداد، حيث استخدم الزجاج المطحون بـاطوال واحجـام مختلفـه كمرشح احادي وكمرشح ثنائي مع الرمل وكذلك مع البورسلينات. تم اعتماد النموذج الرياضي Tufenkji and Elimelech لتقيـيم كفاءة الازاله الابتدائية للمرشحات ، حيث اظهرت النتائج ان القيم النظرية كانت اكبر من القيم العملية للمرشحات الاحاديـه، فـالقيم العمليه للمرشح الزجاجي يمكن الحصول عليها من ضرب القيم النظرية بمعامل 0,945 بينما في حالة المرشـح الرملـي يـستخدم المعامل **0,714** ، اما المرشحات الثنائية فقد كانت القيم النظرية اقل من القيم العملية لكفاءة الازالة الابتدائية حيث اقوى معامل كـان للمرشح الثنائي 35 سم بورسلينات و 35سم زجاج ، وللحصول على كفاءة الازالة الابتدائية العملية تضرب القيمه النظريه بمعامـل **1,374** بالنسبه للمرشح الثنائي من الرمل والزجاج اما المرشحات من الزجاج والبورسلينات تستخدم المعاملات **1,168** و **1,204** .

KEY WORDS: Filtration, Dual filters, Crushed glass, Initial collection efficiency, Models.

INTRODUCTION

Glass can be crushed to meet different gradation specifications which allow it to be used in such filters. Because glass is amorphous and has no internal crystal structure, the particles are homogenous and have no grain boundaries. This gives glass more resistance to break down through filtration and backwashing cycles. Furthermore, the lack of grain boundaries minimizes cracks where bacteria can lodge and resist flushing in backwashing. Glass particles have a slight negative charge on their surface, which tends to hold onto fine particles during the filtration cycle. Upon backwashing, this weak charge apparently releases these fine particles to the effluent thereby contributing to a better filtration process. Theoretically, one could see that less washing water is required, owing to the better permeability in glass filters (CWC, 1997).

Glass is a product of the super-cooling of a melted liquid mixture consisting primarily of sand (silicon dioxide and sodium carbonate) to a rigid condition. This material does not crystallize; and when the glass is crushed to a size similar to natural sand, it exhibits properties of an aggregate material. Coarse angular material is effective in trapping dirt and impurities in the filters for water treatment and offers a greater filtration power than sand. Glass grains are less porous and do not saturate itself compared to traditional sand (do not form a cake in the filter) (Opta Minerals Inc., 2008).

INITIAL COLLECTION EFFICIENCY η_o

The performance of a filter is expressed in terms of the single collector (grain of the filter media) efficiency (η_s) which is defined as the ratio between the quantities of particles in contact with the collector and the flow rate. There are two theoretical methods for calculating the particles deposition rate on the collectors from the flowing suspension, the Lagrangian and Eulerian methods. The Lagrangian method describes the trajectory of the particle approaching the collector which is governed by Newton's second law, while Eulerian method describes the particles concentration in time and space. The trajectory analysis is limited to non Brownian particles as it can not include the effect of diffusion .In the Eulerian approach, the difficulty of accounting for Brownian effects is eliminated. (Jegathesan, 2007). The total amount of mass particles that a filter can retain will depend on the initial collection efficiency η_o , the determination of the initial collection efficiency η_o is important in predicting the performance of a clean bed filter, which can be calculated by the following equation (Jagatheesan, 2007)

$$[Ce/Ci]=\exp[(-3/2)\times(1-\varepsilon)\times\alpha\,\eta_o\times L/a_c] \qquad (1)$$

where

Ci =Influent particle concentration into the filter (mg/l)

Ce =Effluent particle concentration from the filter (mg/l)

L=Depth of filter (m)

ε =Porosity

η_o = Initial Collection Efficiency

a_c =Radius of the filter grain(m)

α =Is The ratio between the number of contacts which succeeded in producing adhesion and the number of collisions which occur between suspended particles and the filter grain.Ideally , α is equal to unity in a completely destabilized system.

Equation 1 provides the basis for determining η_o from the results of the experimental work (Yongwon and Tien,1989).

The basic mechanisms for transporting particles to a single collector are:

Interception

Particles remaining centered on the streamlines, that pass through the collector surface by a distance of half or less than the particle diameter will contact the collector and will be intercepted. For laminar flow, spherical particles and spherical collectors, particle transport by interception is given by the following expression (Yao et al., 1971):

$$\eta_I = (d_p / d_c) \quad (2)$$

Where:

η_I =Transport efficiency due to interception (dimensionless)
d_p= Particle diameter (m)
d_c= Filter grain diameter (m)

Inertia

In general as fluid streamlines curve around the collector, particles can deviate from the streamline and continue downward to contact the collector due to inertial forces. Inertia is important in air filtration systems, but is insignificant in water filtration and collection efficiency. Inertia force has been ignored as it is difficult to calculate, and require numerical solutions for determination.

Sedimentation

Particles with density significantly greater than water tend to deviate from fluid streamlines due to gravitational forces. The collector efficiency (as a result of gravity) has shown to be the ratio of stokes settling velocity to the superficial velocity (Yao et al., 1971) as shown in the expression:

$$\eta_g = [(\rho_P - \rho)\, d_P^{\,2} g]/[18\, \mu\, U_s] \quad (3)$$

η_g =Transport efficiency due to gravity (dimensionless)
g=Gravitional acceleration,m/s^2
U_s = Settling velocity (m/s)
μ, ρ =Water viscosity(kg/m.s), water density(kg/m^3) respectively
ρ_p d_P =Particle density(kg/m^3), particle diameter(m) respectively

Diffusion

Particles are influenced by Brownian motion and will deviate from the fluid streamlines due to diffusion. The transport efficiency due to diffusion is given by the following expression (Levich, 1962):

$$\eta_{pe} = U_s\, d_c / D_{BM} \quad (4)$$

$$D_{BM} = C_s KT / 3\pi\mu\, d_P \quad (5)$$

η_{pe} =Transport efficiency due to diffusion (related to the Peclet number)
U_s = Superficial velocity (m/s)
d_c =Filter-grain diameter(m)
D_{BM}=Brownian diffusivity
C_s =Cunningham s correction factor

$$C_s = 1 + Kn[1.257 + 0.4 \exp(-1.1/Kn)] \quad (6)$$

$Kn=0.06\ \mu/(d_p/2)$

K = Boltzmann constant, 1.381 $\times 10^{-23}$ j/k

T=Absolute temperature, K (273 +C).

d_p =Particle diameter(m)

μ= water viscosity (kg/m.s)

Different models were developed to describe the performance of the filtration process in water treatment.

Yao et al.,1971 developed a model based on an isolated single collector in a uniform flow field . The accumulation of particles in the filter is the product of the total number of collector and the accumulation of particles on one single collectors. They developed a filtration coefficient related to η and α taking in to account porosity, particle size, and depth of the filter. The Yao filtration model may under estimate the number of collisions between particles and collectors when compared to experimental data . Several attempts were performed to refine the Yao model by using different flow regimes or adding more transport mechanisms. Rajagopalan and Tien (1976) developed a fundamental depth filtration .This model correlates to the experimental data more significantly than other models and it is considered more accurate (Logan et al., 1995). Rajagopalan and Tien presented an approximate expression of the initial collector efficiency, η_o, as in the following expression:

$$\eta_o = 1.5\ A_s(1-\varepsilon)^{2/3}\ N_R^{2}[2/3\ N_{Lo}^{1/8}\ N_R^{-1.8} + 2.25*10^{-3}\ N_G^{\ 1.2}\ N_R^{-2.4} + 4(1-\varepsilon)^{2/3}\ A_s^{1/3}\ N_{pe}^{\ -2/3} \quad (7)$$

Where:

η_o =Initial collector efficiency

A_s= Porosity function (dimensionless)

$N_R = \eta_I$ (dimensionless)

$N_G = \eta_G$ (dimensionless)

N_{PE}: Peclet number defined as Us dc/D_{BM}

N_{Lo}= London force parameter, defined as H/(9 π μ a_p^2 Us

H = Hamaker constant describing Van der Waals forces. Its value ranges from 10^{-19} to 10^{-20} J

a_p = radius of partical

The RT model can be used to demonstrate the effect of specifying filter media with a low uniformity coefficient.

Bai and Tien in 1996 developed a correlation for the initial filter coefficient under unfavorable surface interactions. By applying Bukingham π theory,α is shown to be a function of eleven dimensionless parameters. Further, by conducting partial regression analysis to available experimental data, only four of the eleven dimensionless parameters were found to exert strong influence on α.

$$\alpha = 10^{\ -0.2.9949}(N_{Lo})^{0.8495}(N_{E1})^{-0.2676}(N_{E2})^{3.8328}(N_{DL})^{1.6776} \quad (8)$$

where, N_{Lo} is the London number, N_{E1} first electrokinetic parameter, N_{E2} second electrokinetic parameter and N_{DL} is the double layer force parameter.

Cushing and Lawler in 1998 presented an expression based on their respective trajectory calculation results. The expression is:

$$(\eta_s)_o = 0.029\ N_{Lo}^{0.012}\ N_R^{0.023} + 0.48\ N_G^{\ 1.8}\ N_R^{-0.38} \quad (9)$$

The correlations of Tufenkji and Elimelech in 2004 were based on the numerical solution of the convective diffusion equation and gave the following expression (Tien and Ramarao, 2007)

$$(\eta_s)_o = 2.3644\, A_s^{1/3}\, N_R^{-0.029} N_{Lo}^{0.052}\, N_{PE}^{-0.633} + 0.5306\, A_s\, N_R^{1.675}\, N_{LO}^{0.125} + 0.2167\, N_R^{-0.187}\, N_G^{1.11} N_{PE}^{0.053}\, N_{LO}^{0.053} \quad (10)$$

Where $N_R<0.02$

EXPERIMENTAL WORK

A pilot plant was constructed in Al wathba WTP to test the filtration processes using crushed glass as mono and dual filter media. The plant consisted of three filtration columns of a diameter 10cm and height 150cm to hold 70cm filter media. The influent to these filters was the effluent from the sedimentation tank in the plant (the same water flowing to the existing rapid sand filters). The sets of experimental runs were performed on different types of filters as shown in figures 1 and 2. Filter No.2 in the two sets is the sand filter with the same media used in the plant. The filtration rates of each filter in the pilot unit were maintained as the same rates of the filters used in the plant; on a constant rate basis (Kawamura ,2000). The filtration runs were carried out at filtration rates 5, 10 and 15 m/hr. Samples of the influent and effluent were collected for turbidity measurements at certain time intervals during each run.

THE THEORETICAL INITIAL COLLECTION EFFICIENCY FOR EACH FILTER

The mathematical model suggested by Tufenkji and Elimelech (Tien and Ramarao, 2007) was used to determine the initial collection efficiency as follows: The model is:

$$(\eta_s)_o = 2.3644\, A_s^{1/3}\, N_R^{-0.029} N_{Lo}^{0.052}\, N_{PE}^{-0.633} + 0.5306\, A_s\, N_R^{1.675}\, N_{LO}^{0.125} + 0.2167\, N_R^{-0.187}\, N_G^{1.11} N_{PE}^{0.053}\, N_{LO}^{0.053} \quad (11)$$

Where $N_R<0.02$

$(\eta_s)_o$ =Initial collector efficiency for single collector

A_s = Porous function which is Happels parameter defined as $2(1-p^5)/w$

$$P=(1-\varepsilon)^{1/3} \quad (12)$$

$$w=2-3p+3p^5-2p^6 \quad (13)$$

N_R: Interception parameter, defined as d_p / d_c

N_{LO}: London force parameter, defined as $H/(9\pi\mu\, a_p^2\, Us)$ (14)

N_{PE}: Peclet number defined as $Us\, d_c /(D_{BM})$ (15)

N_G: Gravitational parameter, defined as $[(\rho_p - \rho)\, d_p^2 g]/(18\, \mu Us)$ (16)

The values of initial collection efficiencies obtained from the mathematical model were compared with the practical values obtained from the equation:

$$C_e / C_i = \exp[(-3/4)(1-\varepsilon)\, \alpha\, \eta o\, L/ a_C] \quad (17)$$

Where :

C_e and C_i are the effluent and influent concentrations respectively.

The theoretical initial efficiency was determined by applying this model (equation 10) for the filters in Set No.1 and Set No.2, representing the different types of filters of the pilot plant.
The practical initial efficiency was calculated using equation 17. the results are shown in tables 1 to 6 for each filter in the two sets at different flow rates 5,10 and 15 m/hr, taking in to accounts the variation in temperature during the period of the experimental work.

RESULTS AND DISCUSSION

The results in tables 1 to 6 show that ηth and ηprac decreases as the filtration rate increases. Increasing the filtration rate will increase the hydraulic shear force which tends to push the suspended particles deeper in the filter and may carry them out by the effluent. Also high velocities in the pores will lead to higher scour effects on the deposited particles (Cleasby et al.,1992).

For the mono media filters in the two sets the values of ηth were more than ηprac . In sand filters ηprac could be obtained by multiplying ηth by a factor 0.714 for set No.1 and by a factor 0.55 for set No.2, this difference may be due to the variation in temperature. Where the measurement of set No.1 were in a colder climate 10-15 C and for set No.2 20 C. The factor for the glass filter was 0.945.

All the dual filters show that ηth is less than ηprac. Filter No.1 in set No.2 showed the higher collection efficiency than the other two dual filters.

The higher percentage of coarse grains per unit filter depth leads to low numbers of filter media grains per m^2 which will cause a significant reduction in the total surface area of filter media in a unit area so a clear reduction in the removal of suspended solids indicated here as the collection efficiency (Letterman,1987). For the dual filter glass and sand No.3 in set No.1, ηth is multiplies by 1.374 to obtain ηprac. For dual filters glass and porcelanite in set No.2 ηth is multiplied by 1.168 for filter No.1 and by 1.204 for filter No.3

CONCLUSIONS

The collection efficiency varied inversely with the filtration rate. For the mono media filters the theoretical values were more than the practical values calculated from the experimental work. In the glass filter ηprac is obtained by multiplying ηth by a factor 0.945 where this factor was o.714 and 0.55 for the sand filters. All the dual filters showed that ηth was less than ηprac. Whereas the dual filter 35cm porcelanite and 35cm glass showed the highest collection efficiency.

To obtain ηprac in the dual filter glass and sand, ηth is multiplied by 1.374, as for the dual filters porcelanite and glass the factors was 1.168 and 1.204.

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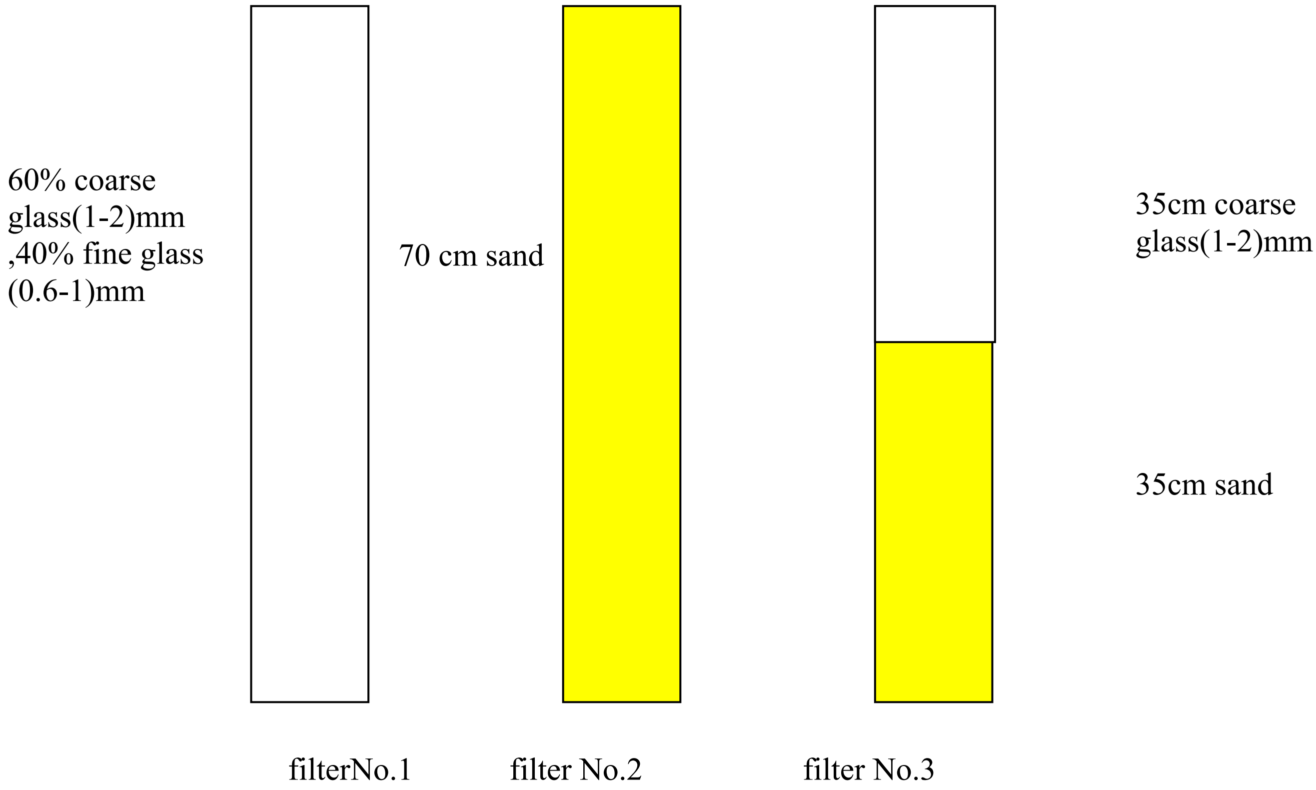

Figure 1 Set No.1

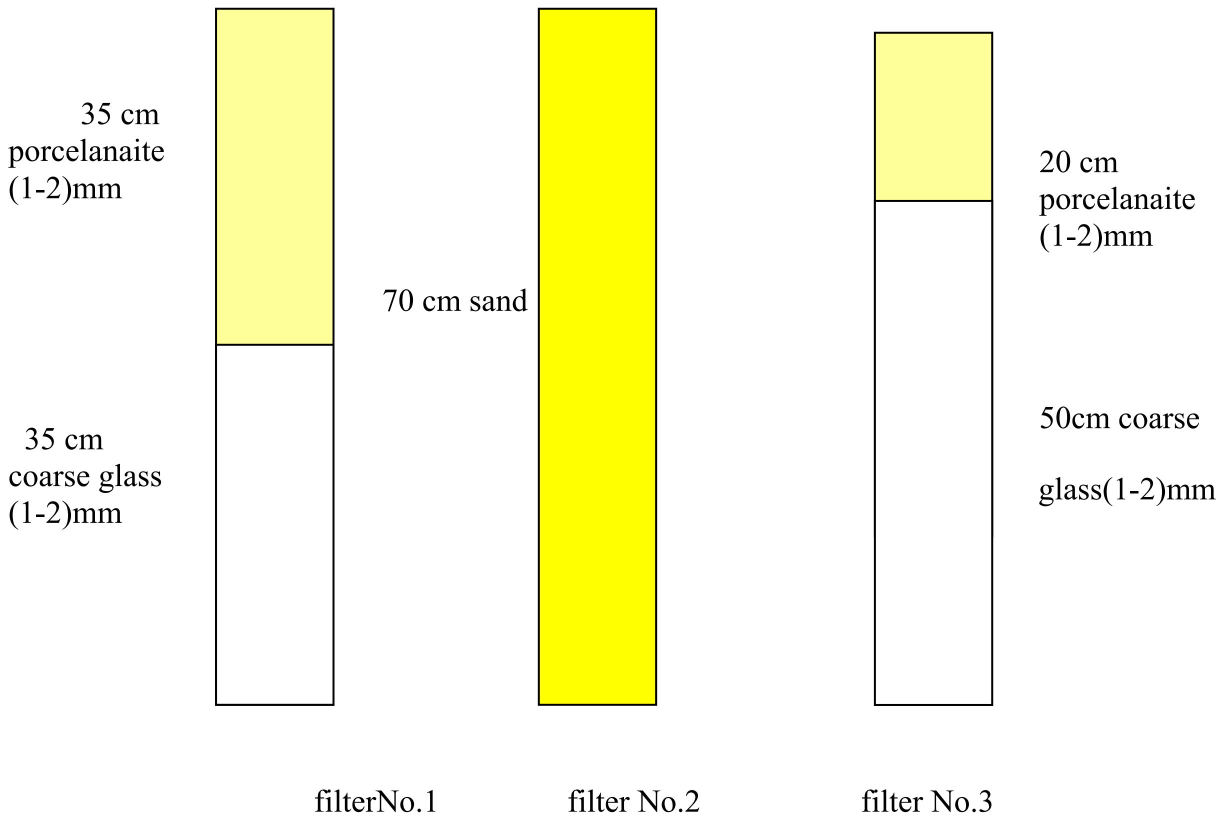

Figure 2 Set No.2

Table 1 Results of Set No. 1, Filter No. 1

Parameters	Filtration Rates		
U_s	5m/hr	10m/hr	15m/hr
T	11°C	13°C	15°C
ε	37%	37%	37%
p	0.825	0.825	0.825
w	0.04	0.04	0.04
A_s	30.891	30.891	30.891
N_R	$4.629*10^{-3}$	$4.629*10^{-3}$	$4.629*10^{-3}$
N_{Lo}	$3.117*10^{-7}$	$1.665*10^{-7}$	$1.192*10^{-7}$
D_{BM}	$6.554*10^{-14}$	$7.053*10^{-14}$	$7.626*10^{-14}$
N_{pe}	22886787	42535091	59008655
N_G	0.0134	$7.174*10^{-3}$	$5.136*10^{-3}$
E	81.458	82.664	67.208
η_{th}*	$3.61*10^{-3}$	$3.38*10^{-3}$	$2.20*10^{-3}$
η_{prac}**	$3.48*10^{-3}$	$3.20*10^{-3}$	$2.04*10^{-3}$

Table 2 Results of Set No. 1, Filter No. 2

Parameters	Filtration Rates		
U_s	5m/hr	10m/hr	15m/hr
T	11 °C	13 °C	15 °C
ε	37%	37%	37%
p	0.857	0.857	0.857
w	0.023	0.023	0.023
A_s	23.379	23.379	23.379
N_R	$4.784*10^{-3}$	$4.784*10^{-3}$	$4.784*10^{-3}$
N_{Lo}	$3.117*10^{-7}$	$1.665*10^{-7}$	$1.192*10^{-7}$
D_{BM}	$6.554*10^{-14}$	$7.053*10^{-14}$	$7.626*10^{-14}$
N_{pe}	22145085	41156639	57096337
N_G	0.0134	$7.174*10^{-3}$	$5.136*10^{-3}$
E	80.209	75.177	75.433
η_{th}*	$5.76*10^{-3}$	$2.99*10^{-3}$	$2.20*10^{-3}$
η_{prac}**	$2.55*10^{-3}$	$2.19*10^{-3}$	$2.13*10^{-3}$

η_{th}* Theoretical efficiency calculated by equation 11
η_{prac}**Practical efficiency calculated by equation 17

Table 3 Results of Set No. 1, Filter No. 3

Parameters	Filtration Rates		
U_s	5m/hr	10m/hr	15m/hr
T	11 °C	13 °C	15 °C
ε	41%	41%	41%
p	0.838	0.838	0.838
w	0.033	0.033	0.033
A_s	17.78	17.78	17.78
N_R	$3.929*10^{-3}$	$3.929*10^{-3}$	$3.929*10^{-3}$
N_{Lo}	$3.117*10^{-7}$	$1.665*10^{-7}$	$1.192*10^{-7}$
D_{BM}	$6.554*10^{-14}$	$7.053*10^{-14}$	$7.626*10^{-14}$
N_{pe}	26955549	50096885	57096337
N_G	0.0134	$7.174*10^{-3}$	$5.136*10^{-3}$
E	84.508	84.772	81.289
η_{th}*	$3.06*10^{-3}$	$3.01*10^{-3}$	$2.10*10^{-3}$
η_{prac}**	$3.82*10^{-3}$	$3.78*10^{-3}$	$3.40*10^{-3}$

Table 4 Results of Set No. 2, Filter No. 1

Parameters	Filtration Rates		
U_s	5m/hr	10m/hr	15m/hr
T	20 °C	22 °C	20 °C
ε	57.5%	57.5%	57.5%
p	0.752	0.752	0.752
w	0.104	0.104	0.104
A_s	14.606	14.606	14.606
N_R	$3.333*10^{-3}$	$3.333*10^{-3}$	$3.333*10^{-3}$
N_{Lo}	$4.074*10^{-7}$	$2.155*10^{-7}$	$1.358*10^{-7}$
D_{BM}	$8.58*10^{-14}$	$9.415*10^{-14}$	$8.837*10^{-14}$
N_{pe}	24281274	42535091	70725359
N_G	0.0175	$9.293*10^{-3}$	$5.853*10^{-3}$
E	81.029	72.256	64.271
η_{th}*	$6.13*10^{-3}$	$4.01*10^{-3}$	$2.41*10^{-3}$
η_{prac}**	$6.26*10^{-3}$	$4.30*10^{-3}$	$3.40*10^{-3}$

Table 5 Results of Set No. 2, Filter No. 2

Parameters	Filtration Rates		
U_s	5m/hr	10m/hr	15m/hr
T	20 °C	22 °C	20 °C
ε	37%	37%	37%
P	0.857	0.857	0.857
w	0.023	0.023	0.023
A_s	23.379	23.379	23.379
N_R	$4.784*10^{-3}$	$4.784*10^{-3}$	$4.784*10^{-3}$
N_{Lo}	$4.074*10^{-7}$	$2.155*10^{-7}$	$1.358*10^{-7}$
D_{BM}	$8.58*10^{-14}$	$9.415*10^{-14}$	$8.837*10^{-14}$
N_{pe}	16915954	30831416	49272000
N_G	0.0175	$9.293*10^{-3}$	$5.853*10^{-3}$
E	87.349	74.750	49.997
η_{th}*	$4.94*10^{-3}$	$3.91*10^{-3}$	$2.43*10^{-3}$
η_{prac}**	$3.24*10^{-3}$	$2.16*10^{-3}$	$1.08*10^{-3}$

Table 6 Results of Set No. 2, Filter No. 3

Parameters	Filtration Rates		
U_s	5m/hr	10m/hr	15m/hr
T	20 °C	22 °C	20 °C
ε	52.1%	52.1%	52.1%
p	0.782	0.782	0.782
w	0.074	0.074	0.074
A_s	19.123	19.123	19.123
N_R	$3.333*10^{-3}$	$3.333*10^{-3}$	$3.333*10^{-3}$
N_{Lo}	$4.074*10^{-7}$	$2.155*10^{-7}$	$1.358*10^{-7}$
D_{BM}	$8.58*10^{-14}$	$9.415*10-^{14}$	$8.837*10^{-14}$
N_{pe}	24281274	44255620	70725359
N_G	0.0175	$9.293*10^{-3}$	$5.853*10^{-3}$
E	87.317	76.188	73.633
η_{th}*	$6.01*10^{-3}$	$4.09*10^{-3}$	$2.49*10^{-3}$
η_{prac}**	$6.15*10^{-3}$	$4.07*10^{-3}$	$3.97*10^{-3}$