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Effect of Grain size of Porous Media on Physical Clogging.

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Abstract

The effect of size of grains of porous media on physical clogging under constant flow rates was investigated experimentally. A sandy soil having particle size ranging from 355 to 1190 µm, fractioned into seven unisizes, was selected as the porous media. Two types of silt soils (smaller than 63 µm) were used as suspensions. Two concentrations (500 and 1000 mg/L) with three flow rates (116, 214 and 353 mL/min) were used. The results showed that, the permeability reduction (K_t/K_i) decreased with decreasing mean grain diameter (D_{50}) of the porous media till a critical value of (D_{50}/d_{50}) after which a surface mat of suspension is formed on the surface of porous media. The effects of suspension type and flow rates on physical clogging seemed to depend on the pores size of the porous media.

Keywords: Bed Clogging, Permeability Reduction, Particle Infiltration, Plugging, Packed bed.

1- Introduction

The term "clogging of a porous media" connotes the phenomenon of retaining fine solid particles, suspended in a liquid flowing through a porous media, such as sand, silt, clay, bacteria, colloidal fines,....etc, in the pores of the media. This leads to a restriction of flow through the pores, which in turn leads to a reduction in hydraulic conductivity (permeability) of the porous media.

This phenomena and the resulting permeability reduction has long been a problem in many industrial and engineering applications. It occurs in many natural and technical processes such as fine particle accumulation in soil filters, water supply filtrations, and petroleum engineering, artificial recharging of waste water into underground formations and lining of canals, reservoirs, and lagoons in hydraulic and agricultural engineering (sealants) [1-8]

A related problem in the earth dam is erosion and piping in soils, which is given an important consideration in the design of earth dams (statistics show that 26% of the earth dam failures surveyed were attributed to the internal erosion and piping in soils) [6,7].

In the related area of pavement design in highway engineering, clogging of filters underneath the pavement section is one of the major reasons which cause early deterioration of pavement (In the united state this phenomenon continues to cost billions of dollars) [6, 7].

In the context of wastewater filtration in environmental engineering, design of porous systems, which are used in the removal of particulate matter in water supplies, entails considerations of changes in energy are required to move the suspension through the bed as the pore spaces get clogged [6].

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during water flooding or clogging due to mobilization of small particles (formation fines), which are present in pore spaces of the reservoir rocks, can hinder the extraction of petroleum from a formation [2, 9-11].

In artificial recharging of wastewater into underground formation, the recharging operations can be hampered if hydraulic conductivity is reduced by particle capturing (clogging) [12-14].

As discussed above the outcome of clogging in the mentioned areas is not desirable and posses a major problem. Thus it is of great importance to understand the clogging behavior of porous media as well as delineate the factors affecting it.

The main purpose of this study is to investigate the effects of size of grains of porous media (using natural granular material) on the physical clogging where chemical and biological clogging are minimized and subsided. Also the effects of flow rate (velocity), suspension concentration and suspension type are studied experimentally, with a total number of thirty five (35) tests.

2- Experimental works

For the purpose of experimentation, a special rig was built in the engineering college laboratory.

Figs. (1,2) show a schematic and photograph of the rig.

2.1 Description of the Rig

2. 1. 1 Component

The instrument used in the experimental program is composed of a constant-flow rate pump, transparent Perspex suspension cylinder, an electrical mixer and the porous media column. The constant-flow rate pump is a metal (aluminum) piston moving through a transparent Perspex cylinder, 190 mm in diameter and 450 mm length, by means of an electrical motor and gearbox (1:100).

This instrument can inject water, under constant-flow rate, with several discharges ranging from 0 to 0.5 l/min at about one bar pressure. It is placed in a 45° inclined position with horizontal for obtaining homogenous suspension concentration produced from the suspension cylinder.

2. 1. 2 Porous Media Column.

The Porous Media column was made of a galvanized iron pipe, 41 mm in diameter and 300 mm in length which was externally threaded at both ends, with two internally threaded brass caps.

To support the porous media inside the column a steel screen with 300 micron openings, enhanced by a perforated steel plate, was used and placed in the lower brass cap.

Hydraulic head distributions along the bed were measured by four pressure gages which were connected laterally to the porous media column.

2.2 Materials

To study the physical clogging of porous media, both the porous media and suspensions should be inert to each other. To obtain that the procedure in reference [15] was followed.

2.2.1 Porous Media

The porous media is consisting of natural sand cleaned and sieved into different sizes. The fractions of sands retained between two nearest standard sieves were taken as a unisize bed. In this study seven unisize sands, ranged from 355 to 1190 μm, were prepared. Table (1) shows some characteristics of the porous media.

2.2.2 Suspended Solids

Two types of natural silty soils were prepared as suspended solids, type A and type B. Table (2) shows some characteristics of suspensions. The first type of the suspensions type (A) is non-uniform natural soil passed sieve No.240 (63 μm). Type B is a natural uniform silt particle having mean particle diameter of about 58 micron (Passed sieve No. 240-63 μm and retained on sieve No. 270-53μm). The water, which is used as a carrier, is the filtered tap water having normal turbidmeter of about (0.02) NTU.

2.3 Experimental Work

2.3.1 Test Setup and Procedure.

When all the sand is placed in the pipe, the column was checked for leakage. After that, filtered tap water was allowed to flow through the bed for about one hour, with small discharges, to release any air bubbles in the bed and to stabilize the bed grains. Then later the suspensions, from the rig, were injected into the porous media column under constant flow rate and concentration.

During testing, the following measurements were taken with time:-

1. Pressure measurement using four pressure gages.
2. Discharge measurement for checking the pump discharges.
3. Effluent turbidity measurement.
4. Temperature measurement.

For each bed, five tests are conducted with different discharges (three tests), concentration (one test) and suspension type (one test). Thus the total number of the experimental runs was 35 runs (7 beds x 5).

3. Results and Discussions

3.1 *Permeability Reduction calculation*

For obtaining the physical reduction of permeability due to suspension (physical clogging), the changes in the fluid properties due to change in temperature was ignored. So that the physical permeability of the soil media used in this study, can be defined as follow:

$$K = \frac{\mu \; Q \; \Delta L}{\gamma \; A \; \Delta H} \qquad ....1$$

Where

μ = absolute viscosity. ((Dyne* s)/cm^2)
Q = flow rate (discharge). (cm^3/s)
ΔL = porous media length (depth). (cm)
ΔH = differential head (Head Loss). (cm)
γ = unit weight of the fluid. (Dyne/cm^3)
A = cross-sectional area of soil. (cm^2)

The permeability reduction is the ratio of permeability of the porous media at any time during testing (at any injected pore volume), K_t, to the initial permeability at time = 0, K_i. So, mathematically, it can be written as follows:

$$\frac{K_t}{K_i} = \frac{(\mu)_t \; \gamma_i \; (\Delta H)_i}{(\mu)_i \; \gamma_t \; (\Delta H)_t} \qquad ....2$$

As shown in Eq. (2), permeability reduction is simply proportional to the ratio between the head loss at any time of the testing and the initial head loss at the same fluid properties. This equation was used for calculating permeability reduction at any time.

3.2 Effect of grain size of porous media on physical clogging

From Fig. (3), for beds having D_{50} larger than 550 μm, the value of K_t/K_i decreased as D_{50} decreased. This due to higher capability of the smaller pore sizes for capturing the suspensions. While for beds having D_{50} equal and smaller than 550 μm, an opposite behavior was observed. This is due to the formation of a surface mat, of suspensions, on the inlet surface of the beds.

It is seen from Fig. (4) that the probability of penetration and transportation of suspensions throughout the beds increased with increasing D_{50}/d_{50} and D_{15}/d_{85} ratios. This is due to the increase of pore sizes relative to suspension sizes. Table (3) shows the behavior of clogging for runs 1 through 7. It is seen from this table that for $D_{50}/d_{50} \geq 23.6$ and $D_{15}/d_{85} \geq 13.5$, the suspensions transported throughout the porous media and their concentration was increased with increasing of injected water volume [Fig. (4)]. For $D_{50}/d_{50} \leq 19.8$ and $D_{15}/d_{85} \leq 11.4$, the suspensions were retained on the top of the bed forming a surface mat. This has been confirmed visually after the end of the experiments. Such a behavior has been suggested by Mcdowell-boyer, et.al. [11], (1986).

3.3 Effect of flow rate on physical clogging

Figs. (6) to (9) represent the effect of flow rates on clogging behavior of four unisize beds (Beds No. 1, 2, 3 and 4). These figures show that flow rate has no considerable effect on the clogging behavior. This is due to the formation of surface mats on all these beds which were confirmed visually after the end of each one. The formation of these mats on the surface of the beds is independent of flowrates; at the same injected water volume with the same suspension type and concentration, the mats were similar in composition and thickness.

Figs. (10-12) represent the effect of flow rates on clogging behavior for the beds where surface mats were not formed and when transportation occurred (Beds No. 5, 6, 7), higher permeability reduction is observed at lower flow rates.

Figs. (13-15) show the value of ratio of suspension concentration at any time to initial suspension concentration, C_t/C_i, for beds where transportation of suspensions is occurred. It is seen from these figures that as the flow rate increases the value of C_t/C_i increases.

The above observations may be explained as follows:

When flow rates are increased, the interstitial velocity is also increased. This means an increase in the hydraulic shear force which leads to push the suspensions deeper into the porous media and ultimately they appear in the effluent. So the amount of suspensions retained or deposited in the porous media is smaller for higher flow rates.

3.4 Effect of concentration of suspensions

Figs. (16-22) show clogging behavior of the (7) beds for two concentrations (500 and 1000 mg/L) of suspension type (A). As expected, the higher concentration of suspensions causes more reduction in permeability for all the bed. This is because of the fact that higher concentrations cause higher retention inside the pores and a thicker surface mat at the surface of the beds.

3.5 Effect of particle size distribution of suspension.

Figs. (23-29) shows the effect of size distribution of the suspension on clogging behavior for the unisize beds for the same flow rate (353 mL/min.) and suspension concentration (1000 mg/L) . It is seen that for beds no. 1, 2, 3 and 4, the type A (the non-uniform suspension) has greater effect on the reduction of permeability {Figs. (23-26)}. This is due to formation of surface mat which has smaller pore sizes for the case of non-uniform suspension compared to the uniform suspensions. While Figs. (27-29) show an opposite behavior for Beds no. 5, 6 and 7. This is because those beds have larger value of D_{50} in which no surface mats were formed. Obviously the uniform suspension has larger d_{50} (58 μm) compared to the non-uniform suspension (33 μm) and caused larger reduction in permeability.

4. Conclusions

As a result of this study, the following conclusions are made:

1. The size of particles of porous media and suspensions, flow rates and concentrations proved to be basic factors in physical clogging.
2. For any type of suspended particle with any concentration and flow rate, the permeability is more reduced for unisize beds having smaller D_{50} than the beds having larger D_{50} until the ratio of D_{50}/d_{50} reaches a limit in which the suspensions will form a horizontal surface mat on the surface of the porous media. After the formation of the mat an opposite behavior was observed.
3. For beds penetrated by suspensions, the uniform suspensions causes more reduction in permeability than non-uniform suspensions. While for beds not penetrated by suspensions (beds clogged due to surface mat-filter cake mechanism), the non-uniform suspensions causes more reduction in permeability than the uniform suspension.
4. Higher concentration of suspensions causes higher reduction in permeability of porous media for unisize beds.
5. Surface mats occurred under the following conditions:

I-) $D_{15}/d_{85} \leq 10$ ($D_{50}/d_{50} \leq 11.3$)
…….For uniform suspensions.
II-) $D_{15}/d_{85} \leq 11.4$($D_{50}/d_{50} \leq 19.8$)
…….For non-uniform suspensions.

6. For beds penetrated by suspensions, permeability was more reduced for lower discharges than higher discharges. While for beds not penetrated by suspensions, beds clogged by surface mat mechanisms, flow rate has no considerable effect on the clogging behavior.
7. For the cases where the formation of surface mat on the bed surfaces and early transportation of suspensions are not desirable, for example in water supply filters, the convenient ratio is $D_{15}/d_{85} = 13.5$ for unisize beds which has smaller increased head loss. While for the cases where transportation of suspensions is not desirable and when small initial and final head losses are required, for example in soil filter of earth dams, the convenient ratio is $D_{15}/d_{85} = 11.4$ ratio for unisize beds which not allowed any suspension penetration and has smaller increased head loss (for the same suspensions).

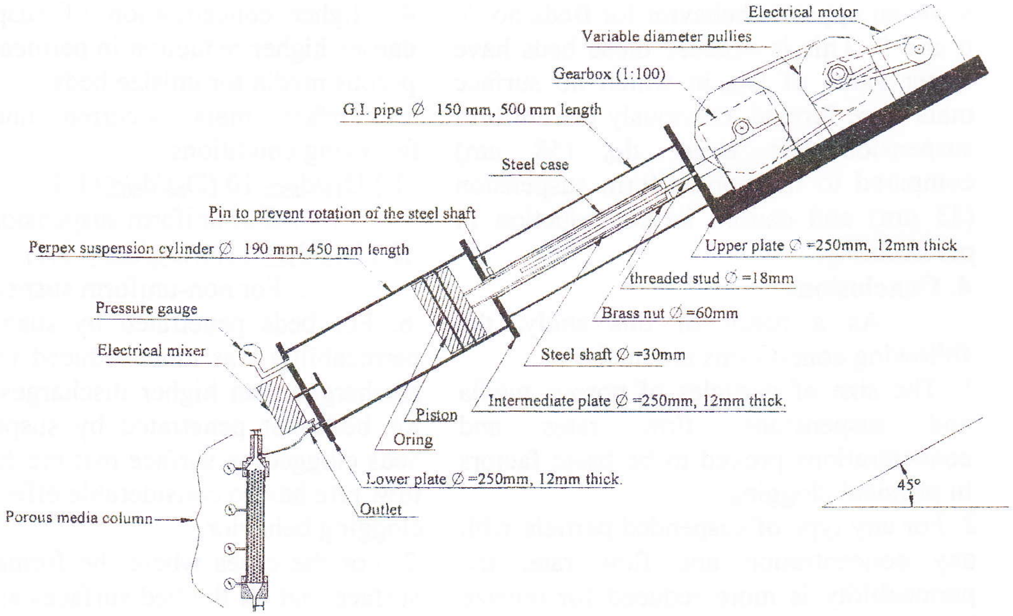


Figure (1) Schematic diagram of the rig

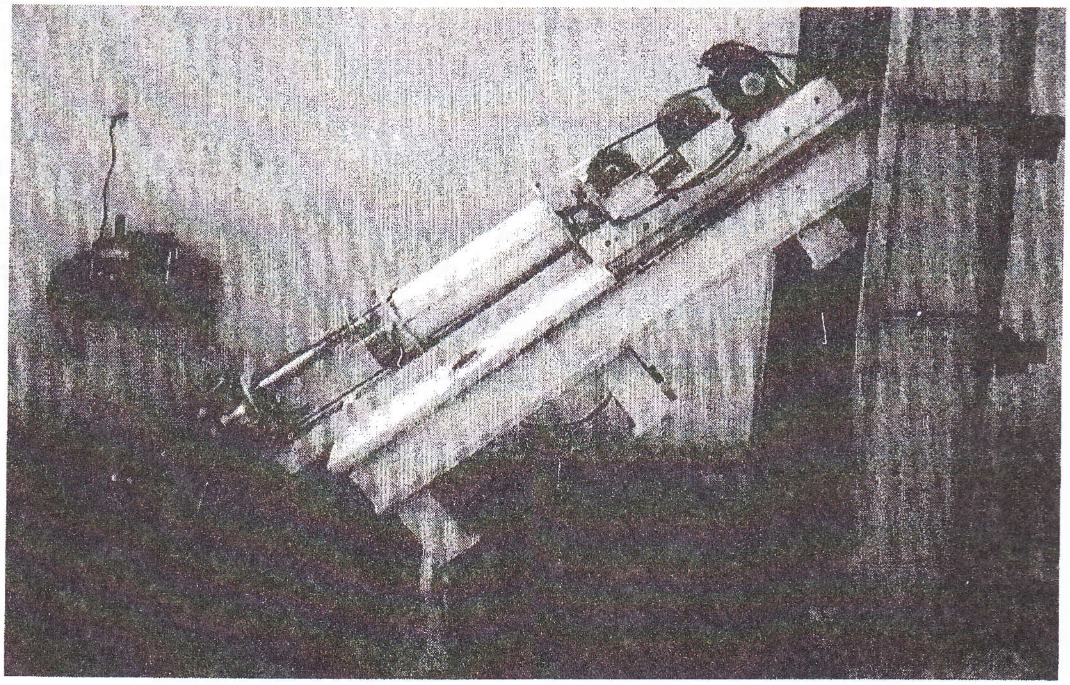


Figure (2) Photograph of the rig

Table (1) Some Characteristics of Porous Media

Bed No.	Porous Media type	D_0 micron	D_{10} micron	D_{15} micron	D_{50} micron	D_{60} micron	D_{100} micron	U.C.	S.G.
1	Unisize	355	362	366	390	397	425	1.097	2.713
2	Unisize	425	433	436	463	470	500	1.085	2.681
3	Unisize	500	510	515	550	560	600	1.098	2.688
4	Unisize	600	611	617	655	666	710	1.090	2.674
5	Unisize	710	724	731	780	794	850	1.097	2.668
6	Unisize	850	865	873	925	940	1000	1.087	2.738
7	Unisize	1000	1019	1029	1095	1114	1190	1.093	2.720

Table (2) Some Characteristics of Suspensions.

Suspension Type	d_0	d_5	d_{10}	d_{15}	d_{50}	d_{60}	d_{85}	d_{100}	U.C.	S.G.
(A) non-uniform	-	-	3.45	7.8	33	39	54	63	11.29	2.763
(B) uniform	53	53.5	54	54.5	58	59	61.5	63	1.093	2.687

Table (3) Clogging Behavior for Unisize Beds.

Run No.	Ratio of D_{50}/d_{50}	Ratio of D_{15}/d_{85}	Initial Head loss, cm	Final Volume of water injected, mL	Final increased Head Loss, cm	Final value of C_t/C_i	Clogging behavior
1	11.8	6.8	170.78	14826	184.7	0	S*
2	14.0	8.1	109.17	15532	163.1	0	S
3	16.7	9.5	83.47	15532	186	0	S
4	19.8	11.4	60.46	23298	198.9	0	S
5	23.6	13.5	41.51	62128	85.9	0.64	T**
6	28.0	16.2	23.24	38830	9.5	0.64	T
7	33.2	19.1	17.83	38830	4.7	0.78	T

S* : Formation of surface mat on the surface of the bed.
T** : Suspensions transported throughout the beds.

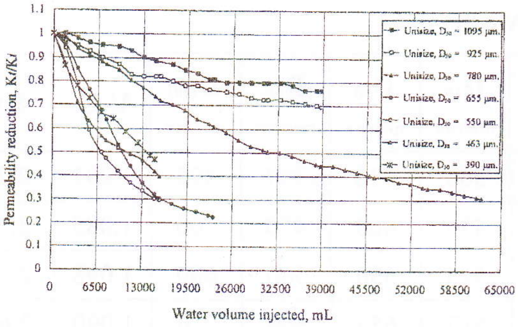


Figure (3) Permeability reduction for different unisize beds, C=1000 mg/L, Q=353 mL/min., suspension type (A).

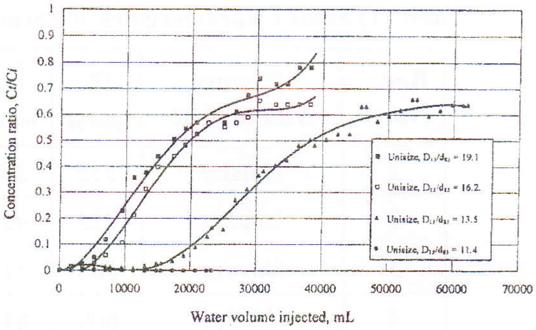


Figure (4) Concentration ration for different D_{15}/d_{85} ratios, C=1000 mg/L, Q = 353 mL/min. Suspension type (A).

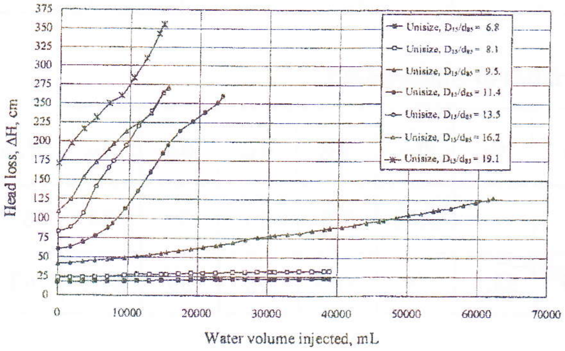


Figure (5) Head loss for different D_{15}/d_{85} ratios, Suspension type (A), C=1000 mg/L,Q=353 mL/min.

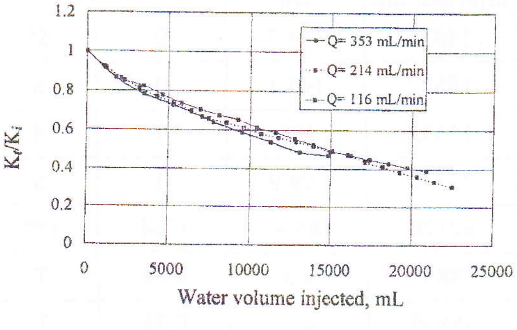


Figure (6) Permeability reduction for different flowrates, Bed No.1, D_{50}= 390 µm, C= 100 0mg/L, Suspension type A.

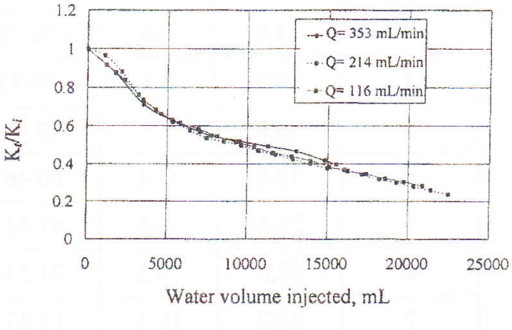


Figure (7) Permeability reduction for different flowrates, Bed No.2, D_{50}= 463 µm, C= 1000 mg/L, Suspension type A.

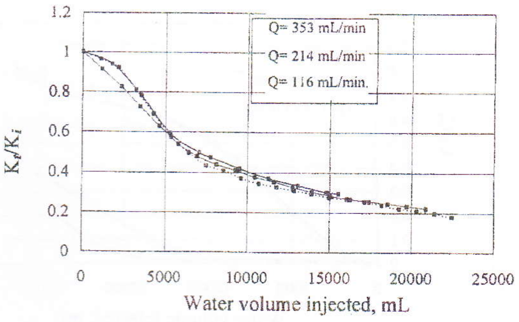


Figure (8 Permeability reduction for different flowrates, Bed No.3, D_{50}= 550 μm, C= 1000 mg/L, Suspension type A.

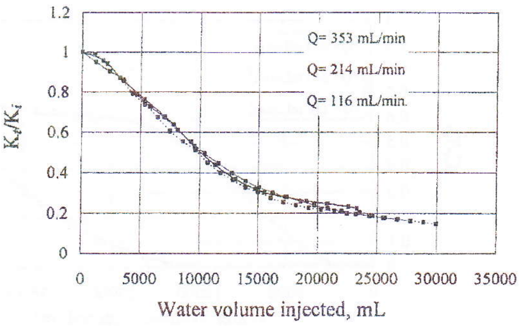


Figure (9) Permeability reduction for different flowrates, Bed No.4, D_{50}= 655 μm, C= 1000 mg/L, Suspension type A.

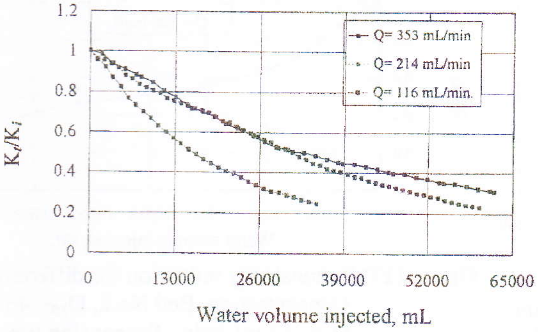


Figure (10) Permeability reduction for different flowrates, Bed No.5, D_{50}= 780 μm, C= 1000 mg/L, Suspension type A.

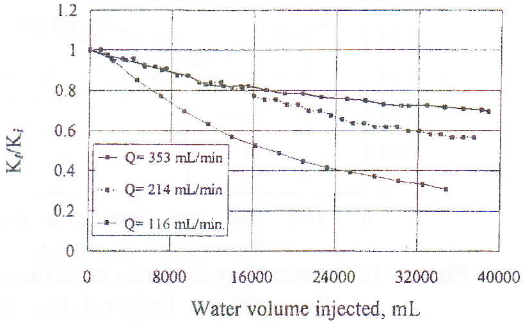


Figure (11) Permeability reduction for different flowrates, Bed No.6, D_{50}= 925 μm, C= 1000 mg/L, Suspension type A.

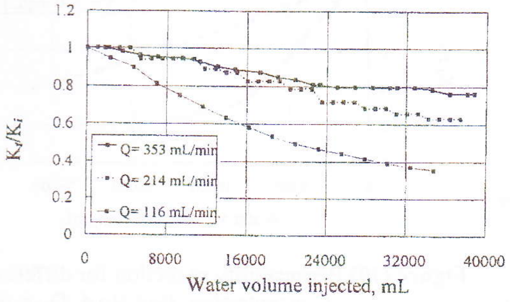


Figure (12) Permeability reduction for different flow rates, Bed No.7, D_{50}= 1095μm, C= 1000 mg/L, Suspension type A.

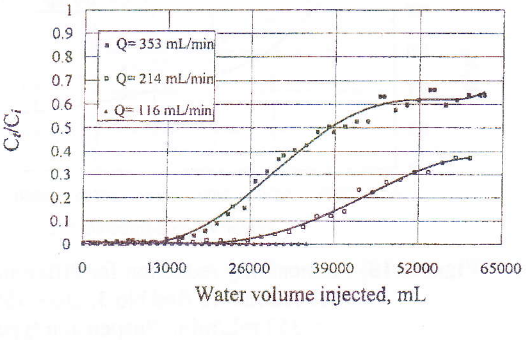


Figure (13) Concentration ratio for different flow rates, Bed No.5, D_{50}= 780 μm, C= 1000 mg/L, Suspension type A.

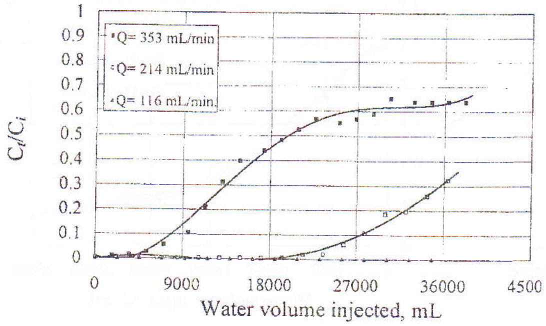


Figure (14) Concentration ratio for different flow rates, Bed No.6, D_{50}= 925 μm, C= 1000 mg/L, Suspension type A.

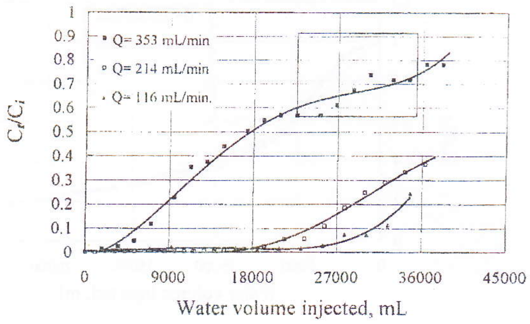


Figure (15) Concentration ratio for different flow rates, Bed No.7, D_{50}= 1095 μm, C= 1000 mg/L, Suspension type A.

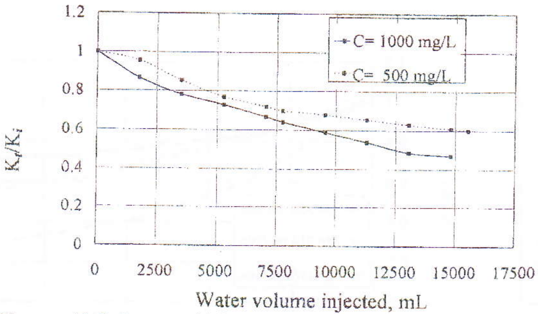


Figure (16) Permeability reduction for different Concentration, Bed No.1, D_{50}= 390μm, Q = 353 mL/min., Suspension type A.

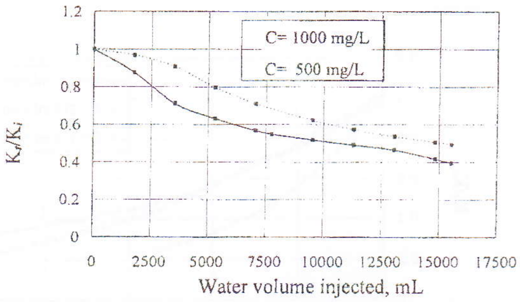


Figure (17) Permeability reduction for different Concentration, Bed No.2, D_{50}= 463μm, Q = 353 mL/min., Suspension type A.

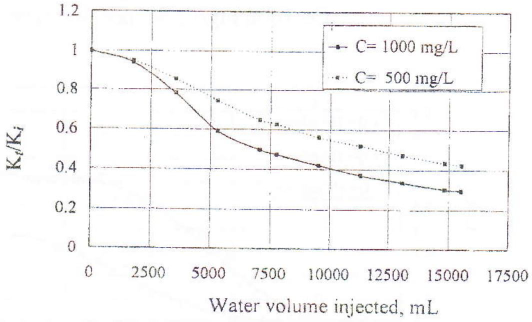


Figure (18) Permeability reduction for different Concentration, Bed No.3, D_{50}= 550μm, Q = 353 mL/min., Suspension type A.

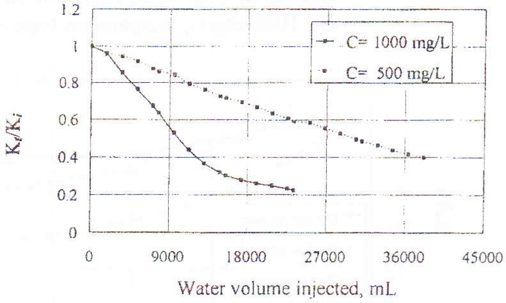
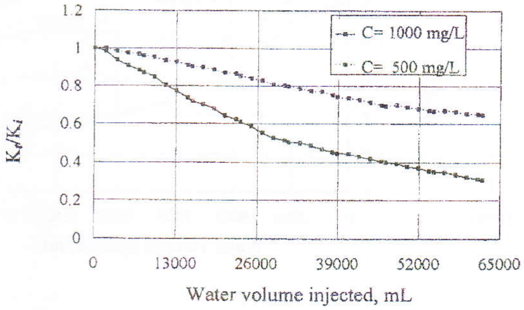
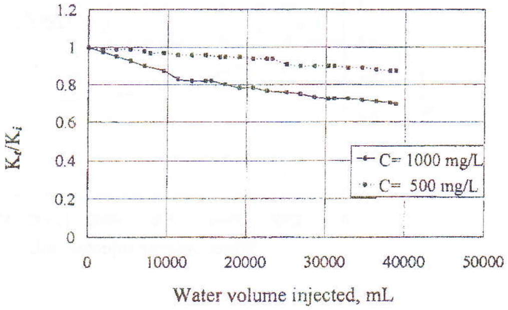
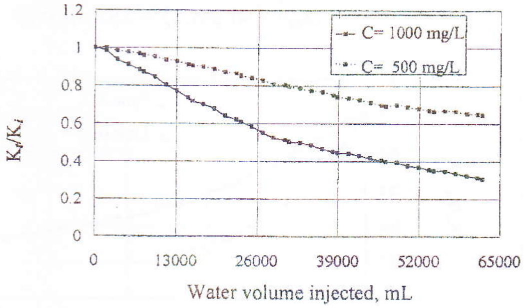


Figure (19) Permeability reduction for different Concentration, Bed No.4, D_{50}= 655μm, Q = 353 mL/min., Suspension type A.







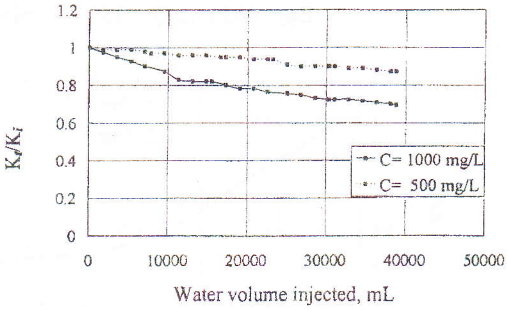


Figure (20) Permeability reduction for different Concentration, Bed No.5, D_{50}= 780μm, Q = 353 mL/min., Suspension type A.

Figure (21) Permeability reduction for different Concentration, Bed No.6, D_{50}= 925μm, Q = 353 mL/min., Suspension type A.

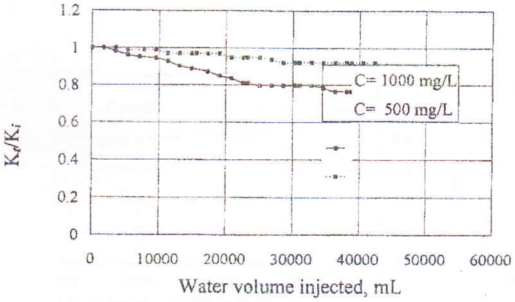


Figure (22) Permeability reduction for different Concentration, Bed No.7, D_{50}= 1095μm, Q = 353 mL/min., Suspension type A.

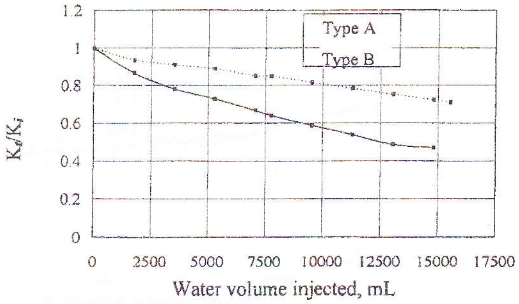


Figure (23) Permeability reduction for different suspension types, Bed No.1, D_{50}= 390 μm, Q = 353 mL/min.

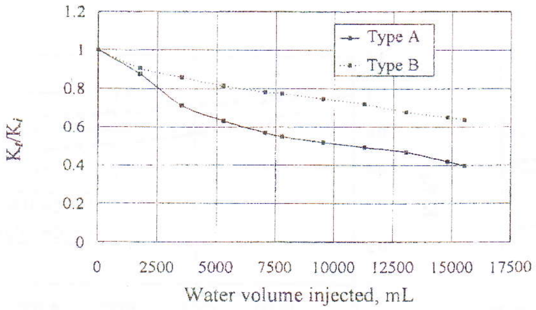


Figure (24) Permeability reduction for different suspension types, Bed No.2, D_{50}= 463 µm, Q = 353 mL/min.

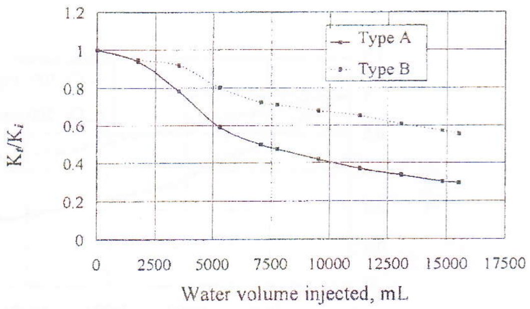


Figure (25) Permeability reduction for different suspension types, Bed No.3, D_{50}= 550 µm, Q = 353 mL/min.

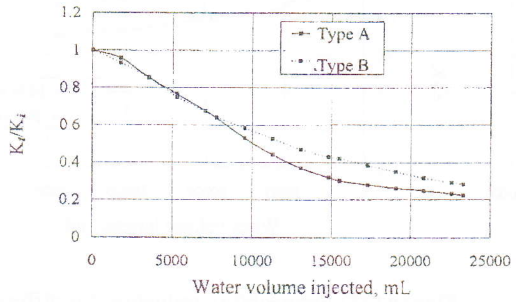


Figure (26) Permeability reduction for different suspension types, Bed No.4, D_{50}= 655 µm, Q = 353 mL/min.

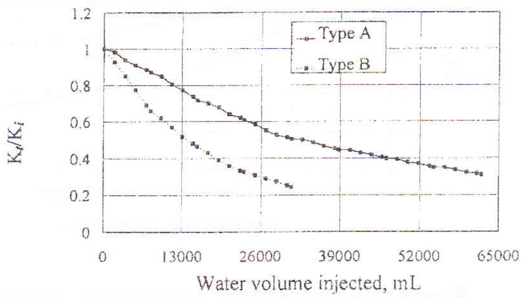


Figure (27) Permeability reduction for different suspension types, Bed No.5, D_{50}= 780 µm, Q = 353 mL/min.

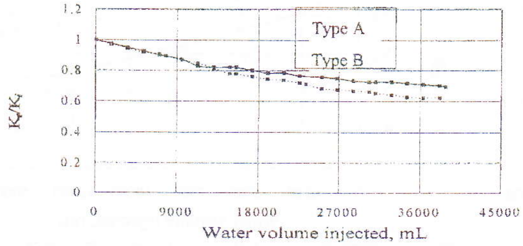


Figure (28) Permeability reduction for different suspension types, Bed No.6, D_{50}= 925 µm, Q = 353 mL/min.

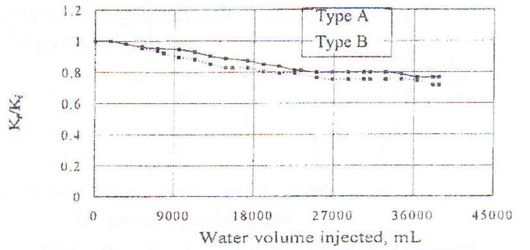


Figure (29) Permeability reduction for different suspension types, Bed No.7, D_{50}= 1095 µm, Q = 353 mL/min.

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کاریگەری قەبارەی دەنکەکانی ناوەندی کونیلەدار لە سەرگیرانی فیزیاوی

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پوختە

لەم توێژینەوەیەدا لە کاریگەری قەبارەی دەنکەکانی ناوەندی کونیلەدار لە سەرگیرانی فیزیاوی بە تێکرای ئاوی رۆیشتووی نەگۆر بە کرداری توێژراوەتەوە. خاکێکی لمی کە ٣٥٥ بۆ ١١٩٠ مایکرۆن قەبارەی دەنکی هەیە، بەکارهێنرا وەکو ناوەندی کونیلەدارو دابەشکرا بۆ حەوت ناوەندی هاو قەبارە لە دەنکدا. دوو جۆر لە قوم (کە دەنکۆلەکانی بچوکتربوون لە ٦٣ مایکرۆن) بەکارهێنران وەکو دەنکۆلە هەلواسراوەکان بە دوو چری جیاواز (٥٠٠ لەگەڵ ١٠٠٠ ملگم/لیتر) هەروەها سێ تێکرایی ئاوی رۆیشتووی نەگۆری جیاواز (١١٦، ٢١٤، ٣٥٣ ملل/خولەك) بەکارهێنراون بۆ ناردنی هەڵواسراوەکان بۆ ناو ناوەندەکان. ئەنجامەکان وا نیشانیاندا کە کەمبوونەوەی هاوکۆلکەی دادان (K_t/K_i) کەم دەکات بە کەمبوونی تێکرای تیرەی دەنکەکانی ناوەندەکە (D_{50}) تا نرخێکی شلۆق بۆ (D_{50}/d_{50}) کە پاش ئەوە رووە چینێك لە دەنکۆڵەی هەڵواسراو لەسەر رووی ناوەندە کونیلەدارەکە دروست دەبێت. کاریگەری جۆری دەنکۆڵەی هەلواسراو و تێکرای ئاوی رۆیشتوو لەسەر گیرانی فیزیاوی وا دەردەکەوێ کە بەندە بە قەبارەی کونیلەکانی ناو ناوەندی کونیلەدارەکە.

تاثيرات حجم الحبيبات لوسط مسامي على الانسداد الفيزياوي

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الخلاصة

شملت هذة الدراسة تاثيرات حجم الحبيبات لوسط مسامي على الانسداد الفيزياوي تحت مختلف معدلات الجريان. تراوحت حجم حبيبات المستخدمة كوسط مسامي بين ٣٥٥ الى ١١٩٠ مايكرون، قسمت الى سبعة اجزاء متساوية من حيث القطر. استخدمت كمادة عالقة نوعان من الترب الغروية (اصغر من ٦٣ مايكرون من حيث القطر) بتراكيز (٥٠٠ و ١٠٠٠ ملغم/لتر) وبمعدل جريانات (١١٦، ٢١٤، ٣٥٣ ملل/دقيقة). أضهرت النتائج أنه في حالة استخدام طبقة رملية متساوية الاقطار كوسط مسامي فان تنقيص النفاذية(K_t/K_i) سوف يقل بانخفاض معدل قطر الحبيبة(D_{50}) للوسط نفسه الى حد الحالة الحرجة(D_{50}/d_{50}) وبعدها سوف تتكون طبقة حصيرية على سطح الوسط. كما لوحظ بان تاثيرات نوع العوالق ومعدل الجريانات على الأنسداد الفيزياوي تعتمد على حجم الفجوات للوسط المسامي.

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