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# Comparison between Graded Crushed Gravel Filter and Textile Filter using Statistical Analysis

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## Abstract

Many researchers have applied several experiments and research studies by developing criteria's design of drainage to improve the drainage process, and to show that the filters plays an important role to improve and maintain the drainage system from being blocked due to siltation. There are several types of filters, including granular mineral materials and organic materials, the other filter that was used is made from a special fabric material such as paper, burlap, or special fabric textile material. The objective of this study is to evaluate the performance of textile filters, and if it is desirable and suitable for Iraqi soil using statistical analysis. This study was conducted in the laboratory using sand tank model and two types of filters (graded crushed gravel and textile) with two types of soil (sandy soil and loamy soil) to compare and evaluate the hydraulic performance and the efficiency of utilizing textile filter instead of graded crushed gravel filter in drainage systems using statistical analysis methods. These statistical analysis show that there was a good agreement between measured and theoretical values of entrance resistance when using the two filters in sandy soil. On the other hand, the results showed that there was a weak performance when textile filters in were used in heavy soil (loamy soil) due to the high value of root mean square error (RMSE) and low value of agreement index (d). The results of statistical analysis show that the textile filter is desirable and suitable for Iraqi soil especially for sandy soil due to low entrance resistance of flow compared to loamy soil.

**Keywords:** Graded Crushed Gravel Filter; Textile Filter; Entrance resistance.

# مقارنة بين الفلتر الحصوي المدرج المكسر والفلتر النسيجي بأستخدام التحليل الاحصائي

عامر حسن الحداد ، رسل لطيف ناجي

**الخلاصة:**

الكثير من الباحثين اجروا مجموعة من التجارب والبحوث وذلك من خلال تطبيق المعاير التصميمية لتحسين الاداء الهيدروليكي لمنظومة المبازل الحقلية ومن خلال استعمال انواع مختلفة من المرشحات (الفلتر) اضافة الى ذلك أهميته لحماية المبازل والحفاظ على منظومة المبازل من الانسداد بسبب الرسوبيات. هنالك عدة انواع من المواد المستعملة كمرشحات في تغليف المبازل المغلقة منها المواد الصخرية مثل الحصو الطبيعي او المكسر والمواد العضوية كاوراق الشجر والألياف النباتية وهنالك أيضا مواد صناعية تصنع من الورق والالياف الزجاجية وتعرف بالمرشحات النسيجية وقد تكون مصنعة من مادة البولي بروبلين والبولستر والبولي اثلين وغيرها من المواد. تهدف الدراسة الى تقييم اداء المرشح النسيجي والمصنوع من الالياف الصناعية ومدى ملأمته للترب العراقية وذلك من خلال أستخدام التحليل الاحصائي. تم أجراء البحث في المختبر وبأستعمال نموذج حوض الرمل ومن خلال استخدام نوعين من المرشحات وهي المرشح الحصوي المكسروالمدرج والمرشح النسيجي الصناعي مع نوعين من الترب وهي تربة رملية وترية

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مزيجية ويهدف البحث ايضا الى امكانية استخدام الفلتر النسيجي بدلا من الفلتر الحصوي المكسروالمدرج في المبازل الحقلية. اظهرت نتائج أستخدام التحليل الاحصائي لتقييم اداء المرشحات وتقييم مقاومة الدخول المقاسة ومدى تطابقها مع القيم المحسوبة نظريا هوملائمة كلا المرشحين عند استعمالها في الترب الخفيفة (الرملية). ومن جانب آخر اظهرت النتائج عدم ملائمة الفلتر النسيجي في الترب الغرينية (المزيجية) وذلك لأرتفاع قيم ((RMSE وأنخفاض قيم التطابق ( d ( واللذان بالامكان اعتبارهما كمؤشرين لمستوى تطابق القيم النظرية مع القيم المقاسة مما يساعد على توقع قيم مقاومة الدخول عند تصميم شبكة المبازل الحقلية وحساب المسافات بين المبازل ولترب مختلفة النسجة وبالنتيجة فأن النوعين من المرشحات ملأئمة للترب الخفيفة وذلك لأنخفاض معدل مقاومة دخول المياه الى المبزل.

**الكلمات الرئيسية:** الفلتر الحصوي المدرج المكسر، الفلتر النسيجي، مقاومة الدخول.

## 1. Introduction

The main objective of drain filter is increasing soil stabilization and improving the permeability around the drain. The porous material placed around a subsurface drain plays a role as well in protecting the drains from sedimentation of fine soil particles in the drains and improve hydraulic performance to control the water table. The purpose of using drain envelope which includes many types of materials placed surrounding a subsurface drain for different reasons **Harr, 1962.) [1]** which are:

- To stabilize the surrounding soil material.
- To increase the hydraulic performance and the permeability of the material around the subsoil drain.
- To provide and support a structural bedding for conduit or the pipe drain.
- To prevent migration particle of soil into the drain.
- To increase the flow through the drain as a result to increasing the effective surface area of flow.

The other hydraulic purpose of using drain envelope is to overcome the hazard of high hydraulic gradient in the subsoil around drain pipe which may cause the soil to be unstable.

### 1-1 Envelope Materials

Envelope material is a porous material placed around a drain, and its role is to improve the hydraulic performance of drain and protect the drain from sediment. These materials may be granular mineral envelope, textile envelope materials and organic material. Mineral granular envelopes include gravel, coarse sand and fine crushed stone. Organic envelopes include wood chips, corncobs reeds, flax stems, linen, sod grass and other materials. Textile envelope is called geotextile when used around subsurface drain (Synthetic materials) and it is specifically manufactured for drainage system. These envelope materials are very effective when installed around the drain pipe for a suitable soil. Geotextile is a known textile material as planar permeable, polymeric (synthetic or natural) and permeable polymer, which can be woven and non-woven or knitted, and be in contact with the soil. It is used in geotechnical applications for civil engineering. This also includes the application in agriculture and it is used in engineering sewage in many countries **FAO, 2005. [2]**. Woven geo-textiles are wrapped, usually at the right angles, with two or more series of yarns, stripe, fibers, thread, or other elements.

The following research were executed to study the influence of filter type on drain flow and their applied efficiencies for different drain types, non-woven geo-textiles papers or web pages, composed of fibers orientation guide or at random, yarns, or other items. By the thermal-mechanical or chemical means which can be bonded with these elements.

**Lyons, et al. 1964.[3]** used 1-inch thickness of glass fiber for enveloping plastic subsurface drain in Sacrament-San delta test. They found that the glass fiber envelope showed good performance, but when using drain with non filter, they found that test was not successful. The drain failure resulted from the stuck mud and soil which reduced water movement into the drain, probably a main reason for frustrating experiences in the Sacrament-San delta test.

**Rapp and Riaz 1975. [4]** Compared some filter materials (gravel, glass fiber felt, poly-underlay, glass fiber mat) using laboratory tank model to determine their relative effect on the flow of sediment and the flow of water into a plastic drain tube. The result showed that the amount of water discharged from drain was higher when using gravel filter and was low in case of no-filter treatments as compared with other treatments. They found that the amount of sediments collected in the drain was higher than that in the gravel filter.

**Rimidis and Dierickx, 2003. [5]** Evaluated performance of subsurface drainage by using organic envelope in Lithuania. The result showed that organic envelope like corn straw and flax seemed unsuitable material due to some degree of decomposition, but the performance of sawdust improved during work and can therefore be a suitable envelope despite organic origin. Also the glass fiber sheet is good because drainage performance did not change extraordinarily with time.

**Muhopadlhay, et al. 2009. [6]** Studied the performance of the horizontal roughing filter (HRF) by using Weglin's design criteria. The study was to validate (HRF) developed in the laboratory with slow sand filter (SSF) as a pretreatment unit with the help of Weglin's design criteria for (HRF) with respect to raw water. Condition and neuro-genetic model developed based on the filter dataset. The results achieved from the different models. They compared and verified the models with Weglin's model using statistical analysis as mean square error (RMSE), correlation coefficient (r), coefficient of efficiency (C.E) and standard deviation (STDEV). The verification of the laboratory model was taken as positive.

**Lal, et al. 2012. [7]** The functioning of geo-synthetic filter materials has been studied as envelope of drain in land reclamation in Haryana, north India. The result of the study shows that the "geo-synthetic envelope materials with $O_{90}$values >300 µm and woven filters with 60 mesh size could be safely used on lateral and collector drains, respectively when applied in medium soil texture".

**Kumar, et al. 2013. [8]** Studied the effect of envelope materials on the hydraulic performance of subsurface drainage systems. To evaluate this system, they also studied the entrance resistance of the envelope and its hydraulic conductivity. Three types of synthetic envelopes such as HG 22, SAPP 240 and CAN 2 were used in sand tank model and permeability instrument. They compared their performances of entrance resistance and hydraulic conductivity of soil envelope; the results showed the hydraulic conductivity of SAPP 240 filter provided the highest value with low entrance resistance.

### 1-2 Entrance Resistance

There are four components of total resistance of seepage to subsurface drain which are: horizontal, vertical, radial and the entry resistance. The first two components depend on the porous medium while the last two components depend on soil, type of drain, and envelope. To reduce the hydraulic gradient, and the entrance resistance it use the envelope on the appropriate drainage tube. As well as equipotential lines become circular and concentric to the drainpipe, which means that the flow is a full flow through the drainage. The overall head losses due to different resistances are:

$$h_T=h_v+h_h+h_r+h_e \qquad (1)$$

where:

$h_v$ = the head losses due to vertical flow (m),
$h_h$ = the head losses due to horizontal flow (m),
$h_r$ = the head losses due to radial flow (m), and
$h_e$ = the head losses due to resistance of entry (m).

The movement of water from the soil to the drain and its passing through the filter that was installed around the pipe of drainage, contributes to losing a part of the flow effort, which can be calculated by the following equation **ILRI,1979 [9]**.

$$he= \alpha \frac{q}{K_F} \qquad (2)$$

where:

$\alpha$ = is Resistance coefficient (dimensionless), [(0.4-0.6) for smooth pipe] , [(0.5-1)for corrugated pipe],
$q$ = drain discharge per unit length ($m^3$/m. day),
and $K_F$= hydraulic conductivity for envelope drain (m/day).

To facilitate the movement of water from the soil into the drain, the total head losses recommended to be a value close to zero. Theses head losses can be measured by indicating the difference in head of two piezometers, one inside pipe drain and the other in the soil at the edge of trench in which pipe drain is placed inside. Several researches have evaluated the performance of subsurface drainage materials depending on the basis of studying the entrance resistance.

This experiment was conducted using aquifer tank model, according to **Luthin and Haig ,1972.[10]** and **Gratn-Lennoz ,1989. [11]**, and by using plastic tank with the dimensions of (60 cm width, 50 cm length and 80 cm height) to execute laboratory work as shown in Fig. (1).

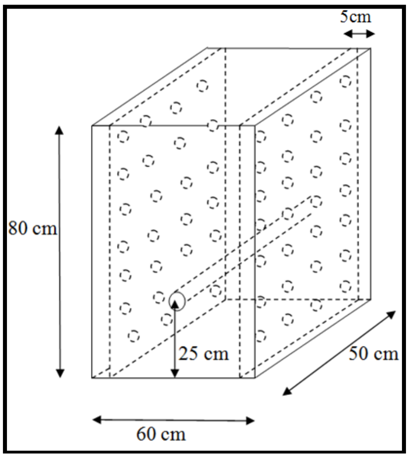



**Figure (1):** The dimension of sand tank model with 5 cm drain pipe.

## 2-Methodology

A pipe drain (polyvinylchloride (PVC) pipe) with (50mm) inner diameter was installed in the middle of the tank, and piezometers A,B,C were installed to measure the entrance resistance (variation of head) as shown in Fig.(2). All the steps of laboratory work were explained with details in the research "Evaluation of Textile Filter in Field Drains" IE-223.

**Figure (2):** The location of piezometer to measure entrance resistance.

## 3-Statistical Analysis

The tool used to compare between filters and to evaluate the textile filter, is the statistical analysis. This analysis is also used to suggest which one of the filters is more suitable for each type of soil. The statistical analysis includes many subjects as the regression analysis which was used to describe the relationship between two values, or more than two values, **Spiegel, 1998 [12]**. This principle of regression analysis was applied to show the trend and the behavior of entrance resistance as function discharge amount. Fig. (3) shows this relation with coefficient of determination which varied between 0.913 value for graded crushed gravel filter with loamy soil and a high value of 0.968 for textile filter with sandy soil. Through the results of regression analysis, it can be concluded that the entrance resistance depend on the amount of supplied discharge and this relation is directly correlated and the best relationship is of the case of textile filter with sandy soil which gives the highest value of coefficient determination which equals 0.968.

The other statistical analysis measurements that were used to measure the goodness fit between estimated values (theoretical values), and measured values are the root mean square error (RMSE) and degree of agreement index (d) **Bakhtiri, et al, 2011 [13].**

The root mean square of error (RMSE) can be calculated as follows:

$$RMSE=\sqrt{\frac{\int_{i=1}^{n}(Co_i-O_i)^2}{n}} \qquad (3)$$

where:

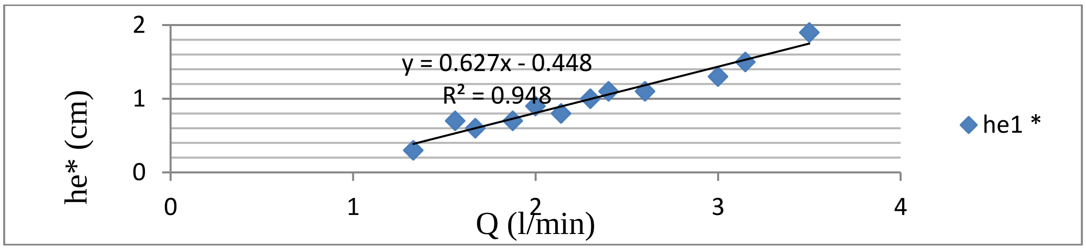
$n$ = number of data,

$Co_i$ = computed entrance resistance (theoretical values), (cm), and

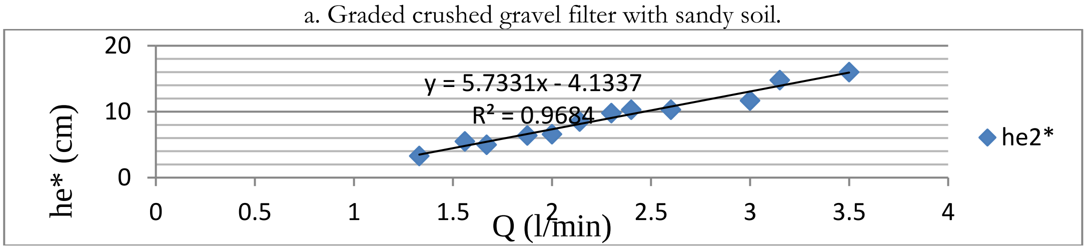
$O_i$= measured value of entrance resistance (cm).

After measuring drain discharge and calculated the hydraulic conductivity for filters, the values of entrance resistance can be estimated using equation (2)**,** knowing that the resistance coefficient (∝) equal to 0.4 for plastic pipe **ILRI, 1979.[9].** The measurement values of entrance resistance can be measured by using the three piezometers readings located approach to outlet of drain (A, B, C) in sand tank model as shown in Fig. (4). Table (3) shows the values of computed entrance resistance and the measurement values for different discharges.

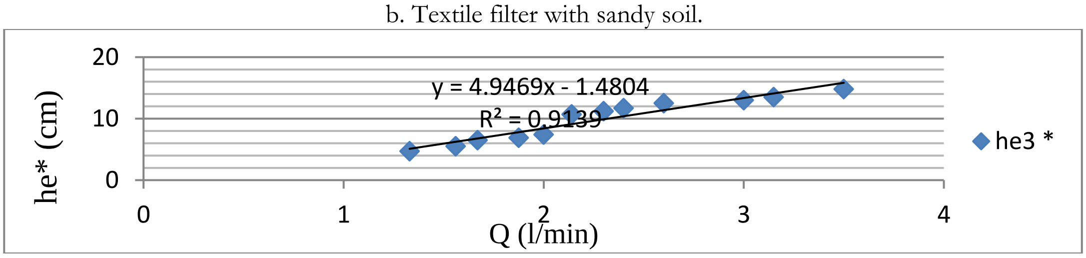
The hydraulic head data for piezometers (A, B, C) when supplying water from surface of sand tank (first stage) and when supplying water from side (second stage) for two types of filter with using two types of soil, as shown in Table (2).



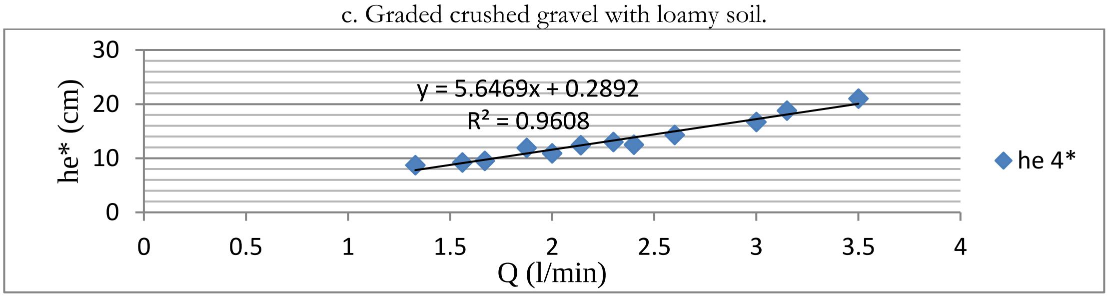

a. Graded crushed gravel filter with sandy soil.




b. Textile filter with sandy soil.




c. Graded crushed gravel with loamy soil.




d. Textile filter with loamy soil.

**Figure (3):** The relation between measured discharge and measured entrance resistance for the four cases.

The other statistical tool (measurement) to measure the agreement between the estimated value of entrance resistance and the measured values is the index of agreement (d) which is a measurement of relative measure of the difference among variables, and defined as:

$$d=1-\frac{\sum_{i=1}^{n}(Co_i-O_i)^2}{\sum_{i=1}^{n}[(Co_i-O_{i_{av}})-(O_i-O_{i_{av}})]^2} \qquad (4)$$

where:

$n$ = number of data,
$Co_i$ = estimated value of entrance resistance, (cm)
$O_i$ =measured value of entrance resistance, (cm) and
$O_{i_{av}}$= measured mean value of entrance resistance (cm).

**Table (1):** All the results of goodness fit, regression equation with coefficient of determination ($R^2$), root mean square error (RMSE), and index of agreement (d) for the four cases of research.

| Test | Equation | $R^2$ | RMSE (cm) | d |
|---|---|---|---|---|
| Case No.1 (crushed gravel filter with sandy soil) | y=1.622x-0.451 | 0.948 | 0.207 | 0.54 |
| Case No.2 ( textile filter with sandy soil) | y=1.52x-4.165 | 0.969 | 1.46 | 0.496 |
| Case N0.3(crushed gravel with loamy soil) | y=3.43x-11.65 | 0.758 | 4.44 | 0.127 |
| Case No.4(textile filter with loamy soil) | y=0.948x-1.984 | 0.834 | 3.19 | 0.1 |

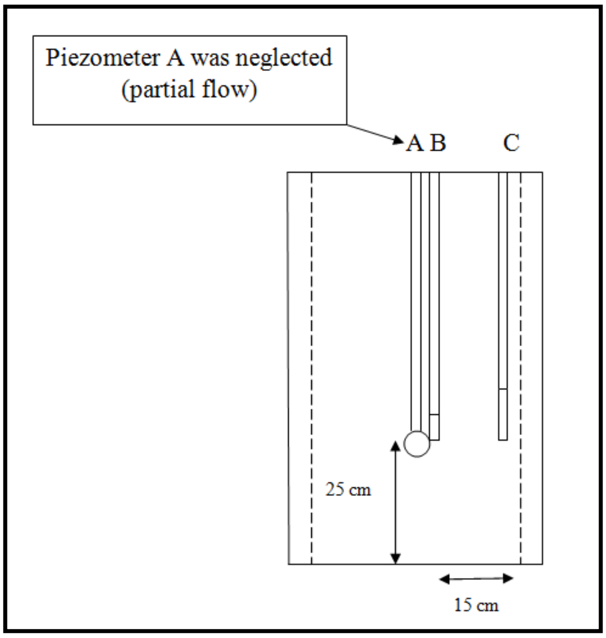



**Figure (4):** The location of piezometers to measure the entrance resistance.

**Table (2):** The piezometers reading that install at outlet of drain for the four cases of study.

| | Case.no.1 | | Case.no.2 | | Case.no.3 | | Case.no.4 | |
|---|---|---|---|---|---|---|---|---|
| Time (day) | B (cm) | C (cm) | B (cm) | C (cm) | B (cm) | C (cm) | B (cm) | C (cm) |
| 1 | 1.5 | 4.3 | 9 | 30 | 14.5 | 32.4 | 15.8 | 44 |
| 2 | 1.5 | 4.3 | 9 | 30 | 14.5 | 32.4 | 15.8 | 44 |
| 3 | 1.9 | 5.5 | 14 | 35 | 15.2 | 32.7 | 15.8 | 44 |
| 4 | 2.4 | 6.1 | 16.2 | 36.9 | 20 | 33.2 | 28.7 | 47.3 |
| 5 | 2.5 | 6.4 | 16.5 | 37 | 20.7 | 33.5 | 30 | 48.5 |
| 6 | 2.6 | 7.3 | 18 | 37.4 | 20.7 | 33.5 | 30.4 | 48.8 |
| 7 | 3 | 7.5 | 18.2 | 37.4 | 21 | 35.6 | 31 | 49.2 |
| 8 | 3.1 | 7.8 | 18.2 | 37.4 | 21 | 35.6 | 32.3 | 50.1 |
| 9 | 3.1 | 10.3 | 18.2 | 37.4 | 21 | 35.6 | 32.3 | 50.2 |
| 10 | 3.1 | 10.3 | 18.2 | 37.4 | 21 | 35.6 | 32.3 | 50.2 |

B & C present readings for two piezometers installed at outlet of drain (reading with time).

**Table (3):** The results of measured and calculated of entrance resistance for four cases studies.

| Supplying discharge for each case Q (l/min) | Case.no.1 Graded crushed gravel with sandy soil | | Case.no.2 Textile filter with sandy soil | | Case.no.3 Graded crushed gravel with loamy soil | | Case.no.4 Textile filter with loamy soil | |
|---|---|---|---|---|---|---|---|---|
| | he * (cm) | he• (cm) | he* (cm) | he• (cm) | he * (cm) | he• (cm) | he * (cm) | he • (cm) |
| 3 | 1.3 | 1.16 | 11.7 | 11.33 | 13 | 7.5 | 16.7 | 20.29 |
| 2.6 | 1.1 | 1.01 | 10.3 | 9.82 | 12.5 | 6.2 | 14.3 | 20.23 |
| 2.3 | 1 | 0.89 | 9.8 | 8.69 | 11.2 | 6.11 | 13 | 16.43 |
| 2.14 | 0.8 | 0.83 | 8.5 | 8.08 | 10.7 | 6 | 12.4 | 15.71 |
| 1.875 | 0.7 | 0.73 | 6.4 | 7.08 | 6.9 | 5.9 | 11.9 | 12.86 |
| 1.67 | 0.6 | 0.65 | 5 | 6.31 | 6.5 | 5.7 | 9.5 | 11.86 |
| 3.5 | 1.9 | 1.36 | 16 | 13.22 | 14.8 | 7.79 | 21 | 20.86 |
| 3.15 | 1.5 | 1.22 | 14.8 | 11.9 | 13.5 | 7.6 | 18.8 | 20.5 |
| 2.4 | 1.1 | 0.93 | 10.3 | 9.07 | 11.7 | 6.11 | 12.5 | 16.43 |
| 2 | 0.9 | 0.78 | 6.6 | 7.55 | 7.4 | 5.9 | 10.9 | 14.86 |
| 1.56 | 0.7 | 0.6 | 5.5 | 5.94 | 5.5 | 5.36 | 9.2 | 11.57 |
| 1.33 | 0.3 | 0.52 | 3.3 | 5.02 | 4.7 | 5.1 | 8.7 | 11.14 |

* Measured value.
• Estimated value using Eq. (1) (using resistance coefficient (α) value of 0.4 for plastic pipe drain, FAO-2005)

## 4-Results and Discussion

The results of regression analysis which presents the variation of entrance resistance due to variation of discharges show that there is a direct relation between the two parameters for the four cases of study. There are high coefficients of determination equal to 0.913 for graded crushed gravel with loamy soil and 0.968 for the case of textile filter with sand soil. For the case of graded crushed gravel filter with sandy soil where (d= 0.54) and (RMSE = 0.207), which is the lowest value, while the textile filter with sandy soil was the RMSE=1.46 cm, and (d= 0.496). Graded crushed gravel with loamy soil gave a higher value of root mean square error (RMSE= 4.44 cm) with low agreement index equal to (0.127). The lowest value of (d) is for the case of textile filter with loamy soil. Table (1) presents all the results of statistical analysis. To show the trend (behavior) between estimated (computed) and measured value, Fig.(5) shows these trends for all cases of study with coefficient of determination varied between (0.758) for graded crushed gravel filter with loamy soil, and (0.969) for the cases textile filter with sandy soil.

## 5-Conclusions

One of the important parameters that affects the field drains efficiency is the entrance resistance. The entrance resistance is a function of many parameters, one of these parameters is the discharge which was affected directly with its amount. The result of the statistical analysis also gives a decision that the textile filters performance plays approximately the same role as the crushed gravel filter in light soil (sandy soil), and the estimated values (computed value) is nearer to measured values for two types of filters. The difference in percentage between the performances of the two filters is about 8.2% in sandy soil and 21% at loamy soil. This high difference between the two filter when using heavy soil (loamy soil), due to the settling of fine soil particles at the voids of the filter which decreases the permeability of the filter especially for textile filter. It can be concluded as well that, due to the statistical analysis, the graded crushed gravel filter is desirable and suitable when used in sandy soil because the root mean square error is at a low value and the coefficient of agreement (d) is at the highest value compared with other cases. This means that the measured values of entrance resistance were approximately correspondent to the estimated values (computed values) with high confidence. So, we can predicate that the actual values of entrance resistance at the field will be at low values for the two types of filters when used in sandy soil, and for different discharges as well.

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## Nomenclature

Co =Computed entrance resistance, (cm).
d =index of agreement, (dimensionless).
h = Hydraulic head,(m).
$h_T$ = Total head losses due to different resistances,(m).
$h_v$ = The head losses due to vertical flow,(m)
$h_h$ = The head losses due to horizontal flow,(m).
$h_e$ = Entrance resistance ,(m).
$O_{iav}$ = Mean of measured value of entrance,(cm).
q = Drain discharge into unit length of drain per unit time,($m^3$/m.day).
RMSE = Root mean square error ,(cm).
n = Number of data .
α =Resistance coefficient, dimensionless.
$K_F$ = Hydraulic conductivity, of the envelope drain ,(m/day).
$O_i$= Measured value of entrance resistance ,(cm).