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GEOTEXTILE AND GEOMEMBRANE USAGE IN AN IRAQI SANDY GEOENVIRONMENT

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ABSTRACT

The work in this research presents an experimental and a theoretical study to obtain the effect of using a low permeability geosynthetic material on the longitudinal and lateral coefficients of dispersion. This would have its effect on the contaminants migration through an isotropic, homogenous and saturated soil. The first stage of this research involves the study of the geosynthetic material and in calculating the longitudinal and lateral coefficients of dispersion for an Iraqi sandy soil by using an experimental set-up to simulate the processes. To investigate the effect of using a geosynethtic material on the dispersion coefficients, the test was conducted for each velocity that was used in the experimental work and as follows:

- without using the geosynethtic material first, and
- by using the geosynthetic material as a base and a cover for the soil sample.

The second stage of this research is interested in developing a numerical model able to simulate the contaminants dispersion phenomenon. To solve the two-dimensional advection-dispersion equation, a numerical model was derived using the finite element method. This numerical model was verified by comparing it with the analytical solution of one-dimensional dispersion. To study the effect of using a geosynethtic material on the contaminants dispersion through soil, a proposed field problem is tested.

الخلاصة

يتضمن هذا البحث دراسة عملية ونظرية لتأثير استخدام مواد صناعية ذات نفاذية واطئة على معامل التشتت بالاتجاه الطولي والعرضي وبالتالي تأثيرها على أرتحال الملوثات خلال ترب موحدة الخواص, متجانسة ومشبعة. تهتم المرحلة الاولى من البحث بدراسة المواد الصناعية و حساب معامل التشتت الطولي ومعامل التشتت العرضي لتربة رملية عراقية عن طريق أستخدام جهاز لتمثيل التشتت الطولي والعرضي بأتجاه واحد ولمعرفة مدى تأثير أستخدام المواد الصناعية على معامل الانتشار فقد تم أجراء التجارب بصورة مكررة لكل سرعة من السرع المستخدمة في الفحص العملي وكالاتي: –

- بدون أسخدام المادة الصناعية.
- وباستخدام المادة الصناعية كقاعدة وغطاء لنموذج التربة .

وتهتم المرحلة الثانية من البحث بتطوير نموذج عددي قادر على حل ظاهرة التشتت للملوثات. وقد تم أستخدام نموذج عددي لحل معادلة التشتت الحملي الثنائية الابعاد بأستخدام طريقة العناصر المحددة وقد جرى التحقق من صحة النموذج من خلال أجراء مقارنة مع الحل النظري التحليلي الاحادي التشتت. هذا وتم فحص مسألة حقلية مفترضة وذلك لغرض دراسة تأثير وجود المادة الصناعية على انتشار الملوثات داخل التربة.

INTRODUCTION

Geotechnical engineering is by now becomes more involved with problems of pollutant migration through soil. This involvement arises from the concern regarding the contamination of soil and the groundwater system which restrict or prevent them from use in the various applications where they normally play a part in(16). The leachate from landfills or industrial waste disposal represents the main problem of soil and groundwater system contamination. Many regulatory authorities now require the use of liners to control pollutants migration and this often involves separating the landfill from the nearby area by using a low permeability material such as a compacted clay liner (CCL) or a geosynthetic material (GCLS)(17).

Geosynthetic Material

In general, geosynthetics are fabric like materials made from polymers. Geotextiles and geomembranes are two types of these materials which include also other types. Each type of geosynthetics performs one or more of the following four major functions(7) (6) (13):

* **Separation**:-

as a separation layer. Geosynthetics are used to prevent adjacent soil layers or fill materials from intermixing. The main use of this function is for road and railway constructions, and hydraulic and landfill engineering, Fig. 1(7) (14).

* **Filtration:-**

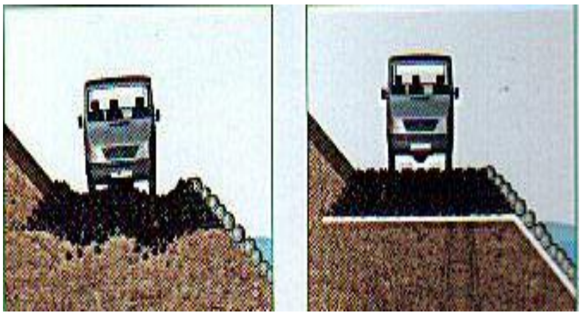
as a filter. When placed in contact with soil, they allow water to pass through while prevent the passage of fine soil particles. Their main uses are as hydraulic engineering materials and drainage systems, Fig. 2 (7).

* **Drainage:-**

as drainage materials where they collect liquids or gases and convey them towards a collection point or an outlet point, Fig. 3 (7).

4- **Reinforcement:-**

Geosynthetics are installed beneath or between soil layers to improve its mechanical properties, by increasing the bearing capacity of the soil and minimizing the deformation, Fig. 4 (7) (14).



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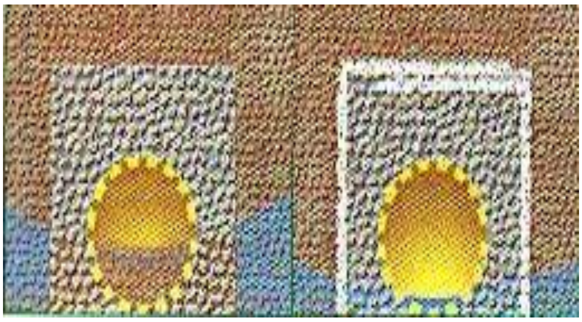

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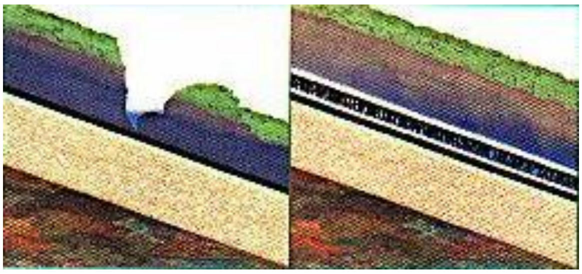

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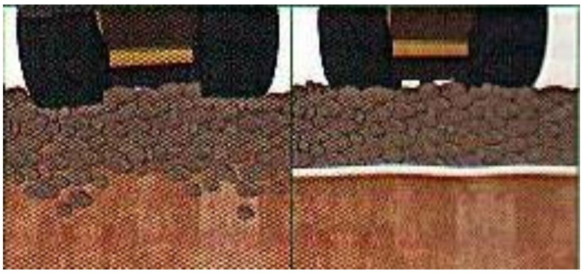


(4)

Figs. (1, 2, 3 and 4) Geosynthetic material applications[7] [14].

<u>Types of Geosynthetic Materials</u>

A- **Geotextile**: -

Defined as permeable fabrics, which act compositely with soils and rocks. They are products of textile industries. There are two main types of geotextiles which are made mainly from four types of synthetic polymers (polyamide, polyester, polyethylene and polypropylene), woven and non- woven geotextiles [7] [6].

B- **Geomembranes: -**

Defined as impermeable liquid barriers made primarily from continuous polymeric sheets that are flexible. Geomembrane types may be classified, according to the type of polymeric material made from, as thermoplastic and thermoset [6].

<u>Geosynthetics in Landfill Engineering</u>

In landfill engineering, geosynthetic materials are used in**: -**

1- basal linings, and

2- caps or covers[14].

Basal Linings:-

The main objective of a base lining is to prevent the escape of contaminants from landfill waste into underlying soils. Properly constructed liner systems should also allow for the controlled collection and removal of landfill leachate for subsequent treatments, Fig. 5 [14].

Types of Geosynthetic Materials Used in Landfill Base Lining:-

1- **Bentofix: -** is a needle- punched reinforced geosynthetic clay liner (GCL) that uses two geotextile layers to encapsulate a layer of natural sodium bentonite. The needle- punched fibers transmit shear forces through the bentonite core. It is used as a sealing barrier against liquid and gases in various civil and environmental applications [12].

2- **Carbofol: -** is a geomembrane made from high density polyethylene used to protect and seal the subsoil from the release of potential contaminants [13].
3- **Secutex: -** is a needle-punched staple fiber nonwoven geotextile used for separation, filtration, protection and drainage. It is used in many civil engineering applications such as hydraulic engineering, landfill engineering and road construction [14].

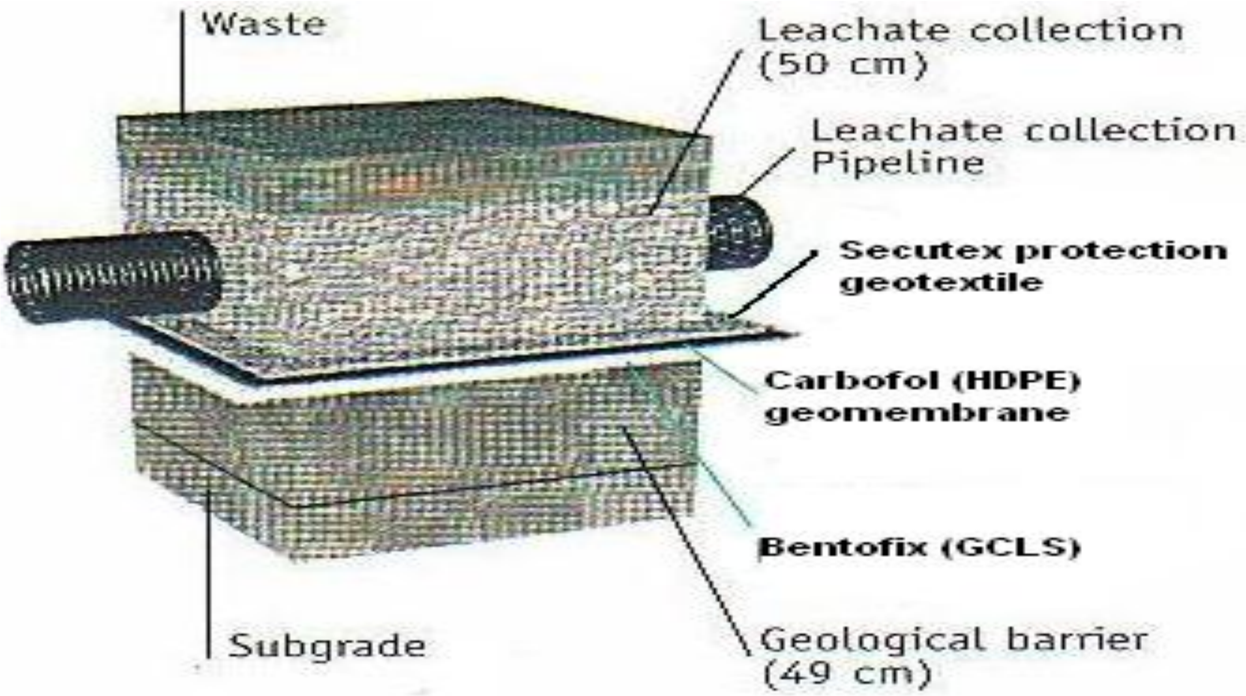


Fig. (5) Basal linings [14].

Landfill Capping (Covering)

The main objective of a cap or cover in landfill engineering is to prevent the intrusion of precipitation into the waste and this will reduce and ultimately stop leachate generation, Fig. 6 [6].

Types of Geosynthetic Materials Used in Landfill Capping:-

In addition to Bentofix and Carbofol which are used in landfill basal lining, landfill capping includes also:

Secudran: - is a three- dimensional drainage system designed to discharge liquids and gases. The secudran geosynthetic drainage system consists of three individual layers made up of the following components [14]:-

1- a filter which protects the drainage layer from clogging,
2- a drainage layer which transmits the water in the filter level, and
3- a filter/protection which serves as a filter or a separation layer to the mineral component or the protection layer for the geomembrane (HDPE).

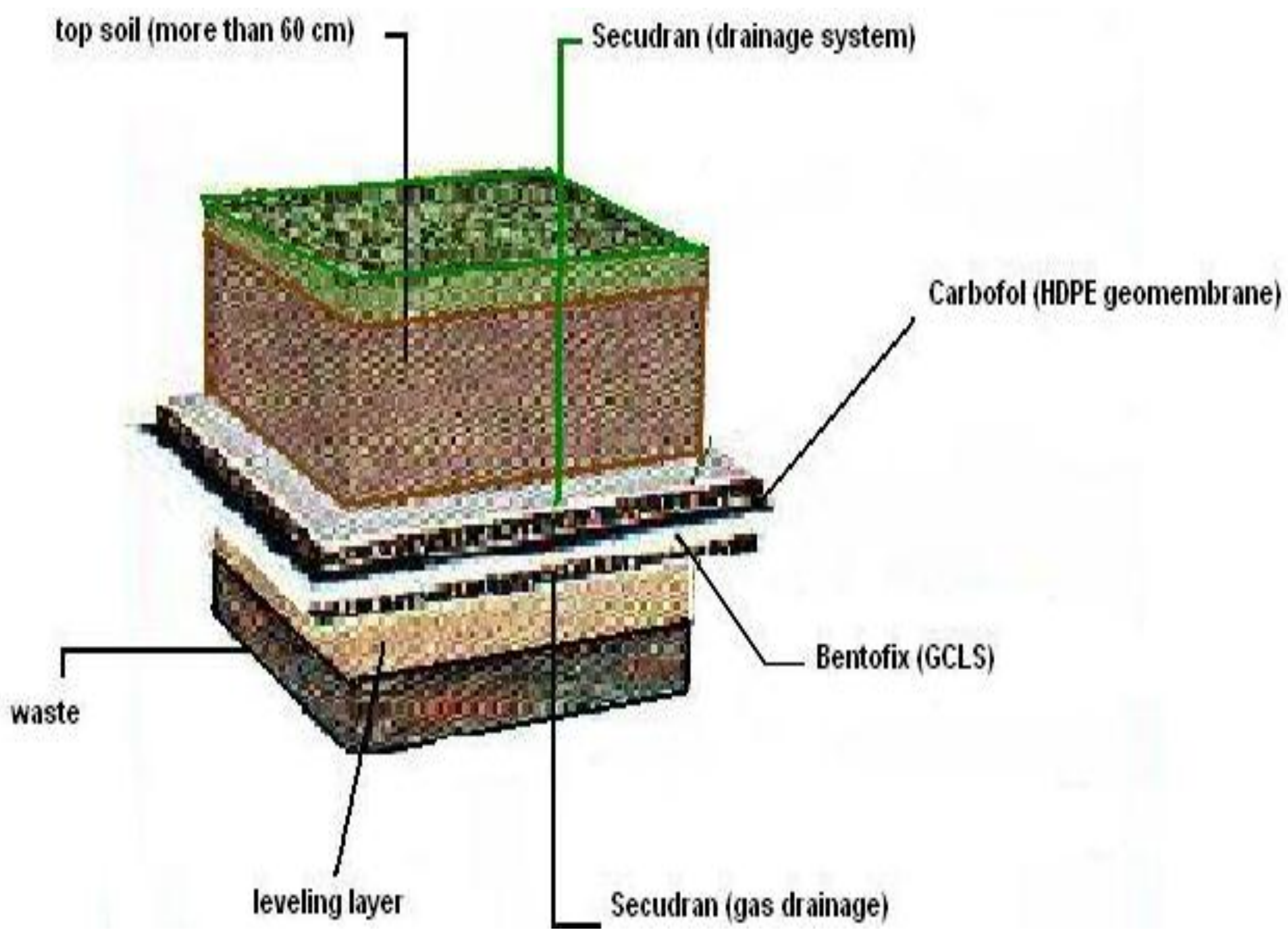


Fig. (6) Landfill capping [14].

***TRANSPORT THROUGH POROUS MEDIA**

One of the earliest observations of the phenomena of transport and dispersion in porous media is reported by Slichter in 1905 [3] [4]. The transport of contaminants or pollutants through porous media is mainly attributed to the advection-dispersion process [4] [9] [20].

Advection Process:-

The transport at the same velocity as groundwater of dissolved solids is called advective transport [20].

Dispersion Process:-

Dispersion refers to mixing and spreading caused in part by molecular diffusion and in part by variations in velocity (mechanical dispersion) within the porous media [20].

Molecular Diffusion:-

is a physical process which depends upon the kinetic properties of the fluid molecules and causes mixing at a contact front between two fluids [5].

Mechanical Dispersion:-

is caused by the difference in velocity of flow inside the porous media [10]. The amount of mechanical dispersion occurring in porous media depends on the physical properties of the soil (size and shape of the pores) and the absolute magnitude of the average linear velocity in porous media [5].

*** MATHEMATICAL MODEL**

The advection-dispersion equation for one dimensional flow, one dimensional dispersion through homogenous, isotropic porous media and steady flow is [5] [18] [11]:-

$$D_L \frac{\partial^2 C}{\partial x^2} - u \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \qquad (1)$$

where:-
C = concentration of contaminant at any time (t) at any distance (x),
D_L = longitudinal coefficient of dispersion (L2/T), and
u = pore or average liner velocity (L/T).
The analytical solution of the governing differential equation under conditions:-
C(x, 0) =0
C (0, t) =Co
C (∞, t) =0
is given by [20] [10]: -

$$2\frac{C}{C_O} = \left[erfc(\frac{x - u.t}{2(D_L t)^{\frac{1}{2}}}) + \exp(\frac{ux}{L}) erfc(\frac{x + u.t}{2(D_L t)^{\frac{1}{2}}}) \right] \qquad (2)$$

The second term is very small compared to the first one and may be neglected; thus:

$$2\frac{C}{C_O} = erfc\left[\frac{((\frac{x}{ut}) - 1)}{2(\frac{D_L}{tu^2})^{\frac{1}{2}}} \right] \qquad (3)$$

where:-
C_O: initial contaminant concentration (mg/l),
x: distance traveled by the contaminant in the direction of flow (L),
t: time.
By using the “inverfc”, eq. (3) can be converted into [2]:-

$$\frac{D_L}{tu^2} = M((\frac{x}{ut}) - 1)^2 \qquad (4)$$

where:-

$$M = 0.25 \left[inverfc(\frac{2C}{C_O}) \right]^{-2} \qquad (5)$$

A similar procedure is applied to the steady state transverse dispersion equation [10]:-

$$u \frac{\partial C}{\partial x} = D_T \frac{\partial^2 C}{\partial y^2} \qquad (6)$$

An analytical solution of the governing differential equation under conditions:-

$\frac{\partial c}{\partial y} = 0$ for y= $\pm\infty$

C (y, 0) =Co for 0<y<+∞

C (y, 0) =0 for -∞<y<0

is obtained [10]:-

$$2\frac{C}{C_O}=\left[1+erf\left(\frac{y}{2\left(\frac{D_T x}{u}\right)^{\frac{1}{2}}}\right)\right] \quad (7)$$

where:-

y: distance traveled by the contaminant in the perpendicular direction of flow (L), and

D_T: transverse coefficient of dispersion (L^2/T).

By using the "inverfc", eq. (7) can be converted into [2]:-

$$D_T = M\left(\frac{y}{\left(\frac{\sqrt{x}}{u}\right)}\right) \quad (8)$$

*** EXPERIMENTAL SIMULATION SET-UP**

The schematic diagram depicted in Fig. 7 shows the experimental apparatus constructed by the authors which was used in the measurement of the distribution of a dilute, salt water tracer. To describe the testing equipment used in the experimental work, the following points are set:-

1. The porous medium box has outer dimensions of (10.5×31×40) cm. It is constructed out of glass sheets of 6 mm thick where the removable upper cover was constructed of Perspex glass of 4 mm thick in order to give flexibility which is required for the tie closer to prevent any leakage. These sheets are supported by a steel frame.
2. Two- galvanized steel tanks of (0.3×0.3×0.3) m, one as a storage tank and the other as a supply constant head tank. The two tanks are connected together by a flexible plastic tube. The amount of salt-water tracer (solution) discharge from the first tank to the second tank is controlled by a tap.
3. Floating equipment are used in order to control the head of the solution in the supply constant head tank.
4. The supply constant head tank provides the porous medium (soil sample) with salt-water tracer (solution) by a flexible plastic tube. A valve is installed at the inlet line to aid in controlling flow into the box.
5. The outlet tube.

Salt-Water Tracer

A solution of tap water and sodium chloride with an initial concentration of 1000 mg/l is used in order to determine the dispersion characteristics of the porous medium. This tracer has been widely used by many investigators [5] [8] [1] due to:-

- safety,
- cheapness and availability, and
- for not being affected by the liquid's density and viscosity.

Concentration measurement is done by using a Total Dissolved Solids (**TDS**) meter, which is a digital device that measures the concentration variations as (mg/L).

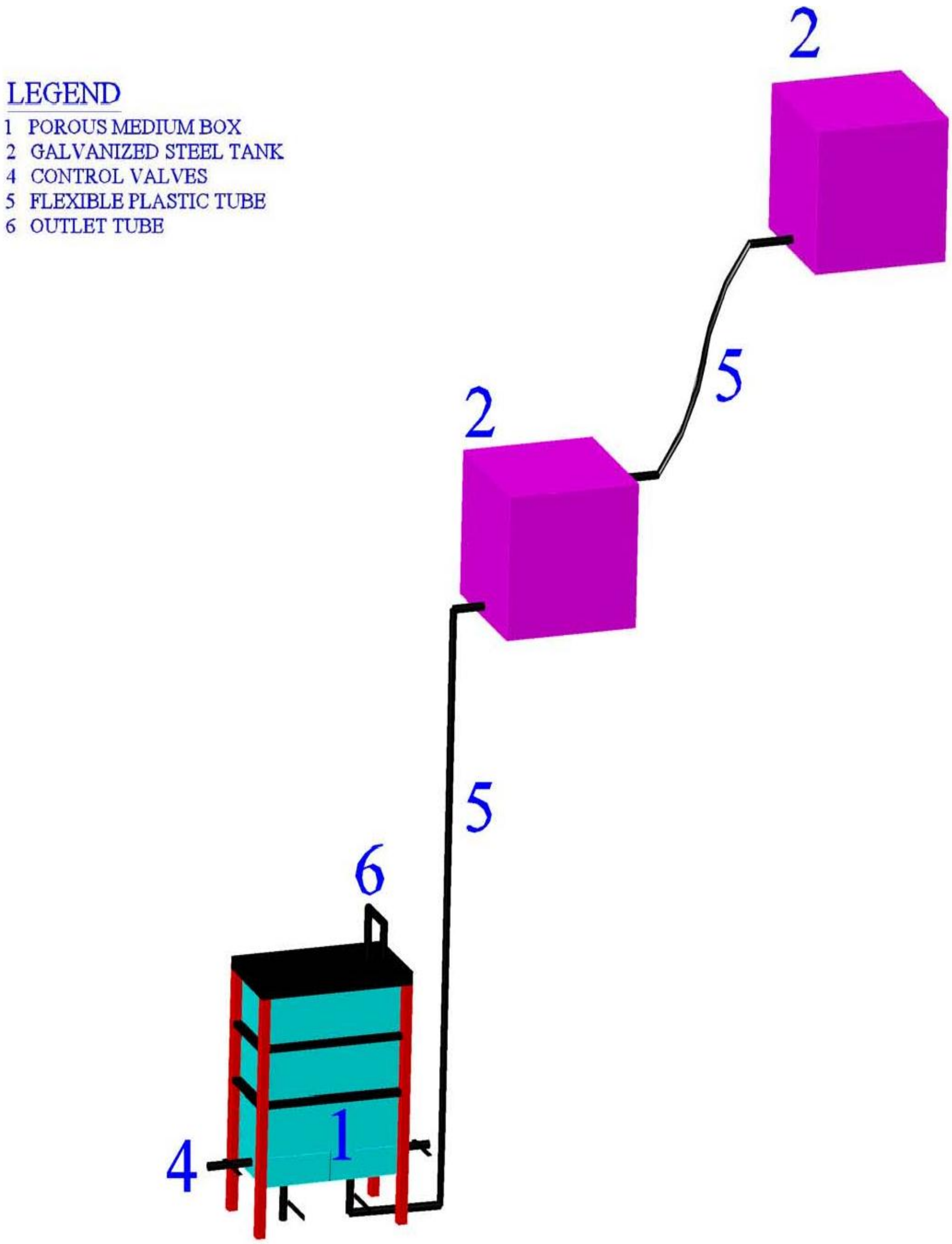


Fig. (7) Schematic diagram of the apparatus for the determination of the longitudinal and lateral dispersion coefficients

Soil Sample and Geotextile Material

Soil Sample

An Iraqi sandy soil is used in the experimental work in order to investigate its dispersion characteristics. The particle size distribution was determined by mechanical sieve analysis. The uniformity coefficient for the tested soil is equal to 2.69. The discharge velocity may be determined by measuring the coefficient of permeability of the soil. A constant head test is used to determine the coefficient of permeability, because constant heads are more suitable for coarse-grained soils that have high coefficients of permeability [14]. The discharge velocity can be calculated as [9]: -

$$v = k \times i \qquad (9)$$

where:-
v: discharge velocity,
k: coefficient of permeability, and
i: hydraulic gradient.

Geotextile Material

The type of geotextile material used in this experimental work is Bentofix (GCLS). Fig. (8) shows photos of the Bentofix material.

Fig. (8) Photos of the Bentofix material

Experimental Work Procedures

This section presents the procedure used in order to obtain the data necessary for the evaluation of the longitudinal and lateral dispersion coefficients for various discharge velocities. This procedure includes:-

1. Preparing an amount of the solution which is used in the experimental work as cited in section (4-1).
2. At first, the soil sample in the test section is saturated with tap water.
3. The valve controlling the flow into the box is opened at a time equal to zero. A sharp interface is created between the salt-water tracer and the tap water. Then, this interface will advect and disperse through the soil sample.
4. The solution from the outlet tube is collected with constant time steps in order to measure the concentration.
5. The same procedures are adopted twice:-

- First without using the geotextile material (W.O.M), and
- Secondly with the use of the geotextile material (W.M) which lays as a base and cover material for the soil sample inside the porous medium box.

6. The test finishes when the concentration reaches the maximum value (C_O).

The Determination of the Dispersion Coefficients

Basak and Murty [2] used a very simple and direct method for determining (D_L) and (D_T), requiring only one experimental point at any early time. Longitudinal dispersion coefficients are determined from the temporal distributions of the tracer breakthrough curves and according to Equation (4). Figs. (9a), (9b) and (9c) represent the test results without using the geotextile material (w.o.m) while Figs. (10a), (10b) and (10c) show the test results by using the geotextile material (w.m). According to Basak and Murty [2] the lateral dispersion coefficients can be calculated by using Equation (8). Table (1) summarizes the dispersion experimental test results.

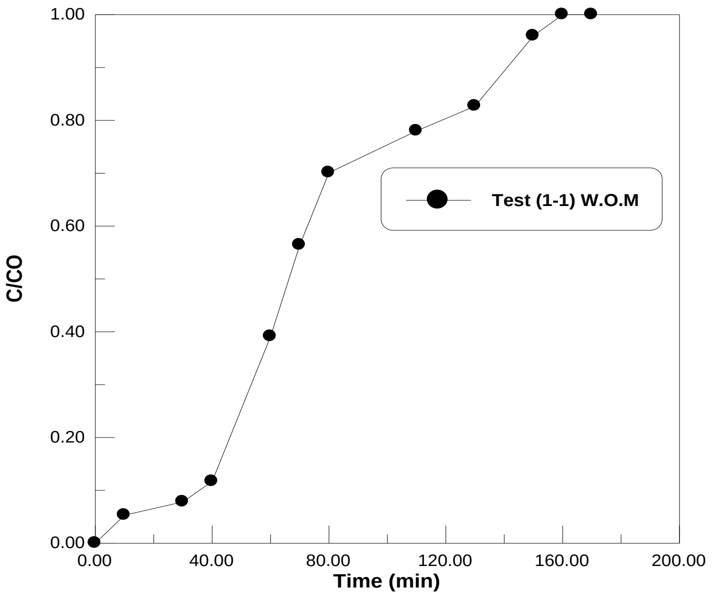
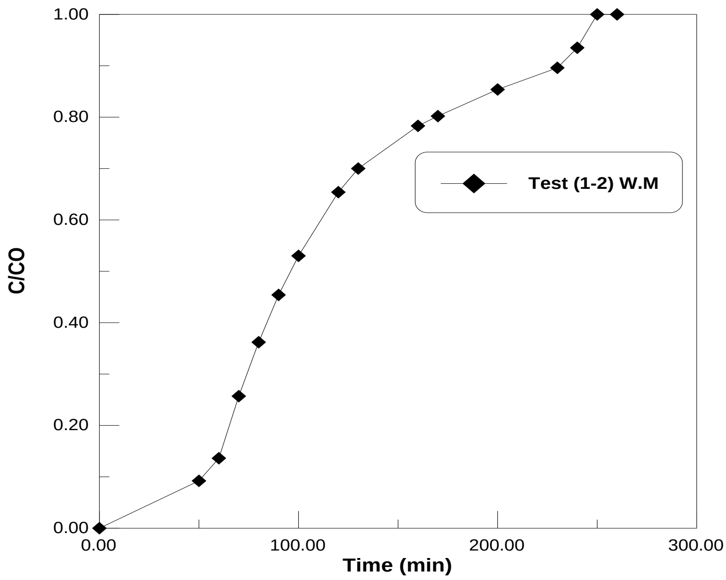


Fig. (9a) longitudinal breakthrough curve for v= 0.584 cm/min.



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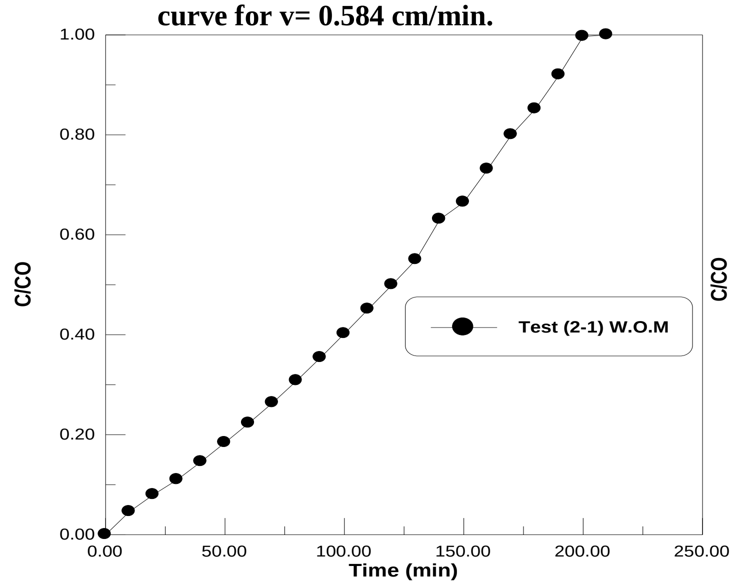


Fig. (9b) longitudinal breakthrough curve for v= 0.70 cm/min.

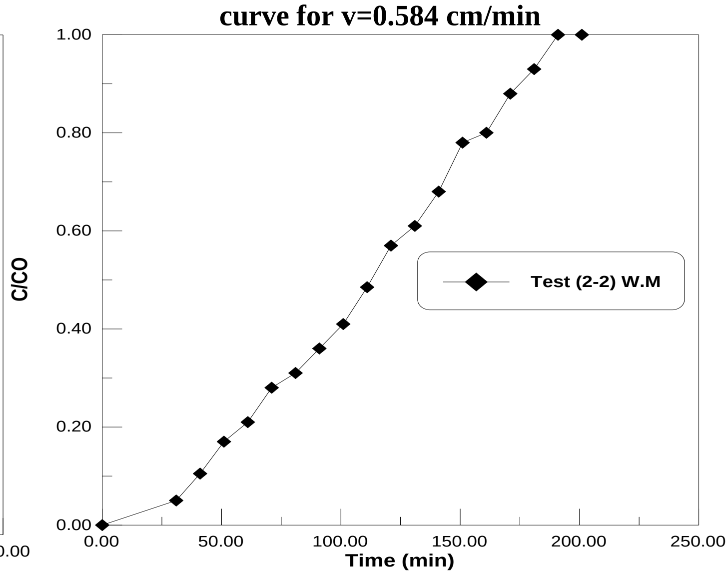


Fig. (10b) longitudinal breakthrough curve for v= 0.70 cm/min.

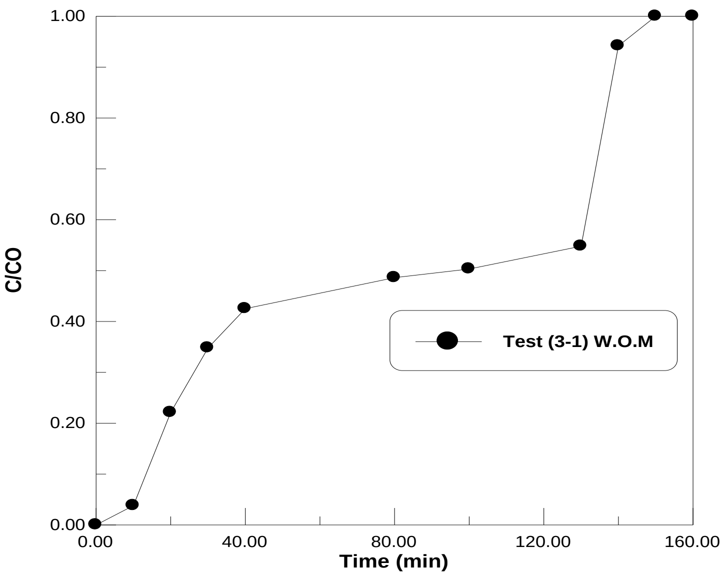


Fig. (9c) longitudinal breakthrough curve for v= 0.852 cm/min.

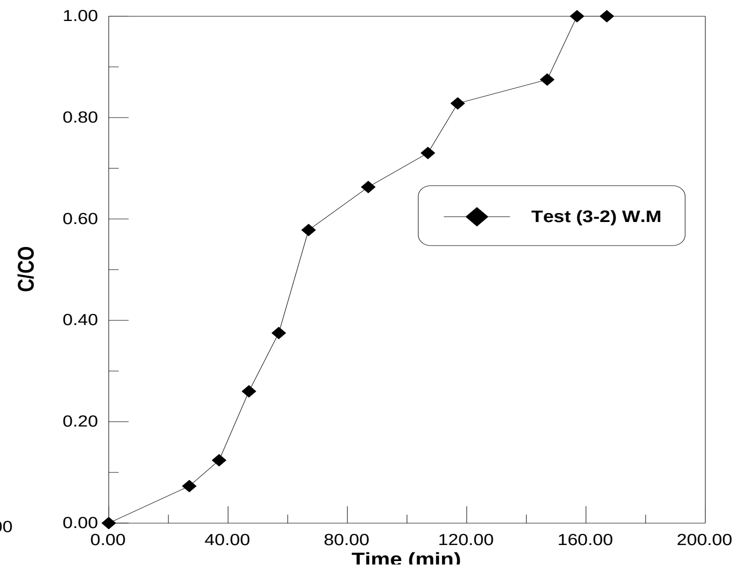


Fig. (10c) longitudinal breakthrough curve for v= 0.852 cm/min.

Table (1) Dispersion experimental test results

Test No.	Type of Test	Discharge velocity (cm/ min)	Time when C/CO =0.1 (min)	D_L Cm^2/min	D_T Cm^2/ min
1	W.O.M	0.548	36	0.892	0.304
	W.M		53.3	0.004	0.304
2	W.O.M	0.70	28.3	1.12	0.5
	W.M		41	0.015	0.5
3	W.O.M	0.852	14.74	6.283	0.74
	W.M		32.8	0.04	0.74

* FINITE ELEMENT SOLUTION OF THE ADVECTION-DISPERSION EQUATION

The following finite element discretization of the differential equation depends on the previous work of Wang and Anderson [20]. The advection-dispersion equation for one dimensional flow and two dimensional dispersion is written as:

$$D_L \frac{\partial^2 C}{\partial x^2} + D_T \frac{\partial^2 C}{\partial y^2} - v_x \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \qquad (10)$$

Assuming a trial function of the form which shows that the trial solution (function) within an element is an interpolation of the nodal values [20] [22]:

$$C \approx \hat{C}_e = \sum_{L=1}^{L=NNODE} C_L(t) N_L(x,y) \qquad (11)$$

where: -

^ = indicates summation,

e = element,

N_L^e = nodal basis (shape) functions, and

L= 1, 2…, NNODE, where the latter is the total number of nodes per element.

Applying the weighted residual method with Galerkin's method to equation (10) yields into the following functional [20] : -

$$\iint_D \left(D_L \frac{\partial^2 \hat{C}}{\partial X^2} + D_T \frac{\partial^2 \hat{C}}{\partial Y^2} - v_x \frac{\partial \hat{C}}{\partial X} - \frac{\partial \hat{C}}{\partial t}\right) N_L(x,y) d_x d_y = 0 \qquad (12)$$

The second spatial derivative terms are integrated by parts and the integration over the problem domain is done element by element [20] : -

$$\sum_e \left\{ \iint_e \left(D_L \frac{\partial \hat{C}_e}{\partial X}\frac{\partial N_L}{\partial X} + D_T \frac{\partial \hat{C}_e}{\partial Y}\frac{\partial N_L}{\partial Y} + \bar{\upsilon}_x \frac{\partial \hat{C}_e}{\partial X} N_L + \frac{\partial \hat{C}_e}{\partial t} N_L\right) dxdy \right\} = \int_\Gamma \left(D_L \frac{\partial \hat{C}}{\partial X} n_x + D_T \frac{\partial \hat{C}}{\partial Y} n_y\right) N_L d\sigma \qquad (13)$$

where: -

Γ = the boundary of the problem domain,

n_x, n_y = the components of a unit vector normal to the boundary, and

σ = the integration variable representing distance along the boundary in counterclockwise sense.

The system of equations represented by eq. (13) can be written in matrix notation in the form:

$$[G]\{C\} + [U]\{C\} + [P]\left\{\frac{\partial C}{\partial t}\right\} = \{f\} \qquad (14)$$

$\{C\}$= the column matrix of nodal concentration,

$\left\{\frac{\partial C}{\partial t}\right\}$ = the column matrix of the time derivative of nodal concentration,

$[G], [U], [P]$= square coefficient matrices corresponding to individual terms in the integral on the left hand side of eq. (13), and

$\{f\}$= column matrix corresponding to the boundary integral on the right hand side of Equation (5-5).

Where: -

$$G^e{}_{L,1} = \int_{-a}^{a}\int_{-b}^{b} \left(D_L \frac{\partial N_1^e}{\partial X}\frac{\partial N_L^e}{\partial X} + D_T \frac{\partial N_1^e}{\partial Y}\frac{\partial N_L^e}{\partial Y}\right) dxdy \qquad (15)$$

$$P_{L,1}^e = \int_{-a}^{a}\int_{-b}^{b} N_1^e N_L^e dxdy \qquad (16)$$

$$U_{L,1}^e = \bar{\upsilon}_x \int_{-a}^{a}\int_{-b}^{b} \frac{\partial N_1^e}{\partial X} N_L^e dxdy \qquad (17)$$

Solution of the Matrix Differential Equation

Eq.(14) is a first-order matrix differential equation. To solve it, a finite difference approximation is made for the time derivative in matrix notation [20] : -

$$\left\{\frac{\partial C}{\partial t}\right\} = \frac{1}{\Delta t}\left(\{C\}^{t+\Delta t} - \{C\}^{t}\right) \tag{18}$$

where: -

Δt : Length of time step,

$\{C\}^{t+\Delta t}$: Concentration value at the new time, and

$\{C\}^{t}$: Concentration value at the old time.

Now, it has to be kept in mind that: $C_L = C_L(t)$ which is the value of the concentration at node (L) at time (t). Thus, the time derivative approximation at a particular node L is:

$$\frac{\partial C_L}{\partial t} = \frac{(C_L)^{t+\Delta t} - (C_L)^{t}}{\Delta t} \tag{19}$$

where:

$\frac{\partial C_L}{\partial t}$: change in nodal concentration with respect to time.

If {C} is approximated at the new time (t+Δt), then the solution of Equation (14) is said to be fully implicit and is given by: -

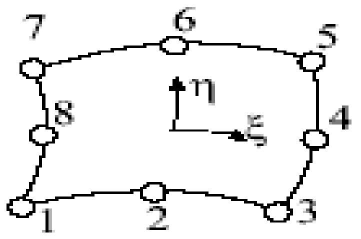
$$[G]\{C\}^{t+\Delta t} + [U]\{C\}^{t+\Delta t} + \frac{1}{\Delta t}[P]\left(\left(\{C\}^{t+\Delta t} - \{C\}^{t}\right)\right) = \{f\} \tag{20}$$

Eq. (20) can be rearranged to have all the concentrations at the old time to be on the right-hand side and all the new time to be on the left-hand side:-

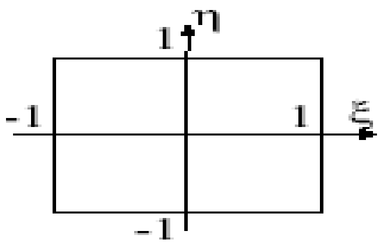
$$\left([G] + [U] + \frac{1}{\Delta t}[P]\right)\{C\}^{t+\Delta t} = \frac{1}{\Delta t}[P]\{C\}^{t} + f \tag{21}$$

The Quadrilateral Element

It is a two-dimensional element known as the multiplex element. The quadrilateral elements with eight-nodes are referred to as the quadratic elements because the interpolation (shape) functions are quadratic along lines of constant ζ or constant η as depicted in Fig.11[19]



(a)



(b)

Fig. (11) (a) Quadratic element
(b) Local coordinate system [15]

*** COMPUTER PROGRAM**

A computer program presented by Wang and Anderson [20] which solves the advection-dispersion equation by using one-dimensional finite elements is extended herein as to include two dimensional multiplex ones. All necessary matrix changes have been done in the program according to Eqs. (19-21). The program has been written in FORTRAN 77 language, and the compiler used is FORTRAN Power Station 04- Microsoft Developer Studio. The program has been modified by the authors in order to carry out the required computations.

Verification Example

The numerical model has been tested to determine its validity. The verification was done by comparing the finite element results with a one-dimensional analytical solution for Eq. 1. The analytical solution for Eq. 1 is presented in Eq. 3. For the verification of the program, input parameters are chosen from the reference of Wang and Anderson [20]. A uniform square element of size of (5×5) m is used to discretize the region. To identify the case solved, the mesh Peclet number is defined as [21]:-

$$Pe = \frac{v_x \times \Delta x}{D_L} \qquad (22)$$

where:-

v_x : discharge velocity, and

Δx : traveled distance.

The Courant number, Cr, which is responsible for the time step evaluation is known as [21] :

$$Cr = \frac{v_x \times \Delta t}{\Delta x} \qquad (23)$$

where:-

Δt : traveled time.

Input data for Eqs. (22) and (23) are [20]:-

- v_x = 0.1 m/day,
- Δx = 5 m,
- D_L = 1.0 m2 /day, and
- Δt = 10.0 days.

The solution results in:-

- $Pe =$ 0.5, and
- $Cr =$ 0.2

Wang and Anderson [20] found that the finite element solution predicts the solute front travel somewhat faster than the analytical solution does. Numerical results are obtained from the developed program and compared with the analytical solution program. Fig. (12) shows this comparison and it can be seen that the developed finite element program results are in agreement with the results obtained by Wang and Anderson [20].

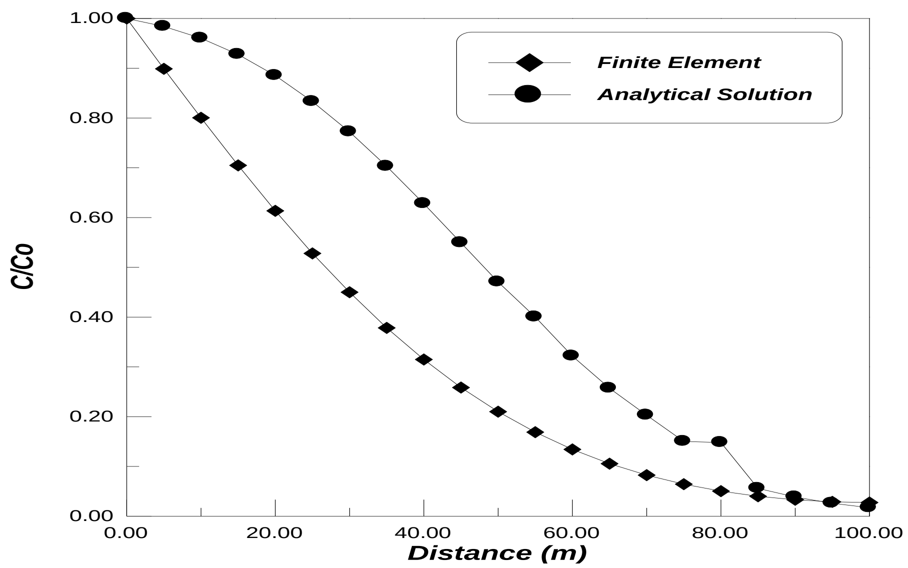


Fig. (12) Comparison curves of the concentration profile at t=400 days, for Pe=0.5

*** FIELD PROBLEM**

A proposed field problem is chosen for the illustration of the effect of using a geosynthetic material on the process of contaminants migration through porous media. Fig. (13) shows the finite element mesh and dimensions of the selected problem. Two types of effects can be obtained when using geosynthetic materials on the process of contaminant's migration. These effects are: -

- The decrease of the longitudinal coefficient of dispersion , and
- The decrease in the volume of solution leachate from the source of pollution according to the low permeability of the geosynthetic material.

According to the effects described above, two field cases are adopted: -

1. without using the geosynthetic material (Fig. 14) : -

velocity= v = 2.5 m/hr. , D_L= 10.0 m^2/hr

D_T = 0.2 m^2/hr , time = 10.0 hr

time interval = Δt = 0.5 hr , initial concentration= C_O= 20000 mg/l

2. with the use of the geosynthetic material (Fig. 15): -

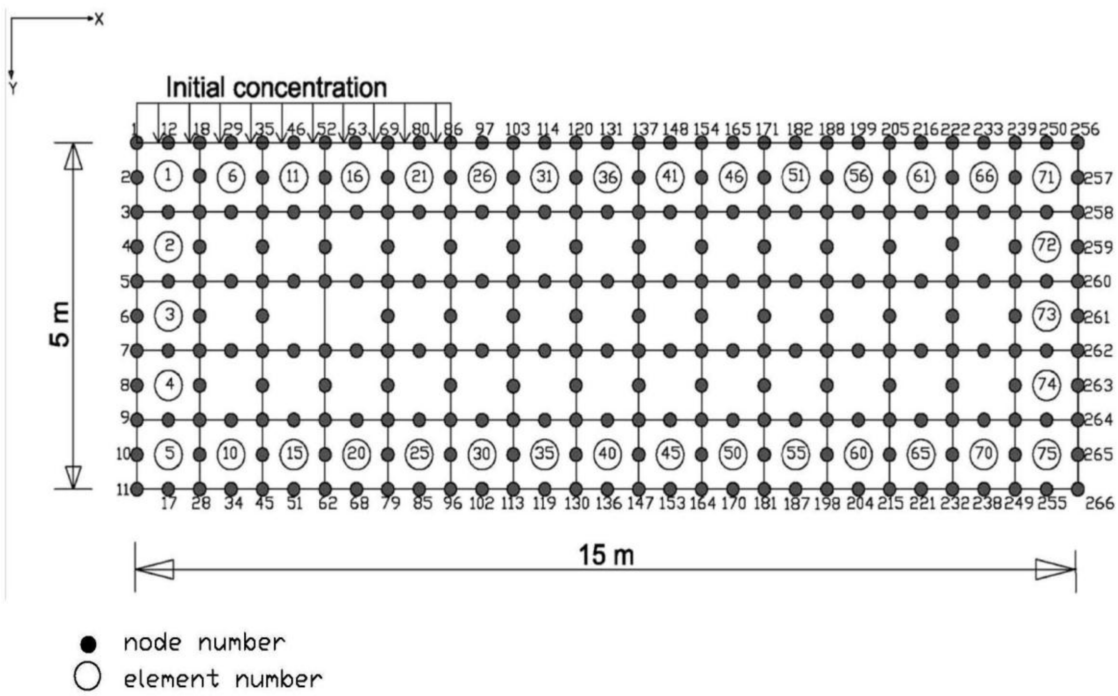
velocity= v = 2.5 m/hr. , D_L= 2.5 m^2/hr

D_T = 0.2 m^2/hr , time = 10.0 hr

time interval = Δt = 0.5 hr , initial concentration= C_O= 1000 mg/l.

Using the above data, the results of the finite element algorithm are presented in:

- Figs. (14) and (15) which show the pollutant concentration as temporal equi-concentration curves.



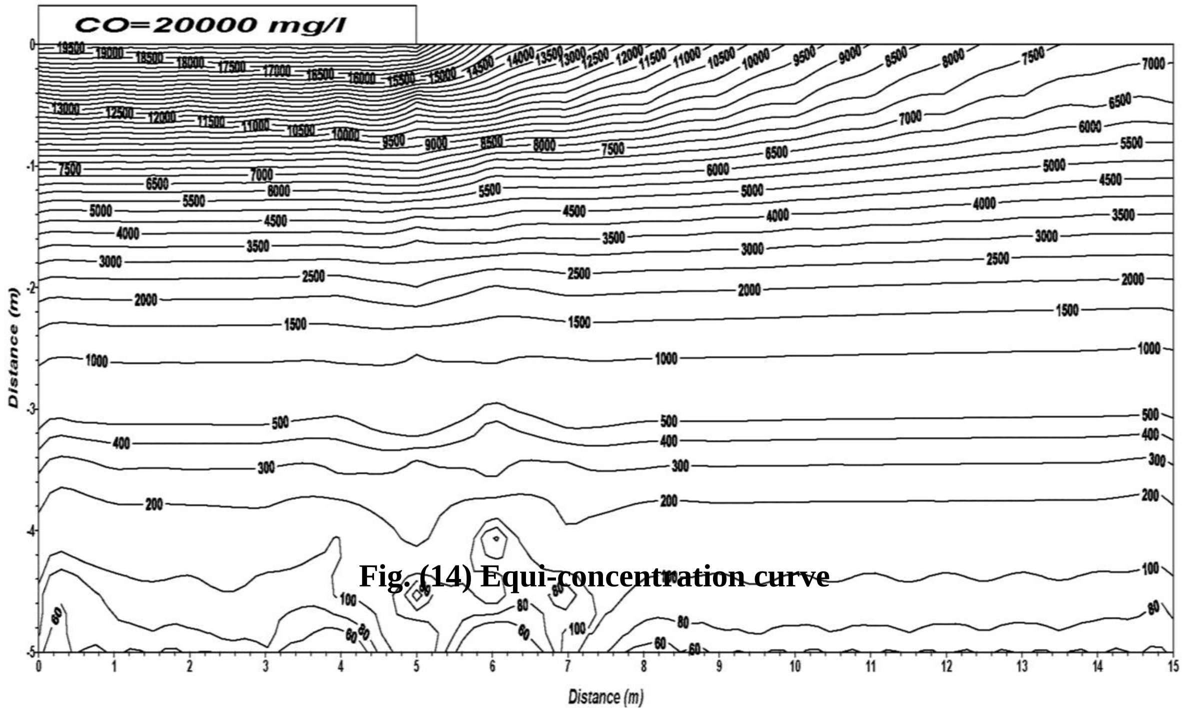
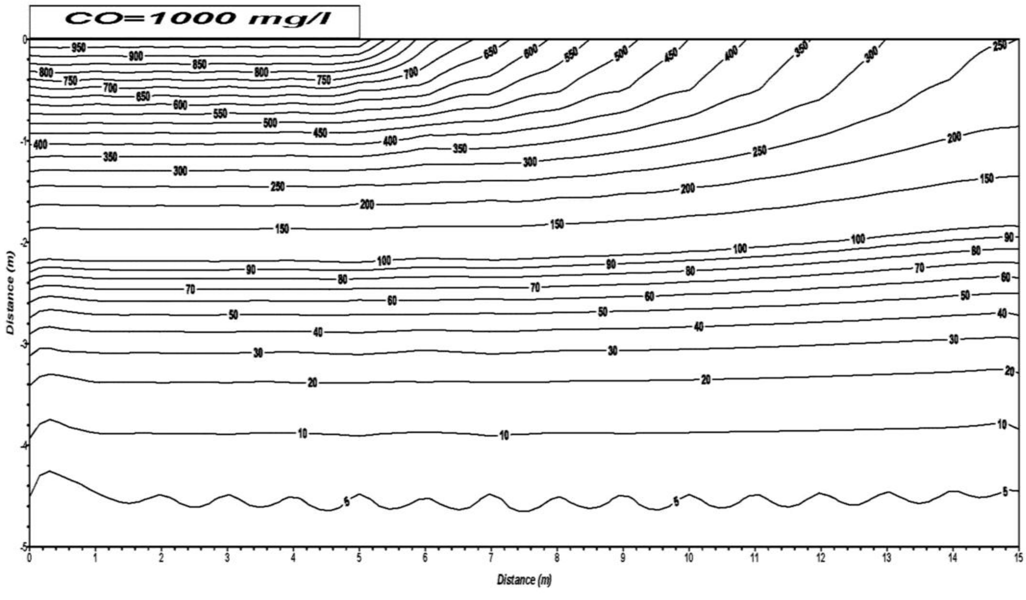


Fig. (14) Equi-concentration curve



CONCLUSIONS

The following, conclusions are drawn from both the experimental and numerical models:-

- In the verification of the numerical model, a good agreement is obtained between the finite element algorithm developed program and the program presented by Wang and Anderson [20]. In

both analyses, it was found that the solute in finite element solutions traveled faster than when using the analytical ones.
- Increasing the value of discharge velocity during the experimental run increases the value of longitudinal and lateral coefficients of dispersion.
- Increasing the value of discharge velocity during the experimental run decreases the time required to reach the 10% of the total concentration.
- A significant effect is obtained by the use of the geosynthetic material represented by the decrease in the longitudinal coefficient of dispersion many times and a reduction in the amount of volume of leachate from the source of pollution. These effects result in decreasing the contaminants migration through the porous media and reducing the distances traveled by them.
- According to the theory adopted to calculate the lateral coefficient of dispersion, there is no effect obtained from the use of a geosynthetic material on the value of the lateral coefficient of dispersion.

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LIST OF SYMBOLS

C	the mass concentration with respect to the fluid.
CCL	compacted clay liner.
CO	initial contaminant concentration.
Cr	Courant number.
DL	longitudinal coefficient of dispersion.
DT	transverse or lateral coefficient of dispersion.
e	element.
GCLS	geosynethetic material.
HDPE	high density polyethylene.
i	hydraulic gradient.
k	coefficient of permeability.
L	number of node.
t	time.
u	pore or average liner velocity.
W.M	with the use of geosynthetic material.
W.O.M	without using the geosynthetic material.
x	distance traveled by the contaminant in the direction of flow.
y	distance traveled by the contaminant in the perpendicular direction of flow.
$\wedge$	indicates summation.

N_L^e	nodal basis (shape) functions.
Γ	the boundary of the problem domain.
n_x, n_y	the components of a unit vector normal to the boundary.
σ	the integration variable representing distance along the boundary in Counterclockwise sense.
$\{C\}$	the column matrix of nodal concentration.
$\left\{\frac{\partial C}{\partial t}\right\}$	the column matrix of the time derivative of nodal concentration.
$[G]$	square coefficient matrix.
$[U]$	square coefficient matrix.
$[P]$	square coefficient matrix.
$\{f\}$	column matrix corresponding to the boundary integral on the right hand side of Equation (5-5).
Δt	length of time.
$\{C\}^{t+\Delta t}$	concentration value at the new time.
$\{C\}^{t}$	concentration value at the old time.
$\frac{\partial C_L}{\partial t}$	change in nodal concentration with respect to time.
Δx	traveled distance.
Pe	Peclet number.
$\xi\ ,\ \eta$	the local coordinates.