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TRANSPORT OF POLLUTANTS UNDER DIFFERENT SOIL MEDIA PART - I



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PREFACE

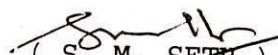
Today a lot of advances have been made in agricultural technology including application of various fertilizers and pesticides. These chemicals are required to meet increasing demand of food production, but at the same time one should not ignore their sweat sword action. These chemicals may change overall crop pattern of soil and with the course of time they may contaminate ground water also.

The solid/liquid waste disposals also pose the problem of pollutant leaching to the sub surface soil and ground water. The deep well disposal of waste and water table recharging wells where surface water is used for charging purpose are highly questionable.

Widespread contamination of the nation's ground water has resulted from the improper production, transportation, use and disposal of potentially harmful organic/inorganic contaminants. Hence prediction and measures for assessment of the fate and transport of contaminants in subsurface environment requires the advances in our understanding of ground water hydrodynamics and subsurface solute reactions. To enhance such understanding it is very important and necessary to rake up laboratory studies.

Keeping the above facts in view, the study of transport of pollutants under different soil media has been taken-up by

Environmental Hydrology Division. It is proposed to carry out the study in two parts firstly review of the available studies and planning of actual studies and the second part of the study shall cover the results of column studies. The present report is the first part of the study. The report has been prepared by Sri. Daya Ram, Sc. 'B', Dr. C. K. Jain, Sc. 'C' and K. K. S. Bhatia, Sc. 'F'.


(S. M. SETH)

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ABSTRACT

The information regarding pollutant transport in the subsurface environment is vital requirement for successful ground water management. The various aspects regarding the contaminants are whether it move with the water phase through the saturated or unsaturated zone, or it is adsorbed on to the subsurface material or is subjected to chemical reactions or biological degradation. This information is important in pollutant transport evaluation and assessment of potential remedial measures.

The present report illustrates the importance of pollutant migration through different soil media by reviewing literature in the field of concern. Various concepts derived from the study of transport of conservative substances to the study of major mechanisms which influence particle transport in porous media have been discussed. Despite different mechanisms influencing transport in laboratory scale columns, one major influence on transport is the heterogeneity of the medium through which the particles are transported. It is inferred that the physical heterogeneity plays a significant role in the transport and deposition of particles within the medium.

In the second part of the study variation of solute concentration will be observed for different media composition and for different depth. In both the experiments the time is also observed, which is useful to see the trend of solute flow with depth and media characteristics.

Public awareness and concerns about the leaching of nutrients and pesticides from agricultural lands has never been higher than it is today. This is not surprising as more and more evidence showed that diffuse (non-point) sources of pollution play a major role in the degradation of quality of our soil and ground water systems. Ground water pollution stemming from diffuse agricultural sources typically involves first transport through the unsaturated zone, followed by transporting in the underlying saturated ground water system.

The movement of particles through a porous media is of interest in a number of fields including ground water flow and transport, transport in petroleum reservoirs, analysis of filtration system, and design of column reactors. A number of mechanisms influence particle transport through porous media, including reaction to physical heterogeneities, adsorption, motility, and changes in the flow fields owing to particle - induce changes in the permeability distribution (Mc Dowell-Boyer, et al., 1986; McCarthy and Degueldre, 1993).

Over a number of years, substantial work has been reported in the ground water literature demonstrating that advective-dispersive transport of conservative, dissolved chemicals in porous media is strongly dependent on the distribution of hydraulic conductivity (Silliman and Simpson, 1987; Neuman, 1993).

More recently, researchers have applied the general concepts derived from the study of the transport of conservative chemicals to the study of major mechanisms which influence particle transport in porous media (Mills et al., 1990; Harvey and Garabedian, 1991; McCarthy and Degueudre, 1993; Harvey et al., 1993). Mills et al. (1990) used a column consisting of concentric cylinders of two different permeability porous media to study the movement of bacteria in the presence of preferred hydraulic pathway.

Harvey et al. (1993) conducted a detailed study of simultaneous transport of bromide (latex particles) and bacteria through a natural sediment (in field) and a reconstructed medium (in the laboratory). The study concluded that despite different mechanisms influencing transport in laboratory columns, one major influence on transport was the heterogeneity of the medium through which the particles are transported. It was concluded that physical heterogeneity plays a significant role in the transport and deposition of particles within a porous medium.

Tindall et al. (1995) conducted various experiments on two contrasting agricultural soils to observe the effect of soil texture, flow and plants on nitrate transport and denitrification under unsaturated conditions. He observed leaching time for different soil textures and when the soil is planted or unplanted. The transformation of N (N cycle) in soils is an integral part of nature but it can be affected greatly by agricultural and industrial operations. Usually, the alterations caused by agricultural and industry results from gains in soil

N owing to fertilization and waste disposal operations. Forms of N added to the soil and N already present can transform readily from one by-product to another depending on the type and environmental conditions.

Hirata and Muraoka (1988) studied the vertical migration of chlorinated organic compounds in porous media made of glass beads with different porosity and different degrees of water content. It was reported that trichloroethylene readily migrated in the completely dry conditions, on the other hand, in the saturated condition it migrated, but part of the test liquid remained stagnant as isolated particles in the pore space of the media. The results further suggests that trichloroethylene, once allowed to enter the soil, will migrate through the unsaturated soil layer at a rather high speed down to the surface of the ground water.

It is stressed that the relative magnitude of the different mechanisms influencing particle transport (e.g. sorption, straining, motility, density segregation, etc.) and the characteristics of the specific particle being transported (relative to the surface chemistry of the medium) must be considered for different media and/or different particles.

The transport and fate of pollutants can be considered in terms of hydrodynamic, abiotic and biotic processes (Canter et al., 1987).

2.1 Hydrodynamic Process

The hydrodynamic process of advection and dispersion are involved in the subsurface transport of contaminants. Advection refers to the transport of a solute at a velocity equivalent to that of ground water movement (Roverts, 1982). This transport occurs via the bulk motion of the flowing ground water. Advection is also referred to as convection. Dispersion refers to the spreading of a solute concentration front as a result of spatial variation in aquifer permeability, fluid mixing and molecular diffusion. Microscale dispersion can result from hydraulic drag in pore channels, differences in pore size, pore channel tortuosity, branching and interfingering. The following transport equation can be used to describe one dimensional, horizontal, single-phase flow in a saturated, unconsolidated homogeneous medium (Roverts, 1982)

$$-u \frac{\partial c}{\partial x} + D \frac{\partial^2 c}{\partial x^2} - \frac{\rho_b \partial S}{\epsilon \partial t} + \left(\frac{\partial c}{\partial t} \right)_{rn} = \frac{\partial c}{\partial t}$$

Eqⁿ 1

where:

u = average fluid velocity (m/sec)

c = solute concentration in aqueous phase (gm/m^3)

x = distance in flow direction (m)

D = dispersion coefficient (m^2/sec)

ρ_b = bulk density of soil (gm/m^3)

ϵ = soil void fraction

s = mass of solute adsorbed per unit dry mass of soil (g/g)

t = time (sec)

rn = chemical reactions and/or biological degradation

The first term in the above equation relates to advection or convection and the second term addresses to the dispersion. Adsorption is incorporated in the third term and other abiotic reactions and biological degradation are accounted for in the fourth term.

2.2 Abiotic Processes

Abiotic processes in the subsurface environment may include sorption of solutes with subsurface materials, ion exchange reactions, ion pairing or complexation, hydrolysis, solution-precipitation reactions, acid-base reaction, and oxidation reduction reactions. Scrivner et al. (1986) found carbonate dissolution, sand dissolution, clay dissolution hydrolysis, co-precipitation and ion exchange in the subsurface at a hazardous waste injection well.

Adsorption is perhaps the most significant abiotic

process in the subsurface environment, mainly when we consider organic contaminants (Roberts et al., 1982). A solute that adsorbed onto subsurface materials are retarded in their movement through the unsaturated and saturated zones. Various factors affect the adsorption, including physical and chemical characteristics of both the adsorbent and adsorbate (Hounslow, 1983).

If it is assumed that the mass transfer of the solute to adsorption site is rapid, and the adsorption equilibrium is linear, then the following relationship may be written:

$$\frac{dS}{dC} = K_d \quad \text{Eq}^n 2$$

where:

S = mass of solute sorbed per unit dry mass of soil (gm/gm)

C = solute concentration in aqueous phase (gm/m³)

K_d = distribution coefficient (m³/gm)

The k_d parameter is highly dependent on the soil resolution system studied. Predictions of contaminants attenuation based upon literature value of k_d are subjected to uncertainty because of the dependence of these values on the variables specific to the system (Melissa, 1995).

If it is assumed that no dispersion occurs and that no biodegradation or chemical reactions occur, then eqⁿ 1 reduces to

$$-u \frac{\partial C}{\partial x} - \frac{\rho_b \partial S}{\epsilon \partial t} = \frac{\partial C}{\partial t} \quad \text{Eq}^n \ 3$$

on merging the equations 2 and 3 we get

$$-u \frac{\partial C}{\partial x} = \left(1 + \frac{\rho_b K_d}{\epsilon}\right) \frac{\partial C}{\partial t} \quad \text{Eq}^n \ 4$$

let

$$\left(1 + \frac{\rho_b K_d}{\epsilon}\right) = R_f$$

where

R_f = Retardation factor (Dimensionless)

then

$$-u \frac{\partial C}{\partial x} = R_f \frac{\partial C}{\partial t} \quad \text{Eq}^n \ 5$$

Hence it is seen that an advancing front of a sorbing solute in the subsurface environment moves at a linear velocity which is smaller than the ground water velocity by the factor of R_f

For a given subsurface environment, R_f is influenced primarily by K_d . The value of K_d is determined by the strength solute - soil interactions; the greater the affinity of the solute for the soil phase, relative to its affinity for water, the more strongly the solute will adsorb, and the greater the value of K_d (Roverts and Valocchi, 1981). The use of k_d implies

that contaminant retardation is modeled as a linear equilibrium partitioning between the aqueous and solid phases (Melissa, 1995).

2.3 Biotic Processes

Biological degradation of organic contaminants can occur in the subsurface environment. This degradation is generally beneficial in terms of ground water contamination since contamination concentration decreased, however, intermediate products produced during degradation can be of concern. The subsurface environment, including the saturated zone, has been found to contain naturally occurring bacteria capable of carrying out biodegradation of organic (Ghiorse and Balkwill, 1981).

3.0

SUBSURFACE POLLUTANT TRANSPORT

3.1 Type of Pollutants

The various ground water pollutants include bacteria, viruses, nitrogen, phosphorus, metals, organic, pesticides and radionuclides, which leach through soil and contaminated ground water.

3.1.1 Bacteria

Pathogenic bacteria can be introduced into the subsurface environment from septic tank systems, land application of municipal wastewaters and sludge, seepage from municipal waste stabilisation ponds. Bacteria in the subsurface environment may undergo natural die-away, or they may be retained in the soil or transported to the ground water. The principal factor determining the survival of bacteria in soil is moisture. Temperature, pH and availability of organic matter also influences the bacterial survival (Gerba, 1975).

Various mechanism may be used to remove bacteria from water percolating to soil. The physical process of straining and chemical process of adsorption appears to be the most significant. The other mechanisms are competition for nutrients and the production of antibiotics by high populations of actinomycetes. Physical straining occurs when the bacteria are larger than the pore openings of the soil. Adsorption appears to be significant in soils having openings several times larger than

typical size of bacteria.

Weaver (1983) conducted a study regarding survival of salmonellae in soil and their tendency to leach through soil under controlled conditions in the laboratory. The time required for 99.9% removal in population was dependent on soil type, incubation temperature and soil moisture.

Mills et al. (1990) used a column consisting of concentric cylinders of two different permeability porous media to study the movement of bacteria in the presence of preferred hydraulic pathway. Harvey et al. (1993) studied the role of physical heterogeneity of media in bacterial transport through a natural sediment, in the field and with a reconstructed medium in the laboratory.

3.1.2 Viruses

Viruses may be introduced into the subsurface environment from septic tank systems, land application of municipal wastewaters and sludge, seepage from municipal waste stabilisation ponds. Viruses in the subsurface environment may undergo natural die-away, or they may be retained in the soil or transported to the ground water. The most important retention mechanisms is via adsorption on soil particles. The transport and fate of viruses in soil is a function of factors influencing virus survival and factors influencing transport and retention. Temperature is the major factor which affect the virus survival. Soil moisture, pH, soil type, virus type and virus association

with soil and other particulate matters also influences virus survival in the soil (Sobsey, 1983). Decreasing the moisture content decreases the survival. Powelson et al. (1993) have experimented the importance of flow media for virus migration in a study of infiltration of viruses with wastewater.

3.1.3 Nitrogen

The transport and fate of nitrogen in the subsurface environment is dependent upon the form of entering nitrogen and various biological conversions which may take place. The four primary forms are organic nitrogen, ammonium nitrogen, nitrites and nitrates. Organic nitrogen can be converted to the ammonium form through biological decomposition processes. Nitrates (NO_3^-) can be formed nitrification involving ammonium ion conversion to nitrites and then to nitrates. Nitrification ($\text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^-$) is an aerobic reaction performed primarily by obligate autotrophic organisms and NO_3^- is the predominant end product. An important aspect of subsurface transport and fate of nitrogen is the rate of ammonium nitrification.

Corey et al. (1976) performed a laboratory experiments to determine the time required for nitrification of ammonium and leaching of nitrates through soils. The transport and fate of nitrate ions may involve movement with the water phase, uptake in plants or crops, or denitrification. The movement with water phase is of much concern. Since nitrate ions (NO_3^-) have a negative charges, they have no attraction with soils due to negative charge of soils. It is also observed that nitrates are

more mobile than ammonium ions in both unsaturated and saturated soils (Corey et al., 1976).

Walter (1974) developed a mathematical model of manurial nitrogen movement through soil profiles under typical early spring conditions. Laboratory scale soil columns were used to investigate flow and transport processes. When nitrogen in the form of nitrate reaches ground water, it becomes very mobile because of its solubility and anionic form. Nitrates can move with ground water with minimal transformation. They can migrate long distances from input areas if there are highly permeable subsurface materials which contains dissolved oxygen.

3.1.4 Phosphorus

Typically, phosphorus is present as phosphate ions in septic tank system effluent, leachate from sanitary landfills, land application system for waste water surface impoundments. Normally it is not major contaminant due to its retainability on surface and subsurface soils due to chemical changes and adsorption. Phosphate ions become chemisorbed on the surface of Fe and Al minerals in strongly acid to neutral systems, and on Ca minerals in neutral to alkaline system.

Sawhney (1977) used laboratory soil columns to assess the ground water pollution potential of phosphorus from septic tank system drain fields. The sorption capacity of various soils were determined over an extended period of time and related to phosphorus movement through the soil columns using solutions

having phosphorus concentration similar to waste waters.

3.1.5 Metals

Metal are the most frequently detected contaminants in municipal wastewater and likely to percolate to ground water (Monteith, 1987; Thirty Seven, 1989). Metals may interact with soil in four ways. These are adsorption, ion exchange, chemical precipitation and complexation with organic substances. Out of these four processes, adsorption seems to be most important for the fixation of heavy metals and their retention in subsurface environment. Laboratory studies of various influence factors on the four major reactions for various metals and soil type have conducted by various workers (Alesii and Fuller, 1976; Fuller et al., 1980; Gambrell et al., 1986; Patel, 1974; Wangen and Stallings, 1984). As it is stated earlier that adsorption is the most important attenuation mechanisms for metals in the subsurface environment. Ion exchange is thought to provide only a temporary mean for the retention of trace and heavy metals. Common metals such as Ca^{+2} , Na^{+} , H^{+} , and K^{+} exhibits the competing effect, which limits the cation exchange sites available for heavy metal removal. Since metals get precipitated at neutral to high pH value, therefore pH may be used for metal fixation in soils. The pH is a controlling factor in adsorption-desorption reactions and precipitation solubilisation reactions. Organic-metal complexes may also facilitate movement of heavy metals through the subsurface environment (Loch et al., 1981). Hence it is concluded that reactions involving in soil attenuation of metals, are dependent on a number of factors such as soil

composition, soil texture, pH and the oxidation-reduction potential of the soil and associated ions (Bates, 1980).

Loch et al. (1981) conducted some laboratory experiments and reported that in the presence of fatty acids from land fill leachate, mobility of zinc, nickel and lead in the soil takes place. It was further reported that the presence of clay increases retention of metals.

Models for predicting the subsurface transport and fate of metals have been developed. Jurinak and Santillan-edrano (1974) developed a one dimensional transport model for the movement of lead and cadmium ions through soils under steady state saturated moisture flow conditions.

3.1.6 Organics

The transport and fate of organic in the subsurface environment is a relatively new area of consideration. Organics can move through various ways such as transport with the water phase, volatilization and loss from the soil system, retention on the soil due to adsorption, incorporation into microbial or plant biomass and bacterial degradation.

Wetherold et al. (1984) conducted a laboratory study to determine the volatile organic emissions resulting from oily petroleum sludge from refineries being disposed into soils. Enfield et al. (1985) developed a methodology for estimating volatilization of organic chemicals from unsaturated soils.

Volatilization was calculated by applying Fick's second law under the experimental conditions.

Adsorption is an abiotic process wherein solutes are adsorbed onto subsurface materials. Therefore, adsorption retards the movement of contaminant chemicals through the unsaturated and saturated zones. Adsorption processes during ground water recharge with treated domestic wastewater were observed by various authors (Hutchins et al., 1984; McCarty et al., 1981). Wilson et al. (1981) studied the transport and fate of organic pollutants in a sandy soil with low organic content. Glass columns were packed with soil in a manner that preserved the original soil profile. Water containing 1.0 or 0.2 mg/L of the organic compound was applied at the rate of 14 cms/day for 45 days. Concentrations of compounds in the effluent and the amounts volatilized were determined and the mass balances calculated.

Organic contaminants can be biologically degraded in the subsurface environment under either aerobic or anaerobic conditions. Biotransformation information can be useful for understanding subsurface transport and fate and for planning and evaluating in-situ remedial action programs. Larson and Ventullo (1983) discussed techniques for measuring the density, heterotrophic activity and biodegradation potential of ground water bacteria. The fate of six organic compounds during rapid infiltration of primary wastewater through soil columns was studied by Hutchins et al. (1984). Feed solutions were prepared containing all six compounds in individual concentrations ranging from 1 to 1000 $\mu\text{g/L}$ and were applied to separate soil columns.

One of the most commonly detected organic contaminants in ground water is trichloroethylene. It is resistant to biodegradation in aerobic subsurface environment, however, it can be biotransferred under anaerobic conditions.

A laboratory scale column study carried out by Carberry and Lee (1990) to simulate the effects of a petroleum leak and effects of a petroleum spill. Columns were operated under sterile conditions and three phase petroleum measurements with time and depth were obtained in order to quantify threats to ground water (Grenny et al., 1987; Symons et al., 1988).

3.1.7 Pesticides

There are three types of studies associated with pesticides, viz. field studies, laboratory studies and modelling. Factors associated with the type and characteristics of the pesticide and the subsurface environment influence pesticide migration to the ground water. The following subsurface characteristics limit the concern about pesticides in ground water (LeGrand, 1970):

1. A water table which allows for sorption of pollutants on earth materials; slows the subsurface movement of pollutants and facilitates oxidation or other beneficial retention or removal mechanism,
2. Sufficient clay in the path of pollutants so that retention or sorption of pollutant is favourable,
3. Water table gradient beneath an application area away from

nearby wells, and

4. Large distance between wells and the application area.

Few typical pesticides on which field studies have been conducted are atrazine (Wehtje, 1981), 2,4-D (Dregne, 1969), bromacil (Hebb, 1978), toxaphene and fluonethuron (Lafleur et al., 1973) and DDT (Scalf et al., 1969).

There are various pesticides such as 2,4-D, atrazine, methyl parathion, terbacil and trifluralin, aldicarb, 1,2-dibromo-3-chloropropane (DBCP), DDT, aldrin, picloram and 3,4-dichloroaniline (DCA), which have been studied for their transport and fate in soils. Davidson et al. (1980) evaluated the adsorption and bacterial degradation of 2,4-D, atrazine, methyl parathion, terbacil and trifluralin in four representing soils at laboratory scale. Solution concentration ranged from zero to aqueous solubility limit for each pesticide. The results were in agreement the adsorption isotherm data. Pesticide degradation rate and soil microbial populations generally declined as the pesticide concentration in soil increased. It was also observed that the mobility of each pesticide increased as its concentration in soil solution increased. The influence of adsorption and/or physical binding of aldicarb to soil particles was investigated by Awad et al. (1984). Eight different but well defined soil were packed in individual glass column and tapped lightly. The soil types included sand, loam, clay, sandy loam, clay loam, silt loam, muck and peat. A particular concentration of aldicarb active ingredient in formulated form were added to the top of each column and mixed thoroughly with the top 3 cms

saprolite having quartz veins. Following saturation of the saprolite, a bromide tracer and dye were applied for a specific time period. The drain fields were then excavated to 90 cms, the dye pattern mapped, and soil samples collected for bromide analysis.

Mathematical models are also available to predict the transport and fate of pollutants in the subsurface environment. Mansell et al. (1976) developed a mathematical model to simulate the transport and physical and chemical reactions for potassium, phosphorus and 2,4-D in two representative soil. Enfield et al. (1982) described three models for estimating the transport of organic chemicals through soils to ground water. The models consider mobility and first order degradation and compared to field data for the pesticides. Javendal et al. (1984) have developed a handbook which introduces various mathematical methods for estimating solute transport in ground water system. Pesticide behaviour in the saturated zone was described with an analytical solution of the mass balance equation for a cylindrical flow system by Beltman et al. (1995). For his simplified model he assumed steady flow, no dispersion, linear sorption and first order transformation. This simplified model for the unsaturated-saturated soil system was developed to identify the processes with the greatest impact on the fraction of applied pesticides reaching a drinking water well. Motz et al. (1991) used a vadose-zone model (LEACHM) developed by Wagenet and Hutson (1989) to calculate vertical fluxes of water and nitrogen reaching the water table.

3.2 Factors Affecting Pollutant Transport

More recently, researchers have applied the general concepts derived from the study of the transport of pollutants to the study of the major mechanism which influence particle transport through a media (Mills et al., 1990; Harvey and Garabedian, 1991; McCarthy and Degueldre, 1993; Harvey et al., 1993; Vandam et al., 1990; Hendrickx et al., 1988). The various factors which governs the pollutant transport may be explained as follow:

3.2.1 Water repellency

Various studies have been performed to see the general behaviour of solute transport through soil. A field study was carried out by Vandam et al. (1990) to study the effect of water repellency on water and bromide movement in a coarse textured soil. The purpose of this study was to analyze the field experiments of Hendrickx et al. (1988) using a relatively simple model describing water flow and solute transport in water repellent soils. Hendrickx in his study on solute movement in a coarse textured water repellent field soil found that their soil is more vulnerable to ground water pollution than a similar wettable soil.

3.2.2 Physical characteristics of media

The physical structure of media plays an important role in both the stability of the particles to be transported and the

distribution of particles deposited within the medium. The permeability and grain size distribution of the medium are main parameters to let transport any contaminant particle (Silliman, 1995). Powelson et al. (1993) also documented the importance of preferred pathways for virus migration in a study of the infiltration of viruses with wastewater. Hence based on the study made by Mills et al. (1990), Harvey et al. (1993) and Powelson et al. (1993), it can be concluded that physical heterogeneity plays as an important role in the transport and fate of pollutants in a porous media. They concluded that flow pathway (Permeability) plays a key role in advancing contaminant particle through a media. Tindall et al. (1995) conducted various experiments on two contrasting agricultural soils to observe the effect of soil texture, flow and plant on nitrate transport. He observed leaching time much higher for clay soil than for sandy soil. In unplanted soil, nitrate leaches up to a significant depth in relative to planted soil. Macropores provide a pathway for ground water contamination (Wildenschild et al., 1994), a laboratory procedure for evaluating the effect of macropores in a given soil is proposed and tested. The laboratory procedure was tested on two large, undisturbed soil monoliths (30 dia) removed from the unsaturated zone.

3.2.3 Chemical characteristics of media

Soil is a complex mixture of minerals having the property of adsorption and ion exchange. The movement of many pollutants in ground water is controlled by adsorption and ion exchange processes. Hence the chemical property of soil governs

the flow of pollutant significantly. Charbeneau (1982) has a simplified method to correlate adsorption and ion exchange chemistry with hydraulics. The combined result gives the effluent concentration as a function of time. In the work of Silliman (1995) he found that the greater number of particles were deposited at media contact.

4.1 Selected experimental designs

Various laboratory scale models (columns) have been used by various authors to study the transport of pollutants under different soil conditions. Some of the experimental designs/columns are discussed in this chapter.

Controversy exists about the best way to construct columns for transport experiments. Pure polypropylene is a rigid material slightly less inert than teflon but much less expensive; and for more inert for sorption than polyethylene, polyvinyl chloride, and silicone rubber (Barcelona et al., 1985).

The United States Environmental Protection Agency (USEPA) provide criteria for identifying and evaluating the source and spread of nonpoint pollution. Nonpoint pollution is the movement of pollutants from diffuse sources into surface or subsurface water bodies and is among the leading causes of water quality problems. Pesticides and herbicides are among the most important nonpoint pollutants carried from agricultural fields to surface waters or infiltrated into ground waters.

Alhajjar et al. (1990) have studied the transport of herbicides using column experiments. The experimental set-up (Fig. 1) consists of twelve polypropylene columns (105 cm long x 29.4 cm internal diameter with 1.7 cm wall thickness). Pure polypropylene plates (35.5 cm x 35.5 cm with 1.7 cm wall

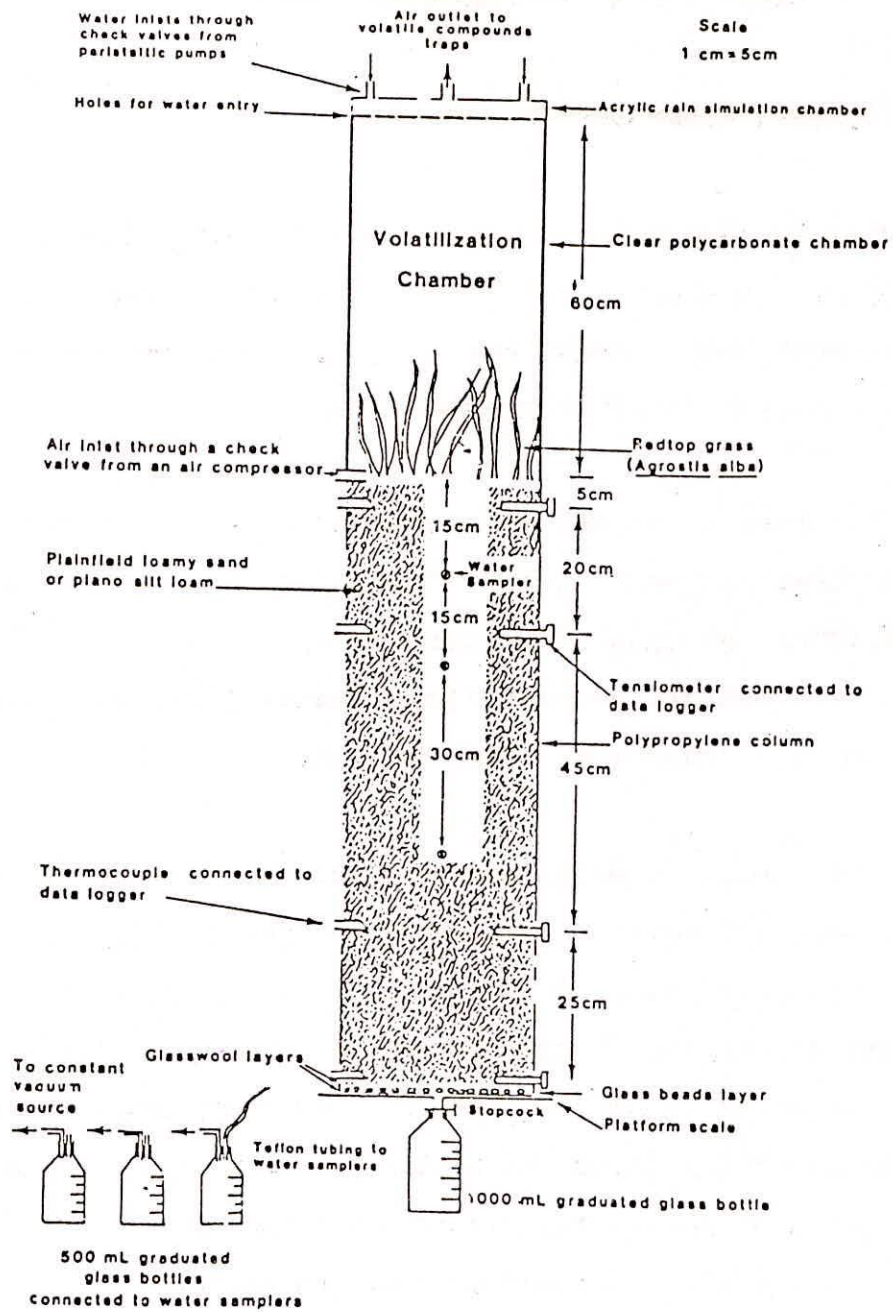


Fig. 1. Experimental Set-up (Alhajjar et al., 1990)

thickness) were cut and securely attached to the bottom of each columns using stainless steel screws mounted into holes die-threaded into the plates and the edges of the columns. The plates were tightly sealed to the columns by placing a teflon ring cut to form a gasket seal along the walls of the columns and plates. Tap-threaded pure polypropylene adapter tubes of 3.2 mm internal diameter were attached to a hole die-threaded into the centre of each plate. The adapter tubes were connected to stopcocks to control the free flow of leachate. To further insure air tight conditions, hot glue was applied with a heat gun to all sealing surface. A layer of fibre glass wool was placed at the bottom of each column above the adapter tube to prevent soil being washed from the columns. Solid glass beads (4 mm in diameter) were layered at a depth of 1 cm above the bottom of each columns to create a saturated boundary. Another layer of fibre glass wool was placed on top of the glass beads to separate the beads from the soil. The soil horizons were carefully packed to their original field bulk density. To draw water samples from several depths of soil columns, vacuum pressure sampling system was used.

Huff et al. (1986) described the use of vadose zone soil column for determining the subsurface transport and fate of contaminants leached from the land treatment and disposal of hazardous wastes. The column design is shown in Fig. 2. All surfaces in contact with the feed water, soil, and/or effluent were either glass or teflon. The soil was separated into 10 cm depth increments when collected. Soil from these 10 cm increments was packed into the column in the same relative position that it occupied in the original profile. The column were saturated by

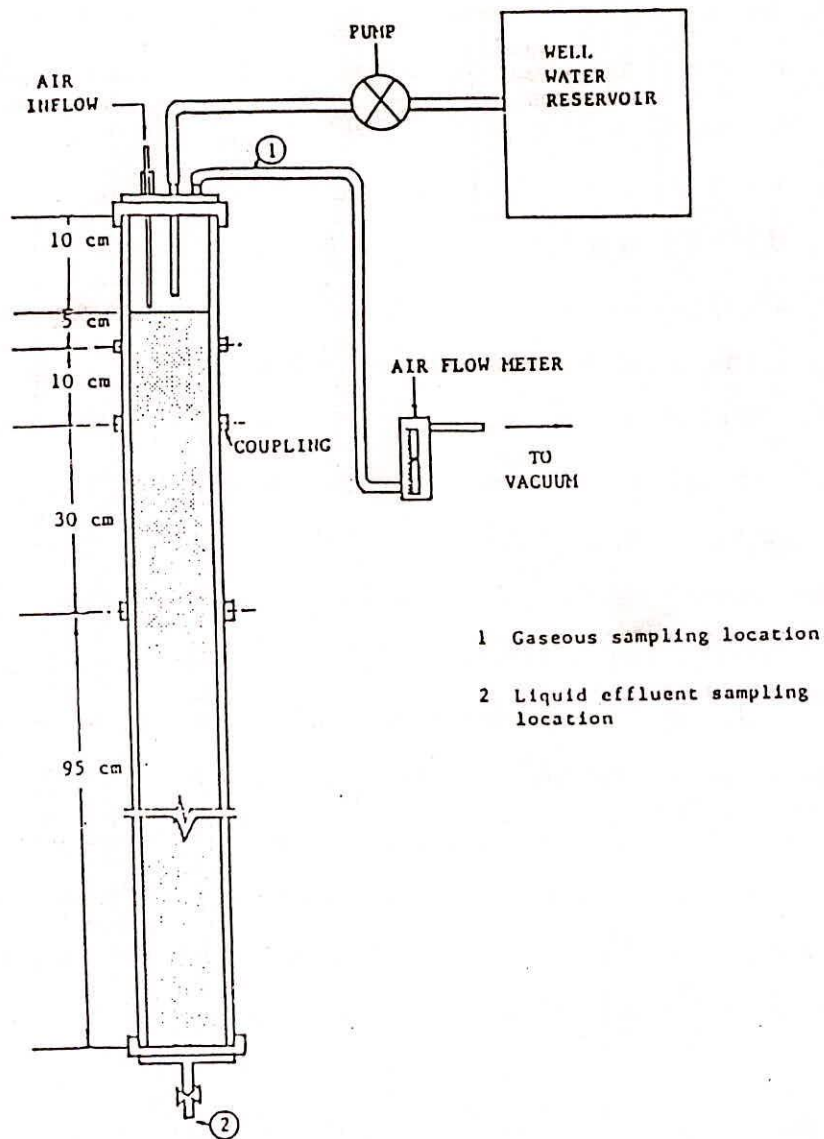


Fig. 2. Design of Vadose Zone Soil Column (Huff et al., 1986)

using standing head reservoir to the bottom cap port. A flow approximately equal to 10% of the saturated hydraulic conductivity was maintained in each column for the study. A total of 14 unsaturated columns were used to study the transport of various organic compounds.

Tindall et al. (1995) used a large undisturbed soil cores placed in a hardboard mould. All the cores were extracted from 0 to 40 cms depth after removing all litter from site. The core extraction method and experimental apparatus is described by Tindall et al. (1992). A modification of the original apparatus is illustrated in Fig. 3. Core extraction is accomplished by removing all litter from the site. The core extraction apparatus is placed hydraulically into the soil. As the core barrel is placed downwards in 5 cm increments, the soil around the exterior of the apparatus is removed to reduce soil resistance and soil compaction. The intact soil core is separated at the bottom interface of the apparatus with the insitu soil with a large knife. The intact soil core can then be removed from the apparatus, sealed, and transported back to the laboratory. Gas sampling ports, tensiometers, soil solution samplers (suction lysimeters), and sets of TDR (time domain reflectometry) rods for determination of volumetric water content were installed in each core at 10, 20 and 30 cm depths. The gas sampling ports were inserted horizontally into the cores. Each tube was perforated with four rows of 5 mm diameter holes about 1.2 cm apart as shown in the figure. The tensiometers were automated with transducers attached to a data logger. The suction lysimeters were constructed of 1 bar high flow, tapered neck, round bottom porous

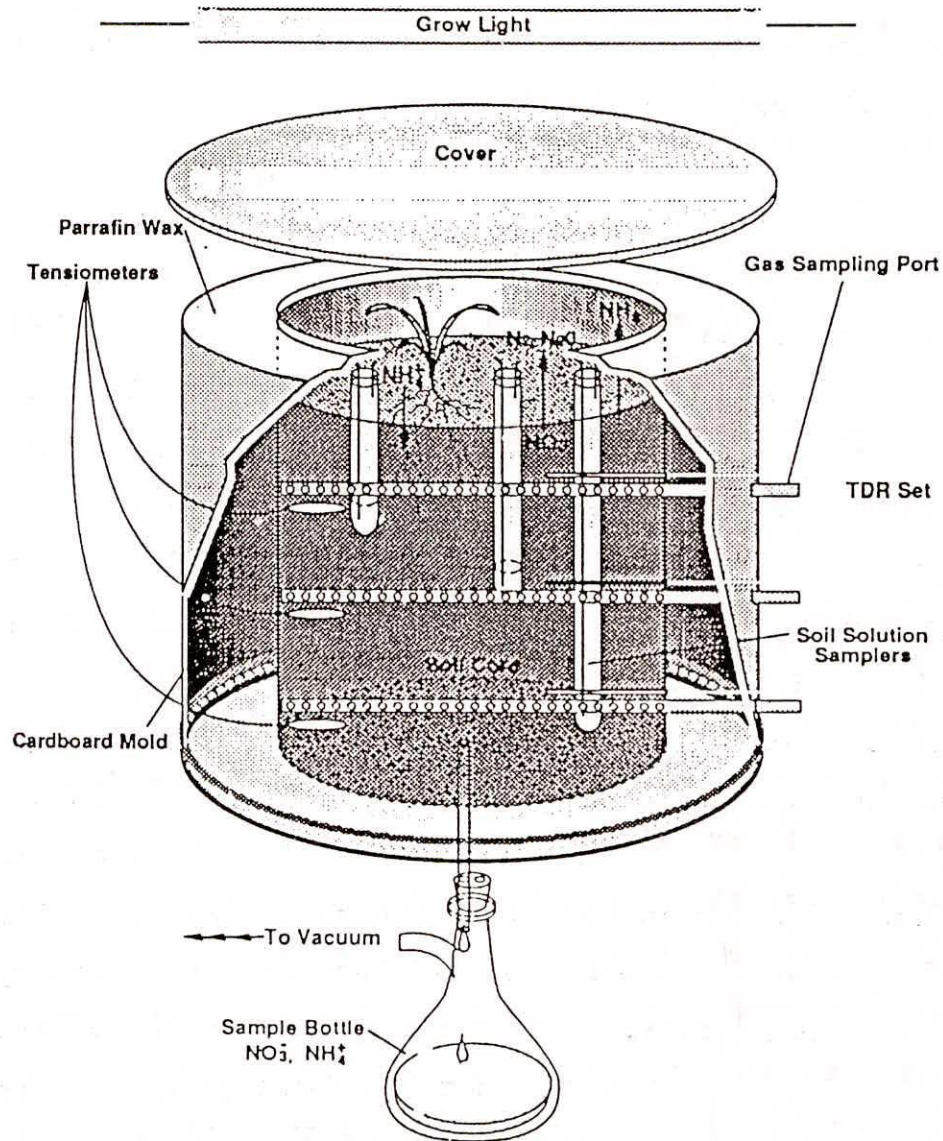


Fig. 3. Experimental Apparatus (Tindall et al., 1995)

ceramic cups attached to the end of schedule 80 pvc pipe (1.5 cm i.d.). Two tubes, one for sample discharge and one for air flow, were threaded through a rubber stopper at the top of the pvc pipe. The suction lysimeter were installed vertically into the cores as shown in the figure with the porous cup placed at the desired sample depth and sealed with bentonite near the soil surface to prevent piping. The TDR rods were connected at one end to a coaxial cable and were used to obtain a measurement of the apparent dielectric constant of the core material contacting and surrounding the rods. Volumetric water content of the soil was calculated from the TDR measurements. A vacuum pump was attached to the cores and a suction of -20 kPa was applied. During the experiments, the soil cores were maintained at a matric potential of -20 kPa which is representative of the matric potential in the rooting zone of many irrigated vegetable crops.

Silliman (1995) addresses the influence on particle transport within the porous media of high permeability pathways and contacts between different grain size distributions. The porous media were constructed from glass beads and the experiments were conducted on two-dimensional flow cells (Fig. 4). The flow was established by injecting into the inflow reservoir at a constant rate and maintaining the outflow reservoir at a constant head. The experimental media were constructed between the soil screens. All experimental media were constructed of technical quality glass beads. Glass beads were selected for the study to allow control over placement and characterization of hydraulic parameters and to reduce uncertainties in the interpretation of results which might be

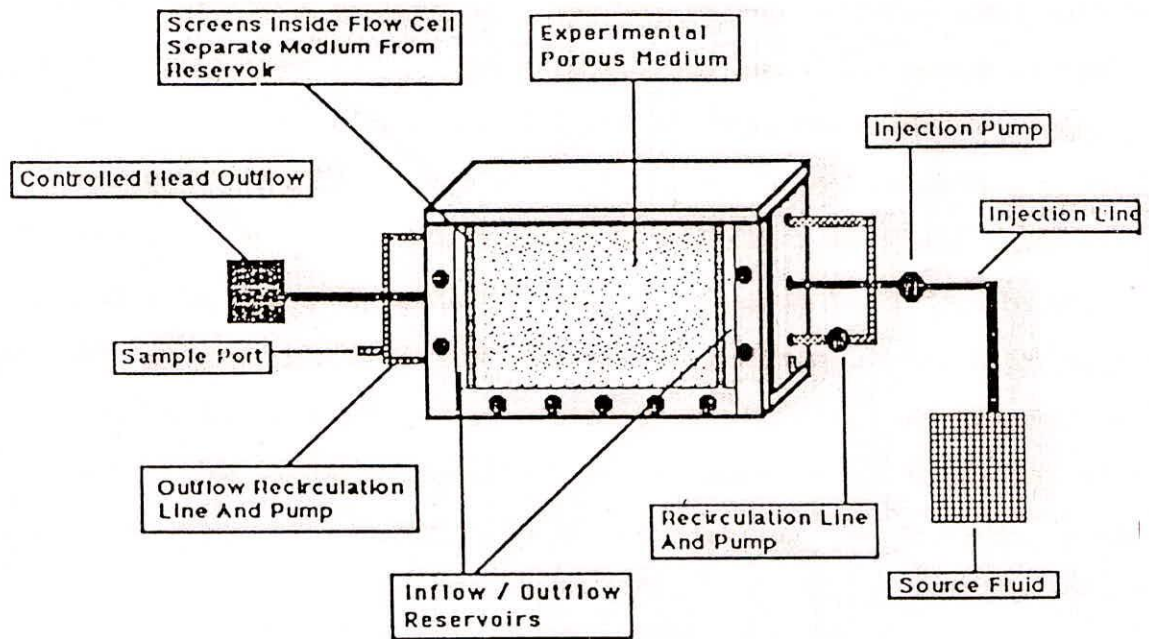


Fig. 4. Flow Cell Design (Silliman, 1995)

related to irregularities in the geometry of individual grains.

Harvey et al. (1993) conducted a detailed study of the simultaneous transport of a conservative chemical (Bromide), latex particles and bacteria through a natural sediment (in the field) and a reconstructed medium (in the laboratory). It was reported that despite different mechanisms influencing transport of latex particles in the field as compared with mechanisms influencing transport in laboratory columns, one major influence on transport was the heterogeneity of the medium through which the particles were transported.

Mills et al. (1990) used a column consisting of concentric cylinders of two different permeability porous media to study the movement of bacteria in the presence of preferred hydraulic pathway. The study showed that the presence of high-permeability finger substantially aided in the transport of the bacteria.

Carberry and Lee (1990) used two different types of soils to observe the migration and/or degradation of petroleum contaminants. Laboratory scale columns containing isotropic samples of two petroleum contaminated soils were operated in order to simulate effects of a petroleum leak and effects of a petroleum spill. Columns fabricated of flexiglass were used to periodically measure volatilized vapour phase petroleum concentration and to remove suspension containing liquid and solid phase petroleum concentrations. These columns simulated unsaturated soil in the vadose zone.

4.2 Experimental apparatus for present study

keeping in mind above studies, columns of different depth have been fabricated with glass. The diameter of each column is kept uniform and numerically it is 50mm. The heights of the columns are kept 30cm, 60cm, 90cm 120cm and 150cm respectively. Columns are made tapered with regulating device at the bottom to collect extracted solute solution. At the tapered end glass wool will be filled to generate a flow pressure and to avoid media soil to come with the extract. The solute solution of known concentration will be filled at the top of column and in the rest part of column remains for soil. The top of the column is made air tight with a cover having Two holes on top first for air inlet to maintain atmospheric conditions inside of column, the second one will be connected with solute supply tube which is connected with the bucket containing solute solution. A comprehensive and self explanatory sketch diagram of setup is shown in figure 5.

4.3 Experimental Objectives

Experiments will be conducted to study the following points.

1. The effect of media texture on pollutant transport,
2. Effect of depth on pollutant transport.

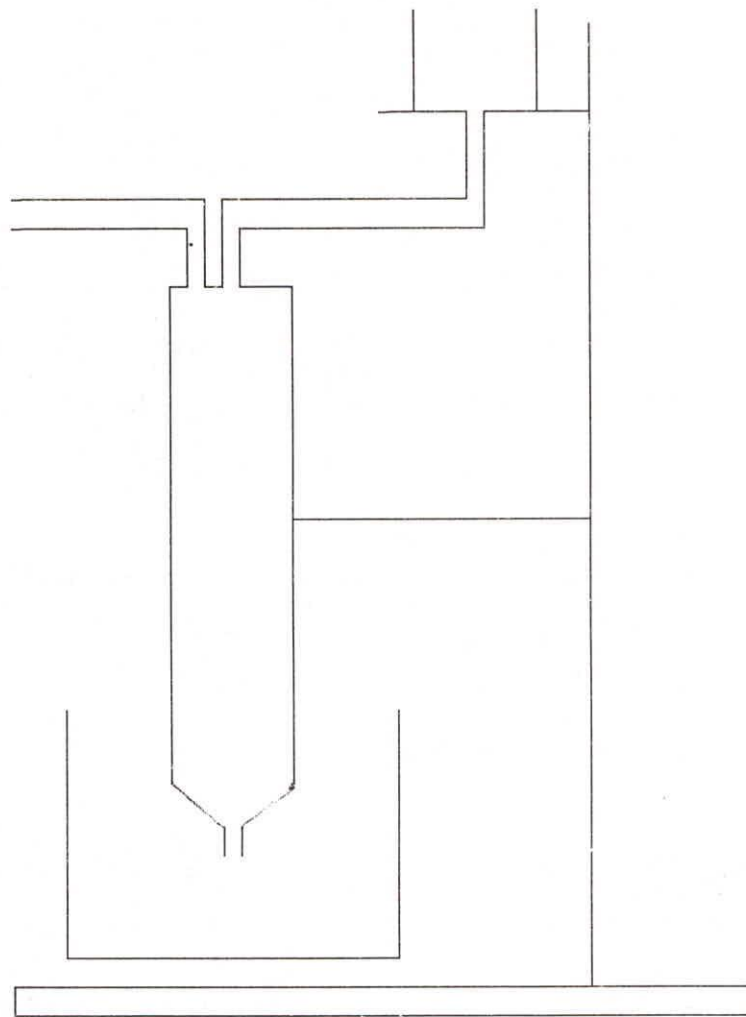


Figure 5

Experimental Setup for Solute Transport Study

4.4 Preparation of Soil

The study have to be conducted with sieved sandy field soil in control conditions. The soil have to be sieved to get different soil fractions. The general characteristics such as specific density and hydraulic conductivity of each soil fraction and natural soil will be determined. The each soil fraction will be tested for retaining capacity of pollutant.

Each fraction of soil will be prepared for column use by washing, air drying and autoclaving.

4.5 Experimental Method

The variation of solute concentration will be observed for different media composition and for different depth. In the first experiment the media composition will be kept constant and the solute concentration be measured for different depth. In the second part of experiment column depth will be kept constant and the measurements be taken for different media composition so that the effect of physical heterogeneity of media on solute flow could be observed. In both the experiments the time is also observed, which is useful to see the trend of solute flow with depth and media characteristics. All the experiments will be performed in saturated soil condition.

The solute transport and geochemical reactions along the solute path are highly complex and sensitive to the media structure. Media heterogeneity may cause channelling effect, which may be the cause of fast/slow solute transport.

Most of the pollutants are trapped at upper layer (upto root zone of general crop). They may be adsorbed, chemisorbed, retained or chemically react with clay minerals. It shows lowering of pollutant concentration with depth.

Media composition also has a vital role to predict pollutant transport pattern. The sandy soil is very easy to pass any solute while the clay soil has a property to retard the flow. Hence as the clay part or finer part increases, the pollutant concentration with the depth decreases also the time of infiltration increases.

The experimental observations will be analysed and discussed in the next report which is extended part of this study where we will discuss the theoretical and experimental pollutant movement in soil subsurface.

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