

THE DEVELOPMENT OF SOIL CLOGGING IN SANDS LEACHED
WITH SEPTIC TANK EFFLUENT

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Soil disposal of septic tank effluent is the most common means of on-site liquid waste disposal for homes in areas without central sewerage systems. Successful operation of the system requires the maintenance of an adequate effluent infiltration rate into the soil.

The situ measurement of K-values in soils with groundwater tables deeper than 1.50 m below the surface has indicated that values at saturation are usually exceeding 1 cm/day, even in compact clayey soils (Bouma, et al., 1972). Assuming a production of 1000 liters (250 gallons) of liquid waste per day for an average family, the minimal seepage area would be 100 m^2 (1111 square feet) if the K-value at saturation were to apply to the infiltration process. Large seepage areas can be constructed and operated without many problems and even larger sizes are recommended by current Health Codes (U.S. Public Health Service, 1967). However, many soils are not capable of accepting liquid wastes adequately, even though saturated hydraulic conductivity (K_{sat}) values may be very high. The reason for this is the occurrence of soil crusting or clogging which forms an inhibiting layer at the infiltrative surface and may result in a large reduction of the infiltration rate. The process of crust genesis is not well understood, as both physical and biochemical processes have been suggested as being active (Thomas, et al., 1966; McGauhey and Krone, 1967; deVries, 1972; Rice, 1974; Daniel and Bouma, 1974). The purpose of this paper is to describe crust genesis in sand columns being dosed with septic tank effluent, using in situ tensiometry and a physical flow model.

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Prolonged infiltration of septic tank effluent into soil materials will cause the development of a crust, or a clogged layer with a low permeability at or in the infiltrative surface. This greatly reduces infiltration into the soil and has been responsible for numerous seepage bed failures as evidenced by seepage of raw effluent which creates a health hazard as well as a nuisance (McGauhey and Winneberger, 1964; Bouma et al., 1972). The clogged layer appears to develop as a surface sludge accumulation at the interface of the soil with the gravel filled seepage bed (Thomas, et al, 1966; Jones and Taylor, 1965; and deVries, 1972). Crust formation may also extend into the upper few centimeters of the soil and is thought to be at least partly a biological phenomenon developing more readily under anaerobic conditions. Relatively large amounts of polysaccharides and polyurines, which are suspected of being the primary clogging agents, have been found in clogged soil (Avnimelech and Nevo, 1964). Rapid crust formation at 4°C (deVries, 1972) may have been due to accumulation of organic compounds that could not rapidly decompose at that temperature.

The low infiltration rate of a clogged soil may be regenerated to its former unclogged level by removing ponded water and allowing the clogged zone to dry out. In addition, organic compounds in the soil pores may decompose by oxidative respiration. As obstacles to flow in the soil pores are removed the initial permeability may be restored.

Physical effects of soil clogging

Any large addition of liquid to the seepage bed will cause saturated flow in the adjacent soil before a clogged layer is formed. Water will move into the soil at a rate which is slower than the K_{sat} of the soil, after formation of a clogged layer. Liquid, therefore, moves through the smaller pores and negative tensions develop below the crust even if effluent is ponded above.

The crust that develops in sands has usually been described as a surface mat of accumulated organic compounds. However, an alternate explanation is that material builds up in the soil pores adjacent to the gravel seepage bed as well as on top of the soil. Thus it is possible that the water retention and K vs θ relationships may be changed in the upper few centimeters of the soil due to clogging.

Starting with Darcy's equation:

$$q = K(dH/dz)$$

where q = water flux in a soil (cm/hr)

k = soil hydraulic conductivity (cm/hr)

H = water potential (cm water)

z = depth (cm)

The flux through a crust can be described as follows:

$$q = \frac{k_c (H_o + \Psi_{sc} + z_c)}{z_c} = \frac{1}{R_c} (H_o + \Psi_{sc} + z_c) \quad (1)$$

where $k_c = K_{sat}$ of the crust (cm/hr)

H_o = head of standing water above the crust

Ψ_{sc} = tension in subcrustal soil (cm water)

z_c = crust thickness (cm)

R_c = crust resistance (hrs)

Assuming that the crust develops at or above the soil surface then:

$$H_1 = H_o + z_c$$

where H_1 = head of standing water measured from soil surface

The crust resistance is then:

$$R_c = z_c / k_c \text{ or}$$

$$R_c = (H_1 + \Psi_{sc}) / q \quad (2)$$

It is thus possible to compare different crust resistances without knowing the crust thickness.

Laboratory and field experiments were carried out to study the physical aspects of soil clogging as occurring after soil percolation with septic tank effluent. The laboratory column experiments were initiated to simulate a mound-type disposal system for problem soils.

Materials and methods

The 14.7 cm wide cylindrical columns were filled with 15 cm gravel (representing creviced bedrock) followed by 30 cm of silt loam (representing the in situ top-soil), 60 cm of sand (fill above original top soil), 30 cm of gravel (the seepage bed), and 30 cm of silt loam (the cover placed on the mound). Septic tank effluent was introduced into the simulated seepage bed. The columns were originally dosed at a rate of 2 cm every 6 hours until they all crusted. They were then allowed to drain and rest for 75 days. Before starting new additions of septic tank effluent, the columns were perforated with 9 mm diameter holes between 12 and 20 cm below the fill-gravel interface. This was done to achieve significant concentrations of oxygen in the columns even after crusting and thus correspond with field conditions where soil contained 19% O_2 at 5 cm below a subsurface crusted seepage bed in sand (Walker, et al., 1973). The new dosing regime followed after the resting period consisted of one 8 cm addition per day.

Details of column design, tensiometer construction, gas analysis, nitrogen, phosphorus, carbon analysis, and bacterial populations were reported elsewhere (Magdoff, et al., 1974a and 1974b). The flow regime in the columns was modeled using a flow model proposed by Hanks, et al. (1969) which utilizes hydraulic conductivity and moisture retention data, the latter incorporating adsorption and desorption processes to describe hysteresis phenomena.

Field data were derived from monitoring of five subsurface seepage beds in sands (Bouma, et al., 1972).

Results and discussion

Tensiometer readings in unclogged soil demonstrate rapid wetting and drying of the upper portions of the fill after an 8 cm addition and decreasing tension fluctuations with depth (Fig. 1). As clogging develops the fluctuations throughout the columns decrease until a near steady state condition develops. Fluctuations of tension still occur then due to changes in the flux of water through the crust resulting from differences in the height of ponded water above the crust.

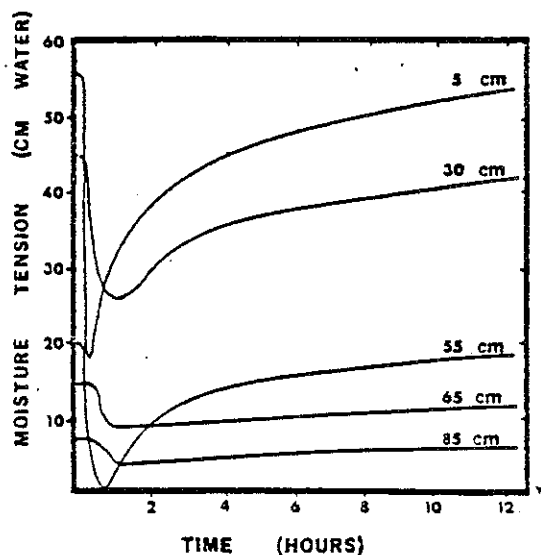


Fig. 1. Soil moisture tension changes after 8 cm addition (only first 12 hrs of 24 hr period shown).

Gas analyses indicate a similar trend. The O_2 and CO_2 concentrations near the developing crust tend toward steady-state concentrations as clogging develops. For example, analyses of the soil atmosphere 5 cm below the sand-gravel interface during the initial stages of clogging showed an O_2 decrease from 20.8 to 14.5% within two hours after an addition. Just

before permanent ponding the O_2 concentration decreased slowly from 19.2% to 16.5% during the first five hours after an addition. After permanent ponding the O_2 concentration fluctuated between 17.5% and 18.4%.

As the clogged layer develops water is ponded for increasingly longer periods. While the initial stages of clogging may or may not be due to the accumulation of anaerobic products, increasingly longer periods of anaerobiosis occur at the fill-gravel interface during a 24-hour cycle. Anaerobic organic compounds produced during these periods are exposed to shorter periods of aerobic metabolic decomposition.

Crust resistance (R_c) can be calculated with equation (2). For the initial stages of clogging the immediate subcrust tensions (ψ_{sc}) may be approximated by tensiometer measurements made at 5 cm below the sand-gravel interface. The average head of ponded effluent during infiltration (H_1) was measured during pre-ponding stages of development and was calculated for the ponding period considering the head to which the influent was brought each day and the daily rate of flow from the column. The average flux during infiltration (q) was estimated from tensiometer measurements which indicate the end of infiltration and the start of redistribution and the known inflow of 8 cm of effluent. Just before permanent ponding and the first day of permanent ponding the flux can be calculated from the quantities of effluent leaving the column.

The relationship of $\log R_c$ versus time gives a sigmoidal curve (Fig. 2). The periods of slow initial crust development, rapid development leading to permanent ponding and the final leveling off of the rate of development have been labeled phases I, II, and III respectively by Thomas, et al. (1966). Thus, while the existence of a clogged layer may in some cases be apparent only after permanent ponding, it is a dynamic phenomenon which starts before, and continues after, permanent ponding.

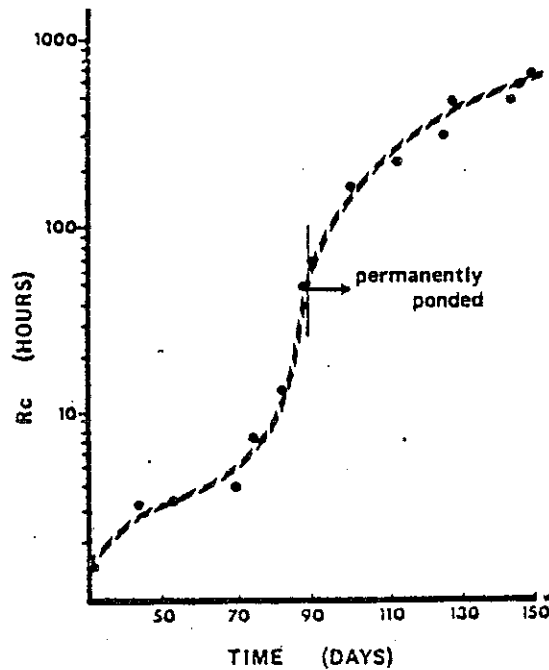


Fig. 2. The development of crust resistance (R_c) with time after addition of one 8 cm daily application.

The R_c of about 500-600 hrs at equilibrium is an overestimate of the resistance of the crustal material itself. The gravel layer had a significant surface area contact with the sand at the gravel-fill interface, which was visually estimated at 60%. The clogged layer does not form underneath the stones at the interface. The resistance of the crustal material itself is, therefore, about 40% of the calculated R_c . Using R_c values calculated from the monitoring data, (assuming the clogged layer was forming on top of the sand) the flow model predicted moisture tensions in the column as a function of time. The calculated and experimental tension vs time curves for 5 cm below the crust agreed quite well for preponding conditions (R_c values of 1.4, 3.1, and 7.0 hours). In both graphs higher R_c values resulted in increased minimum tensions during the cycle and longer infiltration periods per 8 cm addition (Fig. 3). But the experimental

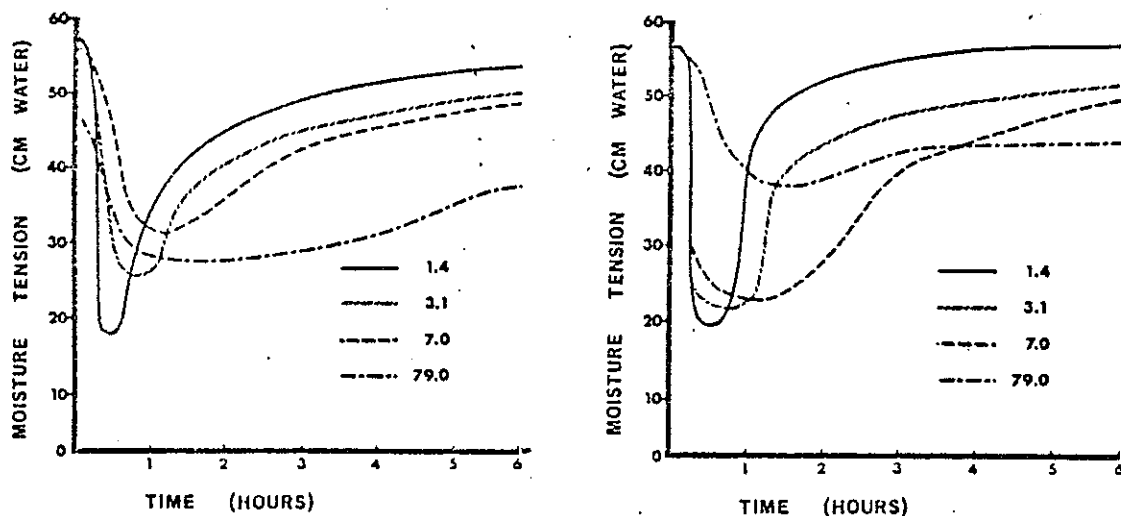


Fig. 3. Moisture tension fluctuations at 5 cm depth for various R_c values after 8 cm influent addition (only first 6 hrs of 24 hr cycle shown) for experimental columns (left) and flow model (right).

tensions after clogging were lower than the calculated ones for R_c values exceeding 70 hours. In fact, the experimental tensions after crusting reached lower values than the calculated ones at $R_c = 7.0$. Since the resistance of the crust increased after ponding, as was evidenced by the decrease of the infiltration rate, the tensions below the crust should have been higher than predicted by the model. The lower measured tensions after crusting may have been caused by new moisture retention characteristics of the soil immediately below the crust where the tensiometer was placed. This could result from an accumulation of colloidal material possibly formed by microbial activity in situ in this zone. The resulting finer porosity would flatten the K vs Ψ curve with the effect of lowering the tension at a particular flux through the soil (Bouma and Anderson, 1973).

Microscopic analysis of freeze-dried sand, sampled three centimeters below the infiltrative surface at the end of the experiments, revealed the

accumulation of isotropic organic compounds and opaque organic fragments in the soil pores which did not occur in the unclogged sand (Fig. 4). In addition, chemical analyses of the soil in the columns confirm the morphological picture by showing an accumulation of organic-N in the upper few cm of the sand fill adjacent to the gravel (Table 1).

Table 1. Nitrogen content in column sections after soil clogging.

Depth (cm)	N (ppm)	Depth (cm)	N (ppm)
0+ (crust)	835	4-5	100
0-1	534	5-6	82
1-2	294	6-8	73
2-3	183	8-10	57
3-4	120	10-20	45
		20-30	40

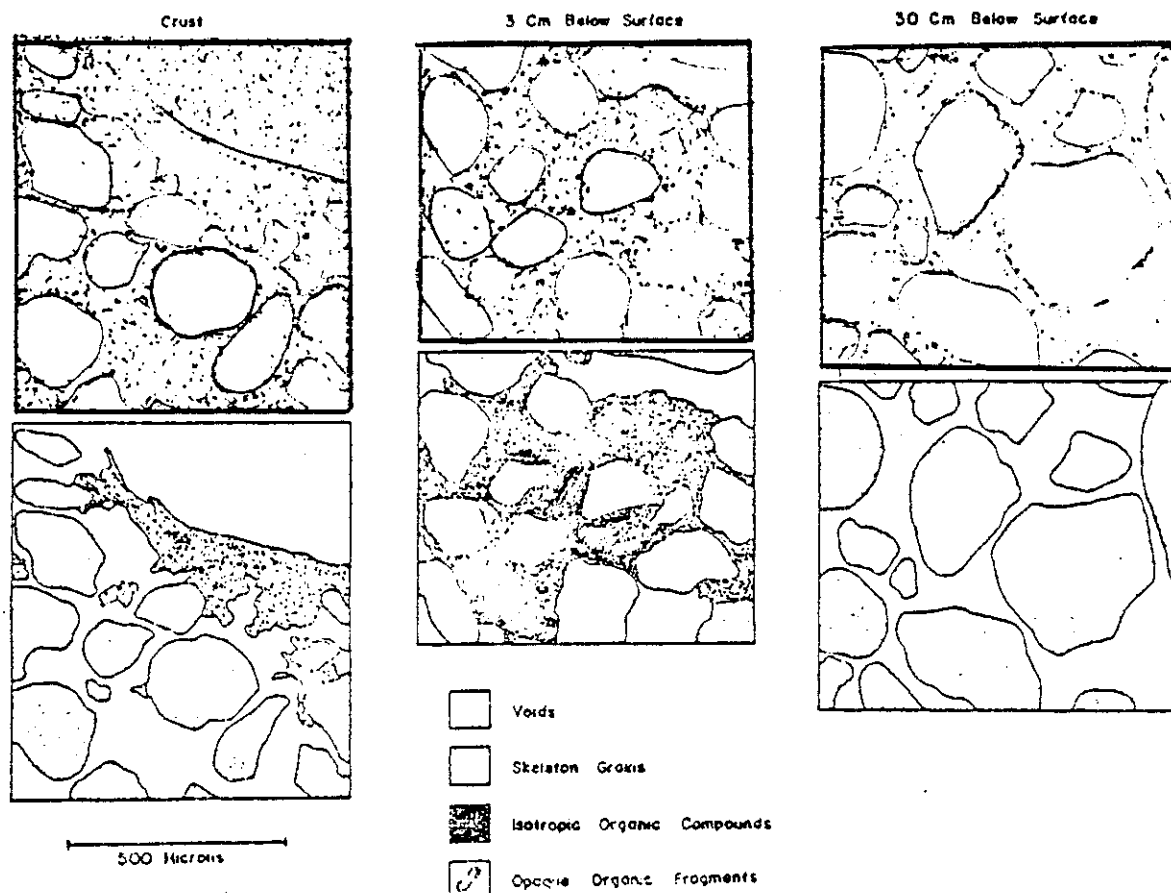


Fig. 4. Pictures from thin sections made from samples taken at different depths in a ponded sand-column dosed with septic tank effluent.

The computer model assumed that the inhibiting layer formed on top of the soil. Agreement between measured and calculated data for preponding conditions confirms this assumption. However, disagreement for ponding conditions indicates the assumption to be incorrect, because clogging then occurs inside the soil pores as indicated by tensiometric, morphological and chemical data.

Relation to field monitoring data

In situ measurement of tensions below four clogged seepage beds in sands (Bouma, et al., 1972) were used to calculate R_c values with equation (2) (Table 2).

Table 2. Physical characteristics of clogged layers in subsurface septic tank seepage beds in sand.

System	Age	H_1 (cm)	ψ_{sc} (cm)	$q(\text{flux})(\text{cm/day})^*$	R_c (hours)
System 1	12 years	25	23	11	105
System 2	5 years	20	25	8	135
System 3	7 years	10	27	8	111
System 4	1 year	20	25	8	135

* derived from K curve.

The average R_c value of 122 hours is in the range of experimental R_c values for column crusts just after permanent ponding. Comparisons between in situ measurements and those made in sand-filled columns are difficult to make because of the different K-characteristics associated with the relatively loose packing of sand in the columns and the more dense packing in situ. However, the approximate agreement between column and field R_c values would indicate that the general conclusions of this study as relating to soil clogging, apply to field conditions.

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