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CHAPTER II

LITERATURE REVIEW

It is generally known that soil has been used directly as solid and liquid waste disposal all the time beside as medium for plant growth and basement for construction. Septic tank soil adsorption system has been used in Thailand about 50 years ago (more or less) according to the elders (personal communications). When it was first used, the author's opinion, no one was interested in studying what would happen to the water that passed through soil or others as long as the system worked well. Until during these few decades, when people studied about soil, environment etc, some began to study the system to see what would happen. The investigation has been carried on mostly in the temperate region and could summarize their studies as follows :

2.1 Permeability of soil and clogging in soil pores.

After domestic wastewater passing through a soil for a period of time, its percolation rate was reduced due to clogging. Chang et al (1974) and Rice (1974) reported that the initial sealing of soil pores was caused by the physical entrapment of suspended particles in soil, followed by a secondary mechanism of microbial growth. Jones and Taylor (1965) suggested that clogging found in sand under both aerobic and anaerobic conditions. Under anaerobic condition, clogging would occur 3 to 10 times more faster than under aerobic condition and sand with high initial hydraulic conductivity would clog at a much slower rate than sand with low initial rate of hydraulic conductitity.

Avnimelech and Nevo (1964) showed that there were two factors which influenced clogging, the C : N ratio of the soil and the decomposition rate of organic matter. Soil with high C : N ratio caused a relatively slower clogging than soil with low C : N ratio, while undercomposed material caused a slightly clogging. The decomposition product produced by bacteria or other microorganisms such as polysaccharide polyuronide and products produced by microorganism such as slime could fill up soil pores and permeability of the soil would be reduced (Allison, 1947, Kristiansen, 1981 a, McCalla, 1950, McCalla, 1945, Mitchell and Nevo, 1964, Thomas et al., 1966, Walsh and Murdock, 1960). McCalla (1950) also suggested that under prolonged submergence the microorganisms in soil may reduce the percolation rate in two ways, one was when they produced gas or highly hydrated organic material such as slimes and the other was that the microorganisms may help in decomposing or changing the structure stabilizing agents which caused the deterioration of soil structure.

2.2 The pH value of effluent changed by soil.

By using columns of sand-clay mixtures as filter for septic tank effluent, Willman et al.(1981) found that the pH value of the filtrates depended upon clay content. The pH value after 23 weeks dropped from 8.05 $\pm$ 0.1 to 6.9 and 5.4 for the filtrate passing the mixture of 12% and 0% clay, respectively. In field study, the pH of groundwater adjacent to septic tank was higher than 7 in the early weeks of loading and then dropped back to slightly acid level (Viraraghavan et al., 1976). Vries (1972) also reported that every sizes of sand in sand filter which treated with primary municipal wastewater were not affected the effluent pH.

2.3 The COD removal by soil.

The organic substance in domestic wastewater should be decreased by soil mechanisms. Magdoff et al.(1974) showed that organic substances were removed by physical and/or biochemical processes. Screening out in the crust zone and sorbed on soil constituent are physical process and aerobic respiration, anaerobic decomposition are biochemical processes. This agreed with Thomas and Bendixen (1969) who found that only 14% of the organic carbon in liquid waste passed through the soil, 9% remained as an undegraded residue in soil and the remaining was degraded to products having no COD. The organic carbon which is more resistant to degradation such as alkyl benzene sulfonate, ABS, may also be removed from domestic wastewater by partial biodegradation especially in unsaturated soil and then absorbed by soil (Robeck et al., 1964). Schwartz and Bendixes (1970) and Viraragharan and Warnock (1976) found that the degree of COD removal in unsaturated zone was directly proportional to the depth of unsaturated zone. The other factor that influenced the physical and biochemical processes of COD removal was the percentage of clay in sand-clay mixtures (Thomas and Benedixen, 1969) the fine texture soil showed a greater rate of organic removal by screening out than did the coarse texture soil while 12% clay in sand-clay mixture induced the optimal pH for development and maintenance of high heterotrophic bacteria to lower the COD.

2.4 The nitrogen removal by soil.

Some nitrogen compounds are considered pollutants in domestic wastewater when present in high amount and may cause health hazard and eutrophication. Urea, the product from protein metabolism, is the largest quantity of nitrogen compounds in domestic wastewater. Follet et al (1981) and Morrison and Boyd (1971) reported that in the presence of acid, base or enzyme urease, urea undergoes hydrolysis to form ammonium ion and carbon dioxide, ammonia and carbonate ion, or ammonia and carbon dioxide, respectively. Thompson and Troeh (1978) showed that soil microorganisms can produce ammonium ion from organic nitrogen with amine group and then entered the soil solution. This process is dependent on moisture, soil temperature and nutrients which are favorable for microbial activities. However, ammonium ions were decreased as the soil solution move through soil by the process of adsorption, fixation or the combination of them. In most soil, the ammonium adsorption capacities depend on pH and texture. The ammonium adsorption of fine texture soils tends to have higher capacities than coarse texture one as the result of their largest available surface area per volume. Moreover, ammonium adsorption capacity is limited by the types clay minerals and amount of humus in soil colloid although they have the same texture. The exchange capacity of Cecil clay which dominance of 1 : 1-type clay mineral is 4.8 meq/100 g of dry soil while Susquchanna clay which dominance of 2 : 1 type clays is 34.2 meq/100 g dry soil

(Preul and Schroepfer, 1968, Strahler and Strahler, 1973, Brady, 1974). The study of Preul and Schroepfer (1968) also showed that ammonium adsorption of Zimmerman sand and Hayden silt increased with time of feeding until the complete equilibrium were met. Zimmerman sand needed 2 hours for 90% of equilibrium and 4 hours for complete equilibrium while Hayden silt needed 6 hours for complete equilibrium. In addition, ammonium adsorption was decreased when potassium ions present in large amount. The adsorption of Zimmerman sand lowered over 10 times if the feeding solution has 1050 mg/1 of potassium ions. Besides the adsorption, both organic and several minerals in soil probably remove ammonium ions by fixation. Ammonium fixation was directly related to percentage of carbon in the organic matter and type of clay especially 2:1 type structure. Vermiculite has the greatest capacity, followed by illite and montmorillonite (Follet et al., 1981, Thompson and Troeh, 1978, Brady, 1974, Lance, 1972). Walsh and Murdock (1960) studied the amounts of native fixed amonium in soils under various types of conditions. The results tend to show larger amounts of ammonium fixed in subsoils because of the higher clay content but all values were less than 1 meq/100 g of soil.

Ammonium ions in soil solution may be reduced by either chemical or biochemical processes which produced another form of nitrogen such as ammonia that volatiles from soil to atmosphere. Wahhab et al., (1957) pointed out that the volatilization of ammonia increases if the equilibrium is shifted to the right which causes increasing the activity of both ammonium ions and hydroxide ions as the result of liming. According to Ernst and Massey (1960), these reaction could be explained in two ways. When liming, the exchange site was saturated with calcium ion which interfered the ammonium adsorption and the other was the increasing activity of hydroxide ions in soil solution. They also showed that over 50% and less than 10% of added nitrogen volatilized after 10 days of addition, as ammonia from Dickson silt loam under the pH values were 7.5 and 5.0, respectively. However, there were no differences in ammonia volatilization from soil treated with either 9.38% solution of urea in water to the surface of soil at moisture equivalent or addition of the same solution to the surface of air-dry soil, followed by sufficient water to bring the soil moisture content to moisture equivalent. Another factors that enchanced ammonium volatilization were temperature and soil moisture. The ammonia losses increased at 1% for every 15°F between 45-90°F and increased in the same level as the initial soil moisture was between 5-21% or 21-37.4%. Another conclusion was reported by Chin and Kroontje (1963) who studied on the rate of ammonia volatilization from Salinas clay and Tatum silt loam. Under dry condition, both soils had a higher rate of ammonia volatilization than under wet condition because ammonia was soluble in water and subsequently adsorbed by soil colloid. The average value of the half-life of the reactions are 2.16 and 3.55 hours for dry and wet conditions, respectively. Furthermore, Overrein and Moe (1967) reported that the ammonia volatilization rate of Chalmers silt loam and Plainfield sand at 28°C increased at an exponential rate as rates of urea application were increased but were inversely proportional to the depth of urea application and decreased more rapidly with depth in wet soil than in moist soil. The effect of the interaction of pH and rate of nitrogen application on total ammonia volatilization was found by Mill et al (1974). As pH value was above 7.2, the rate of ammonia volatilization was very high as the rate of nitrogen application was increased. Moreover, nearly two-third of the nitrogen loss accured on the first and second days after treatment and diminished sharply to 7% per day for the fourth through seventh days.

Ammonium ions may be transformed by two biological processes, nitrification under aerobic condition and followed by denitrification under anaerobic condition to form nitrogen gas which is not result in environmental problems. The fate of those processes depended on the environment that attain the activities of the organisms. Oxygen is necessary to nitrifiers as well as the properties of soil. Many workers found that the nitrification rate increased as temperature and the soil pH increased (Frederick, 1956, Sabey et al., 1959, Sabey, 1956, Morrill and Dawson, 1967, Porter, 1975). The greatest increase of the nitrification rate occured between 7°C and 15°C and the maximum rate of nitrification occured at the pH value between 7.5°C and 7.8°C. Frederick (1956) also suggested that in similar environment, the lag periods of nitrification in the soil with the low numbers of nitrifiers were long. This information agreed with Sabey et al (1956) and Preul and Schroepfer (1968) who indicated that the addition of the initial nitrifier populations, either by inoculation or by pre-incubation, caused a reduction of lag periods but did not greatly influence the magnitude of the maximum rate of nitrification.

Under anaerobic condition, nitrate nitrogen may be transformed to nitrogen gas by soil microorganisms. Limiting factors for denitrifying organisms to be active in this process are pH above 6, nitrate content, the amount of rapidly oxidizable carbonaceous material in the soil for denitrifying organisms, not high or below optimum temperature, 25-30°C (Follet et al., 1981, Lance, 1972). In laboratory study, Magdoff et al.(1974) treated soil column with domestic wastewater that contained 42 mg/l of total nitrogen for a period of time. Ammonia and organic nitrogen were oxidized to nitrate nitrogen under aerobic condition and about 32% of the total nitrogen was lost by denitrification under anaerobic condition at the bottom of the column. In situ, Andreoli et al., (1979) studied a full scale system consisting of a conventional septic tank. By letting wastewater from disposal system into Suffolk and Nassau Soil, he found that denitrification established itself within one month after methanol addition at the first metre and let it travel through the pan where nitrate nitrogen concentration was as low as 0.1 mg/l. The pH value and alkalinity increaesed in the anaerobic portions of the pan where denitrification occured.

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2.5 The phosphorus removal by soil.

Several investigators found that many soils are capable of fixing large quantities of phosphorus after water-soluble phosphorus compounds were added to them either as pure or mixed solution. The mechanism which was suggested by Hemwall (1956) indicated that phosphorus was fixed on clay mineral surface by reacting with exposed aluminium ion which originated from the exchange sites or from lattice dissociation of the clay minerals to form variscite ($AlPO_4.2H_2O$), a highly insoluble aluminium phosphate. Cho and Caldwell (1959) and Jones and Lee (1979) showed that minerology of soil effected the removal phosphates rather than by the soil particle size. In acid soil, phosphate was fixed by aluminium and iron ions but in alkaline soils it was fixed by calcium ion. Viraragharan (1982) concluded that three processes involved in phosphates fixation from septic tank effluent were adsorption, the most important process, replacement in the mineral crystalline structure, and precipitation with iron, aluminium or calcium to form insoluble compounds. Sawhney and Hill (1975) treated six major soils in Connecticut with simulated wastewater containing 2×10^{-4} MP at a rate of 5 cm/week for 2 years, showed the difference of phosphorus sorption capacity from soil to soil. However, their capacities of fixation increased with depth. Nevertheless, the time require for phosphorus saturation which determined from phosphours sorption isotherm of them were less than in field studies caused by the regeneration of sorption sites with time. Sawhney (1977) showed that the columns of Merrimac fine sandy loam and Buxton silt loam were treated with a 2×10^{-5} MP solution over 600 hours phosphorus removal by soils initially were rapid resulted from the adsorption on the mineral surfaces and precipitation in the subsequent slow reaction. The capacity of coarse texture soil trend to increased with reaction time. Furthermore, Stuanes (1984) reported that phosphorus sorption of Hunderfossen, Nordisk fjellskole, and Mageli soils were nearly irreversible reaction and increased with phosphorus concentration. The sorption capacity of Mageli soil which repeated 20 additions of the same solution, 0.39 mMP solution or septic tank effluent also increased. In contrast, the factors which lowered the phosphorus sorption capacity of the Ludlow series at 45 and 75 cm depth were reported by Hilland and Sawhney (1981). The soil was treated by the simulated wastewater containing 12 mg/l P from late April through early December. Phosphorus concentration in the effluents from the soil at 45 and 75 cm depth were about 0.4 and 0.5 mg/l, and then increased under anaerobic condition to 2.5 and 1.5 mg/l, respectively. In addition, the phosphorus concentration in the effluent from the soil at 45 and 75 cm depth seem to increased from 0 to 2.5 mg/l after continued 200 additions and increased from 0 to 1.6 mg/l after continued 400 additions, respectively. However, the relation between the degree of phosphorus removal and the particle sizes were found by de Vries (1972) who applied wastewater containing 6 to 9 mg/l P to soil columns 75 cm long for 240 days at the rate of 20 cm/d for 2 hours a day. The concentration of phosphorus in the effluent solution reached 0.1 mg/l in the column filled with 0.1 to 0.25 mm. soil particles whereas in the effluent from a column containing 0.25 to 5.0 mm. particles it reached a much greater concentration of 5.8 mg/l. Similarly, Magdoff et al (1974) applied septic tank effluent containing 18 mg/l P at a rate of 8 cm/d to column containing 60 cm of sand fill underlain by 30 cm of silt loam. The phosphorus concentration in the effluent, when ponding continuously was 2 to 6 ppm. In field studies, the soils below the trench or the septic system drain field also showed the high potential of phosphorus removal. Bouma et al (1972) analyzed groundwater below five septic systems in sandy soils during August, October, and November, 1971. He found the concentration of dissolved inorganic phosphorus was as high as 1.9 mg/l in the groundwater in August. During the two remaining periods, the concentration of soluble phosphorus in the groundwater was less than 0.25 mg/l in systems with no perched water table. Reneau and Prettry (1976) determined phosphorus content in groundwater of Varina and Goldsboro soils where plinthic horizons (ironrich hard pan) were 54 and 132 cm below the drainline and produced a seasonal perched water table. In Varina soil, the concentration of 1.05 mg/l phosphorus was observed in the perched water 36 cm below and 15 cm away from the drainline while only 0.01 mg/l of phosphorus was observed in soil solution within the plinthic horizon. In Goldsboro soil, the concentration of phosphorus in perched water was only 0.01 mg/l. Sawhney and Starr (1977) studied a 6-years old septic system which used alternatively for about 6 months. They found the concentration of phosphorus in soil solution at 0 to 15 cm below the trench rapidly approached the concentration in the septic tank effluent because the sorption sites of the soil in this zone were saturated with phosphorus. The soil at 15 to 30 cm depth removed most of phosphorus from the effluent eventhough the system had been in operation for aver 6 years and the aberage phosphorus concentration of 0.5 mg/l occured at the 60 cm depth below the trench. Moreover, the soil could regenerate phosphorus sorption sites during the resting periods so that the soil was capable of removing additional phosphorus from wastewater over a longer period of times.

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2.6 The fecal coliform removal by soil.

As domestic wastewater moved through soil a number of entericbacteria were also reduced as the results of adsorption by soil and/or bacterial die-off. The efficiency of soils, that determined by comparing a number of indicator bacteria in the percolates at various depth of soil, depended on several factos. Hagedorn (1981) concluded that soils under unsaturated flow and contained high clay content could retain bacteria more effectively and the depth where bacteria could be found depend on the time of retention. In field study, Brown et, al. (1979) investigated a number of fecal coliforms in the soil below the septic line for 2 years. The soils he used, were Norwood sandy clay and Miller clay which contained 41.2 and 7.6% sand, respectively. The percolation rates of the soils were 3.7 and 0.25 cm/hr and the application rates were 32.7 and 16.4 $1/m^2$ bottom area per day, respectively. After 7 weeks of application fecal coliforms counts of the sample taken at 90 cm depth of Norwood sandy clay was as high as 750 fecal coliforms/g while in the Miller clay soil no fecal coliform was found in the sample collected 1 month after the application began. After 2 years of application, fecal coliforms of both soils were most dense at the interface between the gravel layer and the soils and then greatly decreased to <2 coliforms/g as the depth increased. This data agreed with Bouma et al (1972) who reported that large population of total coliforms and fecal coliforms present in septic tank effluent were reduced within 61 cm below the trench. The most abrupt population declining occured in the "biological mat or clogged zone" located at the interface of drainfield trench and the soil. However, in a new soil adsorption bed the movement of microorganisms through the unclogged soil may be rapid and relatively far. The restriction of the drain field probably due to the straining action of the soil and possibly to adsorption of the bacteria on the soil particles. As the soil was clogged with the sewage solid during a period of use, the movement of sewage bacteria was restricted (Viraraghavan, 1978). Similarly, Reneau and Prettry (1975) reported that fecal coliforms in the septic tank effluent did no move through Varina sandy loam, Goldsboro loamy sand and Beltsville sandy loam dued to the slowly permeable subsurface in them. Another investigation, Bell and Bole (1978) applied unchlorinated sewage lagoon effluent to a stand of reed canary grass (Phalaris arundinacea L.) on Brown Cavendish loamy sand each week at a rate of 1.5 cm/hr. Most of the fecal coliforms in the effluent were retained in the surface 8 cm of the soil in two stages. The initial death rate was about 70% per day within 48 hours after irrigation stop and the subsequent rate was about 33% per day at 15°C and 25% per day at 10°C. In the other hand, Smith et al.(1985) indicated that the efficiency of bacterial filters in soil depended upon the soil structure. The columns of intact and disturbed Crider silt loam, Maury silt loam and Bruno sandy loam were added with the suspensions of E.coli in 0.005 M $CaCl_2$ at the rate of 20 cm/hr for a period of times. The ratios of the mean E.coli effluent concentration and the input concentration of the intact soils, Crider silt loam Maury silt loam and Bruno sandy loam were 0.44, 0.22 and 0.79 whereas the ratios of the disturbed soils were 0.07, 0.002 and 0.05, respectively. Many investigations showed that the elimination of bacterial population in soil-wastewater system was the result of microbial die-off. The microbial die-off rate depended on the properties of soil. The effect of temperature on E. coli die-off rate was shown by Van Donsel et al.(1967) and Reddy et al.(1981). The half-life for the survival of fecal coliforms in summer, fall, winter and spring were 24.8, 44.9, 37.8 and 72.3 hours, respectively. Another investigation, Mc Feters and Stuart (1972) found that in natural water at 5°C the half-life for the survival of E. coli was 110.9 hours and at 25°C the half-life was 12 hours. The E. coli die-off rate also depended on the soil moisture content and the soil pH. Boyd et al.(1969) applied the sewage to Weld fine sandy loam and Greeley fine sandy loam soil at 28°C. The half-life for the survival of E.coli of Weld fine sandy loam with 10% of moisture content was 37.8 hours and increased to 57.4 hours under 50% of soil moisture. The same trend appeared in Greeley fine sandy loam the half-life of E.coli was 36.2 hours under 10% of moisture content and increased to 59.4 hours under 50% of moisture content. The effect of the soil pH on the half-life of E. coli was shown by Reddy et al.(1981). The half-life of E. coli decreased from 5.0 to 7.0 and then increased to 63 hours as the pH increased to 8.0. Furthermore, the die-off rate of organisms was result from the interaction of the soil temperature, soil moisture, the soil pH, and the methods of application. In the other hand, many workers suggest that the die-off of fecal coliform was the result of competition with another organisms. Magdoff et al.(1974) suggested that the columns effluents had no fecal coliform

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eventhough the average value in the influent was 1.7×10^5 col/ 100 ml dued to compete with the genus Pseudomonas.

Another important process that eliminates the number of organisms in soil-waste system is the soil adsorption. Butter et al.(1954) concluded that bacterial removal from liquid percolating through soil was inversely proportional to the particle size of soil. The study of Glantz and Jacks (1967) showed that the 1.3 m depth of light-textured soil in Pennsylvania was enough to free it almost completely of coliform bacteria in the sewage from sprinkler-irrigated. The same trend also occured in the river bed with a fine loamy sand surface underlain by alternating strata of sand and gravel was treated with the sewage effluent of 1 m/d. (Bouwer et al. 1974). Most of the fecal coliforms, originally at concentration of 10^6 col/100 ml were removed in the first 60 cm of soil depth. In contrast, Lance et al.(1975) found that reduction of fecal coliforms from secondary sewage effluent in 250 cm-long columns filled with loamy sand was proportional to the concentration of fecal coliforms that applied at the soil surface. The columns reduced fecal coliform concentration by about 3 log during 9-day flooding periods at infiltration rate of 40-50 cm/day. Another workers, Marshall (1971), and Burge and Enkiri (1978) concluded that the retention of bacteria increased with an increasing of clay content, cation exchange capacity of the soil, the cation concentration of the water, and the specific area of the soil while the retention of bacteria by soil decreased markly as pH increased above 7. In addition, Robeck et al.(1962) showed the influence of synthetic detergent, ABS, on coliform movement under saturated soils. The columns of 0.38 mm Chillicothe sand 0.18 mm Newton sand were added with coliform organisms and ABS at the range of 1 to 10 ppm. The coliform organisms moved much more slowly than ABS and the concentration of ABS at 1-10 ppm did not have any significant influence on the movement of coliform organisms.

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