THE TREATMENT OF POULTRY WASTE BY MEANS OF WASTE STABILIZATION PONDS

BY

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D E C L A R A T I O N

I, NKEIRUKA ENYINNAYA NWIGWE, hereby declare that the studies reported in this thesis was carried out by me. It has not been previously published or accepted elsewhere for a higher degree. All work, opinions and ideas other than mine have been fully acknowledged by means of references.

.....
NWIGWE NKEIRUKA ENYINNAYA
(1992)

D E D I C A T I O N

This work is dedicated to children all over the world - born and yet unborn - for "By the mouths of babes and sucklings hath He ordained praise ..... that He may still the avenger".

C E R T I F I C A T I O N

This thesis entitled "The treatment of Poultry Waste by Means of Waste Stabilization Pond" by NWIGWE, NKEIRUKA ENYINNAYA meets the regulations governing the award of the degree of Master of Engineering of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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to my Lord Jesus Christ who loved me and gave Himself for me and to the Holy Spirit, the greatest teacher who has taught me in the language I can understand.

A B S T R A C T S

This study is on the treatability of poultry wastes by means of waste stabilization ponds. The ponds consisted of an anaerobic pond and a facultative pond in series. The poultry waste was obtained from National Animal Production Research Institute, Ahmadu Bello University, Shika. The ponds were loaded for four different detention periods namely: five, ten, fifteen and twenty days.

The parameters investigated were the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Phosphate, Total Coliform Bacterial Count, Sulphate, Ammonia, Nitrite, Nitrate, Total Solids and pH.

The anaerobic pond effluent was polished by the facultative pond. The five day detention period had overall BOD and COD reductions of 68% and 80% respectively. Sulphate concentration was reduced by 16.7% while Phosphate, Nitrate-nitrogen, Ammonia-nitrogen, Total solids and Total coliform Bacterial concentration were reduced respectively by 26.2%, 75%, 23.5%, 53% and 14%.

Further operation of the treatment plant up to the twenty day detention period gave overall percentage removals for the BOD, COD, Sulphate, Phosphate, ammonia, nitrate and Total solids as 85.4%, 92%, 25.1%, 27.9%, 93%, 4.04% and 60% respectively. Nitrite concen-

tration in the facultative pond for this detention period increased to an amount greater than what was originally fed into the system. The coliform bacterial count was also reduced by 58.8%. Similarly various other reduction percentages were obtained for the ten and fifteen day detention periods for both the anaerobic and facultative ponds.

From the results obtained, a series combination of anaerobic and facultative ponds can be used to treat poultry waste. However, a maturation pond in series with anaerobic and facultative ponds will be required to further reduce the coliform organisms. Also there will be the need for tertiary treatment such as the use of sand filteration and/or chemical coagulation for polishing the effluent.

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ABBREVIATIONS AND SYMBOLS

AE	Anaerobic Pond effluent
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
FE	Facultative Pond effluent
Fig	Figure
gVs	Mass of volatile solids in gramms
mg/l	milligrams per litre
N	Nitrogen
NO_2	Nitrite
NO_3	Nitrate
NH_3	Ammonia
NH_4+	Ammonium ion
sp	species
VS	versus
%	Percentage.

CHAPTER 1

INTRODUCTION

Pollution of a water body is the addition of anything which changes its natural quality so that the downstream user does not receive the natural water of the stream (Sex, 1974).

Various types of pollutants have been conveniently classified by Klein (1962) into four categories viz: chemical, physical, physiological and biological (table 1.1). Chemical materials may be broadly classified into organic and inorganic pollutants. Physical pollutants include colour, turbidity, temperature, suspended solids, foam and radioactivity. Physiological pollutants include those substances that cause taste, and odour while biological pollutants are the undesirable microorganisms that cause diseases.

The perception of pollution arises when there is interference with one or more water uses. The water quality criteria for municipal water supplies arise from the need for palatable and safe finished water free from concentration of coliform bacteria, organic compounds, that may result in offensive taste and odour, inorganic chemicals that may constitute long-term health hazards, and suspended matter.

Polluting substances can be accumulated to some extent within a stream, depending on its temperature,

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TABLE 1.1: NATURE AND SOURCES OF MAJOR WATER POLLUTANTS (Klein, 1962)

Pollutant and Sources			Effect on Waters
SOLIDS			
A.	Particulate	(1) Municipal waste and effluents from certain industries such as pulp and paper, food and tannery.	Degrades aesthetic appearance, utilizes oxygen resources, interferes with bottom life; prevents adequate disinfection and allows disease - causing organisms to live longer in natural waters.
		(2) Silt is runoff from construction sites and agricultural land.	May cover and destroy valuable fish and wild life habitat; makes assimilation of oxygen - demanding wastes more difficult; adds to water treatment costs, degrades aesthetic appearance.
B.	Dissolved:	Municipal and industrial waste water, particularly the mining and chemical industry.	Interference with agricultural and industrial water use; increases hardness of water used for domestic purposes, excessive dissolved salts can also cause a laxative active when present in portable water; adds taste to water.
ORGANIC MATTER			
A.	Biodegradable	Municipal waste water and waste from many industries such as milk, food, pulp and paper; Runoff from areas with high concentration of animals such as zoos, feedlots or barn yard, poultry farms.	Utilizes the oxygen resources of a stream and thus interferes with normal biological life, can cause taste, odours and colour.

B. Non-biodegradable:	Municipal waste water and the waste water from many industries such as milk, food, pulp and paper. Runoff from areas with high co..centrations of animals such as zoos, feedlots, barn yards, farms.	Can cause taste, odours and colour in waters, fish tainting, foam, can become biodegradable.
INFECTIOUS AGENTS		
Bacteria and Viruses:	Domestic waste water, waste from hospitals, research laboratories, agricultural land runoff, some industries such as milk processing and meat packaging.	Present a health hazard to direct and indirect reuse, to water contact recreation.
NUTRIENTS such as		
Nitrogen and Phosphorus:	Municipal waste water, some industrial runoff; runoff from agricultural and urban areas.	Fertilizes the water and thereby stimulates the excessive growth of weeds and algae causing cultural eutrophication.

TOXIC AGENTS		
A. Metals, Acids and Alkalides	Industrial waste water	Harms surface water ecology, interferes with downstream water reuse; potential health hazard; corrodes piers, boats.
B. Pesticides and exotic organics:	Agriculture, forestry, residential and commercial pest control, certain organic chemical industries.	Harms surface water ecology, interferes with downstream reuse, represents potential health hazard.
C. Radioactive Waste:	Nuclear power plants, radioactive materials, reprocessing industry, medical and laboratory radioactivity material uses.	Potential health hazard; potentially harmful to aquatic life.
HEAT	Electric generating plants, steel mills, certain industries, large air conditioning system.	Interferes with normal surface water life by favouring species tolerant to high temperatures; reduces the oxygen saturation concentration of water and increases rate of biological activity thus affecting weed and algae growth.

TASTE, ODOUR AND COLOUR			
A.	Industrial Waste water		Interferes with down stream recreation and reuse.
B.	Oil:	Oil spills during transport or storage, railroad and truck yards, some industry; billige water and ballast water from boats, urban runoff. Water oil from automobiles.	Aesthetic damage, taints fish, kills or injures fish and wild life, interferes with recreational life.

dissolved oxygen concentration, flow rate and other factors. The use of assimilative capacity of a stream must assume that the resultant quality does not impair other beneficial uses. This, of course, is the crux of water pollution control (Klein, 1962).

In the past, all the efforts to maintain and enhance the quality of the environment have been directed towards problems caused by urban centres and industrial operations. Recently, crop and livestock production are of increasing significance as a source of water pollution. Animal excreta especially from animal feedlots and the use of agro chemicals such as fertilizers and herbicides are perhaps the largest waste product from agricultural practices.

Due to factors like topography, precipitation, cover crop, timing and location of chemical or fertilizer application and also cultivation practices, precise relationships between agricultural practices and environmental problems have been difficult to obtain.

Agricultural wastes are not discharged on a regular basis. For example, food processing wastes depend on the foods in season, feedlot and poultry runoffs, depend on rainfall frequency and intensity. The potential environmental quality problems due to agricultural operations are dependent on the production practices, methods of waste management, the size of the farm, the number of animals fed and the volume of waste involved.

The problem of excessive nutrients due to the application of fertilizers is one of the most challenging problems of water quality management. Nitrogen and phosphorus compounds (though needed in small amounts by all living things) when in excess accelerates the process of eutrophication. The form of nitrogen of greatest environmental concern in the soil is nitrate-nitrogen. It is subject to leaching and will move with the soil since the ions are soluble in the soil water (Loehr, 1974). This will eventually be a source of surface and groundwater pollution.

Other factors of concern are ammonia toxicity to fish, the nitrogeneous oxygen demand of reduced nitrogen compounds in surface waters and the altered effectiveness of chlorination by ammonia. A major problem of excessive nutrients is the stimulation of growth of algae and other aquatic plants in streams and reservoirs. As much as 0.01mg/l inorganic phosphorus and 0.3mg/l of inorganic nitrogen may cause nuisance algal growths in lakes (Harms et al., 1974).

As mentioned earlier, the pollution problem associated with livestock waste is a drainage problem. Runoff collection ponds have been suggested (Scalf et al., 1970) to reduce the sediment load and to produce an effluent with less variable characteristics. The quality of the effluent from runoff retention ponds is inadequate for release to streams or reservoirs without further treatment. For example, large quantities of runoff collected in retention ponds to a 45 - acre flood control reservoir

killed essentially all the game fish in the reservoir. The kill was caused by zero dissolved oxygen concentrations and hign free ammonia concentrations (Loehr, 1974).

Storage of manure as is the case with most farms in Nigeria, can also contaminate surface and ground waters as a result of seepage. Although the volume of the seepage may be small, the quantity of the contaminants can be significant.

Apart from nutrients pollution of surface and groundwaters, there is also the bacteriological aspect of the pollution by animal wastes. Whenever there is drainage from animal production units or runoff from agricultural lands into surface waters, a chain for the spread of zoonotic diseases is initiated. Salmonella species have been identified from runoffs from animal housings, carcasses of dead animals and according to Gibson (1967), two species, Salmonella dublin and Salmonella typhimurium were identified. S. typhimurium can infect practically all species of birds, animals and man.

The survival of pathogens on land is dependent on the viability of the organisms in the soil environment, their interaction with the soil and the nature of their transport. Salmonella species have survived for over 40 days in soil with high organic content. In the Snake River Basin, which has at least 300,000 cattle over about 5,300 square miles, the wastes from cattle feedlots were considered to be the principal source of the high bacterial counts in the River with a coliform average of

about 1000MPN/100ml and 10,000MPN/100ml (Anonymous, 1968; Robbins et al., 1972).

Also the use of untreated animal waste for farming also causes aesthetic and odour problems and an increase in the fly population. Compounds identified as parts of the odours from anaerobic poultry manure include ammonia, hydrogen sulfate, two-to-five carbon organic acids, indole, skatoles, diketones, mercaptans and sulfides (Burnet and Sobel, 1968; Merkel, 1981).

Burnet and Sobel (1968) also showed that the organic acids, mercaptans and sulfides were the major malodorous components of the odour. Odour causing compounds exist not only as gases but also as volatile materials associated with particulate matter. Analyses of the volatiles carried out in a poultry house consisted of faecal matter, feed particles, and feather and epidermal fragments.

Gas generated by microbial action in animal housings is detrimental to the health of man and the livestock concerned. The gases of greatest concern are carbon dioxide, ammonia, hydrogen sulfide and methane. Poultry houses in particular have aliphatic aldehydes and sulfur dioxide.

From the foregoing great precaution must be taken against pollution hazards in the use of animal manure as fertilizer or in the case of any form of disposal.

1.1 Objective of the Study

The objective of this study is to determine the treatability of poultry wastes by means of waste stabilization ponds (anaerobic and facultative ponds in series). The anaerobic pond pretreats the waste while the facultative pond polishes the anaerobic pond effluent.

CHAPTER 2

LITERATURE REVIEW

Poultry waste wet treatment has become a necessity because of all shortcomings of other methods of treatment highlighted in this chapter.

Besides wet treatments, a lot of dry treatments have been carried out for a long time. No one type of handling, treatment or disposal of animal excrement will serve effectively as a panacea for the multitude of situations encountered in a region of any size. Nevertheless, each situation should be studied to find the best type of waste handling system that will effectively control fly breeding and protect the receiving waters adequately (Dugan et al., 1973).

2.1 Land Spreading

The old practice of land spreading to recycle the nutrients and condition the general soil characteristics is undoubtedly the best if sufficient land is available (Hobson and Robertson, 1977). Even if handling cost and convenience are disregarded, it is not easy to appropriate the actual quantity that can be applied safely to the land without detrimental results because such results vary greatly with the soil type, vegetative cover, slope, climate and distance to receiving waters. Each individual situation needs to be studied and monitored for a period of time (Hobson and Robertson, 1977).

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2.2 Incineration

Large volume of poultry wastes can be burnt in a furnace to reduce the volume and also to get rid of the bacteria in them. Poultry wastes are autothermic, that is, once the waste is ignited, they will continue to burn without applied heat since they consist of a solids content of above 50% (Hobson and Robertson, 1977).

Different types of incinerators are available and these include multiple hearth furnace, fluidized bed furnace, rotary-drum furnace, slagging furnace and the cyclone furnace. These furnaces completely destroy the organic material of the wastes and leave only ash as a residue which is completely sterile and free from odour. The ash has little value as fertilizer although it still has potash and phosphorus, with other minerals in it. The ash can be used mainly for landfill. A large portion of the non-organic material from farm wastes is cement from pens, grit given to poultry, sand and gravel picked up from the farm.

Though incineration effectively treats poultry wastes, the cost of management of the incinerator is high (Dugan et al., 1973). All incinerators have high capacity and it is unlikely that any farm can produce enough waste per hour to meet with the hourly demand of the incinerator, hence, the purchase of incinerators may not be justified for a farm but could be feasible for a large community.

2.3 Composting

Composting is a means of recovering and reusing a portion of the nutrient and organic fraction in agricultural wastes (Loehr, 1974). Composting is a microbiological process which makes use of fundamental biological waste treatment procedures. Important factors to producing a good compost include intimate mixing of waste, small particle size, oxygen for microbial degradation of the wastes, time to accomplish the composting and moisture. Composting can be done in open windows or in enclosed controlled units. Using the controlled units, composting can be accomplished in five to seven days while in open windows, a satisfactory compost is obtainable in three to eight weeks.

Composting of poultry waste has been shown to be possible (Hobson and Robertson, 1977).

Two, one-million-bird egg producers in California used rotary drum composters with forced - draught aeration. It was found that the waste needed to be only about 35 - 40% moist because higher than this moisture content resulted in difficulties with aeration and bailing up the manure. The drums were used for curing the wastes and this took about 6 days prior to its being taken to the windrows for further treatment after which it can be used for fertilizer (Hobson and Robertson, 1977).

One draw-back to composting is that the soil conditioning and resource values of compost are often too small to make compost attractive. There is also the need to ascertain a ready market before embarking on the process (Dugan et al., 1973).

2.4 Waste Water Treatment

Conventional wastewater treatment processes can readily be used for treating animal wastes. But after treatment, there is still the need for disposal of the sludge and effluent. The use of properly designed stabilization pond (anaerobic, facultative and aerobic), either singularly or in various combinations is very applicable to the tropics.

Nemerow (1969), treated poultry wastes by means of baffled biological basins. A two stage oxidation pond system was constructed. The first stage consisted of a baffled, high rate deep pond to allow sedimentation of heavy solids, floatation of grease or feathers which escaped preliminary treatment by screens, and bacterial degradation of the organic matter. The second stage was a shallow photosynthetic pond designed to remove more organic matter and convert inorganic phosphates and ammonia to algae mass. This was a two-year research and the biochemical oxygen demand (BOD) reduction in the first year was between 75 - 92% while in the second year, it was between 85 - 95%.

Dugan et al (1972), treated poultry wastes in a closed hydraulic system (fig. 2.1). The system involved an aerobic phase in which oxygenation was accomplished either by photosynthetic activity of algae or by mechanical aeration. The algae produced were then utilized to feed the chickens as a protein supplement.

Batteried chickens' excreta was collected carefully and in a trough and flushed down into a sedimentation tank. The supernatant in the sedimentation tank was pumped directly to an algal pond while the settleable solids were collected and heated in a digester. Supernatant from the digester was discharged into the algal pond. The digested sludge was disposed of while some of the supernatant was used for flushing down the manure trough.

Lagoons for livestock wastes are usually operated anaerobically and require considerable water to dilute the wastes. From studies carried out by Vickers and Gentelli (1969), aerobic lagoons used for treating poultry wastes may achieve a BOD reduction of 85% BOD. It was reported that odours were minimized and the solids

was reduced by at least 50% and suspended solids by over 80%.

2.4.1 Waste Stabilization Ponds

Stabilization ponds are shallow ponds in which sewage effluents are stored. Natural biological action takes place during the storage period with resulting oxidation

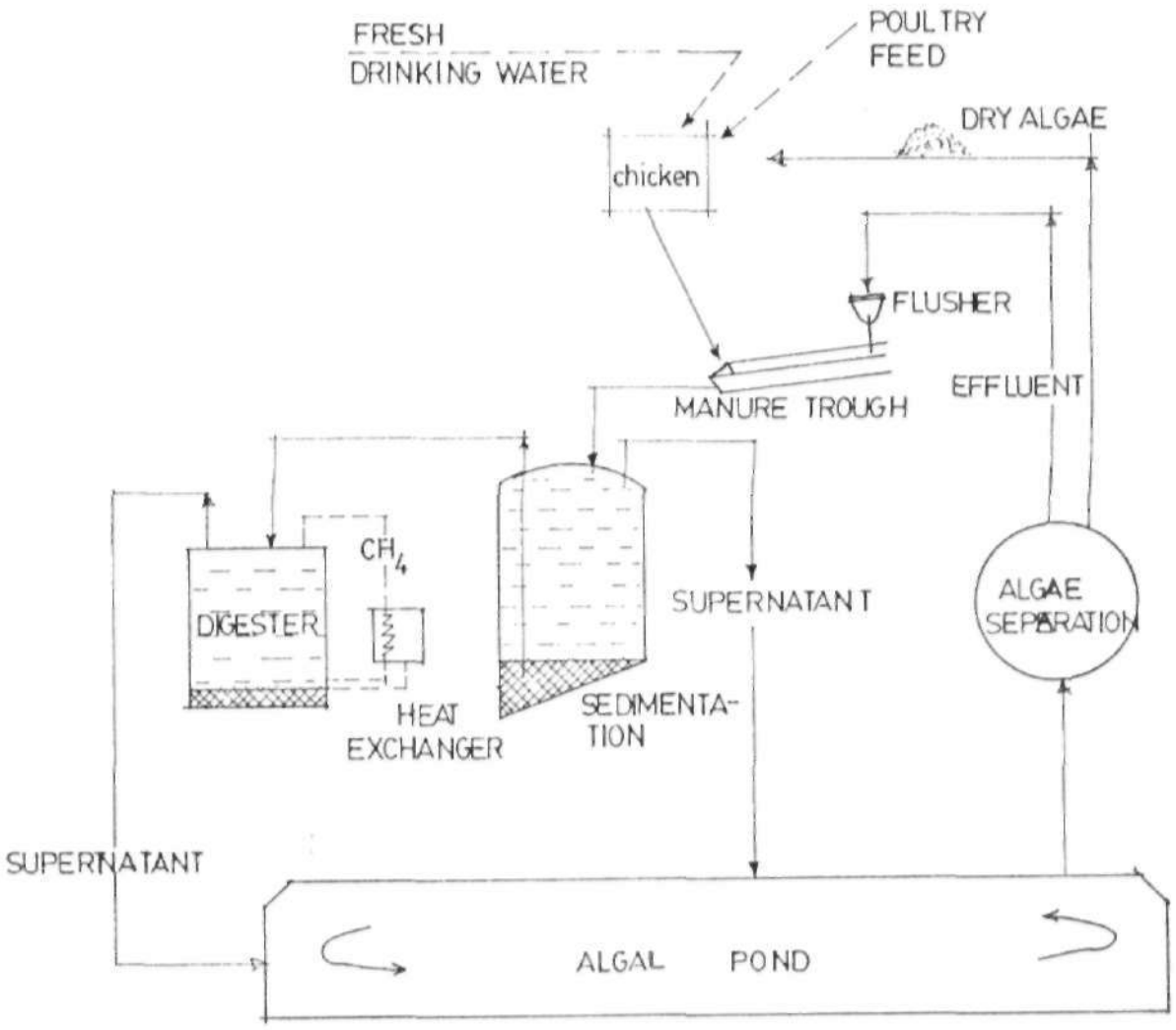


FIG 2.1: FLOW PATTERN FOR GENERALIZED PILOT PLANT

(Source: Dugan et al 1972)

and reduction of organic matter. Oxygen necessary for biological activity is got from reaeration and photosynthesis. In the presence of light, algae utilize the end products of bacterial decomposition of organic matter and liberate oxygen (fig. 2.2).

In a stabilization pond, the waste is added at a single point, either at the middle of the pond or at one end and the effluent is normally removed at a single point at the other end.

Waste stabilization ponds provide reliable and inexpensive treatment (Clyona and Tischer, 1979). Anaerobic ponds are commonly used for industrial wastes involving high biochemical oxygen demands (Hendericks and Pote, 1974). Anaerobic ponds are also adaptable for treating livestock wastes on the farm because they are economical and require very little attention. Microorganisms in the anaerobic ponds stabilize the animal waste and convert it to stable materials that can be spread on the land or used as manure.

2.4.2 Anaerobic Ponds

The anaerobic pond can be defined according to its mode of operation and/or mode of degradation.

Merkel (1981), defined the anaerobic pond as a stabilization pond that carries on the degradation of organic matter without the availability of free molecular oxygen. Oldham and Nemeth (1979), defined it as an open

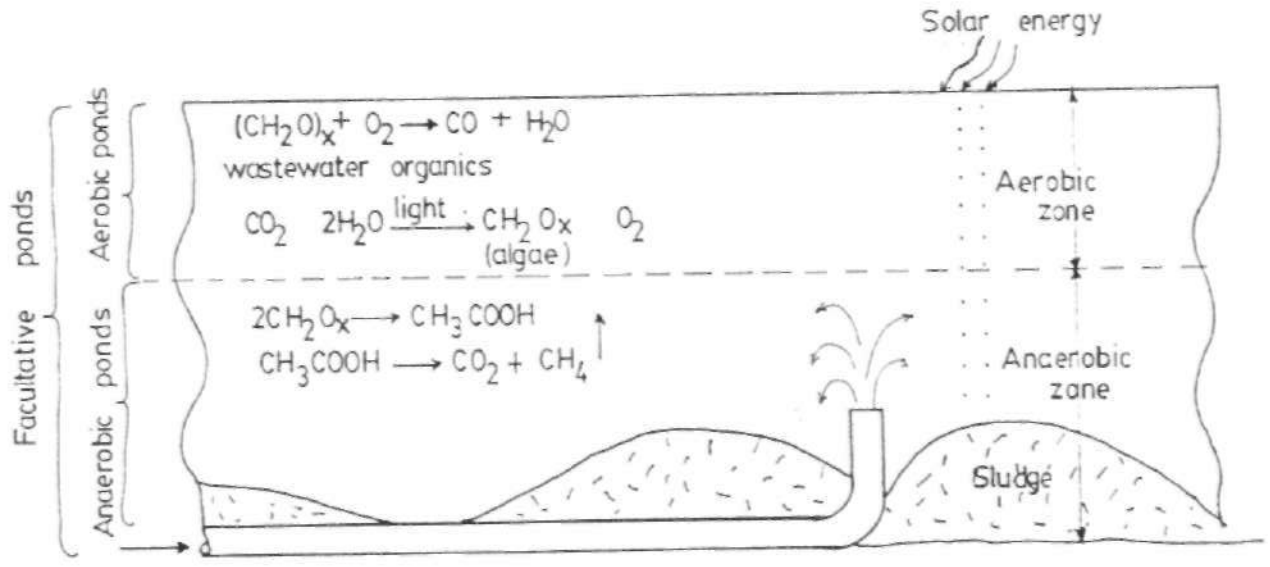


FIG 2.2 SCHEMATIC REPRESENTATION OF A WASTE-STABILIZATION POND

(Source : Metcalf and Eddy 1976)

non-heated digester and if properly designed, an anaerobic pond can remove 30 - 90% of the BOD.

In the anaerobic lagoon, both facultative and anaerobic bacteria are present. The stabilization of organic materials under anaerobic conditions is carried out through several stages starting with hydrolysis and ending with gas production (figs. 2.3 and 2.4). Hydrolysis or digestion is the breakdown of organic molecules into smaller molecules. The molecules are rendered soluble in order to facilitate absorption through the cell. The end product of hydrolysis depends on material being metabolized. Gas is usually the end product and methane and carbon dioxide are mostly produced (Hammer, 1975).

The facultative bacteria convert the complex organic compounds into simpler organic compounds, primarily organic acids. In order for further digestion to occur, second stage gasification is needed to convert the organic acids to methane and carbon dioxide. During the acid producing stage, no appreciable reduction in organic materials occurs as what takes place is a chemical rearrangement of the organic molecules. Methane is a common and abundant product of the action of microorganisms and the product is not dependent upon the nature of the substrate. If the process stops here, the accumulated acids would lower the pH and would

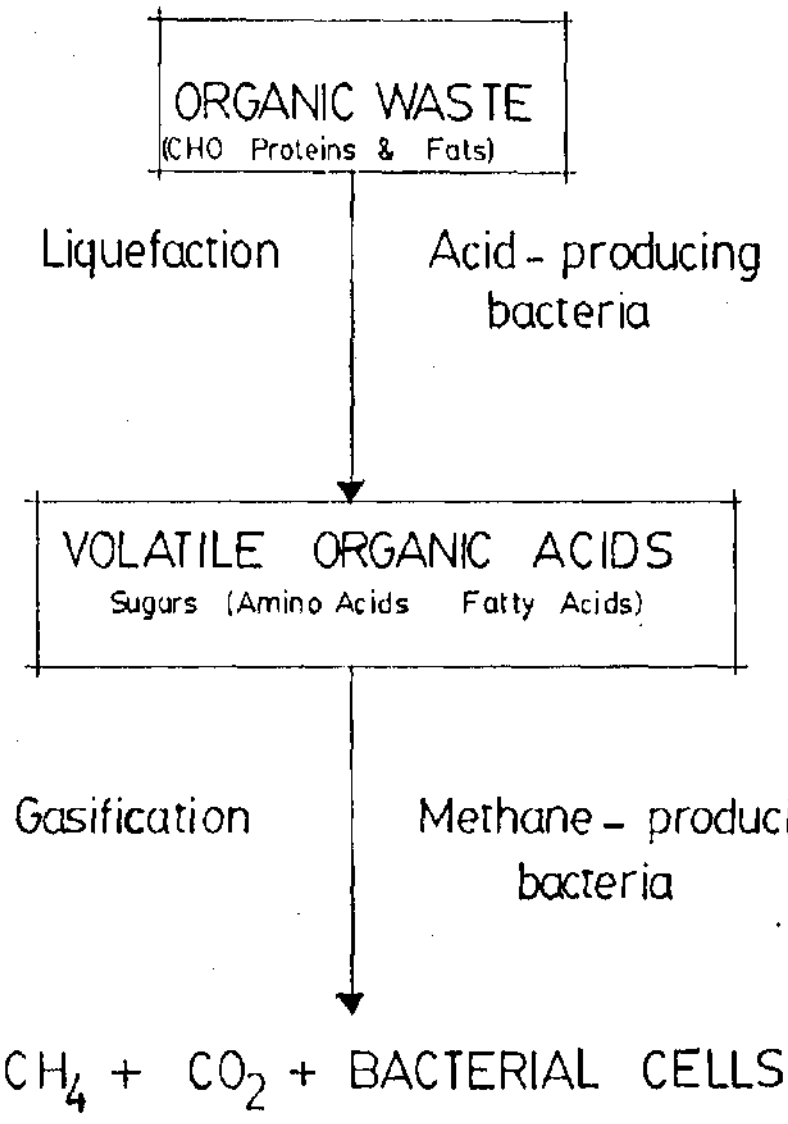


FIG 2.3: SCHEMATIC DIAGRAM OF ANAEROBIC DECOMPOSITION

(Source : Merkel 1981)

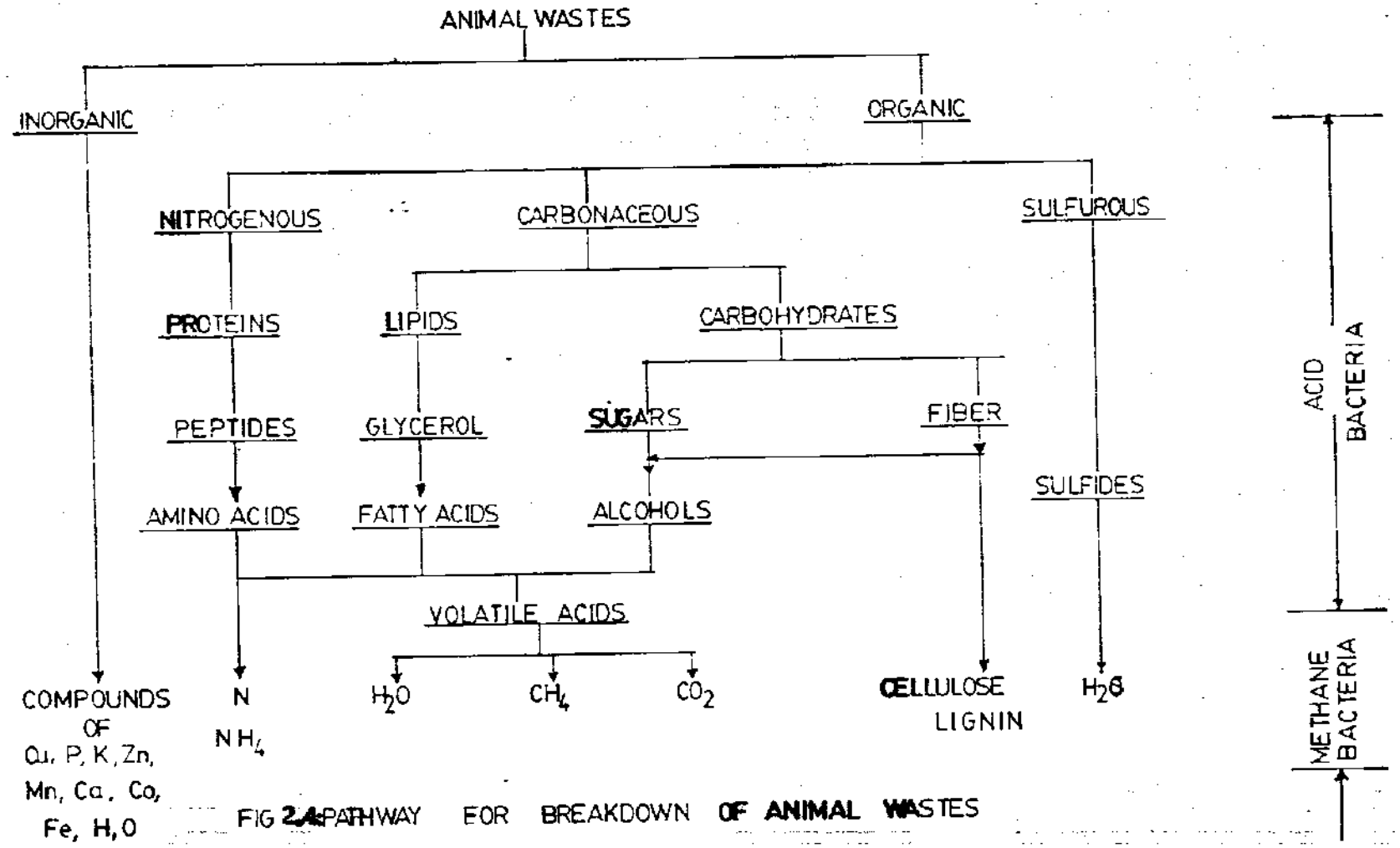


FIG 2.4 PATHWAY FOR BREAKDOWN OF ANIMAL WASTES

(Source : Merkel 1981)

inhibit further digestion by pickling the remaining raw wastes (Merkel, 1981).

Acid splitting methane forming bacteria are strict anaerobes and are very sensitive to environmental conditions like temperature, pH and anaerobiosis. They also have a slower growth rate than the acid formers and are very specific in food supply requirements. Stability of the digestion process relies on proper balance of the two biological stages (Hammer, 1975).

The gas production stage is responsible for the stabilization of organic materials and as such danger is indicated when there is reduction in the quantity of gas produced, sharp rise in temperature and/or pH changes.

According to Hammer (1975), the main advantage of anaerobic treatment compared with the aerobic process is the low production of waste biological sludge. Anaerobic treatment is suitable for the tropics because of the prevalent high ambient temperatures. There are important characteristics which a waste water has to meet to be amenable to anaerobic treatment. These include: high organic content particularly in proteins and fats; relatively high temperature, freedom from toxic materials and sufficient nutrients. The raw waste water may be pretreated before discharge into the anaerobic pond by screening to remove coarse solids. The influent wastes should enter the pond through the bottom so that it mixes with the active microbial solids in the sludge blanket. Located on the opposite end and submerged below the grease cover is the discharge pipe. Upflow of the discharge

allows settling of the bacterial floc so that the anaerobic mixed liquor is retained (fig. 2.5).

The fear of odour release from anaerobic ponds is always present. Yet odour release is unlikely to reach nuisance threshold if the BOD loading is less than 400g/m^3/day (Meiring et al., 1968), and if the alkaline methane fermentation is established so that the predominant species of sulphide present is the odourless sulphide ion (McGarry and Pescod, 1970). A deep pond is more conducive to the establishment and maintenance of alkaline fermentation than is a shallow one. Moreover a deep pond, provided it has sufficient retention time behaves as if its upper half were a facultative pond floating on a lower anaerobic pond (Wachs and Berend, 1968). This is a particular advantage in odour control as any maladorous compound which escapes from the anaerobic section is promptly oxidized in the oxygenated facultative layers.

Lagoons for livestock waste require considerable water to dilute the waste and as such, the land required for the disposal of the effluent would be large. Anaerobic lagoons have been used with success to pre-treat animal wastes. The first step in the breakdown of animal wastes is marked by the rapid disappearance of the available oxygen. Urea, ammonia and other products of digestive putrefactive decomposition are partially oxidized rapidly consuming the available oxygen and causing the wastes to become anaerobic. The second

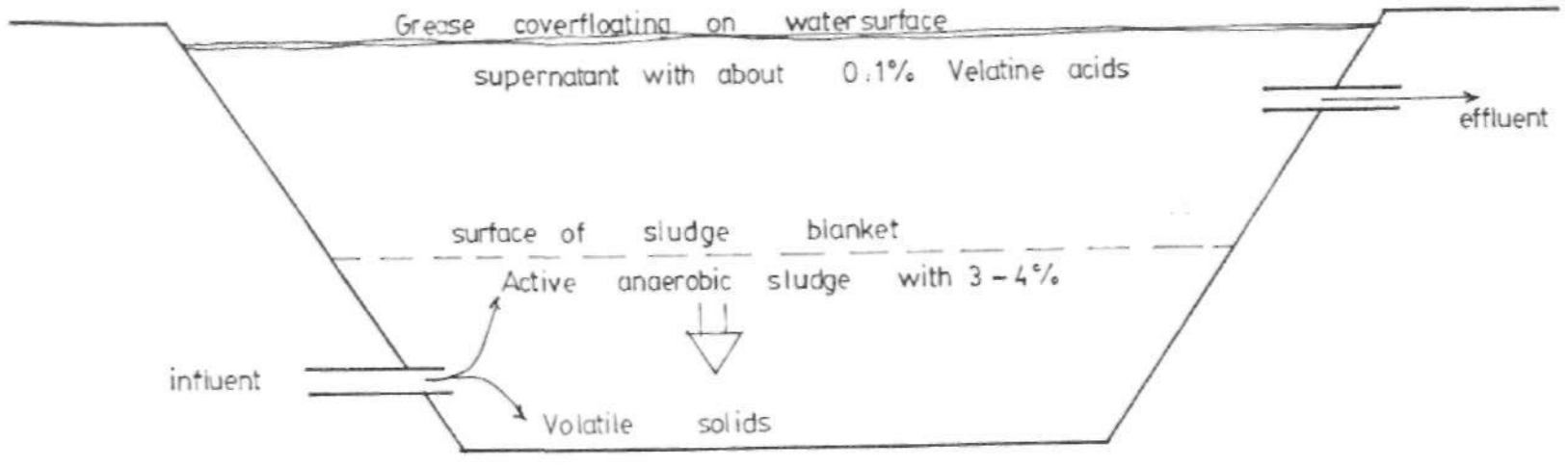


FIG 2.5:SCHEMATIC DIAGRAM OF AN ANAEROBIC LAGOON

(Hammer 1975)

stage is putrefaction in which the action is under anaerobic conditions. Proteins are broken down to form urea, ammonia, the foul-smelling mercaptans, hydrogen sulfide, aliphatic and aromatic acids, amines and amides, fats are broken down into their original fatty acids, water, carbon dioxide, hydrogen, methane and other substances. The third stage is the oxidation or nitrification of the products of decomposition resulting from the putrefactive stage, into nitrates and nitrites which are stable forms of plant food. On treating animal wastes, Topey (1955) and Estrada (1960) found that under optimum environmental conditions, and at five-day detention time, a 70% reduction of the biodegradable organics was achieved and on increasing the detention time to 10 days, a 90% reduction was achieved. Anaerobic ponds are also used to treat wastes which have nigh concentrations of solids (Metcalf and Eddy, 1979).

The loading for the anaerobic pond depends on geograpnical location as well as the constituents of the waste (Merkel, 1981). Various loading rates for anaerobic pond have been used. These vary between 250 and 680kg BOD_5/ha/d (Cooper et al., 1965); 114kg BOD_5/ha/d during winter and 455kg BOD_5/ha/d for summer conditions (Oswald, 1968); 1136kg BOD_5/ha/d and 2045kg BOD_5/ha/d (Parker, 1962) with impressionable percentage removals. On treatment of cannery wastes, Parker and Skerry (1971), found that on loading 128kg BOD_5/ha/d a 75 - 90% removal was obtained.

2.4.1.1 Design of Anaerobic Ponds

Anaerobic breakdown in septic tanks, aqua privies and anaerobic ponds appear to be identical (Glyona, 1971), and so the adaptation of the aqua privy designs to the design of anaerobic pond is appropriate (Mara, 1976).

a) South African Procedure (Vincent, 1963):

In septic tanks and aqua privies, the biochemical oxygen demand reduction can be approximated by the equation below:

$$Lp = \frac{L_o}{K_n \left(\frac{Lp}{L_o}\right)^n R + 1} \qquad 2.1$$

R = detention time for completely mixed system (days)

n = exponent, to be determined by experimentation (for Zambia n = 4.0)

K_n = design coefficient

T = 20^oC

L_o = biochemical oxygen demand of influent into the system.

Lp = expected value of biochemical oxygen demand from the system.

b) Design Guidelines Used in Israel:

In Israel, anaerobic ponds are systematically used for pretreatment of domestic waste waters (Watson, 1962). The general guidelines used by the Israeli Ministry of Health are as follows:-

Primary anaerobic pond: 125kg $BOD_5/1000m^3/d$

Depths are normally 1.2 - 1.5m.

c) Design used by the Melbourne Water Science Institute, Australia:

The ratio between the area of facultative and anaerobic ponds appears to be a significant design factor in Australia (Parker, 1962), where facultative to anaerobic ratios between 10:1 and 5:1 are found useful.

d) Fisher et al. (1977) developed a method for the design of anaerobic lagoons based on degree-days. Degree days is the number of degrees the lagoon is above $10^{o}C$ for each day of the year. The degree-days are compared with the ideal situation for an anaerobic digester according to the relationship.

$$LR = \frac{(DD)^2 \, LR_D}{83.3 \times 10^6} \qquad 2.2$$

where

LR = Loading rates for lagoons (gVs/litre - day)

DD = degree - days for lagoon.

LR_D = established loading rate for an anaerobic digester (gVs/litre - day).

The loading rate is commonly based on various sizes and species of animals (table 2.1), and expressed as mass of volatile solids per unit volume per day.

Table 2.1: Established Loading Rates for Anaerobic Digestion

Species	Loading Rates (gVs/litre-day)
Dairy	6.0
Beef	4.5
Swine	3.0
Poultry	1.5

Source: Merkel, 1981.

2.4.3 Facultative Ponds

Earlier in this century, according to Merkel (1981), livestock producers, constructed aerobic lagoons as part of their waste handling system. These lagoons were mostly underdesigned and quickly became anaerobic, creating serious odour problems. Mechanical aeration was added in an attempt to supply an additional amount of oxygen and to at least keep the surface aerobic. This gave rise to the existence of facultative ponds.

Facultative ponds are stabilization ponds in which the upper layer is aerobic, the central area support facultative

bacteria and the bottom sludge zone consisting of a layer of settleable solids.

The facultative lagoon provides an aquatic environment in which photosynthesis and surface oxygenation supply an aerobic zone in the upper strata, a facultative portion throughout the central portion, and an anaerobic sludge layer at the bottom. More often than not, the photosynthetic activity is the major source of oxygen in the facultative pond. This takes place under the influence of solar radiation. Surface aeration by wind action also takes place in large surface pond. Effective light penetration is normally less than one metre and as such oxygen generation is usually confined to the upper portion.

The heavier suspended solids including biologically formed flocs are allowed to settle on the bottom and undergo anaerobic decomposition. The liquid and gaseous products of decomposition released from the sludge layer are carried by the circulating mixture through the facultative zone and into the aerobic zone. The gases are here utilized by the aerobic bacteria, preventing the release of obnoxious gases to the atmosphere. Wind action is normally the principal source of mixing the water in these ponds, but where the wind is not of significant speed, differential heating also aids mixing (Mara, 1976). When the surface is heated, the density reduces and it sinks downward while the colder part underneath rises up.

Oxygen is maintained in the upper layer by the presence of algae. The organic load must not exceed the amount of oxygen being supplied or else the pond will turn anaerobic all through.

2.4.3.1 Design of Facultative Ponds:

Most facultative lagoons on the farms have been sized according to recommendations based on load per unit area. For a more sophisticated approach, an empirical or a rational formula may be used. Many design equations have been published, but there is no universal equation. This is because to a large extent, the process is undefined because of variableness of nature. For example all predictive equations for effluent quality are essentially meaningless when windy conditions prevail and under such conditions, the effluent quality will be a function of the degree of wind mixing and the quantity of the deposited solids that have been suspended (Frank et al., 1979).

Some design procedures are presented below:-

a) South African Procedure (Marais and Shaw, 1961):

In South Africa, it was noted that

i) The effluent biological oxygen demand remained substantially constant irrespective of seasonal variations in temperature.

ii) Anaerobic condition developed during hot season and in the cold seasons, the facultative ponds operated satisfactorily.

In South and Central Africa, the maximum biochemical oxygen demand load for a facultative pond was initially related to the depth and according to Gloyna (1971):-

$$BOD_{Load} = \frac{600}{2d + 8} \qquad 2.3$$

where

d = depth

The effluent biochemical oxygen demand can be evaluated using

$$Lp = \frac{L_o}{0.17R_T + 1} \qquad 2.4$$

Lp = effluent BOD

L_o = influent BOD

R_T = Retention time

Table 2.2 shows the relationship between recommended depth and environmental conditions.

Table 2.2: Recommended depth of facultative ponds in Relation to Environmental Condition and Type of Waste

Recommended Depth (m)	Environmental Condition and type of Waste
1.0	Uniform warm Temperature; pre-settling waste water.
1.0 - 1.5	Uniform warm temperature; Untreated waste water.
1.5 - 2.0	Moderate seasonal temperature fluctuation - raw waste water containing settleable solids
2.0 - 3.0	Wide seasonal temperature variations, large amounts of settleable grit or settleable solids

Source: Gloyna (1971)

b) Procedure based on Suggestions by the Central Public Health Engineering Research Institute (CPHERI), India:

In tropical India, the design of facultative waste stabilization ponds for domestic waste waters has been based on a loading of 336kg BOD_5/na/d and on operating depth of 1.22m. Studies by the Institute have shown a BOD reduction of about 70 - 85%. To achieve a BOD reduction of about 90%, usually requires an increase in detention time. The average sludge build up is 2 - 4cm per year.

c) Empirical Procedure:

The required volume of a facultative pond can be estimated if the coldest month of the year is known, and cloud cover does not last for more than a few days at a time. The intensity of light, total dissolved solids, winds may influence the required pond volume. Temperature is the most important single consideration if the wastewater is domestic sewage. The basis of procedure is according to Gloyna (1971):

$$V = 3.5 \times 10^{-5} Nq\ L_a\ \theta^{(35 - Tm)} \qquad 2.5$$

where:

V = pond volume (m^3)

N = number of people contributing waste

q = per capita output waste contribution (litres/day)

θ = temperature reaction coefficient = 1.085

T_m = Average water temperature of coldest month in ^oC.

The organic load is a function of N, q and L_a and can be expressed by

$$\theta_L = Nq(L_a \times 10^{-6})$$

where:

θ_L = organic Load in $kgBOD_5/ha/d$

L_a = Biochemical oxygen demand of the waste.

A large volume is required for some industrial wastes due to the fact that they are not readily biodegradable and because they may be toxic to algae.

d) Load per unit Area Procedure:

Foul odours may occur as a result of extremes in seasonal temperatures, uneven distribution of settleable solids, inadequate surface area and liquid depth (Gloyna, 1971). The source continues that while maintenance of liquid depends primarily on the control of seepage and evaporation, the distribution of settleable solids can be improved through the use of multiple inlets and deeper ponds (1.5m - 2.0m). The operation of the entire system depends on the volumetric loading, BOD loading per unit area, and the concentration of organic matter in the wastewater. If the water content is low, it becomes difficult to maintain sufficient liquid over the settled solids. In this situation water needs to be added and the pond designed to function without any overflow (Table 2.3)

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Table 2.3: Generalized BOD loading per unit area per day under various climatic conditions.

Surface loading kgBOD/ ha/d	Population per hectare	Detention time (days)	Environmental conditions
Less than 10	Less than 20	More than 20	Frigid zones with seasonal ice cover, uniformly low water, temperature and variable cloud cover.
10 - 15	200-1000	200-100	Cold seasonal climate with seasonal ice cover and temporary summer temperatures, for short season.
50-150	1000-3000	100-33	Temperature to semi-tropical, occassional ice cover, no prolonged cloud cover.
150-350	3000-7000	33 - 17	Tropical uniformly distributed sunshine and temperature and no seasonal cloud cover.

Source: Gloyna, 1971.

2.4.4 Maturation Ponds

These are shallow fully aerobic ponds with very low organic loadings of less than .01kg $BOD_5/m^2/d$. They are used as a secondary stage of treatment following a facultative pond. They can also follow any other biological treatment unit. Large algal growth occur here but their most important feature is the high removal of pathogenic bacteria because of the unfavourable environment for such organisms in the pond. (Tebutt, 1983). The residual solids are endogeneously respired, and ammonia is converted to nitrate using the oxygen supplied from surface reaeration and from algae. To provide a reliably nitrified effluent that is low in BOD and suspended solids, an efficient and reliable effluent solids removal process will be required (Metcalf and Eddy Inc, 1975).

2.5 Hydraulic Flow Patterns in Waste Stabilization Ponds

Thirumurthi (1969), asserts that flow patterns have not been given much attention in research. Hydraulic flow characteristics have an effect on molecular and turbulent diffusivity as well as on detention time, and eventually on BOD removal efficiency.

The flow patterns include the plug flow pattern, the dispersed and completely mixed flow patterns. The plug flow is an ideal case of a fluid flowing through a long rectangular tank. No lateral diffusion or mixing

takes place and a given mass of liquid passes through the tank without lateral disturbance. All elements are moving with equal velocity and so none passes another (Fig. 2.6). A chemical reactor with plug flow is characterized by a first order chemical reaction equation, given by Thirumurthi (1969) as

$$\frac{C_e}{C_i} = e^{-Kt} \qquad 2.7$$

where:

C_e = effluent concentration

C_i = influent concentration

K = first order reaction constant

t = detention time or mean residence time.

A completely mixed reactor experiences a great amount of mixing he contents are of uniform composition. This is normally accomplished by attaching paddles to mix the ponds (fig. 2.7). The design equation representing the completely mixed flow pattern is given by Thirumurthi (1969) as

$$\frac{C_e}{C_i} = \frac{1}{1 + Kt} \qquad 2.8$$

C_e = effluent concentration

C_i = influent concentration

K = first order reaction constant

t = detention or mean residence time.

The two flow patterns described above represent the extreme flow patterns. It has been suggested that for a waste stabilization pond, an intermediate system is more applicable. This intermediate system described as dispersed flow pattern (fig. 2.8). Wehner and Wilhem (1959) derived an

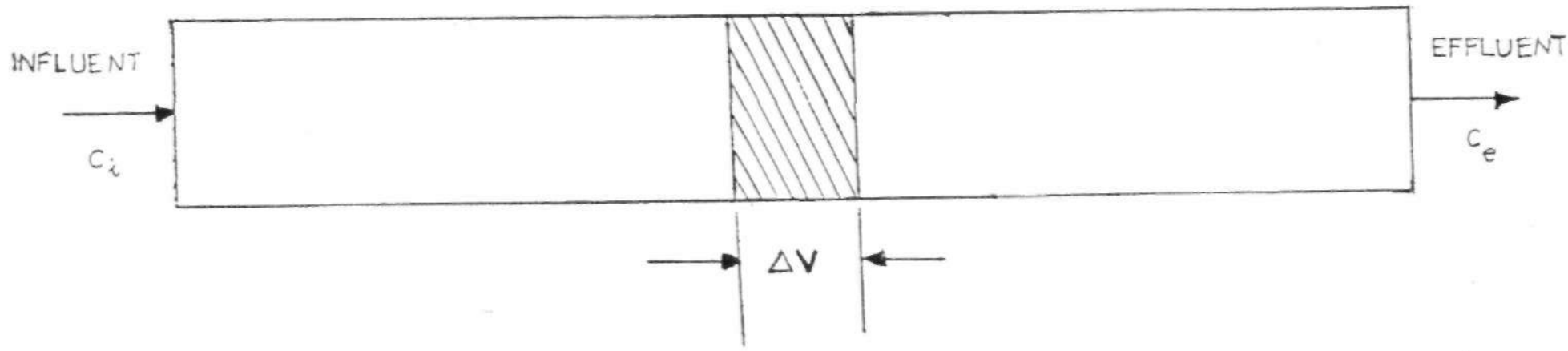


FIG 2.6: FLOW REGIMES IN PONDS (PLUG FLOW)

(Source : Thirumurthi 1969)

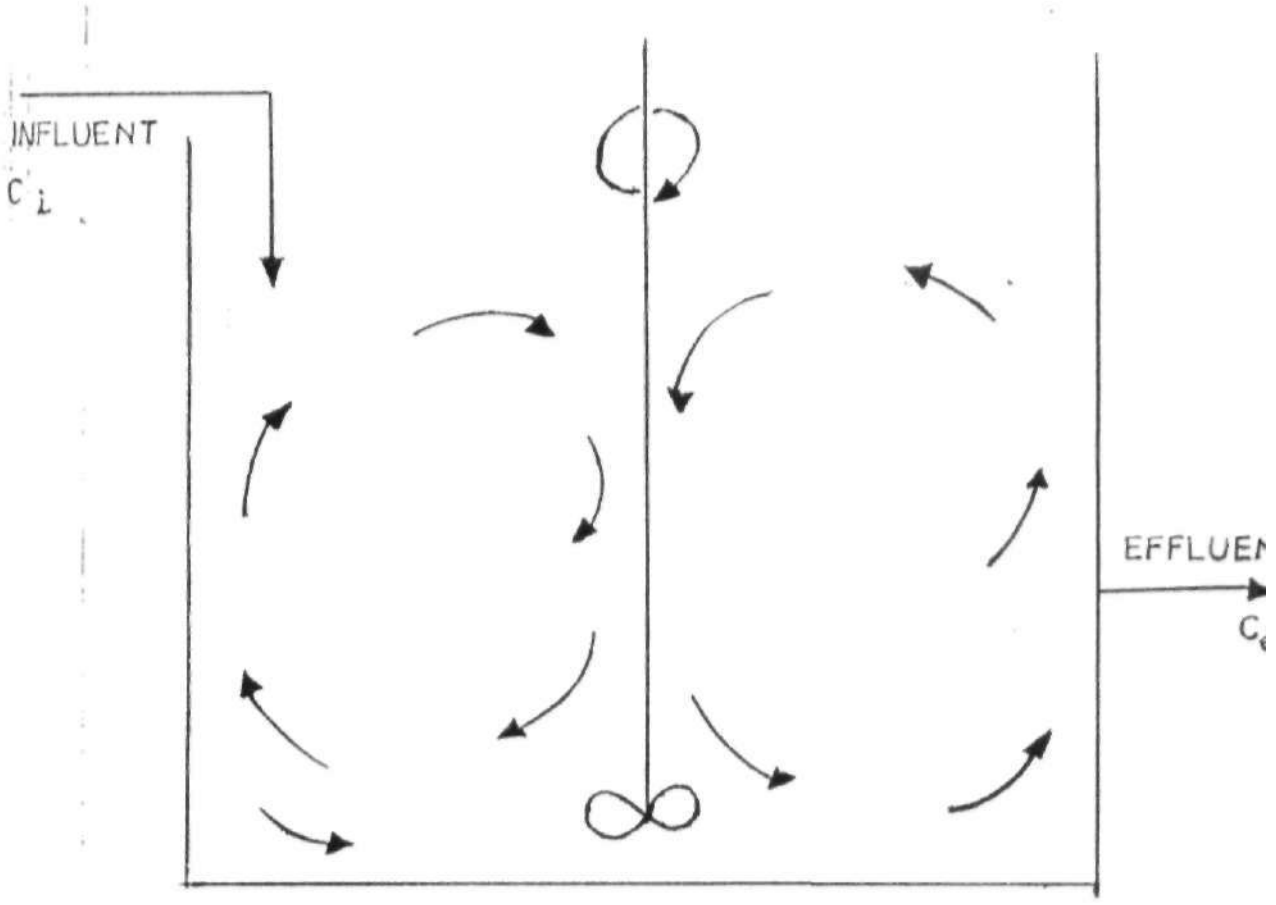


FIG 2.7: FLOW REGIMES IN POND

(COMPLETE MIXED FLOW)

(Source : Thirumurthi 1969)

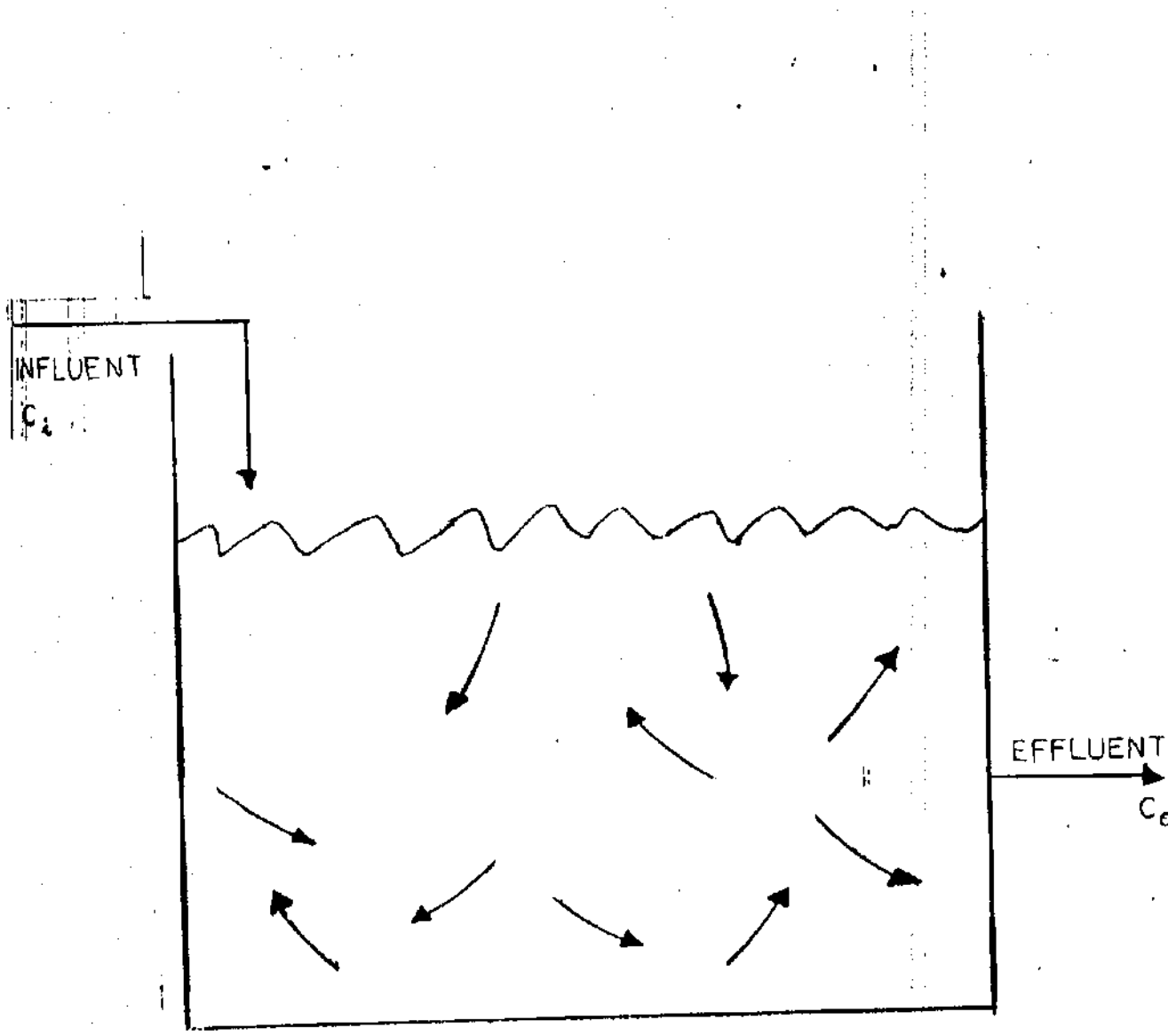


FIG 2.8: FLOW REGIMES IN POND

(DISPERSED FLOW)

(Source : Thirumurthi 1969)

equation for chemical reactors which exhibit a dispersed mixing property as

$$\frac{C_e}{C_i} = \frac{4ae^{\frac{1}{2}d}}{(1+a)^2 e^{a/2d} - (1-a)^2 e^{a/2d}} \qquad 2.9$$

where

$$a = 1 + 4Ktd$$

$$d = \frac{D}{UL} = \frac{Dt}{L^2}$$

and

d = diffusivity constant or dispersion number (dimensionless)

D = axial dispersion coefficient (Sq ft per hour)

U = fluid velocity (ft per hour)

L = characteristic length of travel path of a typical particle in the tank (ft.).

The formula may also be simplified to give by Thirumurthy (1969) as

$$\frac{C_e}{C_i} = \frac{4_{ae}(1-a)/2d}{(1+a)^2} \qquad 2.10$$

Equation 2.9 should be used to design biological waste treatment systems. This equation is computed for use and so a design formula chart was prepared as shown in Fig. 2.9.

With the approximated equation 2.10 the error may be significant when value of d exceeds 2.0 but for waste stabilization ponds, d seldom exceeds 1.0 because of low hydraulic loads (Thirumurthy, 1969).

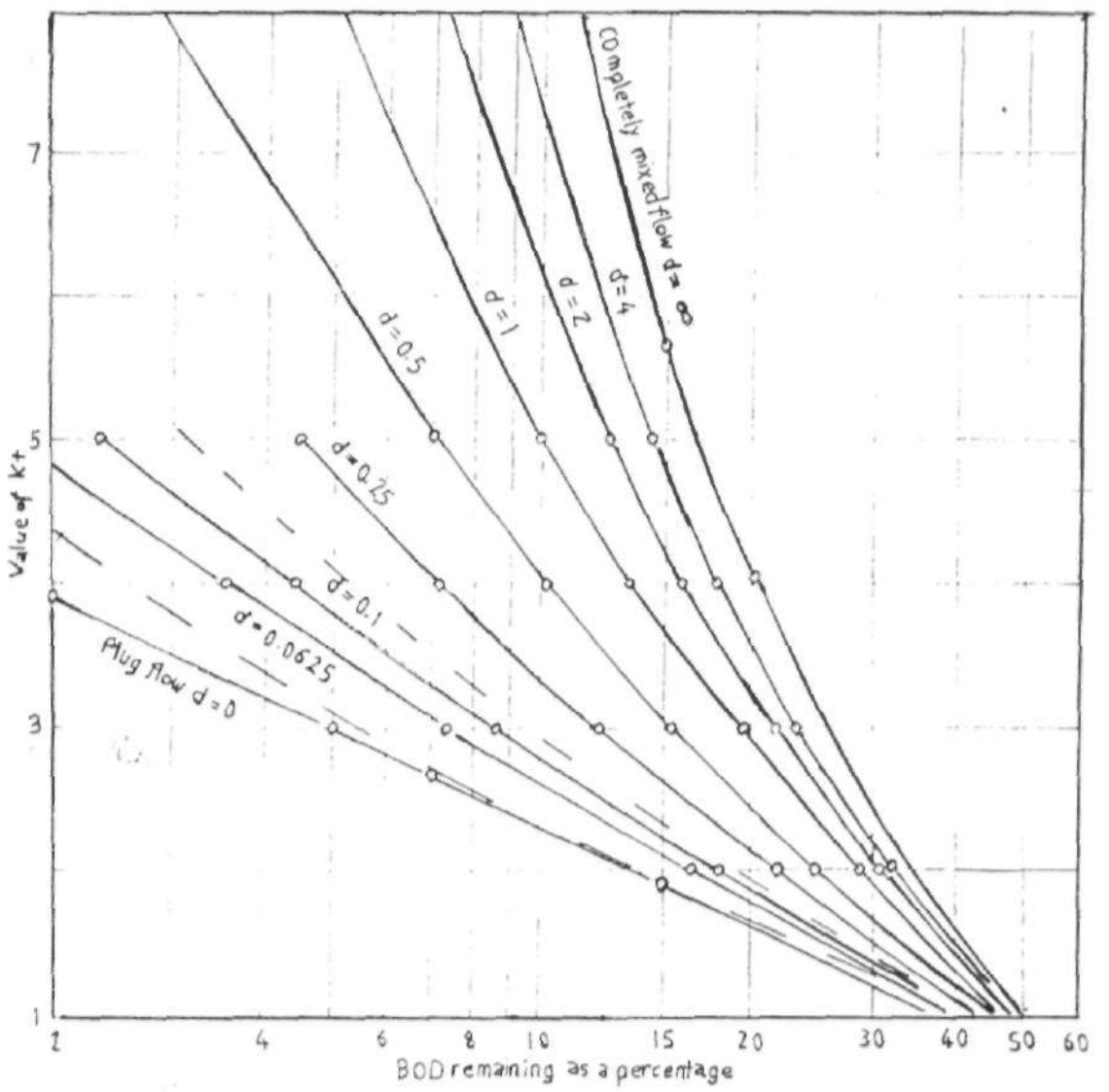


FIG 2.9: THIRUMURTHI CHART FOR WEHNER-WILHELM EQUATION. (Wehner and Wilhem 1959)

2.6 Definition of Parameters

2.6.1 The Nitrogen Cycle:

This study is on an agricultural waste and as such, the nitrogen cycle becomes an important phenomenon. This is because, any treatment process being used to treat animal waste in general or poultry wastes in particular revolves round the nitrogen cycle, this makes a good knowledge of the processes involved important (Fig. 2.10).

Nitrogen is one of the most important nutrients to the growth of plants even though trace quantities of other elements such as iron, are also needed for biological growth.

The nitrogen present in fresh waste water is primarily combined in proteinaceous matter and urea or uric acid in the case of poultry waste. Decomposition by bacteria readily changes the form to ammonia. The ammonia can then be oxidized to nitrites and then to nitrates. The predominance of nitrate nitrogen in waste indicates that the waste has been stabilized with respect to oxygen demand. Nitrates can be used by algae and other aquatic plants to form plant protein which in turn can be used by animals to form animal protein. Death and decomposition of the plant and animal protein by bacteria again yields ammonia.

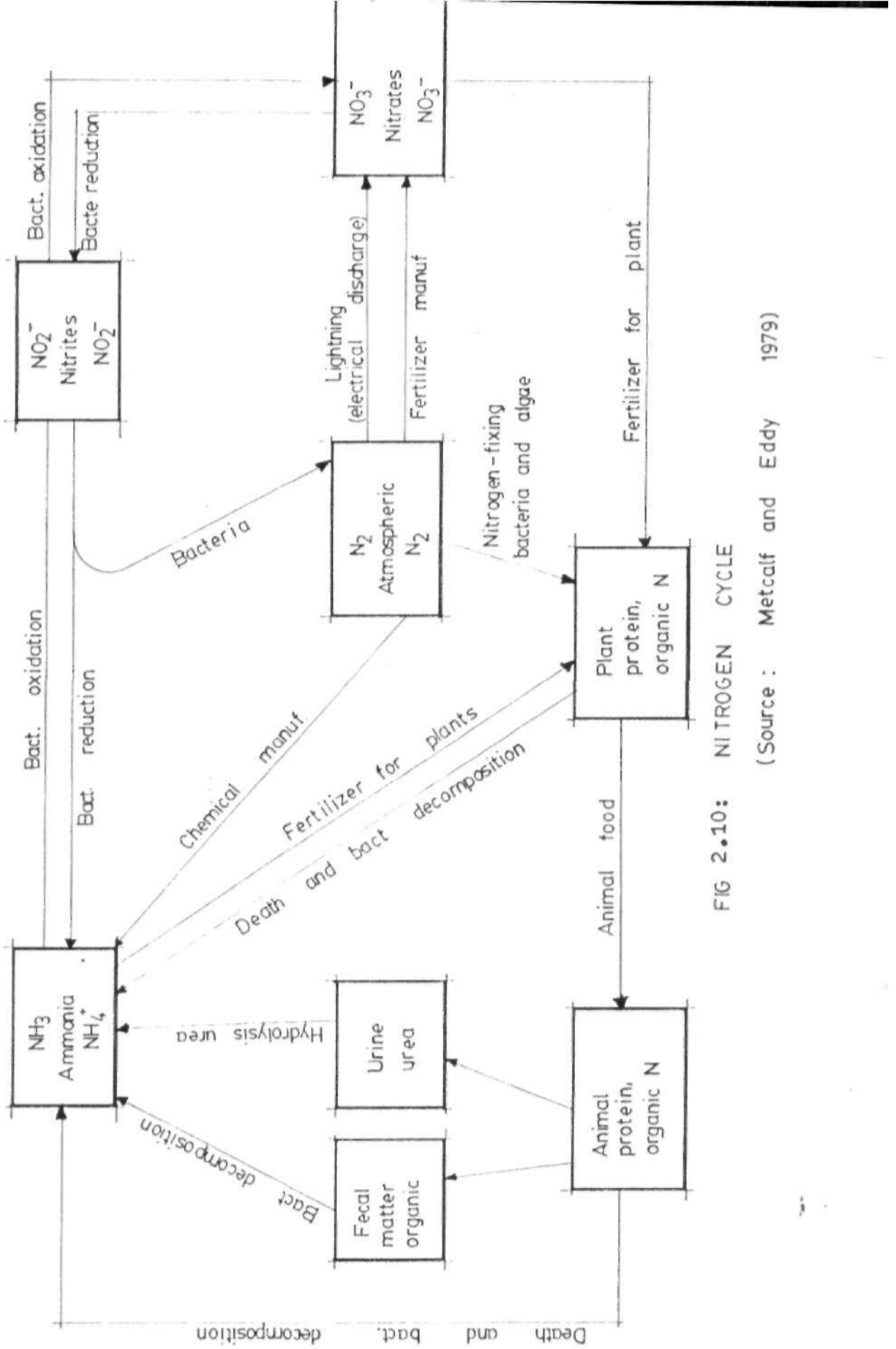


FIG 2.10: NITROGEN CYCLE

(Source : Metcalf and Eddy 1979)

2.6.2 Phosphorus

Phosphorus is essential to the growth of algae and other biological organisms. This leads to abundant algae growth and to prevent this, the quantity of phosphorus from domestic and industrial sewage and agricultural runoff should be controlled. Phosphorus is usually present in aqueous solutions in the form of orthophosphate, polyphospnate and organic phosphates. The orthophosphates are available for biological metabolism without further breakdown (Metcalf and Eddy, 1979).

2.6.3 Total Coliform

Coliforms are countless rod - shaped bacteria found in the intestinal tract of man and animals. They are harmless to man and are useful in destroying organic matter in biological waste treatment processes. But because the number of pathogenic organisms in wastes and polluted waters are few and difficult to isolate, the coliform organisms which are more numerous and more easily found, are used as an indicator organism. The presence of coliform organisms is seen as an indication that pathogenic organisms may also be present, and the absence of coliform organisms is taken as an indication that the water may be free from pathogenic organisms (Metcalf and Eddy, 1979).

2.6.4 pH

The hydrogen - ion concentration is an important quality parameter of both natural waters and waste waters. The concentration range suitable for the existence of most biological life is quite narrow. Waste water with and adverse concentration of the hydrogen ion is difficult to treat, and so before treatment, the pH has to be adjusted (Metcalf and Eddy, 1979).

2.6.5 Sulphate

These occur naturally in most waters and is also found in the waste waters. Sulphates reduce to sulphides in digesters and may offset biological process if the concentration is too high (Metcalf and Eddy, 1979).

CHAPTER 3

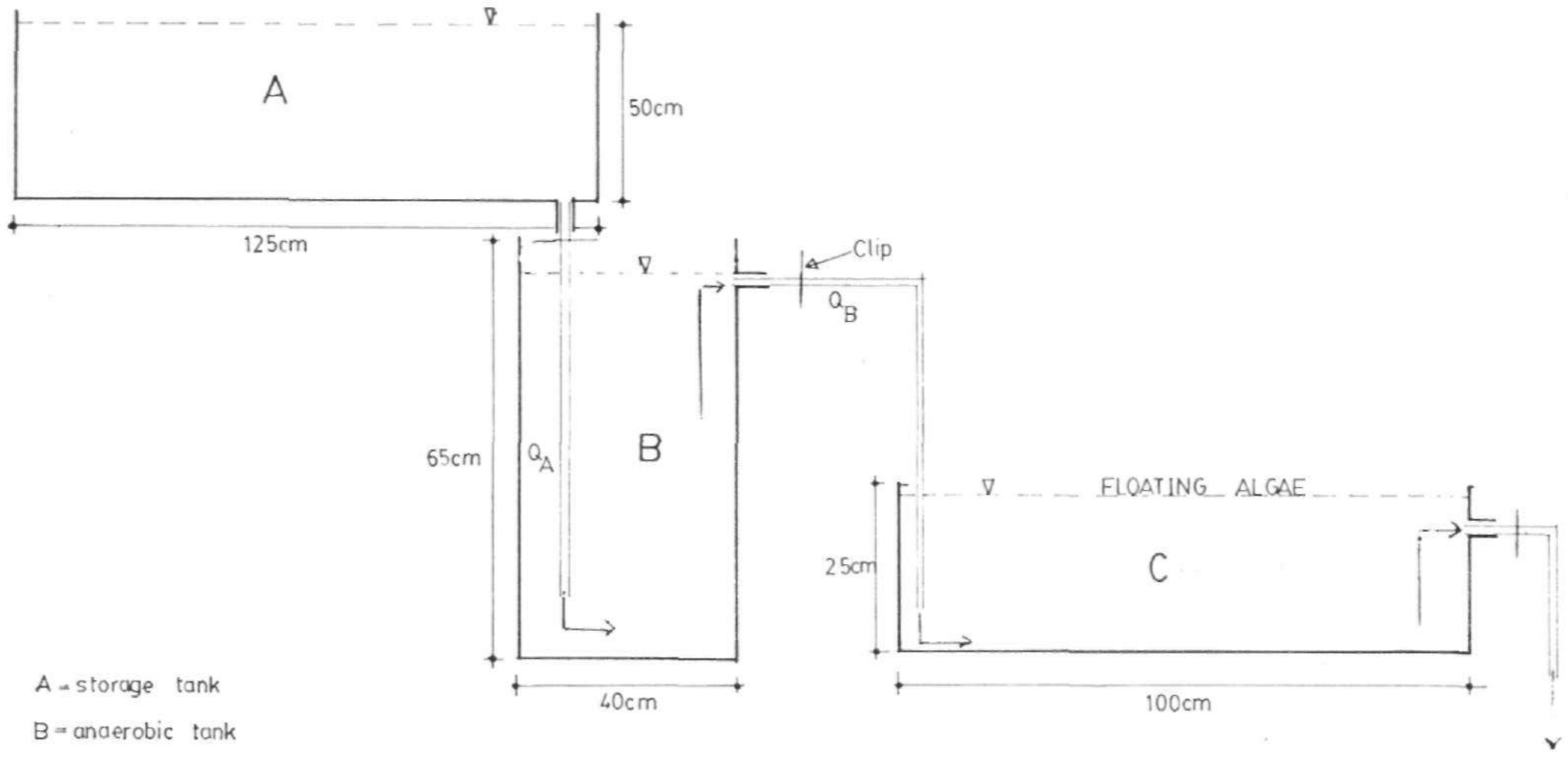
MATERIALS AND METHODS

3.1 Materials

The experimental set up consisted of three tanks namely:- the storage tank, an anaerobic and a facultative tank.

The storage tank was made of galvanized iron and measured 125cm x 50cm x 25cm. The anaerobic pond was made of perspex glass and had a working capacity of 60 litres (65cm x 40cm x 25cm). The facultative pond was also made up of perspex glass with a working capacity of 50 litres (100cm x 50cm x 10cm). The anaerobic tank was covered with a black polythene to prevent the entrance of light rays. Light was provided for the facultative pond by six 100 watts flourescent bulbs located above the liquid surface. The tanks were connected in series and arranged to allow for a gravity flow. Rubber tubings were used to connect the ponds while adjustable clips were used to regulate the flow system. The arrangement for the inflow into the anaerobic pond was such that the sediments at the bottom of the anaerobic tank was not distributed. The experimental set up is shown in Figure 3.1.

The poultry wastes was used as the substrate. It was collected from the National Animal Production and Research Institute, Ahmadu Bello University, Zaria located in Shika.



A = storage tank

B = anaerobic tank

C = facultative tank

$Q_A = Q_B$

FIG 3.1: FLOW PATTERN OF TREATMENT PLANT

3.2 Method

A slurry of poultry waste was made by grinding five grams of the waste and mixing thoroughly with some quantities of tap water. The mixture was then made up to 1 litre with tap water. This concentration of feed water gave an influent BOD_5 within the range of 91mg/l to 96mg/l. At each feed preparation, this concentration was maintained throughout the experimental runs.

During the initial start up of the experiments, the anaerobic pond was filled with 30 litres of tap water, 20 litres of raw sewage from the Ahmadu Bello University sewage treatment plant and 10 litres of poultry waste slurry. The raw sewage waste was used as seed in order to provide adequate bacteria required for the waste treatment. The facultative pond was also filled with tap water and seeded with raw wastes and algae obtained from the Ahmadu Bello University waste treatment plant and some quantity of poultry waste slurry. The contents of the ponds were thoroughly mixed and left for some days for algal suspension to develop in the facultative pond.

The test runs of experiments were carried out under batch flow conditions. The poultry waste slurry was admitted by gravity into the anaerobic pond from the storage tank at average flow rates of 12, 6, 4, 3 litres per day providing retention times of 5, 10, 15, and 20

days respectively. The effluent from the anaerobic pond was admitted by gravity into the facultative pond at the same flow rate as for the anaerobic pond. Sampling of the effluent from the anaerobic and the facultative ponds began after the initial contents of the pond appears to have been flushed out completely. Similar procedure was adapted for the facultative pond which received the effluents from the anaerobic pond.

The influent poultry waste into the anaerobic pond was analysed for the following parameters in accordance with American Public Health Association (1971, 1985) for the determination of water and waste water.

a Biochemical Oxygen Demand

b Chemical Oxygen Demand

c Phosphate

d Nitrate - Nitrogen

e Nitrite - Nitrogen

f Ammonia - Nitrogen

g Sulphate

h Total Solids

i Total Coliform

j pH.

The performances of the units were evaluated by the daily analysis of the influents and the corresponding effluent samples. For each run, the experiments were terminated after about 10 days of operation when sufficient data had been collected for analysis and discussions.

CHAPTER 4

4.1 Results

4.1.1 Organic Removal

Tables 4.1 and 4.2 show the BOD and COD removal efficiencies at different detention periods while table 4.3 show the ratio of COD to BOD.

Figures 4.1 and 4.2 show the COD - BOD relationships for the effluent samples while Fig. 4.3 shows the relationship between the non-biodegradable portion of the waste and the detention times.

Table 4.1: Average BOD Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	BOD Concentrations (mg/L)			Percentage Removal		
	Raw Waste	Anaerobic Effluents	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	91.2	49	29	46	41	68
10	91.0	30	22	67	27	76
15	94.0	25	19	73	24	80
20	96.0	21	14	78	33	86

Table 4.2: Average COD Concentrations and Percentage Removal at different Detention Periods (days).

Detention Time (days)	COD Concentrations (mg/L)			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	850	291	170	66	42	80
10	852	230	130	73	44	85
15	850	190	100	77	47	88
20	870	170	70	80	59	92

Table 4.3: COD to BOD Ratios for different Detention Periods (days)

Parameter \ Detention Time	5-day	10-day	15-day	20-day
COD(mg/l)	850	852	850	870
BOD(mg/l)	91.2	91.0	94.0	96.0
COD/BOD	9.3	9.4	9.0	9.1

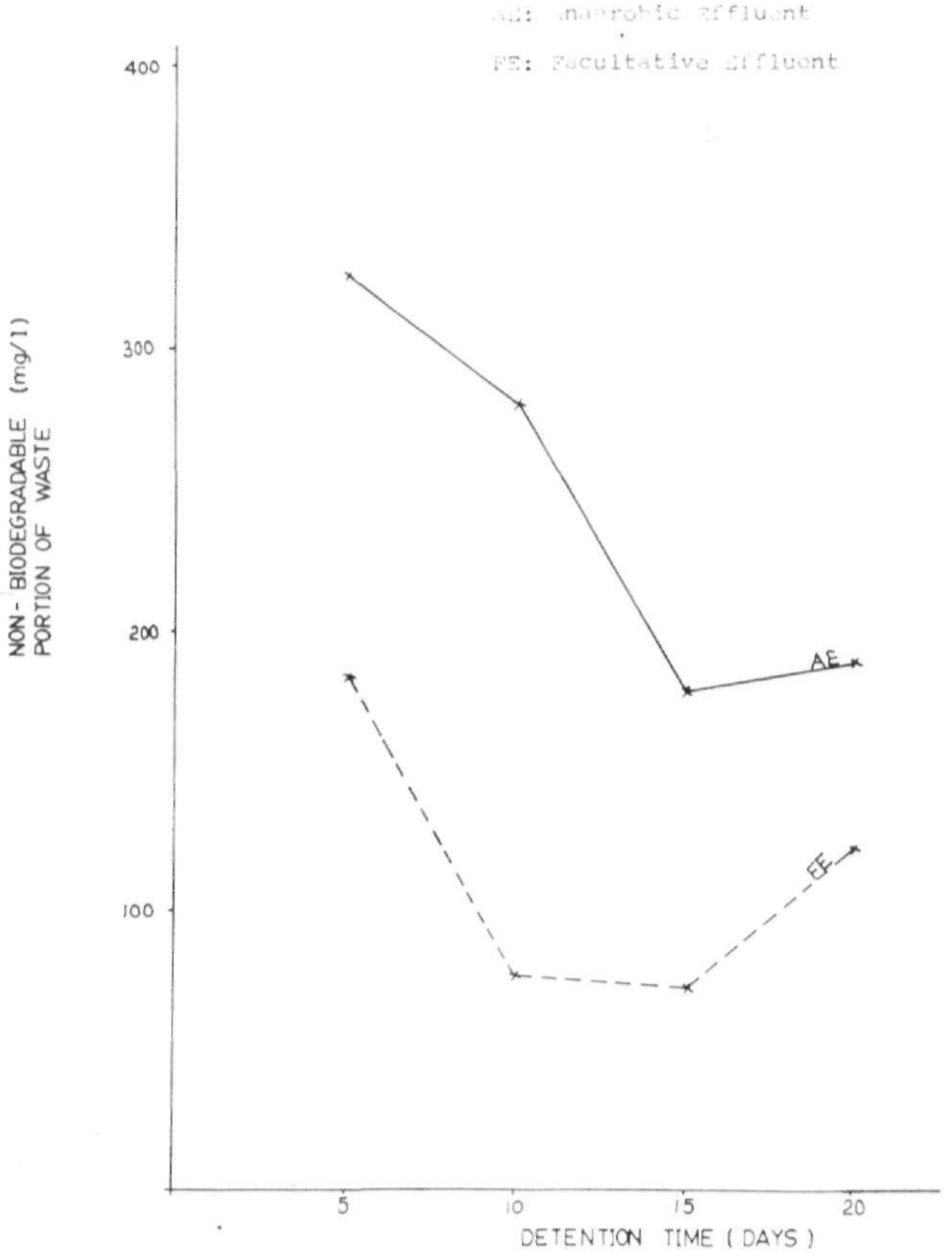


FIG 4.1 : PLOT OF NON - BIODEGRADABLE PORTION OF THE WASTE AGAINST DETENTION TIME

AE: Anaerobic Effluent

FE: Facultative Effluent

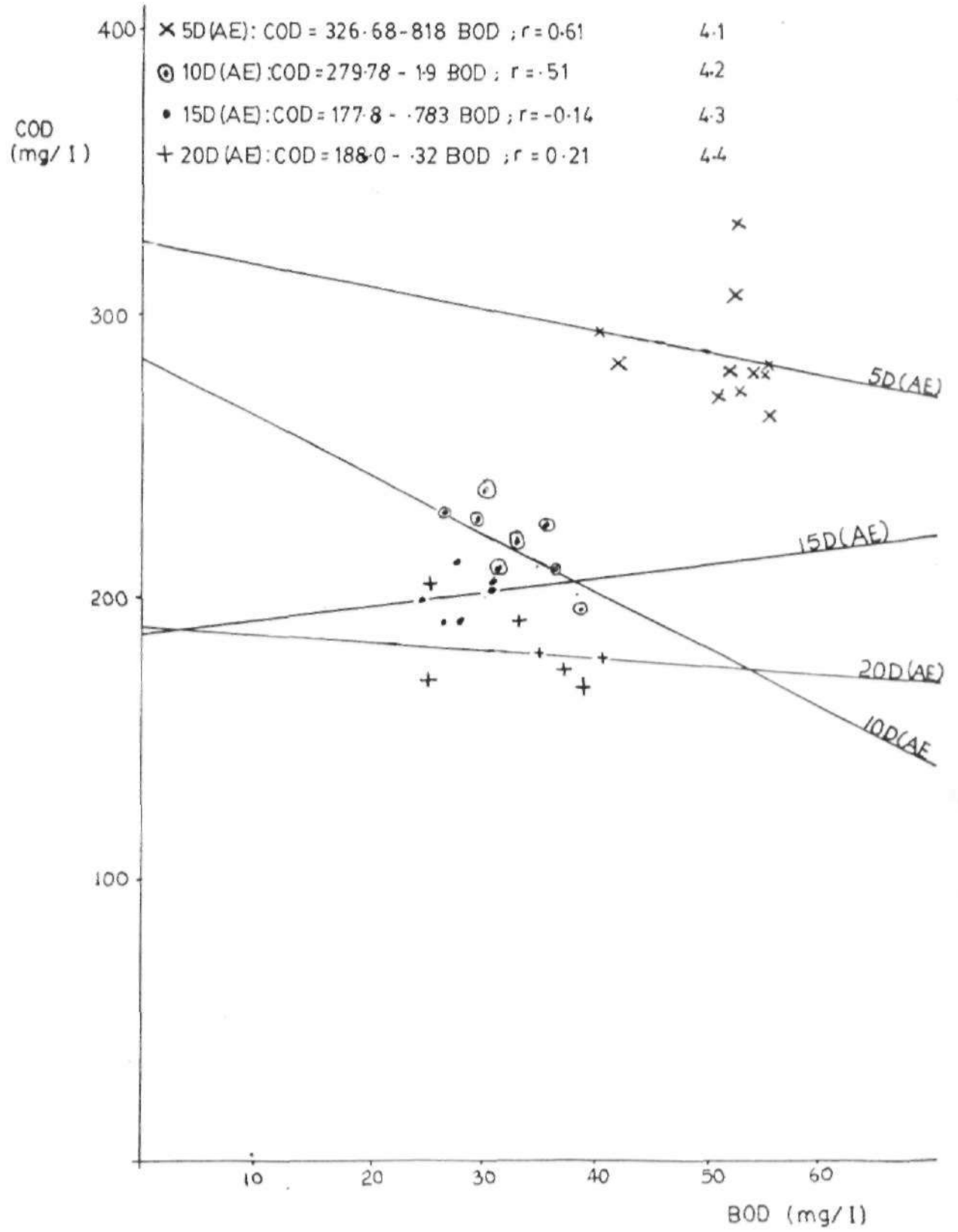


FIG. 4.2: LINEAR REGRESSION OF COD AGAINST BOD FOR THE ANAEROBIC POND FOR ALL DETENTION PERIODS.

AE: Anaerobic Effluent

FE: Facultative Effluent

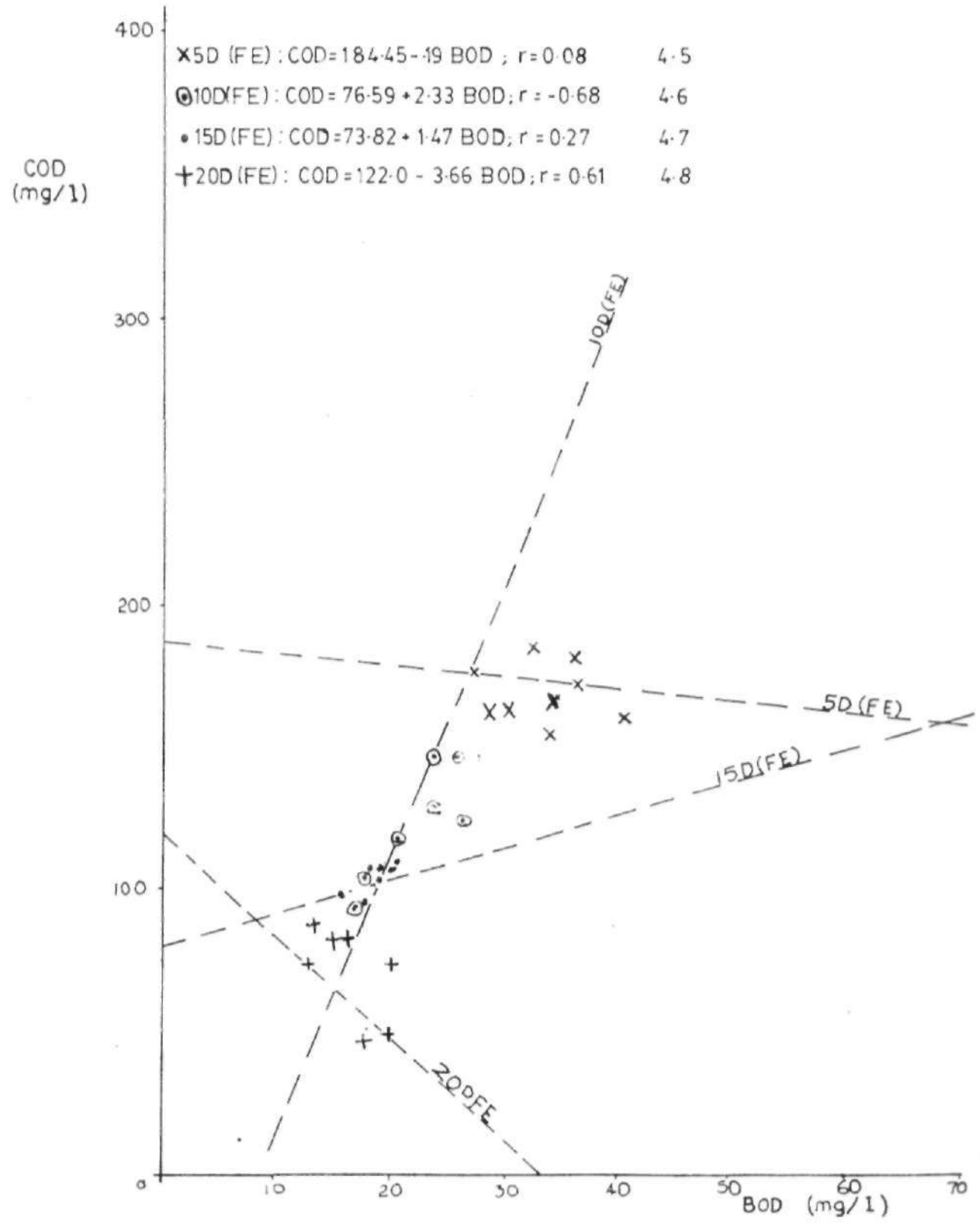


FIG 4.3 : LINEAR REGRESSION OF COD AGAINST BOD FOR THE FACULTATIVE POND FOR ALL DETENTION PERIODS.

4.1.2 Sulphate Removal

Table 4.4 shows the average sulphate concentrations and percentage removal at different detention periods.

Table 4.4: Average Sulphate Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	Sulphate Concentration (mg/l)			Percentage Removal		
	Raw Waste	Anaerobic Effl-	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	900	800	750	11.1	6.3	16.7
10	830	760	688	8.4	9.5	17.1
15	850	750	678	11.8	10.0	20.6
20	863	796	646	7.8	19.0	25.1

4.1.3 Phosphate Removal

Table 4.5 show the phosphate concentration and percentage removal of the phosphates at different detention time.

Table 4.5: Average Phosphate Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	Phosphate Concentration (mg/l)			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	15.5	13.8	11.3	11.0	18	26.2
10	15.5	13.0	10.3	16.0	21	34.0
15	16.0	13.0	8.2	19.0	37	48.8
20	15.3	13.3	11.0	NIL	40	28.0

4.1.4 Nitrite - Nitrogen, Nitrate - Nitrogen and Ammonia - Nitrogen Removal

Tables 4.6, 4.7 and 4.8 shows the concentration of nitrate - nitrogen, nitrite - nitrogen and ammonia - nitrogen and their percentage removal at different detention times.

Table 4.6: Average Nitrate-Nitrogen Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	Nitrate-Nitrogen Concentration (mg/l)			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	198	60	50	70	17	75
10	198	70	71	65	NIL	64
15	196	66	117	66	NIL	40
20	196	78	190	60	NIL	4

Table 4.7: Average Nitrite-Nitrogen Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	Nitrite-Nitrogen Concentration (mg/l)			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	1.04	0.80	1.04	23	NIL	0
10	1.08	0.40	2.10	63	NIL	NIL
15	2.00	0.00	5.10	100	NIL	NIL
20	3.50	0.00	6.10	100	NIL	NIL

Table 4.8: Average Ammonia-Nitrogen Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	Ammonia-Nitrogen Concentration (mg/l)			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	17	23	13	NIL	43	23.5
10	16	28	6	NIL	79	62.5
15	16	32	3	NIL	91	81.3
20	14	36	1	NIL	97	93.0

4.1.5 Solids Removal

Table 4.9 show the concentration of total solids of the effluent sample and the percentage removal at different detention periods.

Table 4.9: Average Total Solids Concentrations and Percentage Removal at different Detention Periods (days)

Detention Time (days)	Total Solids Concentration (mg/l)			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	1350	570	630	58	NIL	53.0
10	1316	456	524	65.3	NIL	60.0
15	1300	420	480	67.8	NIL	63.1
20	1330	513	433	62.0	16	68.0

4.1.6 pH

Table 4.10 shows the pH values of the effluent samples from both the anaerobic and facultative pond effluents.

Table 4.10: pH Readings for different Detention Periods (days)

Detention Time (days)	Raw Waste	Anaerobic Effluent	Facultative Effluent
5	6.7	6.9	6.8
10	6.9	6.8	6.8
15	7.1	6.8	6.9
20	7.0	6.9	6.8

4.1.7 Coliform Bacterial Counts

Table 4.11 show the coliform bacteria concentration and the percentage removal from the effluents at different detention times.

Table 4.11: Average Total Coliform Bacteria Concentration and Percentage Removal at different Detention Periods (days)

Detention (Time (days)	Coliform Bacterial Count			Percentage Removal		
	Raw Waste	Anaerobic Effluent	Facultative Effluent	Anaerobic Pond	Facultative Pond	Overall Removal
5	2.2×10^4	3.2×10^4	1.9×10^4	NIL	40	14
10	2.8×10^4	1.3×10^4	1.6×10^4	46	23	43.2
15	2.3×10^4	4.9×10^3	2.7×10^3	98	45	88.3
20	2.5×10^4	1.4×10^4	1.1×10^4	44	42	58.8

4.1.8 Regression Analyses

Multiple regression of organic BOD and COD loadings, organic BOD and COD removals and detention times are given as follows:

a) COD

(i) Anaerobic Pond

$$COD_{Loading} = 1.313\ COD_{removal} + 2.21\ DT + 37.0 \quad 4.9$$

$$r = .9997$$

$$r^2 = .9994$$

(ii) Facultative Pond

$$COD_{Loading} = 1.71\ COD_{removal} + 3.2\ DT - 167.7 \quad 4.10$$

$$r = 1.00$$

$$r^2 = 1.00$$

b) BOD

(i) Anaerobic Pond

$$BOD_{Loading} = 0.29\ BOD_{removal} + 0.08\ DT + 46.64 \quad 4.11$$

$$r = .929$$

$$r^2 = .863$$

(ii) Facultative Pond

$$BOD_{Loading} = 488.4 - 15.91\ BOD_{removal} - 25.8\ DT \quad 4.12$$

$$r = .892$$

$$r^2 = .796$$

4.2 Discussion

4.2.1 Organic Removal

4.2.1(i) Biochemical Oxygen Demand:

Poultry faeces frequently contain inorganic feed additives. Some of these are inhibitory to microorganisms and thus may affect the performance of biological units used in the treatment of the wastes (Loehr, 1974).

Robbins et al. (1972) also observed that biochemical oxygen demand readings are not reliable for characterizing animal wastes because of interferences which are attributed to solids and toxic substances in the feed.

Clark (1965) worked with hog manure and had problems characterizing the waste in terms of BOD because of the high antibiotic level present in the feed.

From table 4.1 it is observed that the raw waste had a low BOD values compared with the COD values. The waste used in this study contains a lot of saw dust and wood shavings because of the deep - litter system being employed by the National Animal Production Research Institute, Ahmadu Bello University, Shika. The saw dust and wood shavings contains lignin and cellulose. Lignin though chemically oxidizable, may be resistant to biochemical oxidation. Cellulose is susceptible to biochemical oxidation but this takes time to accomplish (Loehr, 1974). Therefore the 5-days in which the BOD was

performed was not long enough to achieve the bio-oxidation of cellulose to any appreciable extent.

The anaerobic pond has efficiency of BOD removal of 46, 67, 73 and 78% for the 5, 10, 15 and 20 days' detention times respectively, it would appear that increasing the detention time to periods longer than 20 days may not necessarily produce much better quality effluents.

The facultative pond efficiencies are 5, 10, 15 and 20 days' detention ponds are respectively 41, 27, 24 and 33%. This shows that most of the biological decomposition takes place in the anaerobic pond while the remainder is polished in the facultative.

For the five day detention period, an overall percentage removal of 68.2 was obtained, 76% for 10-day detention time, 79.8% for 15-day detention time, and 85.4% for the 20-day detention time. This trend is to be expected because the longer the contact time, the microbes have with the waste, the more the chances that they have in degrading the organic substance.

4.2.1(ii) Chemical Oxygen Demand

The influent COD is quite high compared with the BOD values. As was pointed out earlier, a high percentage of the waste are chemically oxidizable.

The anaerobic pond was able to achieve removal efficiencies of 66, 73, 77 and 80% respectively for 5, 10, 15 and 20 days detention periods. The results show a decreasing rate of increase in percentage removal.

The facultative pond on treating the effluent from the anaerobic pond, gave 42, 44, 47 and 59% removal for the 5, 10, 15 and 20 days detention periods respectively.

The overall percentage removals of 80, 85, 88.2 and 92% for the 5, 10, 15 and 20 days detention periods is quite satisfactory.

4.2.1(iii) Non-biodegradable Organic Matter

The algae population was visibly reduced during the twenty days detention period. Loehr (1974) reports that nutrients from dead algae cells are released to surface waters for a long period of time. These nutrients include carbon dioxide, ammonia, nitrate and phosphates and are non-biodegradable. From fig. 4.1 it is observed that the non-biodegradability reduced upto 20 days detention period when it increased again. This most probably is due to the release of non-biodegradable nutrients by the dead algae.

4.2.1(iv) COD/BOD Relationship and Regression Equations

According to Loehr (1974), a low COD to BOD ratio shows that the waste is readily biodegradable but a high value shows that the waste is not readily available. From table 4.3, the COD value obtained is 860mg/l and that of BOD is 93mg/l on the average. The waste used has a lot of saw dust and wood shavings. This gives rise to a high cellulose and lignin content in the waste. Cellulose is biodegradable but this takes a longer time to achieve, and again happens anaerobically. Due to the above reason, cellulose content of a waste does not affect the BOD readings because the BOD determination is an aerobic one. This is why the COD is predominantly higher than the BOD in the water (Winkler, 1981).

From the table, the COD - BOD ratios are 9.32 for the 5-day detention period, 9.36 for the 10-day detention period, 9.04 for the 15 day detention period and 9.06 for the 20 day detention period. These high ratios mean that the waste is not easily biodegradable. Nearly every organic substance is oxidized during the COD test because it gives a measure of the total organic content of the waste, whether they are biodegradable or non-biodegradable.

From equations 4.1 to 4.8, the calculated correlation coefficients are: 0.61 and 0.087 for the 5 day detention time; 0.51 and 0.603 for the ten day detention time; -0.14 and 0.27 for the 15 day detention time; and 0.21 and 0.61 for the 20 day detention time. The value

of correlation coefficients measures the degree of the relationship between the parameters in the equations obtained during regression (Spiegel, 1972). A high correlation coefficient show a high linear correlation between the variables.

From the above figures, a high correlation coefficient, like 0.51, -0.683 and 0.61, mean that biochemical oxygen demand is linearly related to the chemical oxygen demand. If the correlation coefficient is low as is the case with the facultative pond for the 5 and 15 days' detention periods; anaerobic pond for the 15 and 20 day detention periods, then COD and BOD are not linearly related to each other.

A linear relationship between any two parameters may mean positive or a negative slope. For the two parameters being considered (COD vs BOD), as the COD increases, the BOD also increases for the anaerobic pond during the 5 day detention period because of the positive sign which accompanies the coefficient of correlation. The same also holds for both the anaerobic and facultative ponds during the 10 day detention time and also for the facultative pond during the 20 day detention period. When the coefficient of correlation is negative as is the case in the facultative pond during the 5 - day detention time, it means that the COD is inversely proportional to BOD. That is to say that the COD increases with a reduction in BOD value. For coefficients of correlation below $\pm$ 0.3, the linear relationships between COD and BOD is not defined.

For the multiple regressions, the values of r are quite higher being between 0.89 and 1.00. This shows that the relationships are defined between the COD, BOD loadings and detention periods studied. According to Spiegel (1972), the COD loading, BOD removal, and detention time for the facultative pond have a perfect relationship since the coefficient of correlation is 1.00.

4.2.2 Sulphates

In the anaerobic pond, the removals obtained were 11.1, 8.4, 11.8 and 7.8% respectively for the detention periods. The reduction in sulphate may be attributed to the activities of a highly specialized group of bacteria known as Desultovibrio sp which utilize sulfates as their hydrogen acceptor reducing them to sulfides (McKinney, 1971). This group of bacteria may be present in the pond.

Percentage sulphate removal from the anaerobic effluent by facultative pond were 6.3, 9.5, 10.0 and 19.0% respectively for 5, 10, 15 and 20 days detention times. The overall percentage removals recorded for 5, 10, 15 and 20 day detention periods are 16.7, 17.1, 20.6 and 25.1% respectively.

4.2.3 Phosphates

The system was not very efficient in the removal of phosphates. The percentage phosphate removal in the anaerobic pond were 11, 16 and 19 respectively for the detention time of 5, 10 and 15 days. It is observed that the sulphate contents increased when the detention period was 20 days.

The facultative pond had an efficiency removal of 18, 21, 37 and 40% for the 5, 10, 15 and 20 days detention period from treatment of anaerobic effluent. This gave overall removals of 26.2, 34.0, 48.8 and 28.0% respectively for all the detention periods studied.

From the above, it is evident that the performance of the system is not adequate for phosphate removal. According to Winker (1981), phosphorus removal makes use of the ability of some microorganisms to take up phosphorus in such an amount that have an excess over their immediate nutritional requirements and this they store within their microbial cells in the form of polyphosphates. In addition, Metcalf and Eddy (1979), stated that algae make use of phosphorus compounds converting this to furtner algae mass. The above are responsible for the reduction in the amount of phosphorus present in the effluents. During the 20 day detention time, the facultative pond had an increase in the phosphate concentration instead of a decrease. This may be due to the decline in the growth of the algae which was caused by accumulation of solids and therefore reduce the intensity of light into the pond. At this point in time, the

liquid was also coloured brown and Loehr (1974) says that algae with blooms only when there is sufficient sunlight to penetrate the liquid for algae will not thrive where there is a high turbidity (most probably due to solids - whether suspended or floating) or where the liquid is coloured. Hence the above contributed to this decline in the algae population. This decline left the phosphate of the influent into the pond unutilized. It is also opined by the author that there is the possibility of dead algae releasing nutrients into the pond with the possibility of increasing the quantity of phosphorus in the facultative pond.

The increase in phosphate concentration in the anaerobic pond for the 20 - day detention time may be due to evaporation during long periods of exposure of the pond to the atmosphere (Jewell, 1977).

4.2.4 Nitrate-Nitrogen, Nitrite-Nitrogen and Ammonia-Nitrogen

Nitrate-nitrogen is formed from oxidation of nitrites and represents the most stable form of nitrogen. Nitrite is from the bacterial oxidation of ammonia and its presence indicates partial decomposition of the waste (Merkel, 1981). Ammonia is as a result of bacterial decomposition of organic matter, specifically proteins.

Under anaerobic conditions, nitrates and nitrites undergo biological removal process called denitrification in which these compounds are converted to nitroge.. ga .

From table 4.4, it is observed that for all the detention periods, there is a decrease in the concentration of nitrates up to 70% average. This is also true in the case of nitrite for 5 and 10 days detention periods where the nitrite concentrations were respectively reduced from 1.04mg/l to 0.8mg/l and 1.08mg/l to 0.4mg/l. Also in anaerobic conditions there is bacterial decomposition of organic matter and that is why the ammonia content increased, as the decomposition produced ammonia (table 4.6). The increases were 17mg/l to 23mg/l for 5 days detention period, 16mg/l to 28mg/l in the 10 days detention period, 16mg/l to 32mg/l in the 15 days detention period and 14mg/l to 36mg/l in the 20 days detention period. Still under anaerobic conditions, during the 15 and 20 days detention periods, there was no trace of nitrite in the anaerobic pond and this according to Merkel (1981), means that there is no partial decomposition of organic matter taking place in the pond at these periods.

From table 4.4 - 4.6, it is seen that there is an eventual decreasing trend in the ammonia, increases in nitrite and nitrate concentrations. The above is due to the fact that protein is progressively being stabilized.

Nitrification which is the conversion of ammonia to nitrite and then to nitrate takes place under aerobic and facultative conditions. Table 4.6 shows a decline in the facultative effluent content of ammonia which is from 23mg/l to 13mg/l for the 5 days detention period, 28mg/l

to 6mg/l in the 10 days detention period, 32mg/l to 3mg/l in the 15 days detention period and 36mg/l to 1mg/l in 20 day detention period. That this is converted to nitrite and then to nitrate is evident from tables 4.4 and 4.5. Under facultative conditions nitrate concentration was on the increase as well as nitrites. This explains why the ammonia concentration is low. These are converted to nitrates and nitrites. As long as there is ammonia in the facultative pond, the nitrite concentration will be on the increase and this consequently increases the nitrate concentration.

McKinney (1971) is of the view that facultative bacteria also utilize nitrites and nitrates as their hydrogen acceptors thus reducing these compounds to nitrogen gas. This may be the reason why during the 5 days detention time, there was a decrease in the concentration of nitrate in the facultative effluent from 60mg/l to 50mg/l. Again, it is apparent that the removal of nitrate from this treatment system is low because nitrate is a stable oxidation product though some may be absorbed as already mentioned.

4.2.5 Total Solids

This includes all manner of solids that may be present in the waste. From table 4.9, the solids content of the anaerobic effluent is low. This is most likely due to sedimentation. For the 10 day detention period, the anaerobic pond reduced the solids content by 65.3%,

67.8% for the 15 day detention time; and 62% for the 20 day detention time. In the facultative effluent, the solids content is higher than that of the anaerobic pond effluent for the 10 and 15 day detention periods, rising from 456mg/l to 524mg/l and from 420mg/l to 480mg/l respectively. This is attributed to the production of algae in the facultative pond. During the 20 days detention period, there is a reduction in the solids content of the facultative effluent when compared to the anaerobic effluent. This is because during this detention period, there was a noticeable decline in the algal population due to accumulation of solids in the pond. This accumulation made it difficult for light to penetrate and hence photosynthesis was interfered with.

4.2.6 pH

pH determination is essential and valuable for the proper design and operation of anaerobic digester. Merkel (1981) observes that anaerobic decomposition is affected by pH as methane formers in the system are very sensitive to pH shift, below pH 6.6, the methane formers are significantly inhibited. When the digestion process is properly operated, the biochemical reactions maintain the pH in the proper range. The range suggested is 6.6 to 7.6. From table 4.10, a pH range of 6.8 to 6.9 is maintained through the experiment with anaerobic pond showing that methane production was probably not innibited. The pH in the facultative pond effluent was also in the range of 6.8 to 6.9

4.2.7 Coliform Bacteria

Table 4.11 shows that the system of anaerobic and facultative ponds connected in series did not completely eliminate coliform from the waste water. Also there was no defined pattern of removal in the coliform concentrations of the effluents of both the anaerobic and facultative ponds as the detention times increased.

Each detention period experienced this fluctuation also especially an initial increase within the first 24 - 48 hours of the detention time. After this initial increase, then there were reductions in the bacterial population although these were accompanied by the rise and fall pattern in the bacterial population as well (see Appendix B, total coliform column of 5-day detention time).

The inability of the ponds to totally remove all coliform bacteria present may be due to coliform bacterial regrowth. This can occur according to Deamer and Kevvi (1969), in waters with minimal nutrients where some coliform bacterial can thrive and multiply. Temperature of above 15°C is needed for the regrowth to take place, and the laboratory where this research was carried out had an average temperature of 26°C. Hence the atmosphere was quite conducive for the bacteria to thrive and regrow.

Zanoni and Fleissner (1982), also discovered that there was consistent initial bacterial replication activity despite all efforts to eliminate coliform from the sample. The research was carried out on the survival of coliform bacteria in the laboratory.

Scarce et al. (1964) agreed with the above authors in concluding that there is always an initial multiplication of the coliform bacteria population with the highest population at about 1 day after introduction of waste into a treatment system. One thing worthy of note is the reduction that follows immediately after this peak population even though fluctuation accompany this reduction.

4.1.8 Design of Anaerobic and Facultative Ponds For National Animal Production Research Institute, Shika

For this design purpose, it is important to know the capacity of the poultry farm. From the data available at the Institute, the capacity is 10,000 chickens. According to Dugan et. al. (1973), a poultry farm of 100,000 chickens generates 20 tons of wastes daily.

Using the dilution employed in this research (5g of poultry waste diluted in 1 litre of water), a flow rate can be established for the design. Also due to the fact that no data exists on the amount of waste generated in NAPRI, the information given by Dugan et. al. (1973) has to be utilized.

From the above data, the flow rate of the treatment plant to be designed is $10,000m^3$/day.

(i) Design of Anaerobic Pond

$$A = \frac{Qt}{D} \qquad 4.1$$

A = Surface area (m^2)

Q = Flow rate (m^3/d)

t = Retention time (d)

D = depth of pond (m)

Assume a depth of 4m,

$$A = \frac{10,000\ (m^3/d) \times 15\ (d)}{4(m)} = 37,500m^2$$

Use A = $40,000m^2$

= 4.0ha.

(ii) Design of Facultative Pond

$$A = \frac{Q(Li - 60)}{18D(1.05)^{T-20}}$$

Q = Flow rate (m^3/d)

Li = Inflow BOD into the facultative pond (mg/l)

D = Depth (m)

T = Temperature

$$A = \frac{10,000 \times 190}{18 \times 1.5(1.05^6} = 52520m^2$$

Use $60,000m^2$

= 6.0ha.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

In the light of the results, the following conclusions and recommendations are made:

5.1 Conclusion

1) The anaerobic pond aided the settlement of solids so that the facultative pond polished the anaerobic pond effluent with less problems with the total solid content of the waste.
2) The regression analyses of BOD or COD removals, BOD or COD loadings and Detention time gave coefficients of correlation such as 0.99, 1.00, .93 and .892. This shows that the parameter are related.
3) During the five, ten, fifteen and twenty days detention periods, the BOD removals were 68%, 76%, 80% and 86%. This in consonance with the tradition BOD equation which says that organic content of a waste reduces with increase in detention time.
4) The facultative pond was able to remove about 58.8% of the Total Coliform concentration and as such is not sufficient for the removal of all the bacteria present.

5.2 Recommendations

The following are suggested for further research.

- Further treatment is needed before the effluent can be discharged into a receiving body of water to get rid of all the nutrients that can cause eutrophication. This may involve tertiary treatment such as the use of sand filtration and/or chemical coagulation for polishing the effluent.

- A maturation pond in connection in series with the anaerobic and facultative ponds may be necessary to further reduce the coliform organisms.

- The possibility of the facultative pond effluent being used for agriculture and aquaculture should be investigated.

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APPENDIX A

SAMPLE CALCULATIONS FOR LINEAR AND MULTIPLE REGRESSION

a) Linear regression of COD against BOD for the anaerobic pond during the five day detention period

The linear regression equations of COD to BOD were obtained as follows:

Y = COD effluent from anaerobic pond

X = BOD effluent from anaerobic pond.

The two major equation governing this approach are

$$\Sigma Y = a_o N + a_1 \Sigma X \qquad A1$$

$$\Sigma XY = a_o X + a_1 \Sigma X^2 \qquad A2$$

a_1 and a_o are constants

N = number of terms.

From the results obtained

$\Sigma Y = 2581$

$\Sigma X = 439$

$\Sigma X^2 = 21629$

$\Sigma Y^2 = 240555$

$\Sigma XY = 125721$.

Substituting the above information into equations A1 and A2 gives

$$2581 = 9a_o + 439a_1 \qquad A3$$

$$125721 = 439a_o + 21629a_1 \qquad A4$$

Solving A3 and A4 simultaneously

$a_o = -.818$ and $a_1 = 326.68$.

These are substituted into the equation of linear regression which is

$$Y = a_1 + a_o X \qquad A5$$

giving

$$\underline{COD = 326.68 - .818\ BOD} \qquad A6$$

b) Multiple Regression

A typical sample calculation for obtaining the multiple regression equation for organic BOD and COD loadings, organic BOD and COD removals and detention times, is shown below:

Organic COD loading, organic removal and detention time

$$X_1 = \left(\frac{r_{12} - r_{13}\, r_{23}}{1 - r_{23}^2}\right)\left(\frac{S_1}{S_2}\right) X_2 + \left(\frac{r_{13} - r_{12}\, r_{23}}{1 - r_{23}^2}\right)\left(\frac{S_1}{S_3}\right)\left(X_3\right) \qquad A7$$

where: (1) $x_1 = X_1 - \bar{X}_1$

$x_2 = X_2 - \bar{X}_2$

$x_3 = X_3 - \bar{X}_3$

(2) $\bar{X}_1 = \frac{\Sigma X_1}{N}$; $\bar{X}_2 = \frac{\Sigma X_2}{N}$; $\bar{X}_3 = \frac{\Sigma X_3}{N}$

(3) $$r_{12} = \frac{N\Sigma X_1X_2 - (\Sigma X_1)(\Sigma X_2)}{\sqrt{[N\Sigma X_1^2 - (\Sigma X_1)^2][N\Sigma X_2^2 - (\Sigma X_2)^2]}} \quad A8$$

r_{13} and r_{23} are obtained likewise .

(4) $$\frac{S_1}{S_2} = \sqrt{\frac{\Sigma X_1^2}{N} - \left(\frac{\Sigma X_1}{N}\right)^2} \quad A9$$

X_1 = organic COD loading

X_2 = organic COD removals (facultative pond)

X_3 = Detention time.

From the results obtained

$\Sigma X_1 = 614.2$

$\Sigma X_2 = 271$

$\Sigma X_3 = 50$

$\Sigma X_1^2 = 149222$

$\Sigma X_2^2 = 26821$

$\Sigma X_3^2 = 750$

$\Sigma X_1X_2 = 63180$

$\Sigma X_1X_3 = 5286$

$\Sigma X_2X_3 = 2466$

Substituting the above into equation A8

$$r_{12} = \frac{4 \times 63180 - (614.2)(271)}{\sqrt{[4 \times 149222 - (614.2)^2][4 \times 26821 - (271)^2]}}$$

$= 1.00$

Similarly $r_{13} = -0.912$

$r_{23} = -0.89.$

From equation A9

$$S_1 = \sqrt{\frac{149222}{4} - \left(\frac{614.2}{4}\right)^2}$$

$$= 117.1$$

Likewise $S_2 = 80.93$

$S_3 = 5.60$

Therefore

$$\frac{S_1}{S_3} = 20.9 \; ; \; \frac{S_1}{S_2} = 1.45$$

Then

$$\mathcal{X}_1 = X_1 - 153.6$$

$$\mathcal{X}_2 = X_2 - 67.75$$

$$\mathcal{X}_3 = X_3 - 12.50.$$

Substituting all the above information into equation A7,

$$X_1 = 1.313\, X_2 + 2.21\, X_3 + 37.0 \qquad \text{A10}$$

which means that

$$COD_{loading} = 1.313\, COD_{removal} + 2.21\, DT + 37.0. \qquad \text{A11}$$

APPENDIX B - RAW DATA OF RESULTS

Detention Time (days)		BOD			COD			Sulphate			Phosphate			pH			Nitrate			Nitrite			Ammonia			Total Solids			Total Coliform ($X10^4$)		
		Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE	Inf	AE	FE
5-day detention time	1				835	359			750		16.25	14.5		7.1															3	16	
	2				767	291		925	800		17.5	17.5		6.9			196	65		0.86	1.0	1.0	18	20						30	
	3				806	311		900	775		15.25	10.5		6.8			196	65.2		1.1	.76	1.0	16	14					.3		
	4		50			330		975	825		16.0	11.75		6.9	6.8		198	54		1.04	.68	1.0	20	16					.5	3	
	5	84			840	311		950	900		15.5	14		7.2	6.9		198	62		1.06	.82	1.06	18	24							
	6	92	50		864	291		900	850		15.0	14		7.3	7.1		196	60		1.06	.82	1.04	16	22							
	7	93	52		825	272		900	800		13.5	14		7.1	7.2		198	63		1.04	.90	1.2	18	24					.5	3	
	8	92	40		815	291		900	800		15	13.25		6.9	6.9		198	61	52	1.04	.86	1.04	18	24					1.7	5	
	9	90	40	36	835	291	175	925	800	750	15	13.75	11	6.6	7.1	6.9	196	60	52	1.06	.90	1.0	16	22	12				3.0	2.4	
	10				845	281	185	850	775	725	15	13.75	11.25	7.1	6.9	7.0	196	56	48	1.37	.94	0.94	16	22	14	1360	600	650	3.0	3.5	3.5
	11	91.5	49	28	786	281	194	900	775	750	15.5	14.25	11.75	7.2	6.8	6.6	198	54	50	1.25	.60	.96	18	24	12	1300	540	660	5.0	2.4	1.7
	12	91.5	50	29	806	282	185	850	800	750	15	13.25	11.75	6.9	7.1	6.7	198	56	52	1.04	.70	1.04	18	22	14	1400	540	620			
	13	93	52	24	854	291	175	900	800	750	15.25	13.75	11.25	6.8	6.8	6.5	198	58	50	1.04	.82	1.04	16	24	14	1380	560	630			1.7
	14	94	52	29	840	291	170	850	775	750				6.8	6.9	6.9							18	24	12	1340	580	630			1.3
	15	90	54	27	835	291	175	850	775	750				6.9	6.9	6.8							18	24	14	1400	580	620	2.3	3.0	1.3
10-day detention time	1				830	270	140	825	725	688	13.5	16	13.8	7.1	7.1	6.9	198	54	63	1.0	0.4	2.5	18	28	16						
	2				780	220	190	825	750	688	13.5	16.5	13.8	6.5	6.8	6.8	196	53	70	0.82	0.4	2.2	16	28	14						
	3	77	35	21	840	230	160	838	750	688	16	13.8	11.8	7.1	7.0	7.1	199	70	72	1.3	0.6	2.1	18	26	10				2.5	.34	5
	4				866	250	130	800	775	688	15.75	13.8	11.5	7.3	6.9	7.1	196	70	71	1.1	0.7	2.1	14	28	8						
	5	82	36	23	820	200	120	838	775	688	17.5	13.8	11	7.1	7.1	6.9	198	76	71	1.08	0.4	2.3	16	26	6						
	6				920	220		800	775	688	15.75	13.8	10.3	7.2	6.8	7.0	196	68	71	1.04	0.4	2.1	12	26	6				1.7	.27	8
	7	96	26	22	820	230	130	838	750	688	16.5	15	10.3	6.8	6.8	6.9	196	70	72	1.05	0.6	2.2	16	28	8	1380	420	500	3.5	.17	3
	8	92	30	23	860	205	120	800	775	688	16.0	13.8	10.5	7.1	6.6	7.1	196	69	72	1.06	0.45	2.5	14	26	6	1320	460	440	2.8	.5	1.7
	9	108	26	24	900	230	130				15	13.3	10.5	7.0	6.9	6.8	196	70	72	1.07	0.4	2.1	12	28	6	1200	420	540	3.5	1.3	1.4
	10	90	31	21	820	220	140				15	13.8	10.5	6.9	7.1	7.1	198	68	70	1.06	0.4	2.1	14	28	6	1400	480	560	3.5	1.1	1.4
	11	76	29	22	900	235	120				15	12.5	10.5	6.9	6.8	6.8	196	68	72							1260	500	580	2.2	1.4	1.7
15-day detention time	1	94	25	19	850	190	110	838	775	650	16.25	12.5	6.5	7.1	6.9	6.9	196	63	126	2.02	0	4.5	14	28	3	1240	400	500	1.3	.5	.17
	2	92	30	17	830	200	100	850	775	600	17.5	12.5	6.0	7.1	6.9	6.8	196	63	108	1.5	0	5.0	14	32	3	1300	420	500	1.7	.49	.22
	3	102	25	16	850	220	100	850	750	675	17.5	13.8	5.3	6.9	6.8	6.9	196	64	106	1.8	0	5.6	16	28	4	1300	420	490	3.5	.43	.27
	4	96	25	18	860	190	90	850	750	675	16.3	13.8	9.5	7.1	6.8	6.8	196	66	126	2.06	0	5.6	18	28	3	1180	400	480	4.3	.49	.27
	5	90	24	19	880	190	100	850	750	675	15.0	12.5	13.8	7.2	6.8	6.9	196	60	128	2.5	0	5.0	18	32	3	1200	380	460	1.3	.46	.25
20-day detention time	1	98	30	20	910	190	66	838	775	650	14.5	22.8	14.3	7.0	6.9	7.1	196	70	190	2.35	0	6.0	14	32	3	1300	500	360	2.5	3.5	1.1
	2	96	37	16.5	810	170	40	900	800	625	12.5	19	15	7.1	6.7	6.6	196	78	194	3.4	0	6.3	12	32	3	1320	480	380	5.4	2.4	2.2
	3	80	34	15	845	180	70	900	850	625	15	16.8	11	6.6	7.1	6.6	198	76	190	3.95	0	7.0	14	36	2	1280	660	460			
	4	102	21	14	820	200	70	838	800	650	15	17.5	10	7.1	6.8	6.8	198	82	188	2.6	0	6.4	12	36	1	1340	500	500	2.8	1.7	.34
	5	92	21	15	900	170	70	850	775	625	15	17.5	11	7.2	6.8	6.8	198	80	190	2.6	0	66.1	14	36	1	1540	440	480	2.5	1.1	.72
	6	96	22	13	910	170	80	850	775	700	16	16	11	7.3	6.9	6.9	198	80	186	3.7	0	6.1	14	40	1	1240	500	420	2.2	1.3	.79