A STUDY OF THREE ROTATING DISC TREATMENT UNITS OPERATING AT DIFFERENT TEMPERATURES

BY

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CONTENTS

Summary

Three laboratory scale, biological, waste-water treatment units incorporating the rotating disc principal were tested, to evaluate their performance at three different temperatures, using a local supply of settled sewage. The units consisted of twenty eight, 200 mm diameter discs divided into seven stages. The secondary sludge produced was removed frequently by a rotating screw (Archimedian-Type) in order to maintain aerobic conditions inside the reaction vessel of the unit.

The variables tested beside the temperature, were the waste water residence time, the disc rotational speed and the area of disc submersion. The investigation also included the effect of effluent recycle on the unit efficiency and the relationship between the BOD and the COD

Inspite of the short residence time (usually 1-2 hours) of the waste water held by the tank, the plant achieved a high efficiency in removing BOD, suspended solids and ammoniacal nitrogen. The results obtained demonstrated that an improvement in efficiency is achieved with increasing temperatures in the range of 10°C to 20°C, although the further increase in efficiency with increasing temperatures in the range of 20°C to 30°C is limited. The variations in the area of disc submersion affected the unit to a considerable extent.

At the three waste water temperatures of 11°C, 18°C and 27°C the units demonstrated their ability to remove more than 90% of the applied BOD at a loading rate in excess of 15 g/m^2 day. At the same loading rate the plants achieved more than 90% suspended solids removal yielding an effluent well within the Royal Commission recommendations. The ammonia nitrogen was removed by oxidation to nitrite and nitrate. The units also showed a high efficiency in COD and detergent removal.

The rotating Disc Treatment Unit (R.D.T.U.) during the test programme, demonstrated not only its high capacity in waste water purification but also its low operational costs, power consumption and minimal maintenance requirements.

SECTION ONE

INTRODUCTION

1.1 BIOLOGICAL TREATMENT

1.1.1 General

Scientists and engineers have been trying to develop more efficient waste water treatment systems for years. Although there are many different forms of waste water treatment, the various types of biological treatments are the most important for the removal of soluble and colloidal organics. The rate of improvement in biological treatment methods has been related largely to the need for higher quality effluent prior to their discharge to receiving bodies of water.

In approaching any waste water treatment problem the engineer is presented with a waste and specific volume, definite flow characteristics and nature of chemical composition. He must consider these facts together with a knowledge of the ultimate receiving body of water and arrive at the degree of treatment which must be applied to the waste water. Several basic types of biological processes have long been used for waste water treatment. These include the activated sludge process, the percolating filters, oxidation ponds and anaerobic digestion. From a biological point of view most of these processes may be classified as continuous flow, enrichment cultures of micro-organisms with the pre-dominant species being determined by the characteristics of the input wastes and the environmental conditions created through process design and operation, (Andrews J.F.)[3]. Basically, the organisms responsible for treatment possess the ability to decompose organic compounds, and to use the energy so liberated for their bodily functions: reproduction, growth, locomotion and so on.

1.1.2 Major Biological Reactions

The first step is to identify the major reactions involved in the biological process. These may be roughly classified as aerobic, anaerobic and photosynthetic according to the pre-dominant type of microbial activity.

There are several basic principles which are common to these classifications. In each case a source of cellular building blocks, such as carbon, oxygen, hydrogen, nitrogen and phosphorous compounds must first be transported into the cell in a soluble form. Hydrogen acceptors must be present and aerobic organisms use oxygen for this purpose while anaerobic organisms use such compounds as sulphates, nitrates, carbon dioxide or organic compounds.

Energy must be supplied to the organisms either in the form of energy contained in chemical compounds or as radiant energy from sunlight. A fraction of this energy is used to drive synthesis reactions for the production of more micro-organisms, while the remainder is dissipated as heat. Thus the removal of organic matter from liquid wastes is achieved by absolute destruction (oxidation) which yields energy and hence synthesis.

There are three main types of organic matter to be considered in water quality control.

1.1.2.1 Carbohydrates

These are composed of carbon, hydrogen and oxygen. The ratio of hydrogen to oxygen is always 2:1 as in water. Carbohydrates are a major source of food energy.

1.1.2.2 Proteins

These are organic substances of large molecular size and contain carbon, hydrogen, oxygen and nitrogen and sometimes sulphur. Among the proteins are some enzymes (organic catalysts).

1.1.2.3 Lipids or fats

These are composed of carbon, hydrogen and oxygen. Lipids are esters of long-chain carboxylic acids. Fats, the most important members of this class, are esters of glycerol and usually contain more than one kind of fatty acid residue. They have in common the property of being soluble in organic solvents and only sparingly soluble in water.

The biological oxidation-reduction reaction may be regarded as the transfer of hydrogen atoms from the substance oxidised to oxygen, the hydrogen acceptor.

$$\text{organic hydrogen} + O_2 \xrightarrow[\text{oxidation}]{\text{bacteria}} H_2O + \text{energy}$$

The initial dehydrogenation of organic matter is catalized by enzymes and the transfer of hydrogen takes place by one or more intermediate carriers. These intermediate carriers are called coenzymes and form what is termed a respiratory pathway (Clark)[14]. The respiratory pathway traps and stores chemical energy which is released for subsequent use by the cell. That part of organic matter used to produce energy is converted to essentially stable end-products. The more desirable of these end-products are gases such as carbon dioxide, nitrogen, oxygen or methane, which can be easily separated from the liquids phase. Some gases and volatile compounds such as hydrogen sulphide, amines etc., are undesirable because of their odour, which may create air pollution problems in the vicinity of the treatment plant. From a pollution view-point the micro-organisms produced must also be considered as undesirable products since, being organic matter, they can place a pollutional burden on the receiving waters. A special requirement for most biological processes used in waste water treatment is the production of flocculant micro-organisms that can be easily separated from liquid stream by such physical processes as gravity sedimentation or vacuum filtration.

Typical net reactions for aerobic, anaerobic and photosynthetic microbial reactions are as follows:-

1.1.2.4 Aerobic Oxidation

Organic matter + Aerobic bacteria + O_2 → New cells
(COHNS) → CO_2, H_2O, NH_3 etc. + energy

and with suitable conditions for development of nitrifying bacteria, the ammonia would be oxidized to nitrate.

1.1.2.5 Anaerobic Oxidation

Organic matter + bacteria → New cells

Organic matter + bacteria → Alcohols and acids + bacteria → New cells

Alcohols and acids + bacteria → CO_2, H_2O, NH_3, H_2S, CH_4 etc.

1.1.2.6 Photosynthetic

$CO_2 + H_2O$ + Photosynthetic micro-organisms → New cells

$CO_2 + H_2O$ + Photosynthetic micro-organisms → O_2

Aerobic biological systems are designed to maintain an adequate dissolved oxygen in the biological reaction mixture at all times. Apart from the excess microbes produced by biological reaction, all of the end-products of aerobic, organic degradation such as CO_2, H_2O in their most stable (oxidized) form are produced.

In an absence of oxygen, anaerobic reactions occur which convert the organic matter in the wastes to the lowest possible stable form. Some microbes can use the oxygen contained in nitrates for oxidation. Others use sulphates and organic compounds. Nitrates are reduced to ammonia and nitrogen gas. Sulphates are used as a source of oxygen with the production of hydrogen sulphide. Unless the hydrogen sulphide is discharged to the atmosphere or precipitated as the insoluble metallic sulphide, the oxygen demanding potential of the treated wastes can be nearly the same as the untreated waste (McKinney)[25].

In general, the decomposition of the complex organic matter is accompanied by production of intermediate and end-products. Such compounds as organic acids, alcohols and methane are the main products of decomposition of carbonaceous organic material. Similarly, degradation of proteins will result in compounds such as ammonia, amino acids and hydrogen sulphide.

The most important anaerobic microbial system is connected with methane formation. Carbon dioxide and organic acids are readily converted to methane. Since methane is relatively insoluble, the treated waste water will contain only excess microbes, a small amount of methane and stable end products. Usually anaerobic systems are used to treat concentrated organic wastes where a highly purified effluent is not required.

All the three of the above listed reactions may occur in the same reactor, for example in a lagoon where photosynthetic, aerobic and anaerobic reactions may take place in the upper, middle and bottom portions of the lagoon respectively. A disadvantage of photosynthetic reactions as compared to the other reactions is that inorganic carbon can be converted to organic carbon which can itself be a pollutant.

Each aerobic, anaerobic or photosynthetic process may be subdivided into three divisions, respiration, synthesis and decay. An example of an aerobic process is given below in which the organic substrate is assumed to be a carbohydrate and the micro-organism to have an empirical composition of $C_5H_7NO_2$ then

1.1.2.7 Respiration

$$C_x(H_2O)_y + XO_2 \xrightarrow{\text{bacteria}} XCO_2 + yH_2O + \text{Energy}$$

1.1.2.8 Cell Material Synthesis

if glucose is the carbohydrate taken

$$5C_6H_{12}O + 6NH_4^+ + \text{Energy} \xrightarrow{\text{bacteria}} \underset{\text{bacterial cell}}{6C_5H_7NO_2} + 18H_2O + 6H^+$$

1.1.2.9 Decay

$$\underset{\text{bacterial cell}}{C_5H_7NO_2} + H^+ + 5O_2 \xrightarrow{\text{bacteria}} 5CO_2 + NH_4^+ + 2H_2O$$

It should be noted that there are certain key nutrient elements in the growth of microbial cells such as nitrogen and phosphorous. It is necessary to have sufficient nitrogen and phosphorous available for the micro-organisms so that their growth is not restricted. Since the synthesis per unit of BOD is less for anaerobic systems than for aerobic systems the nutrient element requirements are definitely lower for anaerobic than for aerobic processes. Nutrient element deficiency is not a problem with domestic sewage but may be a problem with industrial wastes.

1.1.3 Support Media

In the treatment of liquid,either some surface must be provided to support the micro-organisms or, as in the case of activated sludge, intensive re-circulation of the sludge must be carried out. In biological filters, support for the micro-organisms is provided by the large surface area of the media in the biological reactor and this is composed of the stones of the filter which provide a permanent surface to which the micro-organisms are attached, and from which they attack the organic compounds in the waste flowing past them. In the activated sludge process the aeration tank may be considered as the biological reactor where a high concentration of micro-organisms, present as a re-circulated floc, are kept suspended by agitation. The effectiveness of the process depends on the return of a portion of the separated sludge (living micro-organisms) to the aeration zone to recommence stabilization. In a diffused-air system much of the air is utilized for agitation and only a small amount is actually utilized for the oxidation reactions. In the absence of agitation the solids quickly settle to the bottom and lose contact with the organic matter in the polluted liquid.

In sludge digestion, however, the primary and secondary sludge particles themselves provide a large total surface area to which the anaerobic organisms are attached. However, where liquid wastes are to be treated in anaerobic digesters, some surface must be provided for the micro-organisms or intensive recirculation of the contents must be carried out, otherwise the anaerobic organisms will settle out and not come into intimate contact with all of the liquid.

In the rotating disc processes, the large surface area of the discs provides the support for aerobic organisms and the rotation of the discs provides the intimate contact between the waste water and the organisms, where the micro-organisms are passed over the waste water and not the waste water over the micro-organisms as in the case of the percolating filter process.

1.2 Literature Survey and Review of Present Situation

The rotating disc process is a secondary biological treatment unit system for waste water. The original conception of the principle behind the unit should be credited to Buswell[12] who evaluated a unit of this type back in 1929. He referred to the unit as a biological wheel. The earliest report on waste treatment using rotating biological discs may be that of Doman[16], 1929, who even suggested using an Imhoff tank design to help in removing the solids from the disc section. In 1952 Gloya used the "rotating bacteria disc".

The rotating disc process was developed initially in Europe in the mid 1950's. Further development of the process began in the United States in 1965 and has continued to the present time.

In Germany, Hans Hartman [19,20] patented the invention of the "Immersion Dripper Unit" for use in an installation for the purification of sewage effluents. This consisted of at least one immersion dripper unit, comprising several circular plates combined to form the assembly and adapted to be immersed up to approximately half their diameter in an immersion tank.

This process has been operated for some years in Europe, mainly in Germany, Austria, France and Switzerland. It has been used for the treatment of a variety of domestic and industrial wastes. It is normally presented as a package plant for small communities.

In the United States many extensive laboratory studies of this process have been carried out since 1965 and the process has been successfully applied to water from the municipal, dairy and food processing industries.

At Rutgers University, Tropey[32] and his associates operated a rotating disc pilot plant that treated effluent from the primary tanks of the Jamaica water pollution control plant in New York City. Also Borchardt[10] operated a rotating disc unit at the University of Michigan.

In recent years the unit has been referred to as R.B.C. (Rotating Biological Contactors) and R.B.S. (Rotating Biological Surfaces) and there are now several installations working. The Allis-Chalmers Company has been engaged in developing the R.B.S.process by conducting research into their application since 1965. As a result Antonie[4-8] and Welch[5], who are working in the Research Division of Allis-Chalmers, published a series of papers which described the development and commercial use of the rotating disc process known under Allis-Chalmers trademark as the "Bio-Disc" process.

In 1968 the engineering firm of Foth and Van Dyke and Associates in Green Bay, Wisconsin, determined that the "bio-Disc" process with its unique capabilities would best meet the requirements that Eiler Cheese Company required for treating their cheese processing wastes. Subsequently, a contract was awarded to Autotrol Corporation to supply a Bio-Disc Unit.

In the village of Milwaukee, Wisconsin, the U.S. Environment Protection Agency[34] constructed a rotating disc unit and tested it under field conditions with 400,000 GPD of municipal waste water. The results obtained were encouraging.

Following investigation carried out since 1966 by J.R. Simpson[29] at Newcastle University and by the Water Pollution Research Laboratory at Stevenage, the application of the Bio-Disc in this country became a distinct possibility. Simpson combined primary, secondary and sludge holding facilities on a one-tank unit. For almost three years this work has been continued by Ames Crosta Ltd., who have had prototype units operating at sewage works in the vicinity of Heywood as well as at the Water Research Laboratory at Stevenage.

Recently, plants of the rotating disc type have been marketed by two different firms in this country. One of the two firms is Ames Crosta Ltd., who have designed and manufactured the Bio-Disc plant under licence from the National Research and Development Corporation. The other firm is the C.J.B. Developments Ltd. This latter firm has arranged with J. Conrad Stengelin of Tuttlingen, Germany, to carry out the marketing, design, manufacture and installation of C.S. Rotating Disc plants in the U.K. and Eire.

The A.C.M. Bio-Disc is a one-piece unit offered in a range of sizes to treat the sewage arising from communities of 5 to 500 people. The C.J.B. Rotating Disc process requires separate primary and final settlement units and has been installed for a range of applications, serving from 50 people to populations of 100,000. Over 700 C.S. disc plants have been built in Europe over the last ten years.

In developing countries such units have not been installed so far, but laboratory research work was carried on by A.N. Khan and R.H. Siddiqu[23] in India on a bench-scale rotating-disc unit for a nine month period to elaborate design criteria for such units, with a view to incorporating them in sewage treatment plants in India. Also M.B. Pescod and J.V. Nair[26] conducted an extensive laboratory study on a laboratory scale rotating disc at the Environmental Engineering Division, Asian Institute of Technology, Bangkok, Thailand. Pescod and Nair combined the biological filtration and the anaerobic digestion in a single unit and they reported that the unit was very efficient under the tropical conditions.

Because the unit is mechanically simple, little skill is required to operate and maintain it and hence the unit would appear to be suitable for the requirements of developing countries as well as for the industrial ones.

In this project further references to the unit will designate this treatment device as a Rotating Disc Treatment Unit (R.D.T.U.).

The purpose of this report is to present the results obtained during an investigation, carried out between January, 1973 and March, 1974, into the ability of laboratory scale R.D.T.U. plant to treat the settled sewage obtained from a local sewage treatment works (Shepshed U.D.C.). The investigation was carried out at three different temperatures of 10°C, 20°C and 30°C

SECTION TWO

EXPERIMENTAL

2.1 DESCRIPTION OF THE TEST UNIT

2.1.1 Unit Specifications

The figures 1,2,3 and 4 show the drawings submitted for the fabrication of the R.D.T. Units used for the investigation. Fig. 1 shows the plan of the unit. Fig. 2 shows the vertical sections of the deep and shallow ends of the unit. The deep end is the back of the unit and the shallow end is the front of the unit. Fig. 3 shows the dimensions of the first and second baffles or partitions. Fig. 3 can be modified to give the dimensions of the rest of the baffles at the different positions in the tank.

Fig. 4 shows the frontview of the unit and Fig. 5 is a photograph of the unit before being commissioned.

The unit consists of:-

1. 28 discs of 200 mm dia. each, mounted on a 20 mm dia. horizontal shaft driven by 1/15 H.P. electric motor.
2. There were seven stages to the process and each stage was formed of 4 discs. The discs were 200 mm dia., 3 mm thickness and spaced 10 mm centre to centre.
3. The disc and shaft assembly was placed in a tank which had a rectangular surface area and which was tapered down from top to the bottom at both sides in order to help the settlement of the solids.
4. The electric motor was mounted on the tank back and the drive was transmitted to the shaft by a nylon chain.
5. The tank bottom was tapered also by increasing its depth from inlet to outlet. This design was incorporated in order that the retention time in each stage could be increased from inlet to outlet in an endeavour to spread the work of purification more evenly along the whole length of the apparatus.

FIGURE 1 : PLAN OF THE R.D.T. UNIT

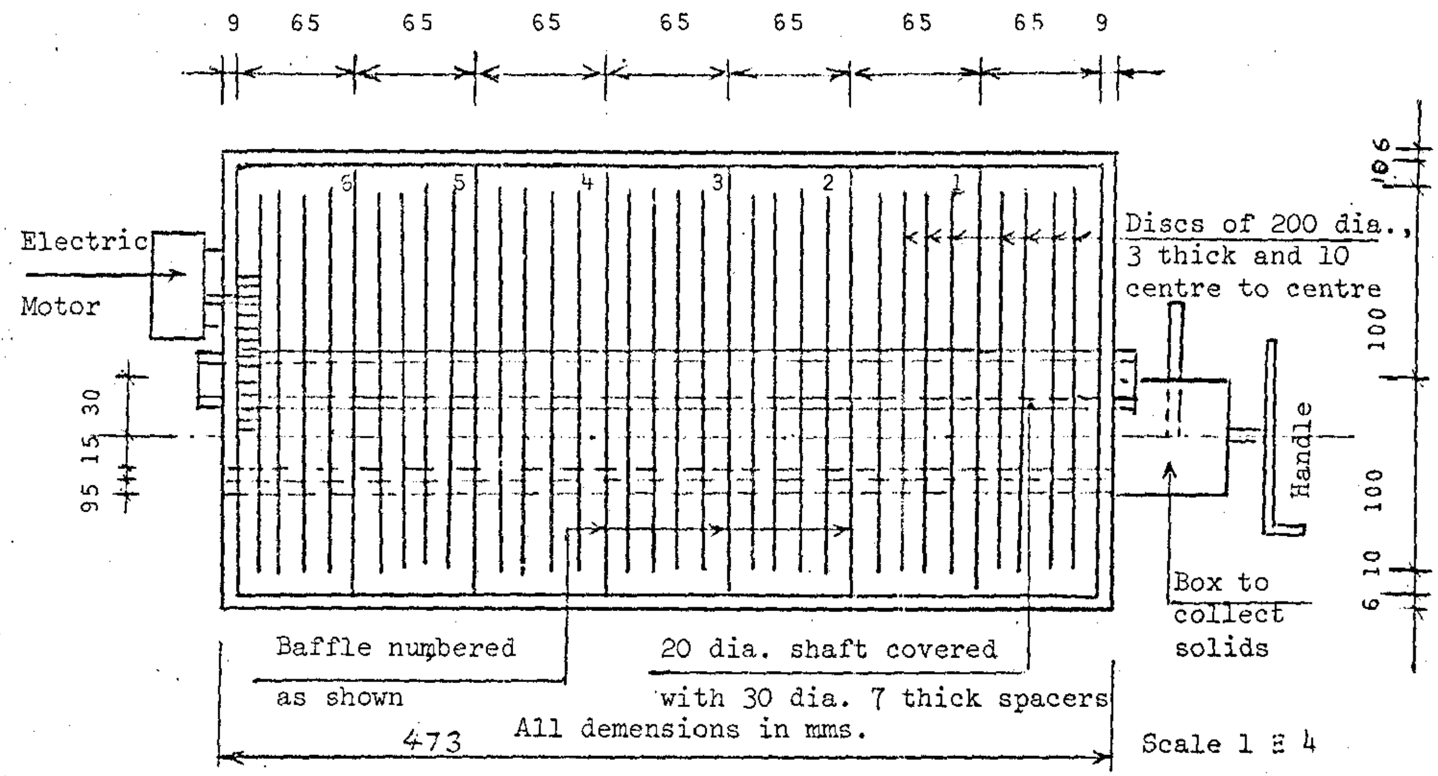
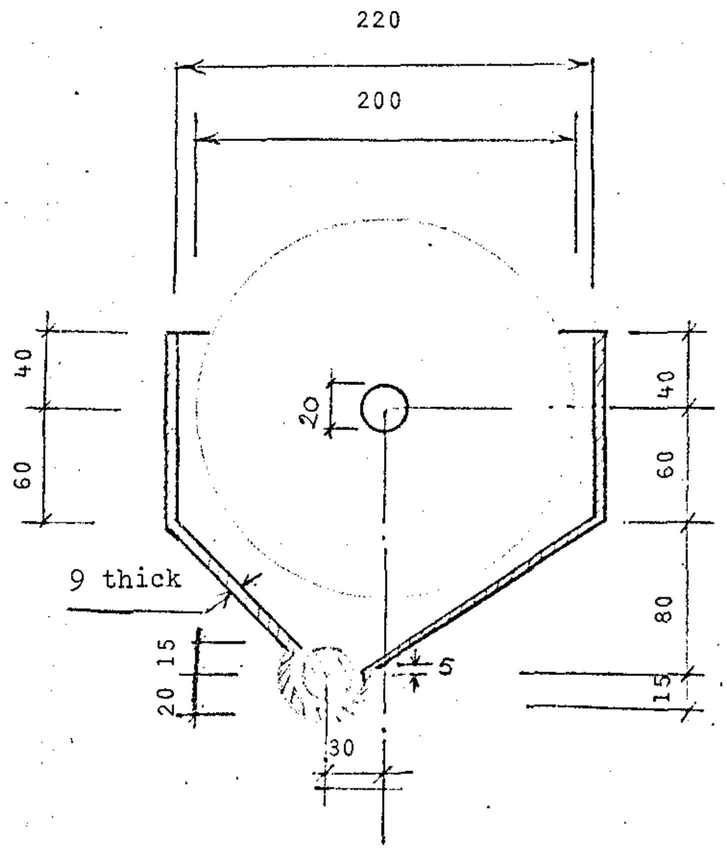
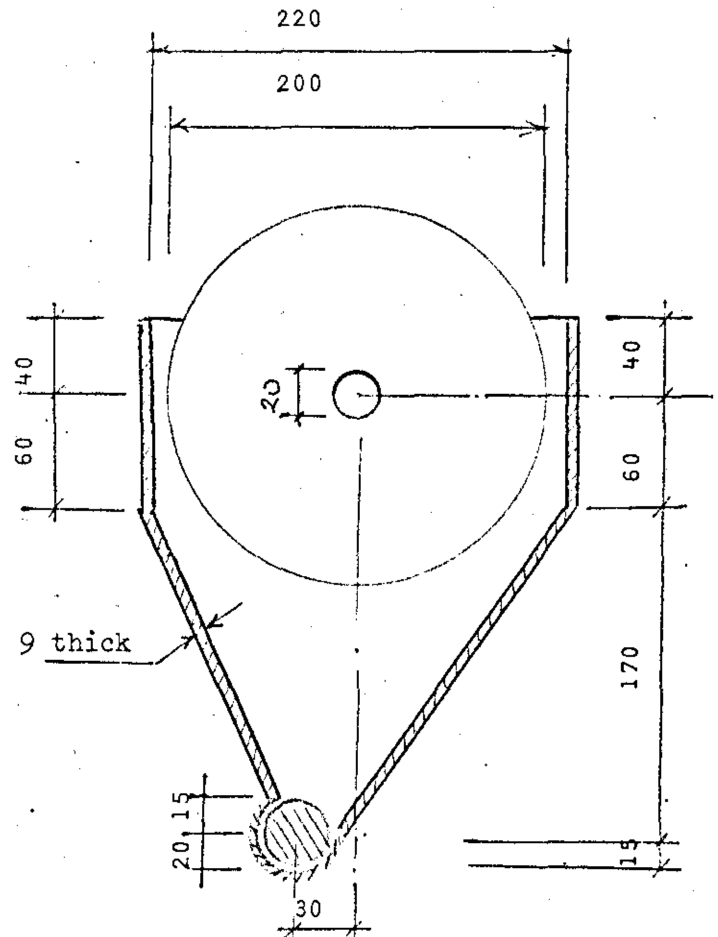


FIGURE 2.



All dimensions are in mms. Scale 1:4

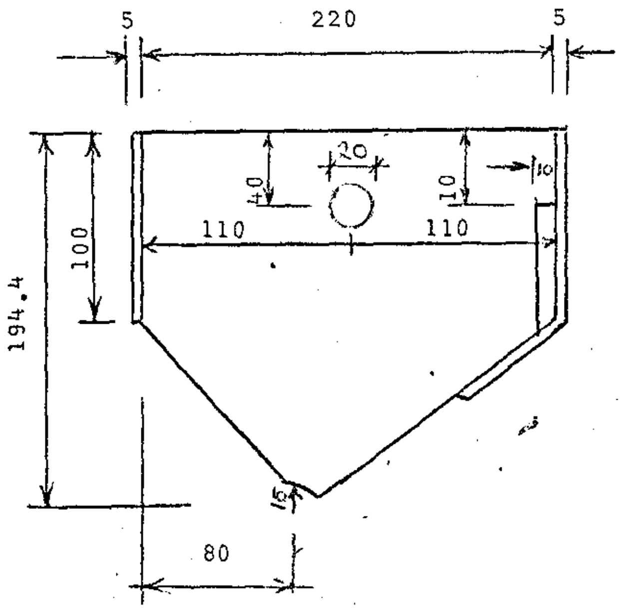
SHALLOW END CROSS-SECTION



All dimensions are in mms. Scale 1:4

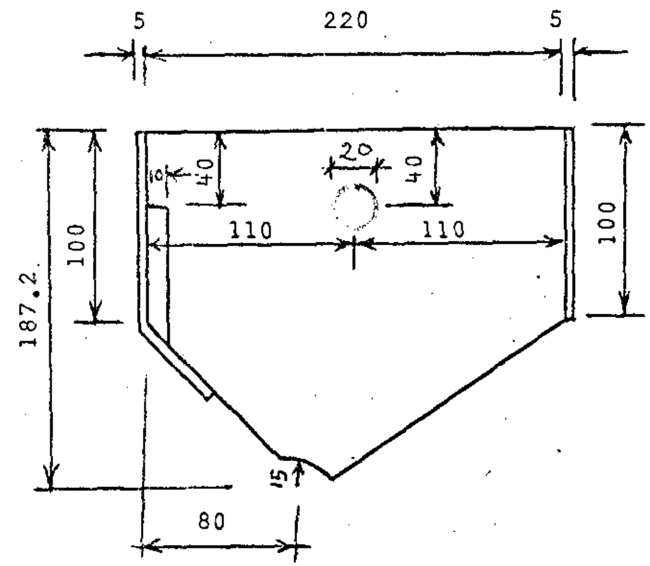
DEEP END CROSS-SECTION

FIGURE 3



All dimensions are in mms.
Scale 1:4

PARTITION 2



All dimensions are in mms.
Scale 1:4

PARTITION 1

FIGURE 4 FRONT VIEW OF THE TEST UNIT

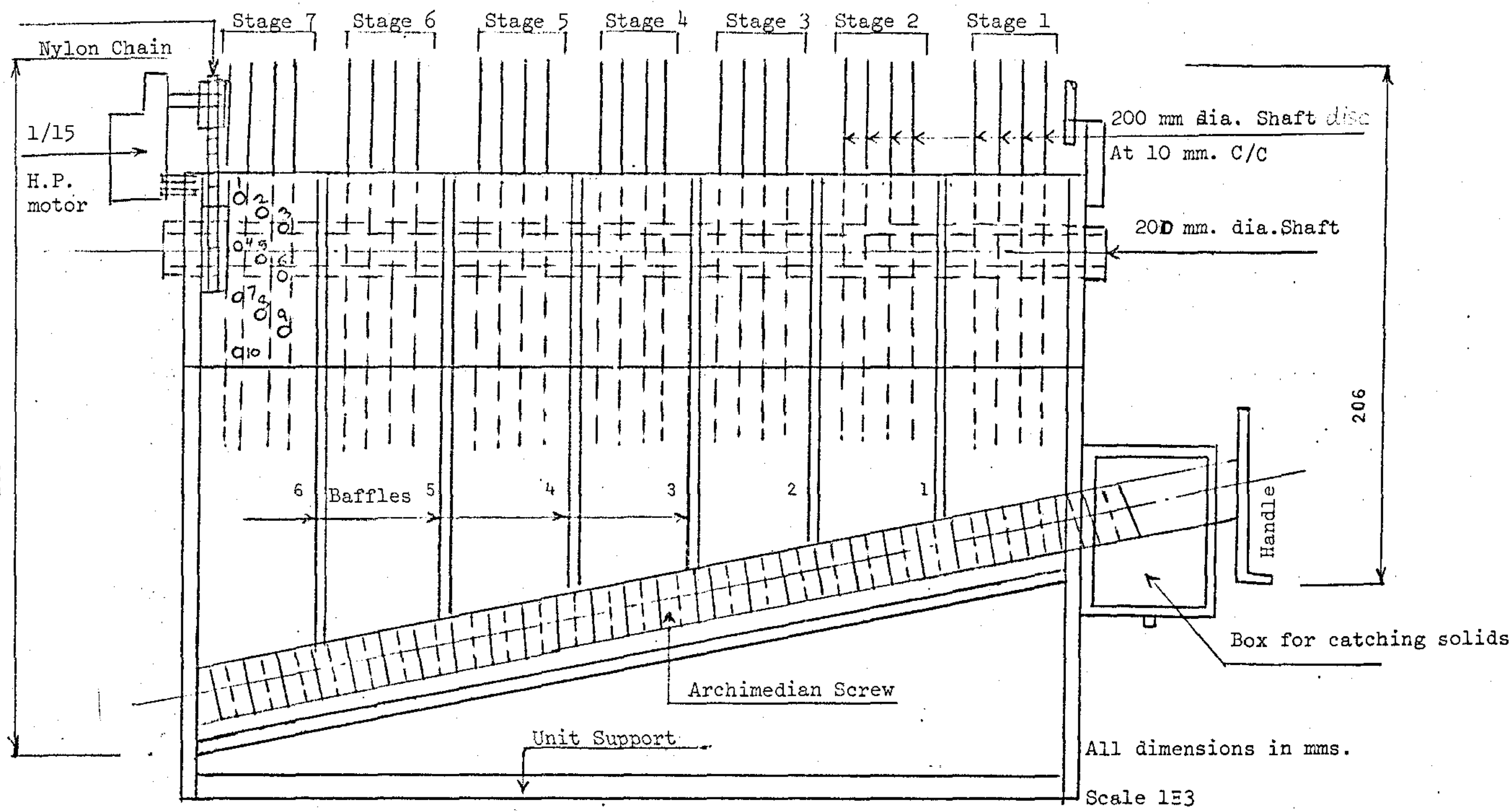


FIGURE 5 : A PHOTOGRAPH OF THE UNIT BEFORE BEING COMMISSIONED

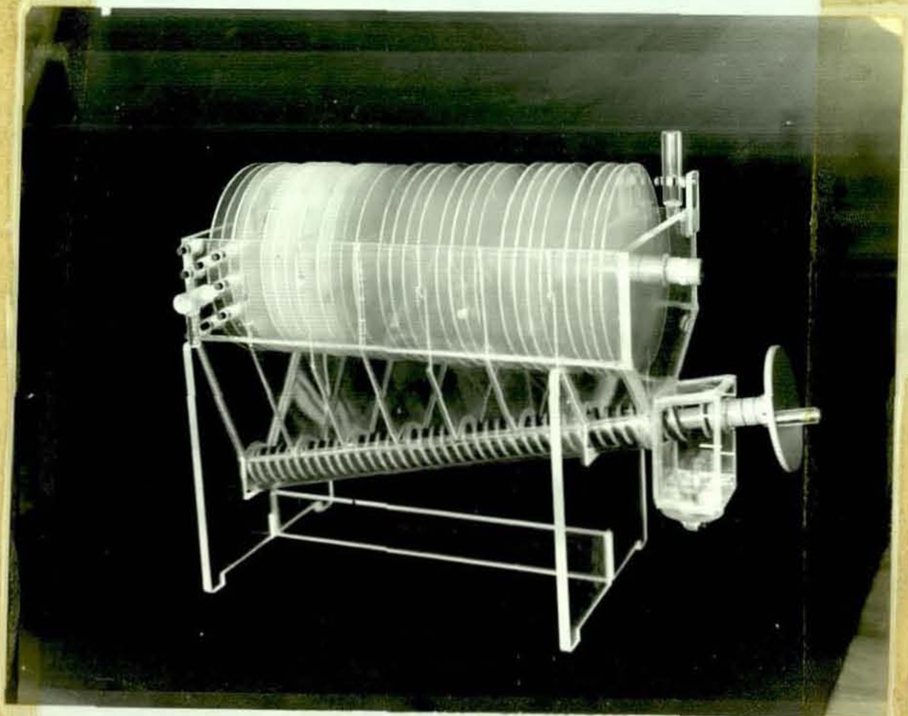


TABLE 1 : SPECIFICATIONS OF TANK CAPACITY AND PERCENTAGE AREA OF DISCS SUBMERGED, CORRESPONDING TO EACH ORIFICE

Orifice Serial Number	Distance of orifice from top of tank in mms.	Capacity of tank at each orifice position in litres	Area of discs submerged at each orifice position in m^2	Percentage area of disc submerged at each orifice position
1	8	14.16	1.248548	69.4%
2	13	13.66	1.198596	66.5%
3	20	12.89	1.113700	61.9%
4	30	12.09	0.973112	54.0%
5	40	11.39	0.896784	50.0%
6	50	10.79	0.820456	45.6%
7	60	9.95	0.679840	37.8%
8	72	9.29	0.547064	30.4%
9	80	8.49	0.463540	25.7%
10	90	7.69	0.360864	20.0%

6. The stages were separated by baffles to reduce short circuiting.

7. The waste water flowed through each compartment across the breadth of the unit, so the flow was parallel with the length of the discs. It then left the reaction vessel through a submerged orifice.

8. The outlet consisted of a series of orifices set at specific heights, each corresponding to a certain volume and level of waste water in the reaction tank. Considering the highest outlet as zero, then the orifices'position from this top level of the tank can be shown in Table 1 together with the tank volumes and the area of disc submersion.

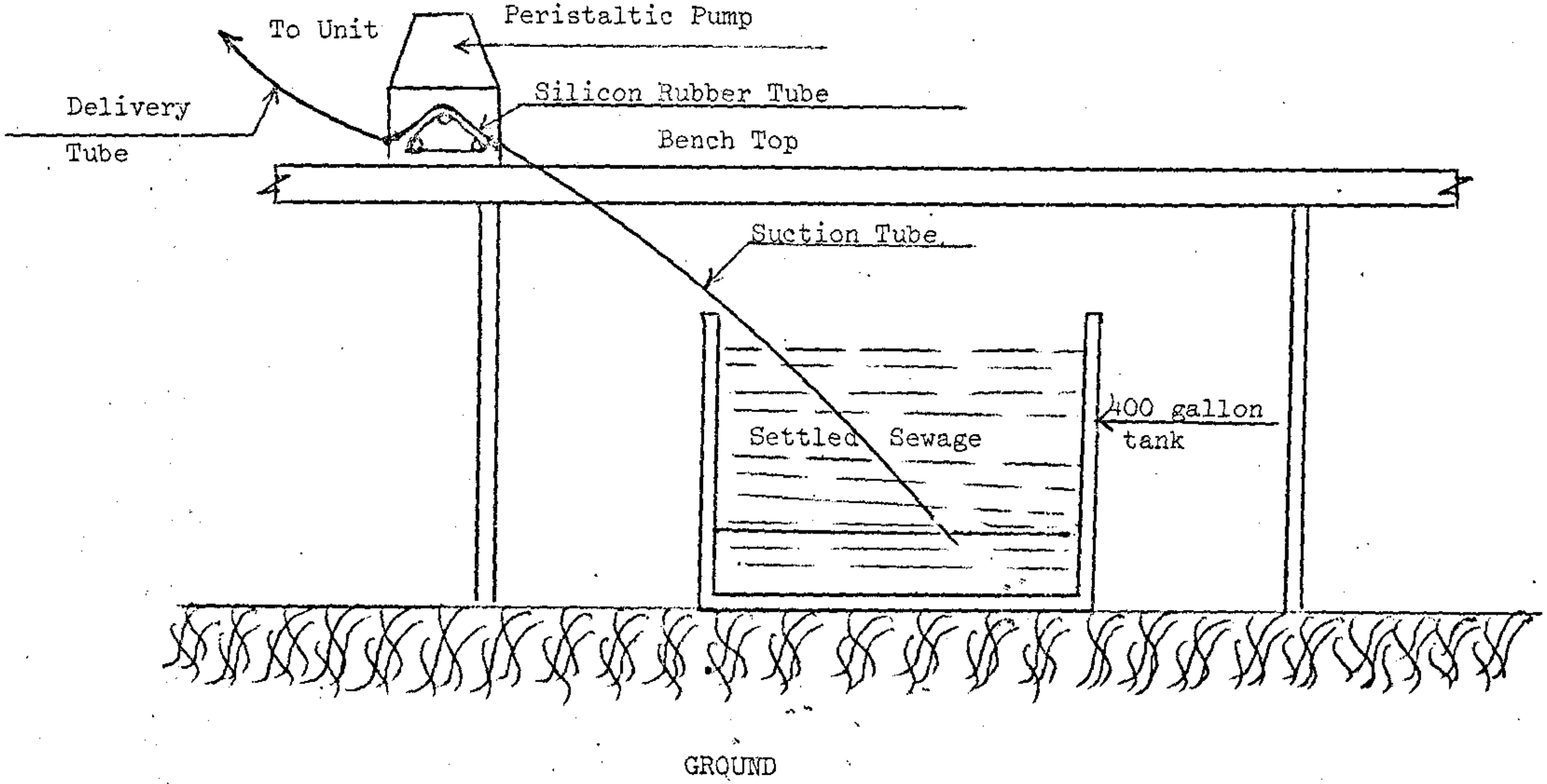
   The maximum and minimum capacities of the tank were 14.2 and 7.7 litres respectively. The total available surface area was 1.80058 m^2

9. There was no final settlement tank. The tank acted as a reaction vessel and a secondary clarifier. Final settling of the R.D.T.U. sludge was accomplished in the bottom of the reaction vessel. The settled sludge was then removed by an Archimedian screw and was collected in a box attached to the front of the tank. The Archimedian screw was 30 mm in external diameter and was rotated by a handle.

2.1.2 Feed System

The settled sewage was brought by a truck daily from a local sewage works (Shepshed U.D.C.) and poured into a 400 gallon capacity tank. The sewage was then supplied to the units by a pumping mechanism. A Watson-Marlow peristaltic pump was used for this purpose. An SRT/4, 4 mm internal dia., 6 mm external dia., and 102 mm length silicon rubber tube was used to connect the suction and delivery tubes as well as to maintain the tension required for the pump. The feed rate was maintained by the pump speed and the flexible length of the silicon rubber tube .

FIGURE 6 : FEED SYSTEM



This peristaltic pump fed the unit from the sewage holding tank into the first R.D.T.U. stage.

Fig. 6 shows the feed system described above.

2.2 DESCRIPTION OF THE PROCESS

2.2.1 General

Waste water usually undergoes four main processes or operations during conventional treatment. These can be summarised below:-

1. Primary Sedimentation

   In this process the raw settleable solids are removed by gravity to form the primary sludge.

2. Aerobic biological treatment, where the dissolved and colloidal organic matter is oxidized to carbon dioxide, water and other end products or synthesized into biological sludge.

3. Secondary sedimentation, where the settleable biological solids are removed by gravity to form the secondary sludge.

4. The treatment of the mixed sludges, often by anaerobic digestion, is followed by a de-watering process before its ultimate disposal.

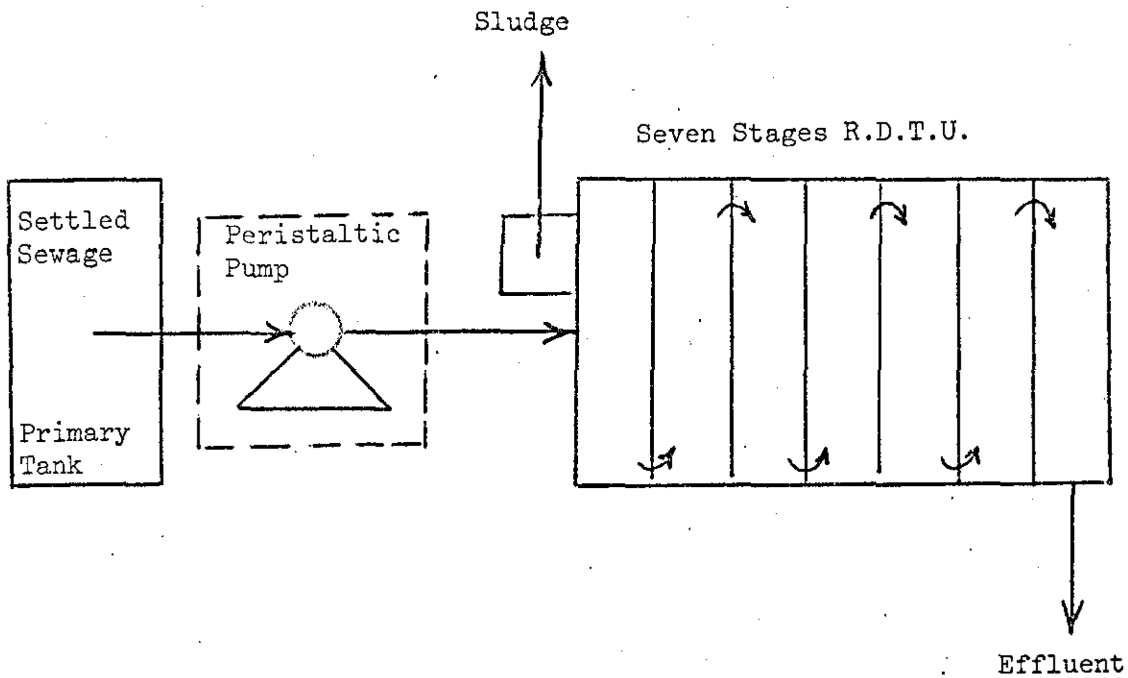
Fig. 7 illustrates that the unit described above is designed to afford the second and the third of the above conventional processes.

2.2.2 Operation of the Unit

In essence the system depended wholly on the discs. These were constructed of perspex because it possesses greater resistance to chemical action and does not deteriorate with age. These properties agree with the comments in the Water Pollution Research Laboratory notes No. 40 which discuss the subject of the filter media.

"The essential requirements for a biological filter medium are that it should be inert, of sound mechanical strength, and possess within its bulk an extensive area of exposed surface over which the liquid to be treated can be passed and in which microbiological growth necessary to purification can be supplied".

FIGURE 7 : SCHEMATIC DIAGRAM OF THE R.D.T. PLANT INSTALLED



The discs fulfil three main functions.

1. A support media for the bio-mass. The micro-organisms which are present naturally in the waste water adhere to the disc surface and multiply quickly within a few days of start-up and they cover the entire surface area of the discs.

2. An aeration device for the treatment process. The dissolved oxygen content in the mixed liquor is increased by increasing the rotation speed of the discs.

3. To ensure contact between the biological growth and the waste water. The rotation alternately submerges the attached biological growths and then exposes them to air. The mixing and agitation enables food and oxygen to penetrate further into the bio-mass. The excess biological mass held can be cleaned by gently reversing the direction of rotation.

2.2.3 Removal of Organic Matter

The polluting matter is removed naturally by the aerobic micro-organisms which use it as a source of energy. The complex chemicals constituting the polluting load, such as carbohydrates, proteins and lipids, are transformed biochemically to further biological growth and to stable inorganic compounds.

As the discs rotate through the reaction vessel a thin film of liquid adheres to the surface of the biological slime that has developed on the disc surfaces. Once free of the bulk of the liquid this thin film is free to adsorb oxygen from the air. (The biological slime on the submerged portion of the discs surfaces may also adsorb oxygen from any reserve of dissolved oxygen in the bulk of the liquid).

The process is continuous as the biological slime is alternately exposed to the waste water and then to the air. This provides a means of exposing the biological growth to the organic polluting load and of aerating the waste water. Thus the removal of the organic matter is achieved by biological oxidation which yields energy as well as stable end-products. Hence the carbonaceous matter is transformed into energy, carbon dioxide, ammonia and water and also into fresh protoplasm in the form of new bacterial cells. When the concentration of the nitrifying bacteria is sufficiently increased, the ammonia in the water is further oxidized to nitrite and nitrate, plus more of the nitrifying cells.

2.3 TESTS AND ANALYSIS PROGRAMME

2.3.1 Sampling

Grab (or spot) samples were taken for all effluents and influents, six days per week. The samples were usually taken at the end of the day and stored in the refrigerator overnight. The analysis was then carried out on the samples the next morning during the first ten months of the investigation. For the rest of the investigation period the analysis of the composited samples of Monday and Tuesday, Wednesday and Thursday, Friday and Sunday were carried out on Wednesday, Thursday and Monday, respectively.

2.3.2 Analysis

The procedures employed in these analyses were those recommended in the official publication "The analysis of Raw, Potable and Waste Waters" (H.M.S.O., 1972).[15]

The laboratory analyses performed were as follows:-

2.3.2.1 The Biochemical Oxygen Demand - B.O.D.

Micro-organisms bring about the biochemical oxidation because they utilize the polluting substance as sources of carbon while consuming atmospheric oxygen dissolved in the water, for respiration.

The amount of biochemically degradable organic matter is measured by the quantity of oxygen consumed from the water. The B.O.D. is the measure of the dissolved oxygen required by a definite volume of liquid for the process of biochemical oxidation during five days at 20°C. The test is simple. A known volume of sample was diluted with a standard water. The test dilutions were well mixed and poured into 250 ml. glass-stoppered bottles. One bottle was used for the initial determination of dissolved oxygen and another was incubated at 20°C for five days.

The "Rideal-Stewart Modification" for the determination of the dissolved oxygen was used.

2.3.2.2 Chemical Oxygen Demand - C.O.D.

This is the measure of oxygen consumed from acid potassium dichromate solution under standard conditions. The mixture of the sample and acid potassium dichromate was boiled under a reflux condensor for two hours. The quantity of organic matter oxidized was determined from the oxygen consumed from the acid potassium dichromate.

2.3.2.3 Permanganate Value - P.V.

The P.V. test has been used as a quick means of providing an indication of the polluting properties of liquids. The oxidizable organic matter in the waste water consumes the oxygen from the acid permanganate. The quantity of organic matter oxidized was measured by the amount of oxygen consumed from the acid permanganate in 4 hours at 27°C

2.3.2.4 Free and Saline Ammonia

The method used for the determination of ammonia in the sample was a distillation technique. The distilled ammonia was then determined colorimetrically after the addition of Nessler's reagent.

2.3.2.5 Nitrite Nitrogen

A purplish-pink azo dye is formed when sulphanilic acid is diazotized with nitrite in acid solution and the resulting diazo compound coupled with 1-naphthylamine-7-sulphonic acid.

2.3.2.6 Nitrate Nitrogen

The method is based upon the reaction of the nitrate with phenoldisulphonic acid in acid solution to give a nitro-derivative which, when made alkaline, develops a yellow colour.

2.3.2.7 Suspended Solids

The suspended solids were determined by filtration through glass fibre filter papers ($\frac{GF}{C}$ grade) in a 3-component Hartley-Type filter funnel, and the necessary reduced pressure was obtained by an electrically operated vacuum pump. The paper was dried at 105°C in an oven and weighed after being cooled in desiccator.

2.3.2.8 Anionic Synthetic Detergents

The method for the determination of anionic synthetic detergent is based upon the development of a blue complex between the syndet and the dye methylene blue. The density of the resultant colour complex was determined spectrophotometrically.

2.3.2.9 pH

The pH can be taken as the logarithm to the base 10 of the reciprocal of the hydrogen ion concentration. Values below 7 are increasingly acid while values from 7 to 14 are increasingly alkaline. 7 is neutral. The pH was measured by an electrometric method.

2.3.2.10 Determination of Solids Wasted from Biological Reactor

The solid content of the sludge removed from the bottom of the reaction vessel was determined by a centrifugal method.

The sample was placed into a cone-shaped centrifuge tube of 50 mls. capacity and centrifuged for five minutes at a standard speed. The supernatant liquid was decanted and the residue was washed with a little water into tared pyrex dishes. The residue was then dried, initially on a water bath and then in an oven at 105°C for one hour. Finally, it was cooled in a desiccator and weighed.

2.3.2.11 Specific Resistance to Filtration

The specific resistance to filtration is a quantitative measure of the de-watering characteristics of a sludge and may be defined as the pressure required to produce unit rate of flow through a cake having unit weight of dry solids per unit area when the viscosity of the liquid is unity.

The basic techniques involve filtration of sludge in a Buchner funnel. The apparatus used in this investigation was a 90 mm size Buchner funnel and No. 1 Whatman filter papers. The filtrate was collected in a graduate 100 ml. cylinder. The filtration pressure was maintained by a suction pump in conjunction with a vacuum reservoir.

The apparent specific resistance was calculated from the relationship.

$$r = \frac{2B}{\eta C} . P$$

where P is the pressure drop across filter cake and medium. C is the weight of dry solids deposited on the cake per unit volume of filtrate. η is the viscosity of the water and B is the gradient of the straight line derived by plotting time per unit volume of filtrate collected against volume. The pressure drop P was maintained in the range of 62 to 65 cm Hg.

2.3.3 Average Waste Water Characteristics

From the results obtained as a result of the analysis carried out on the waste water used throughout the investigation, the average strength of the feed liquid can be summarized below:-

	mg/ℓ
B.O.D.	245
Suspended Solids	122
C.O.D.	374
Ammonia Nitrogen	32
Anionic detergents	9.5
pH.	6.5 - 7.5
P.V.	66

2.4 PRELIMINARY OPERATION

The preliminary operation was used to evaluate approximately the treatment capabilities of the equipment to check the feasibility of the unit design, to establish guidelines for obtaining the best operating conditions and to gain reasonable experience in running the unit.

Three discs were operated as follows:-

Disc "4" was commissioned on the 5th of April, 1973 and was operated for about 14 weeks at room temperature (average of 16.5°C), 4 hours retention time and the area of submersion of the discs of 50%. During this time the speed of rotation of the discs was changed from 5 rev/min. to 10 rev/min. and then to 2 rev/min. These alterations were made on the 22nd of May and on the 17th of June respectively.

Disc "5" was commissioned on the 4th of May, 1973 and was kept running for about 10 weeks at a room temperature of 27 - 29°C, with 4 hours retention time, 5 rev/min. disc speed and the area of submersion of the discs of 50%

Disc "7" was started on the 16th of June, 1973 and was run under the same conditions as Disc "5".

During this initial operation much experience and practice was gained in operating the discs and two problems concerning the design arose while running them.

It was found necessary to alter the drive mechanism on the apparatus operating at 30°C, from a chain drive (nylon chain) to a direct gear arrangement. Expansion of the nylon chain at this higher temperature led to a succession of failures. Also a further problem was the severe drop in the temperature of the liquid interaction vessel due to the excessive water evaporation from the exposed discs. This difficulty was partially overcome by manufacturing polythene lids to loosely cover the apparatus.

During this period daily analysis of the units' effluents were carried out. The samples taken, including the substrates, were examined for B.O.D., C.O.D., S.S., P.V., NH_3 - N, pH., Nitrite - N, Nitrate - N and detergents.

The sludge was also removed periodically at two day intervals and its concentration was determined.

2.5 INVESTIGATION INTO THE OPTIMUM CONDITIONS OF OPERATION

2.5.1 General

The research was carried out using three identical R.D.T. units and each unit was put in a separate room resembling a certain environment.

Disc 7 was installed in a constant temperature room at 10°C.

Disc 4 was installed in a constant temperature room at 20°C

Disc 5 was installed in a constant temperature room at 30°C

Operating in these constant temperature rooms, it was possible to maintain the temperature of the liquid in the reaction vessels at the following temperatures:-

1. The waste water temperature in Disc 7 was maintained at (10.5 - 11.5)°C
2. The waste water temperature in Disc 4 was maintained at (17.5 - 18.5)°C
3. The waste water temperature in Disc 5 was maintained at (26 - 28)°C

2.5.2 Effect of Retention Time on Unit Performance

The three units were operated under the conditions below:-

1. The area of disc submersion was 50%
2. The disc rotational speed was kept at 4 rev/min.

The operation of the three different temperatures R.D.T. units was started on the 13th of July, 1973, with a retention time of 4 hours.

On the 17th of August, 1973, $R.D.T.U._4$ retention time was changed to 2 hours. On the 31st of August, 1973, $R.D.T.U._5$ was changed to 2 hours retention time. On the 1st of September, 1973, $R.D.T.U._7$ retention time was changed to 2.43 hours. Then on the 19th September, 1973, the three R.D.T.U. units were changed to 3 hours retention time and were kept running in this manner until the 12th of October, 1973.

During this period the analysis was carried out on the 6 days per week samples and the results were recorded. The graphs (5-11) show the performance of the R.D.T. units and their change of efficiency with respect to retention times which were plotted for average results. The optimum retention time for the $R.D.T.U._4$ and $R.D.T.U._5$ was found to be 3 hours and for $R.D.T.U._7$ 4 hours.

2.5.3 Effect of Disc Submersion on Unit Performance

As stated earlier, the outlet from the reaction vessel consisted of a series of orifices set at specific height, each corresponding to a certain volume and level of waste water in the tank. Table 1 shows the orifices' positions and the corresponding area of disc submersion, tank capacities and percentage of disc submersion.

For this section of the work the three R.D.T. units were operated under the conditions stated below:-

1. The speed of rotation was maintained at 4 rev/min.
2. The retention time was kept at 3 hours for both $R.D.T.U._4$ and $R.D.T.U._5$ while $R.D.T.U._7$ operated at a 4 hour retention time.

On the 12th October, 1973 the outlets of the three units were changed from orifice 5 to orifice 9. On the 22nd October, 1973 $R.D.T.U._4$ and $R.D.T.U._5$ retention times were changed to 2.2 hours while $R.D.T.U._7$ retention time was changed to 3 hours.

On the 5th November the three units outlets were changed from orifice 9 to orifice 1. The units were first operated under 3.75 hours retention times for $R.D.T.U._5$ and $R.D.T.U._4$ and 5 hours retention time for $R.D.T.U._7$. On the 15th November, 1973, $R.D.T.U._4$ and $R.D.T.U._5$ retention times were changed to 3 hours and $R.D.T.U._7$ retention time was changed to 4 hours, in order to maintain the conditions stated above.

On the 29th November, 1973, the three units' outlets were changed from orifice 1 to orifice 7. The units were operated under the specified retention times stated above. On the 14th December, 1973, the units' outlets were changed from orifice 7 to orifice 10. The units were operated under the specific retention times stated above.

During this period the analysis was carried out on the 6 days per week samples and the results were recorded. The graphs (16-21) were plotted for the average results and the optimum percentage area of submersion was found.

2.5.4 Investigation of R.D.T.U. Performance at Optimum Operational Condition (Percentage Disc Submersion)

The next step in the investigation was to find the increase in the treatment capacity of the units when operating at the optimum area of disc submersion.

From the results recorded and the graphs plotted for the performance of the unit at different degrees of area of disc submersion, it was found that the optimum percentage area of disc submersion was 25.7 (corresponding to orifice 9).

During this period of operation the units were operated under orifice 9 and the discs rotation speed was maintained at 4 rev/min.

On the 29th December, 1973, the units' retention time was changed to 2.2 hours (132 minutes). On the 22nd January, 1974, the units' retention time was lowered to 97 minutes. On the 11th February, 1974, the units' retention time was lowered again to 60 minutes. On the 15th March the units were stopped.

During this period the analysis was carried out on the 6 days per week samples and the results were recorded. The graphs (22-29) were plotted for average results.

The results shown by the graphs in question were the best results recorded during the whole investigation. All effluents produced after being retained in the reaction vessel for 97 minutes or more can be classified as first class effluents. Reduction of retention time to 60 minutes lowered the quality of the effluent evolved.

2.6 EFFECT OF EFFLUENT RECIRCULATION ON UNIT PERFORMANCE

The investigation was carried out by installing two new, identical R.D.T. units in the 20°C room. One of the two units had its effluent re-cycled. Both units were operated for about 9 weeks under the same conditions of operation, except that for the unit operating with recirculation the rate of flow of the recycled effluent was maintained at the same rate as that of the flow of substrate.

Synthetic sewage was used to feed the units during the whole period of installation.

The synthetic sewage recipe was obtained from a paper presented by N.V. Williams and H.M. Taylor[37]

This was slightly modified by Loughborough University of Technology.

The synthetic sewage used in the investigation has the following characteristics:-

		mg/l
1.	Dextrin	150
2.	Ammonium Chloride	130
3.	Yeast Extract	120
4.	Glucose	100
5.	Starch	100
6.	Sodium Carbonate	100
7.	Detergent (OMO)	50
8.	Sodium Dihydrogen Phosphate ($Na\ H_2\ PO_4$)	20
9.	Potassium Sulphate (K_2SO_4)	8.3

During this period of operation the analysis was carried out on samples taken 6 days per week and the results were recorded.

The average results of the B.O.D., C.O.D., NH_3-N, N_2O-N, NO_3-N and S.S. are shown on Table 14 and the efficiency of each unit was measured by its ability in removing the polluting load applied to it, as well as the degree of total oxidized nitrogen formed.

2.7 OPERATIONAL DIFFICULTIES

Before discussing the results obtained during the investigations, it is worth recording some of the difficulties encountered during the period of research and to what extent they were overcome.

2.7.1 Temperature Control

As stated earlier, due to the large surface area and the high room temperatures, a great drop in waste water temperature occurred by evaporation.

This cooling rate was reduced by loosely covering the R.D.T. units with polythene lids. Also during the colder weather the waste water brought from the local sewage works was cold. This led to a temperature reduction in the R.D.T.U.$_5$ (30°C room), which was overcome by passing the sewage feed through an electric heater before entering the unit.

Much effort had been put into maintaining the constant room temperatures to the accuracy of less than 1°C difference. This had not always been successful because of the size of the rooms and the considerable variations in the external temperature.

2.7.2 The Feed System

A lot of time and much effort has been given to maintaining the constant feed rate required. The sewage was pumped by a peristaltic pump from the main 400 gallon tank to feed the units. The delivery rate was not constant over long periods due to the variation of the level of the sewage in the 400 gallon tank. It was very difficult to maintain a constant head in the tank because the waste water was transported periodically from the local sewage works.

To overcome this difficulty the pump speed was adjusted every two hours during the day. The other difficulty was the rate of wear of the rubber friction tubes used to connect the suction to the delivery tubes in the peristaltic pump. The rubber tubes were not strong enough to last for a long period, so they were changed frequently.

2.7.3 The Feasibility of the Design

As far as these investigations were concerned, it can be said that the design of the unit was quite satisfactory.

During the whole period of operation the units were not given any sort of maintenance except for oiling the motors and changing the fuses of the peristaltic pumps. The perspex material, of which the units were made, was still strong and showed no sign of deterioration with age at the end of the investigation.

The gear arrangement introduced after the failure of the nylon chain drive functioned well.

The Archimedian screw used for the sludge removal was quite satisfactory.

It seems that the provision of gradually increasing compartmental volume was an advantage because most of the work was still carried out in the first two compartments.

SECTION THREE

DISCUSSIONS I (GENERAL)

3.1 MEASURE OF UNITS' EFFICIENCY

The unit efficiency is measured by its ability to remove the organic pollutants. The organic pollutants are generally unstable and may be oxidized biologically or chemically to stabilize relatively inert end products such as CO_2, H_2O and NO_3. An indication of the organic content of the unit effluent can be obtained by measuring the amount of oxygen required for its stabilization.

3.1.1 Oxygen Demand in Aerobic Oxidation

The amount of oxygen required to completely stabilize a waste could be calculated on the basis of a complete chemical analysis of the samples, e.g. in the equation below, each molecule of glucose requires six molecules of oxygen for complete conversion to carbon dioxide.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{bacteria}} 6CO_2 + 6\,H_2O$$

In the case of more complex compounds found in most samples (e.g. proteins), the reaction becomes more difficult to understand. The necessary work for the complete chemical analysis of a sample would be difficult and most time-consuming. Hence, several other methods of calculating the oxygen demand have been proposed (Tebbutt)[33] e.g.

Theoretical Ultimate Oxygen Demand (U.O.D.) mg/ℓ =

$$2.67 \times \text{Organic Carbon mg}/\ell + 4.57\,(\text{Organic Nitrogen + Ammoniacal N})\ \text{mg}/\ell + 1.14\ NO_2\text{-N mg}/\ell$$

This equation should be modified according to whether any of the major elements are absent or other additional elements like phosphorous are present.

Widely accepted methods of measuring the amount of oxygen required by the sample of water are the 5 day Biochemical Oxygen Demand (B.O.D.), which is the measure of oxygen demanded by micro-organisms whilst breaking down organic matter, and the Chemical Oxygen Demand (C.O.D.) (either using boiling potassium dichromate in concentration of sulphuric acid or using potassium permanganate solution in 25% sulphuric acid). These are the best parameters used in assessing the quantity of pollution discharged to receiving waters and the overall performance of treatment plants, in spite of the limitations and shortcomings that each test has got.

The B.O.D. test was originally intended to simulate conditions which occurred following the discharge of an effluent to a river. Some of the limitations of the B.O.D. test can be shown by the following observations:-

1. The B.O.D. test uses small cultures of micro-organisms to stabilize organic matter in quiescent conditions,while in biological treatment plants high concentrations of micro-organisms are continuously agitated to keep them in contact with the concentrated substrate and an excess dissolved oxygen is supplied.
2. The 5 day B.O.D. gives no indication of the rate of oxygen uptake unless B.O.D.s are determined at daily intervals over a period, instead of the standard 5 day period.
3. The oxidation in the B.O.D. test proceeds relatively slowly and is not usually completed in the standard 5 day period of incubation. Compounds like glucose are almost completely oxidized in 5 days, but domestic sewage is only 65% oxidized and complex organic compounds might be only 40% oxidized in this period.

The Chemical Oxygen Demand determinations have also two basic disadvantages.

1. They give no indication of whether or not the substance is degradable biologically, nor do they indicate the rate at which oxygen would be required in biological systems.

2. The test does not simulate conditions in a treatment plant or receiving waters, and it is not affected by factors which influence biological activity e.g. inhibitor substances, lack of nutrients and pH.

The additional limitation for the potassium permanganate (P.V.) test is that the test results are considerably less than the dichromate results and the B.O.D. results. This means that the P.V. test measures a small fraction of organic matter in the waste. Such organic matter may or may not be metabolized in biological treatment.

For a given waste the D.V. is always much greater than the P.V. and the D.V. results usually approach the theoretical oxygen demand values. For this reason the D.V. are more useful and capable of meaningful interpretation than the permanganate.

It should be noted that for wastes which can be metabolized by micro-organisms the values of the B.O.D. and the C.O.D. (D.V.), have a constant relationship. The relationship between the B.O.D. and the P.V. values can not always be relied upon.

In spite of the limitations of the B.O.D. test, the B.O.D. data has wide applications in public health engineering practice. This is because it is the only test that can be applied to give a measure of the amount of the biologically oxidizable organic matter present that can be used to determine the rates at which oxidation will occur or B.O.D. will be exerted in receiving bodies of water. It is also used as the major parameter in process design and loading and as a measure of plant efficiency.

The dichromate value is also among the most important tests made in public health engineering to determine quickly the strength of sewage, plants, effluents in industrial waste or polluted water.

However, the standard B.O.D. or D.V. tests are not by themselves satisfactory tools for ascertaining the strength of polluting liquids, (because of the limitations that each has got), and must be used in conjunction with other tests.

3.1.2 Other Parameters of Effluent Quality

For this investigation the other parameters considered to be of importance in addition to those already mentioned are:-

1. Free and Saline Ammonia
2. Total Organic Nitrogen
3. Total Oxidized Nitrogen
4. Suspended Solids
5. Synthetic Detergents (anionic)
6. pH.

3.1.2.1 Nitrogen

Nitrogen exists in three main forms as far as public health engineering is concerned.

(a) Organic Nitrogen

Nitrogen in the form of proteins, amino acids and urea.

(b) Ammonia Nitrogen

Nitrogen as ammonium salts {e.g. $(NH_4)_2 CO_3$} or as free ammonia.

(c) Oxidized Nitrogen

Oxidized nitrogen may be either nitrite nitrogen or nitrate nitrogen.

(i) Nitrite Nitrogen

An intermediate oxidation stage not normally present in large amounts.

(ii) Nitrate Nitrogen

This is the final oxidation product of nitrogen.

The relative concentration of different forms of nitrogen give a useful indication of the nature and strength of the sample.

A water containing higher organic nitrogen and ammoniacal nitrogen with little NO_2-N and NO_3-N would be considered to be highly polluted.

On the other hand, a water with no organic nitrogen and ammoniacal nitrogen but some nitrate nitrogen, would generally be considered as unpolluted.

It should be noted that before the B.O.D. concept was introduced into the management of waste water treatment works, plants and effluents were generally considered satisfactory when they were rich in nitrates (Tebbutt).

3.1.2.2 Suspended Solids

Suspended solids determinations are used to evaluate the strength of both domestic and industrial wastes. From the view point of stream pollution control, the removal of suspended solids is sometimes regarded as being as important as B.O.D. removal. The Royal Commission on Sewage Disposal in their Eighth Report (1912) considered the adoption of quality standards and proposed the two basic criteria, B.O.D. and S.S.

3.1.2.3 Synthetic Detergents

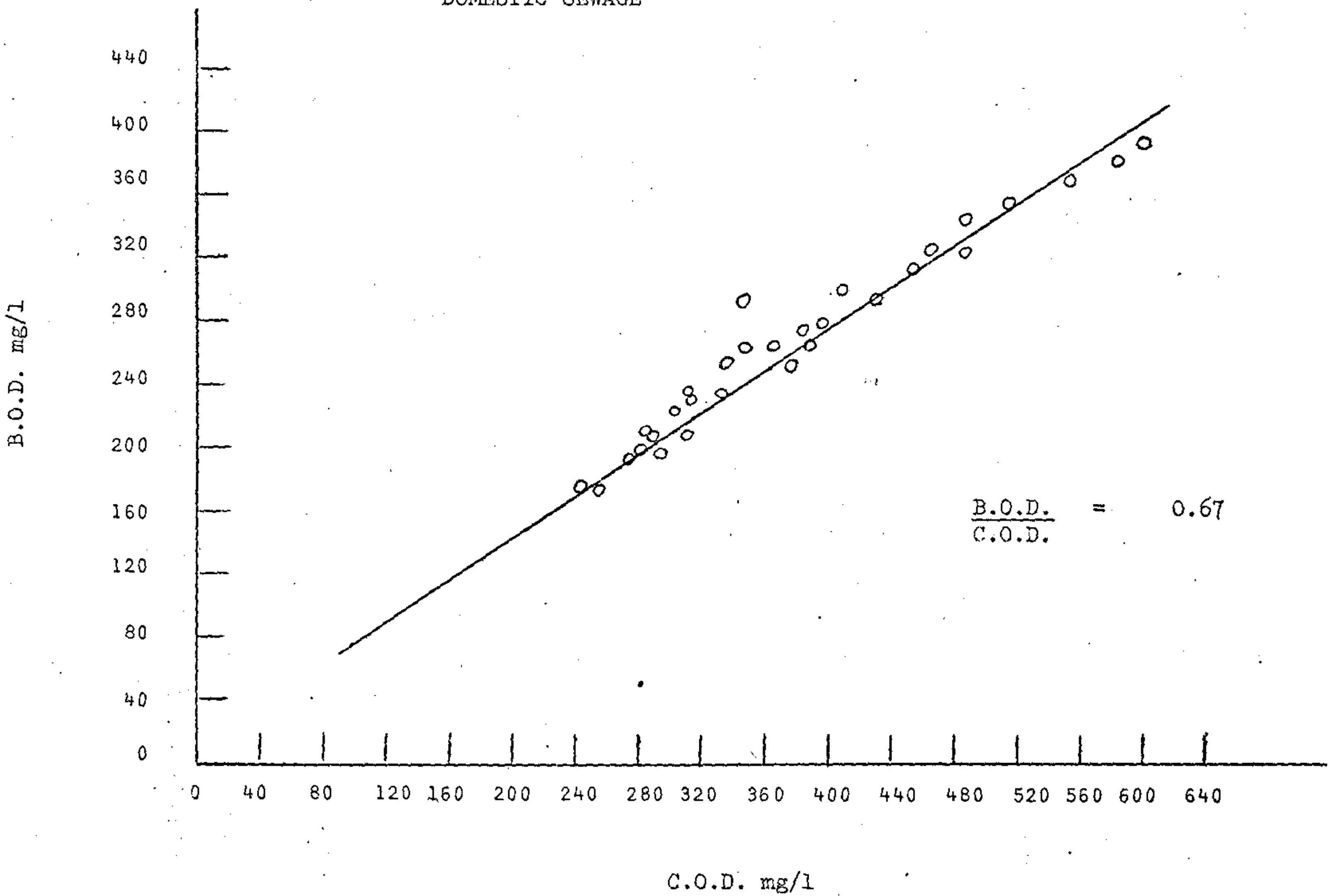
The presence of even small amounts of synthetic detergents in sewage effluents, have resulted in foaming at sewage works and rivers. They exist in the form of protective film on the water surface which reduces the rate of oxygen transfer and may thus amplify the deleterious effects of oxygen consuming substances.

3.1.2.4 pH.

pH. is a term used rather universally to express the intensity of the acid or alkaline condition of a solution. In the field of waste water treatment employing biological processes, pH. must be controlled with a range favourable to the particular organisms involved.

The efficiency of the unit is then measured by its ability to remove B.O.D., C.O.D. etc., and the degree of oxidized nitrogen formed.

GRAPH NO. 1
B.O.D./C.O.D. RATIO FOR
DOMESTIC SEWAGE



3.1.3 B.O.D. - C.O.D. Correlation

The relationship between the C.O.D. and B.O.D. can be of some considerable value. The time needed for the determination of the B.O.D. test is too long, while the C.O.D. results can be obtained within a short time of only two hours.

The C.O.D. test is widely used not only in the analysis of the industrial wastes but also it is used in the control of treatment processes because of the speed with which results can be obtained.

It follows that if a constant relationship between the C.O.D. and the B.O.D. occurs, then the B.O.D. results can be calculated from the C.O.D. results by applying a constant factor.

Graph 1 shows the correlation between the C.O.D. and the B.O.D. The relationship is observed to be nearly direct and a ratio of 0.67 can be applied to describe the relation of $\frac{\text{B.O.D.}}{\text{C.O.D.}}$ for the domestic sewage used for this investigation.

Aluko[2] obtained a mean B.O.D. of 411 mg/ℓ and a mean C.O.D. of 584 mg/ℓ for a glucose substrate which gave a ratio of 0.71 for $\frac{\text{B.O.D.}}{\text{C.O.D.}}$

3.2 FACTORS AFFECTING THE R.D.T.U. EFFICIENCY

It is believed that the unit efficiency was affected by the following factors:-

1. The retention time of the waste water and the organic loading put into the system.
2. The nature of the biomass; its structure and thickness.
3. The temperature of the waste water.
4. The speed of rotation of the disc.
5. The degree of immersion of the discs in the mixed liquor.
6. The spacing between the discs.
7. The tank dimension, especially the ratio of the tank surface area to the volume.

3.2.1 The Retention Time

The increase in the retention of the waste water in the tank is expected to increase the efficiency of removal of polluting material.

At low retention times the B.O.D. loadings put into the system will be high, because the variation in the concentration of the feed is not much.

Also, the longer the time that the organic matter stays in the tank the greater the chance of it being attacked by the micro-organisms. Also, the rate at which the chemical reactions proceed, depends on the time of exposure of water to the purifying conditions.

On the assumption of instantaneous and perfect mixing in the unit as a whole, the change in concentration of organic pollutants in water (dc) in a time(dt)is proportional to some function of the concentration (c) of the waste water as shown by the equation below.

$$-\frac{dc}{dt} = k\Phi(c)$$

where k is the reaction rate constant, $\Phi(c)$ is some function of the concentration of the waste water.

Integrating between the limits c = o at t = o and c = c at t = t gives the purification function:

$$c = c_o e^{-kt} \quad \text{if} \quad \Phi(c) = c \text{———} \quad (1) \text{ and}$$

$$c = c_o \{ 1 - e^{-kt} \} \text{ when } \Phi(c) = c_o - c \text{———} \quad (2)$$

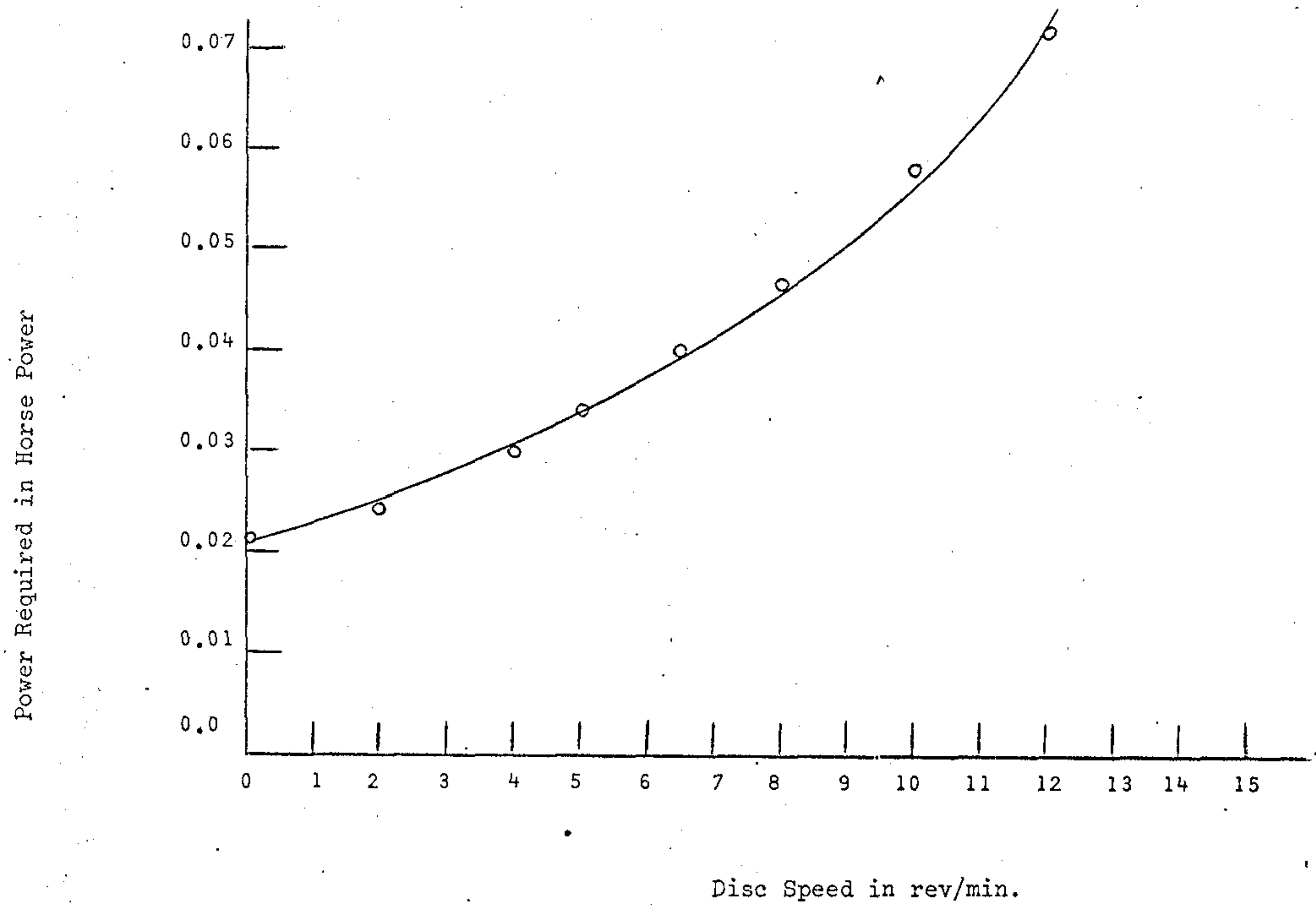
The latter first-order equation was used in 1925 by Streeter and Phelps to describe the course of biochemical oxygen demand of polluted waters. Much of the waste water treatment has been concerned with the identification of $\Phi(c)$.

3.2.2 The Rotation Speed of the Discs

Generally, better efficiency might be expected with high speeds of disc rotation rather than with low speeds. The increase in speed increases the mixing and agitation of the waste water and also the floculation of the suspended solids. Also an increase in the disc speed should raise the concentration of oxygen dissolved in the water. This is because, at a higher speed the rate of absorption of air by water increases, due to the continuous renewal of the air-liquid interface and also the rate of oxygen dispersion through the water increases, due to increased eddy diffusion.

On the other hand, the increase in the disc speed also increases the shearing force of the liquid on the biological growth held on the discs. This causes more of the biomass to slough off into the mixed liquor where it is then kept in suspension by the high agitation action of the rapidly turning discs. Because no clarifier is used in series with this unit, the effluent evolved from such a situation would have a high content of suspended solids. The other disadvantage of increasing the disc speed is the greater power consumption.

GRAPH NO. 2
POWER REQUIRED AT DIFFERENT DISC SPEEDS



For a prototype R.D.T. unit the optimum rotation speed of the disc would be when the highest possible treatment efficiency was obtained for the lowest operational expenses.

Graph 2 shows the power (in horse-power H.P.) required to rotate the discs of the test unit at different disc speeds. The graph shows that the power needed to rotate the discs was very little. Most of the power was required to overcome the friction formed due to the gear arrangement and the transmission efficiencies.

The graph also showed that the power increased rapidly with the increase in the discs' speed. The power required to rotate the disc in the range of (1-5) rev/min. was much less than that required for the range of (8-12) rev/min.

3.2.3 The Degree of Disc Submersion

The performance of the units is postulated to be greatly affected by the percentage area of the disc submersion. The optimum area of the disc submerged is expected when an equilibrium between oxygen supply and micro-organisms demand is reached.

When the disc is submerged in water the micro-organisms obtain oxygen after it has been absorbed by the surface layers of the water and then diffused to the inner layers. However, this process of diffusion is extremely slow and the organisms positioned away from the surface-saturated liquid layers could hardly get enough oxygen.

On the other hand, when the disc is free from the water the micro-organisms will have a greater chance to pick up oxygen either directly from the atmosphere or by diffusion through a thin layer of the film of water and biomass. Hence more oxygen or most of the oxygen needed, will be transported to the system when the portion of the disc submerged is minimum.

The micro-organism population which is responsible for the treatment process is increased by the increase of surface area of the disc holding it. The effective surface area of the disc, which supports the micro-organisms, will decrease at lower degrees of disc submersion. This is because the water will not cover those parts of the disc round its centre when the disc is submerged at lower degrees.

Hence at lower degrees of disc submersion, the micro-organisms will decrease and the oxygen supply will increase and vice versa.

It follows that an optimum degree of disc submersion occurs when an equilibrium between the oxygen supply and the micro-organisms demand is reached.

3.2.4 Temperature

One of the most important factors affecting biological processes is the variation in temperature. It has been generally stated that the rate of microbial growth doubles with every 10°C increase in temperature up to the limiting temperature which is about 35°C for most of the aerobic organisms. Further increases in temperature result in a decrease in rate for mesophilic organisms. Thermophilic organisms will exert a maximum rate over a temperature range of 35-65°C

The magnitude of the temperature effect however, depends in great measure on the nature of the process. High temperature may have a bad effect on process performance by inhibiting some enzyme systems.

The maintenance of aerobic conditions within the biological mass depends on the adsorption of oxygen from the atmosphere and the diffusion of oxygen from the surface-saturated liquid layers. Both adsorption and diffusion of oxygen are affected by the temperature variation.

TABLE 2 : SOLUBILITY OF OXYGEN IN WATER AT DIFFERENT TEMPERATURES

Temperature in °C	Solubility of Oxygen in Water in equilibrium with Air at 760 mm.
0.0	14.63 mg/l
10	11.28 mg/l
11	11.02 mg/l
18	9.46 mg/l
20	9.08 mg/l
27	7.97 mg/l
30	7.57 mg/l

The saturation concentration of gas in liquid such as oxygen in water, is decreased by rising temperatures. Saturation values for oxygen in water at different temperatures are given in Table 2.

The rate of gas adsorption, such as oxygen in water, is increased with rise in temperature.

The rate of oxygen diffusion through the water increases with rise in temperature.

Hence the increase in temperature increases the micro-organism population, the rate of respiration, the rate of oxygen diffusion and the rate of oxygen adsorption, while it decreases the saturation value of oxygen in water.

However, vant Hoff-Arrhenius generally identified the response of chemically and biologically activated process to varying operating temperatures of treatment systems by the following equation:

$$\frac{d}{dt} (\ln k) = \frac{E}{RT^2} \qquad 3$$

in which k is the reaction rate constant, T the temperature in degrees Kelvin, E the activation energy and R is the gas constant. Integrating between the limits T and T_o gives:

$$\frac{K}{K_o} = \exp \left[\frac{E}{R} \left(\frac{T - T_o}{TT_o} \right) \right] \qquad 4$$

where the subscript zero denotes a reference temperature.

In general the empirical formula found by Streeter and Phelps (1925)

$$\frac{Kt_1}{Kt_2} = \Phi^{t_1 - t_2} \qquad 5$$

where K is the reaction rate constant and Φ is the temperature coefficient, is the one widely used to indicate the relationship between temperature and the rate coefficient because it is based on the gross effects of temperature.

Wuhrmann simplified this relationship to produce:

$$\frac{K_1}{K_2} = 1.074^{t_1 - t_2} \qquad \text{———————} \qquad 5^1$$

Eckenfelder considered it to be:

$$\frac{K_1}{K_2} = 1.085^{t_1 - t_2} \qquad \text{———————} \qquad 5^2$$

It should be noted that most of the research work in literature about the reaction-temperature dependency is concerned with the evaluation of the temperature coefficient Φ.

However, Eckenfelder simplified the above equation to express the relationship between the efficiency and the temperature (for the percolating filter) by the following equation:

$$\frac{E_t}{E_{20}} = 1.035^{t-20} \qquad \text{———————} \qquad 6$$

where E = filter efficiency

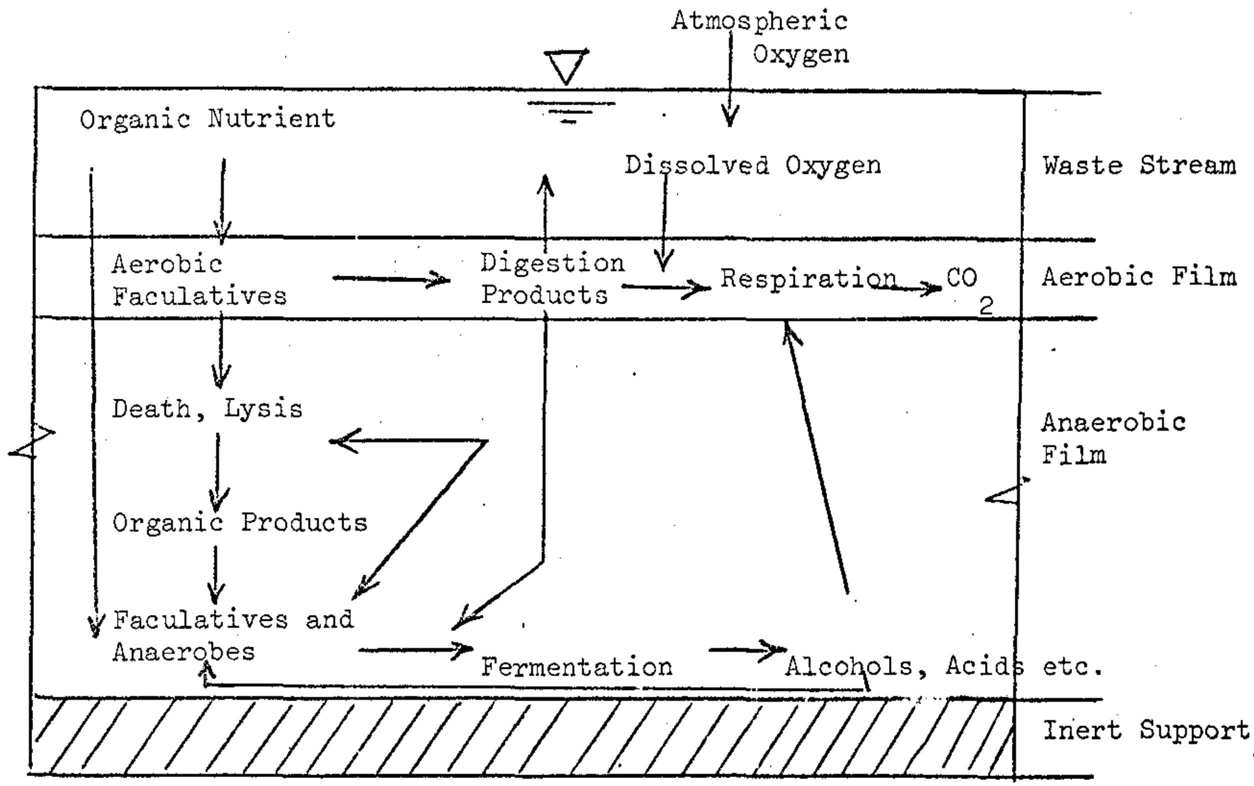
t = temperature, $^{\circ}C$

and E_{20} is the filter efficiency at the reference temperature of $20^{\circ}C$

3.2.5 Biological Slime

As stated before, the purification of waste water is brought about by the micro-organisms because they use the polluting matter as a source of energy. In the R.D.T. system, like the other biological waste treatment systems, the naturally occuring cultures are mixtures of bacteria growing in mutual association and with other micro-organisms such as fungi, algae and protozoa.

FIGURE NO. 8 : CURRENTLY ACCEPTED CONCEPTS OF THE STRUCTURE AND METABOLISM OF A MATURE BIOLOGICAL FILM COMMUNITY



A high percentage of organic pollutants is expected to be removed by a large number of active micro-organisms. It is known that the abilities of micro-organisms to degrade organic pollutants vary with the species of organisms, where each group of micro-organisms is responsible for the removal of a certain organic waste and under certain environmental conditions. There is, as yet, insufficient knowledge concerning types of micro-organisms present and the particular substrate that they metabolize.

One of the most important aspects of microbial growth is thought to be the thickness of its media. It is believed that the unit will show a better performance if the thickness of the biological film (slime) is kept to a minimum.

This can be explained by the currently accepted concepts of the structure and metabolism of a mature biological film community described by Hoehn and Ray[21] in Fig. 8.

When adequate quantities of organic nutrient, mineral salts and oxygen are available, growth of micro-organisms continues until they entirely cover the solid surface supporting them. Further growth occurs when food and oxygen are supplied throughout the film by diffusion. The supply of food and oxygen will continue until the thickness of the biological film becomes great enough to impede their passage to the basal layer. One layer, the aerobic portion, is characterized by the availability of oxygen throughout its depth, while the other, the anaerobic layer, is void of oxygen.

Aerobes present in the anaerobic layer eventually die and lyse when stressed by an inadequate oxygen supply. Their cell constituents become available to surviving facultatives and anaerobes supplementing the existing food supply.

The thickness of the biological film community described above by this model is an important parameter in the regulation of the biological film (slime) community and metabolism.

When the film is sufficiently thick to become anaerobic at the base, the fermentation products (such as organic acids and alcohols), liberated by the basal organisms would diffuse into the aerobic layers above and provide nutrition in addition to that received from the waste stream passing over the film surface. The effect would be to reduce the uptake rate of nutrients from the waste stream passing over the film surface.

3.2.6 Disc Spacing

Experimental work is the only guide for obtaining the optimum space between the discs. Bridging of the biomass across the discs and a subsequent reduction of biological surface is expected, with small distances between the discs.

On the other hand, an excessive distance between the rotating discs would also reduce the efficiency of the unit by decreasing the disc surface available.

Obviously, the phenomenon of bridging reduces the effective area of the disc surfaces and hence decreases the unit treatment capacity.

An optimum distance of separation is expected to be found experimentally, where a minimum thickness of biological film occurs.

For the laboratory apparatus used for this investigation, the distance of separation is 10 mm centre to centre.

SECTION FOUR

DISCUSSIONS II (OPERATIONAL RESULTS)

4.1 LOADING INTENSITIES AND PRESENTATION OF RESULTS

4.1.1 Loading Intensities Used in Operational Results

To relate loadings to performance and make comparisons between them possible, sensible loading parameters must be chosen. Two principal loading parameters were used in this investigation.

4.1.1.1. The Hydraulic Loads

These are normally reported as rates of flow, such as million gallons per day. Their intensities can then be related to flow velocities or times of passage or exposure within treatment units such as cubic metres per day/square metres or gallons per day per 1000 cubic feet.

4.1.1.2 The Process Loads

These refer to the degradable organic matter or nutrients contained in the applied waste water. They are rationally expressed by the weight of impurity, e.g. pounds or kilograms of B.O.D., C.O.D. and suspended solids loadings applied each day and these may be related to a measure of unit capacity such as square metres of disc area, cubic metres of filter area or volume of aeration capacity available.

In this investigation the majority of the correlations are represented as a function of the process loadings and they are principally expressed as grams of B.O.D., C.O.D., suspended solids per unit surface area (in m^2) of the discs per day.

4.1.2 Presentation of Results

The rotating disc treatment units were operated for a minimum period of three weeks under each set of operating conditions.

The results were taken for each set of operating conditions after the units had reached the steady state. Because of the variability of the feed strength, the results recorded were averaged arithmetically.

The steady state for this investigation is defined as the state at which the unit shows a constant percentage removal of B.O.D., C.O.D. etc., and a constant high percentage of detergents removal, as well as a steady rate of nitrate formation.

The collected results have been presented both graphically and in the form of tables.

4.2 RESULTS OF THE PRELIMINARY OPERATION

As stated earlier, the preliminary operation was used to evaluate approximately the treatment capabilities of the R.D.T. unit and to establish guidelines for obtaining the best operating conditions.

Throughout this period of operation the R.D.T. unit showed a high efficiency.

The high efficiency of the R.D.T. units was demonstrated by the results obtained. Operating at a retention time of 4 hours and with 50% of the disc area submerged:-

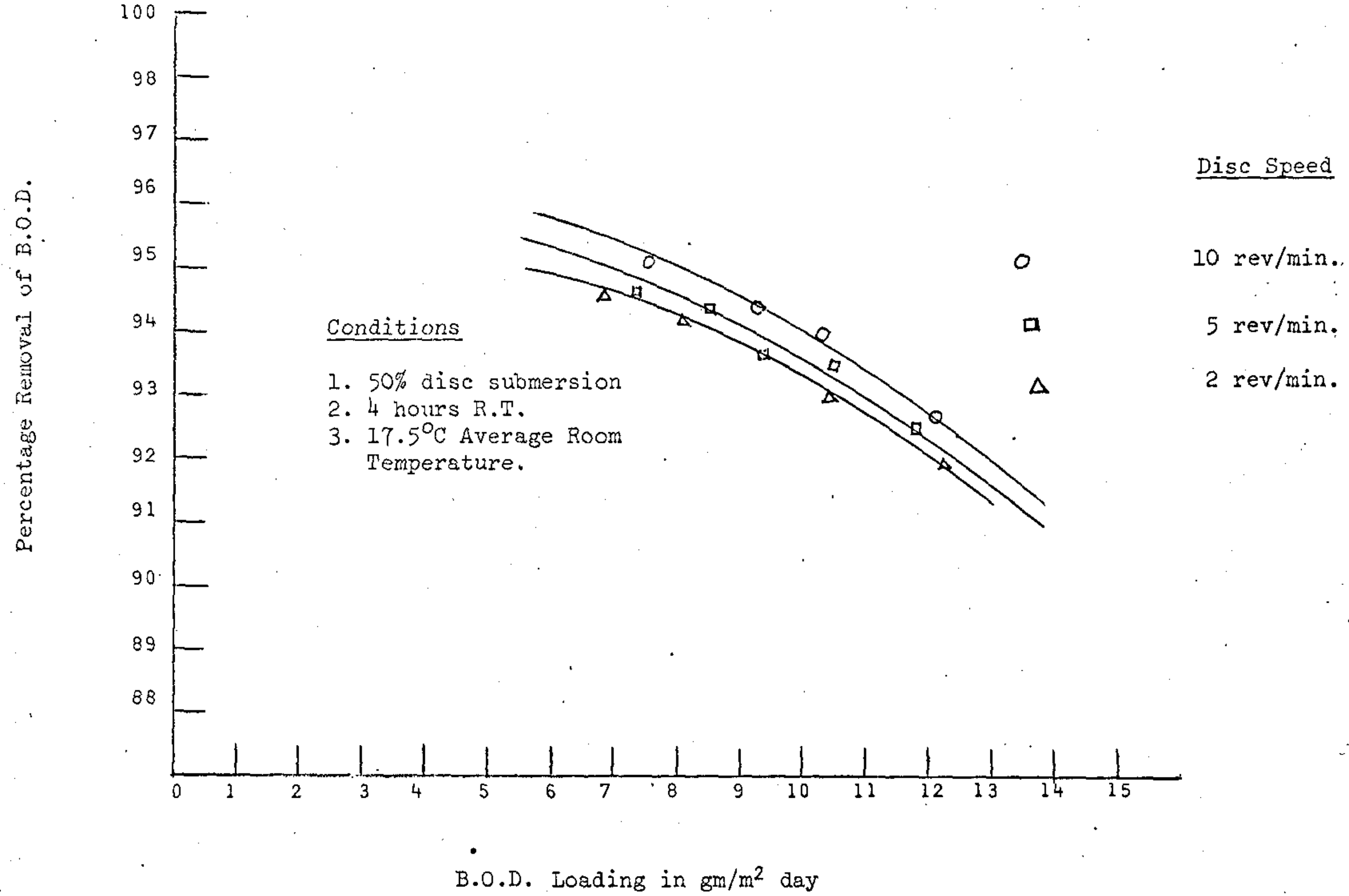
1. More than 95% B.O.D. removal was obtained.
2. The units were demonstrated to be highly efficient in removing detergents. More than 95% of the anionic synthetic detergents were removed.
3. The ammonia nitrogen was removed by oxidation to nitrites and nitrates. More than 95% of ammonia nitrogen was removed and an average of 25 mg/L of total oxidized nitrogen was formed.

In this operation the investigation covered the performance of the unit under three different disc speeds of 2,5 and 10 rev/min.

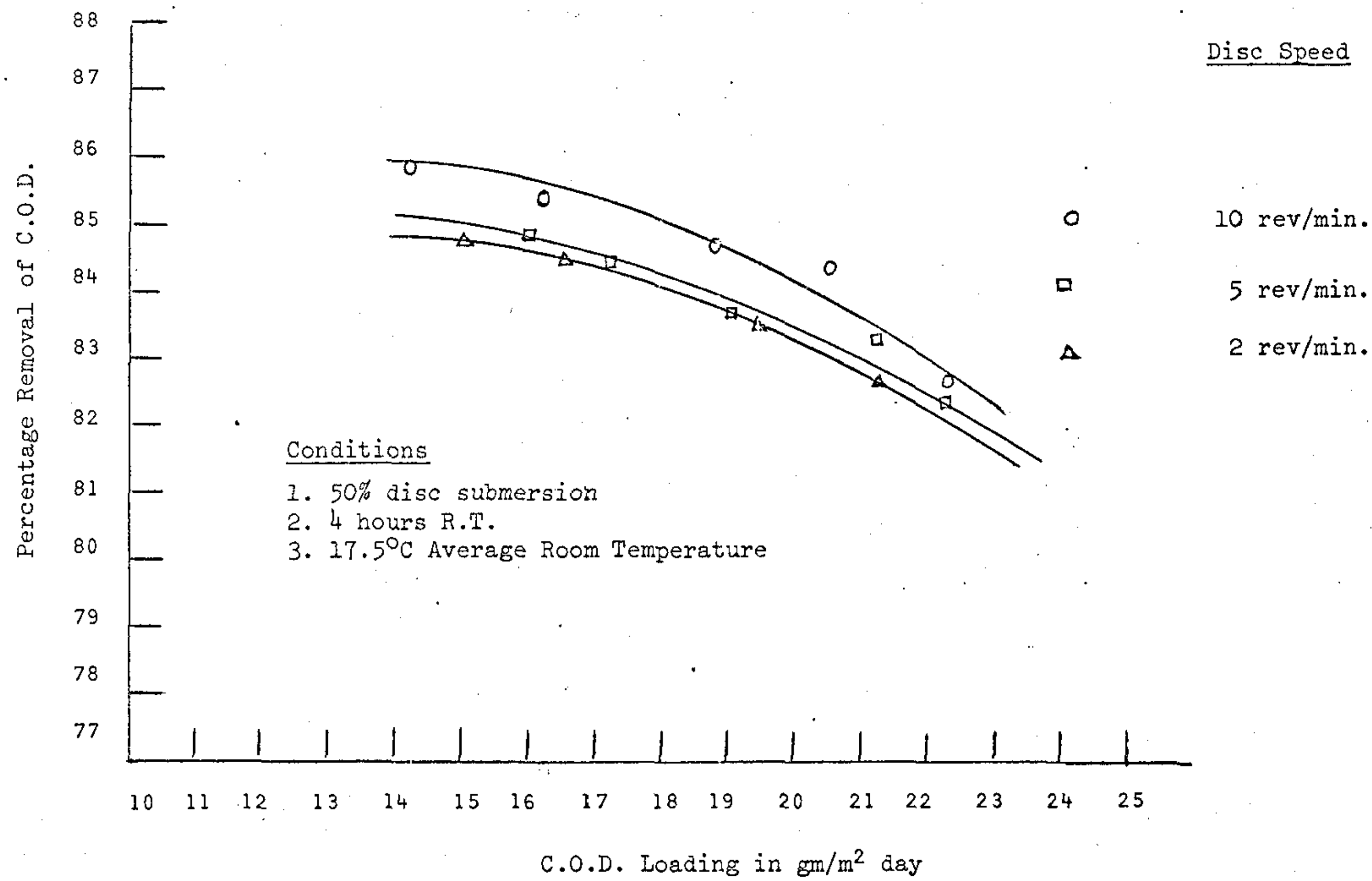
It was observed that the discs revolving at 10 rev/min. showed a tendency to slough biomass from the growth on the discs. Also, the thickness of the growth was thin compared to that of the unit operating at 2 rev/min. The accumulated sludge in the reaction vessel was difficult to remove at the 10 rev/min. speed. This was because the solid matter was kept in suspension by the excessive mixing action of the rotating discs.

Graphs 3 and 4 show the performance of the unit in removing B.O.D.,and C.O.D. at the different disc speeds applied.

GRAPH NO. 3 : B.O.D. REMOVAL AS A FUNCTION OF B.O.D. LOADING



GRAPH NO. 4 : C.O.D. REMOVAL AS A FUNCTION OF C.O.D. LOADING



Although the dissolved oxygen present in the reaction vessel operating with a disc speed of 10 rev/min. was expected to be greater than that working at 5 rev/min., the apparent B.O.D. removal was nearly the same. This was thought to be due to the high content of the suspended solids in the effluents in the 10 rev/min. unit. Also, the C.O.D. removal for both conditions did not show a substantial difference. The removal of the suspended solids in the 10 rev/min. unit was much lower than that at 2 rev/min. or 5 rev/min.

The conclusions drawn from this preliminary operation were:-

1. The optimum rotation speed of the discs was thought to be in the range of (1-5) rev/min. At these speeds the power required to rotate the discs would be very little and there was a decrease in the amount of solids in the effluents. (There was no clarifier used in series with the test unit).
2. The optimum retention time was less than 4 hours.
3. The discs of the first two stages built up the heaviest growth of the biomass although the waste water residence time in these was significantly shorter than in the other stages.
4. The excess biomass generated through the cell synthesis was stripped from the discs by shearing forces exerted on the biomass as it passed through the waste water.

4.3 THE DETERMINATION OF AN OPTIMUM PERIOD OF RETENTION

The variations in efficiency resulting from the alteration in the retention periods are illustrated by the graphs (5 - 11)

Throughout this stage the following operational conditions were maintained:-

1. 50% , disc submersion.
2. 4 rev/min. , disc speed.

All the results indicated that the time of residence of the waste water in the tank greatly affected the performance of the R.D.T. units.

All the results showed that the efficiency of the units increases with the increase of the waste water residence time.

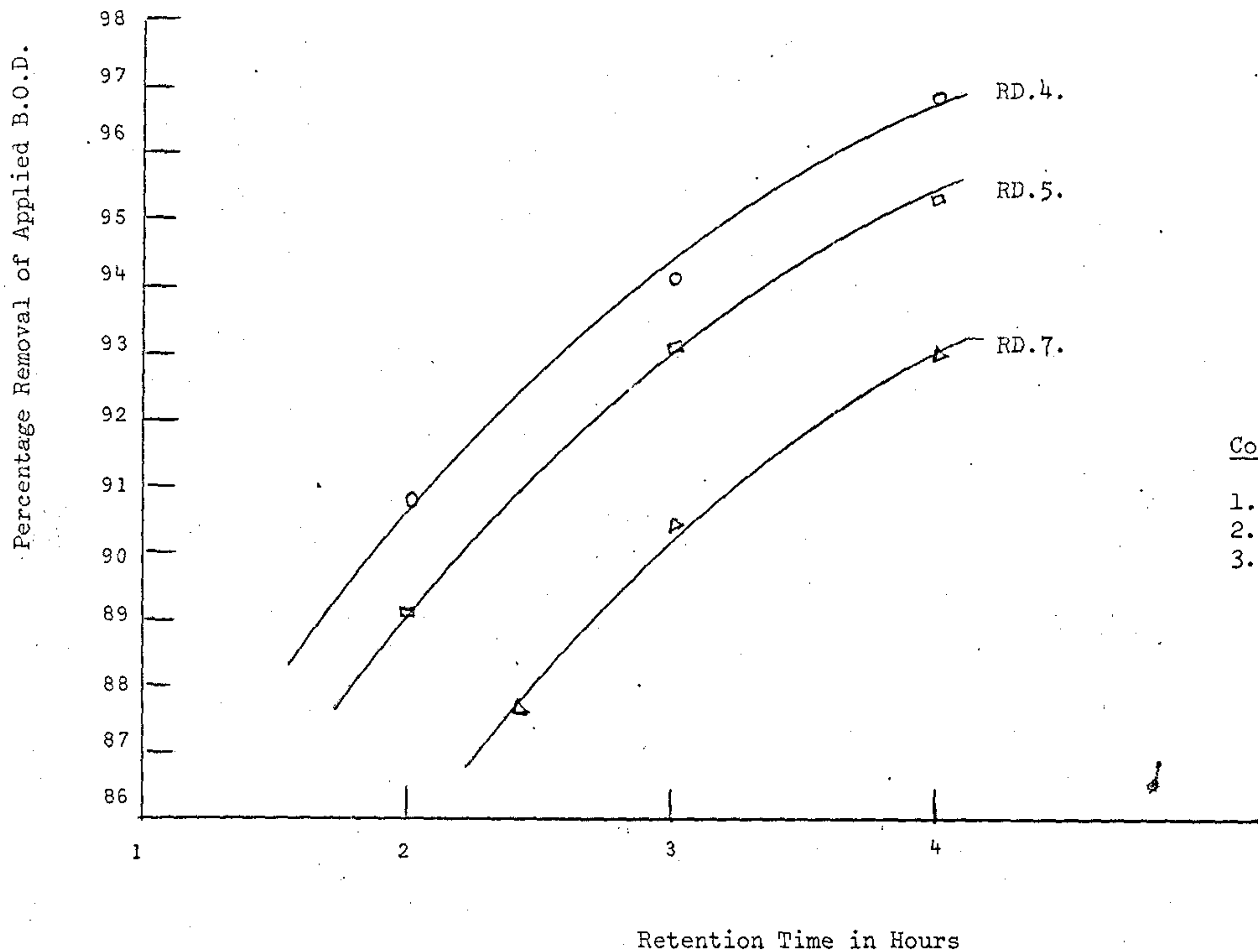
Graph 5 shows the percentage removal of B.O.D. as a function of residence time. As indicated by the graph, more than 95% of the B.O.D. was removed in under 4 hours retention time, while just about 90% B.O.D. was removed when the retention period was less than two hours, and even less than 90% in the case of R.D.T.U.$_7$

Graph 6 shows the percentage removal of C.O.D. as a function of retention time. More than 85% of C.O.D. was removed in 4 hours.

Graphs 7 and 8 show the percentage removal of B.O.D. and C.O.D. as a function of B.O.D. and C.O.D. loadings respectively. Higher loadings correspond to lower retention times. The graphs show better B.O.D. and C.O.D. removal under lower loadings, i.e. under higher retention times.

Graph 9 shows the percentage removal of detergents as a function of retention time. Although the concentration of detergents in the feed might not have been constant throughout the time of exposure, the results obtained indicated that higher percentage removal of detergents occurred at higher retention times.

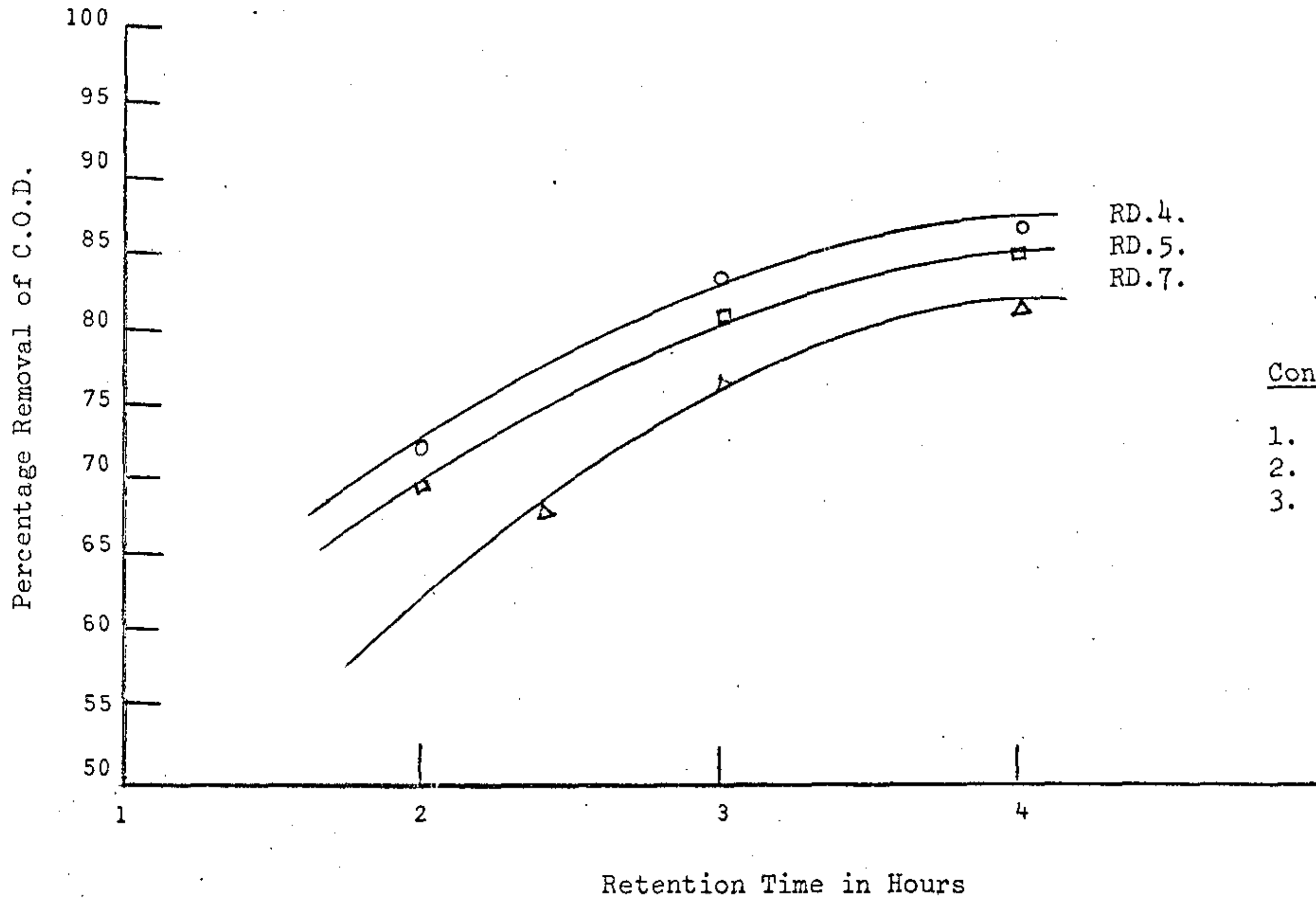
GRAPH NO. 5 : B.O.D. REMOVAL AS A FUNCTION OF RETENTION TIME



<u>Conditions</u>

1. 50% disc submersion
2. 4 rev/min. Disc Speed
3. RD.4. at 20°C Room
   RD.5. at 30°C Room
   RD.7. at 10°C Room

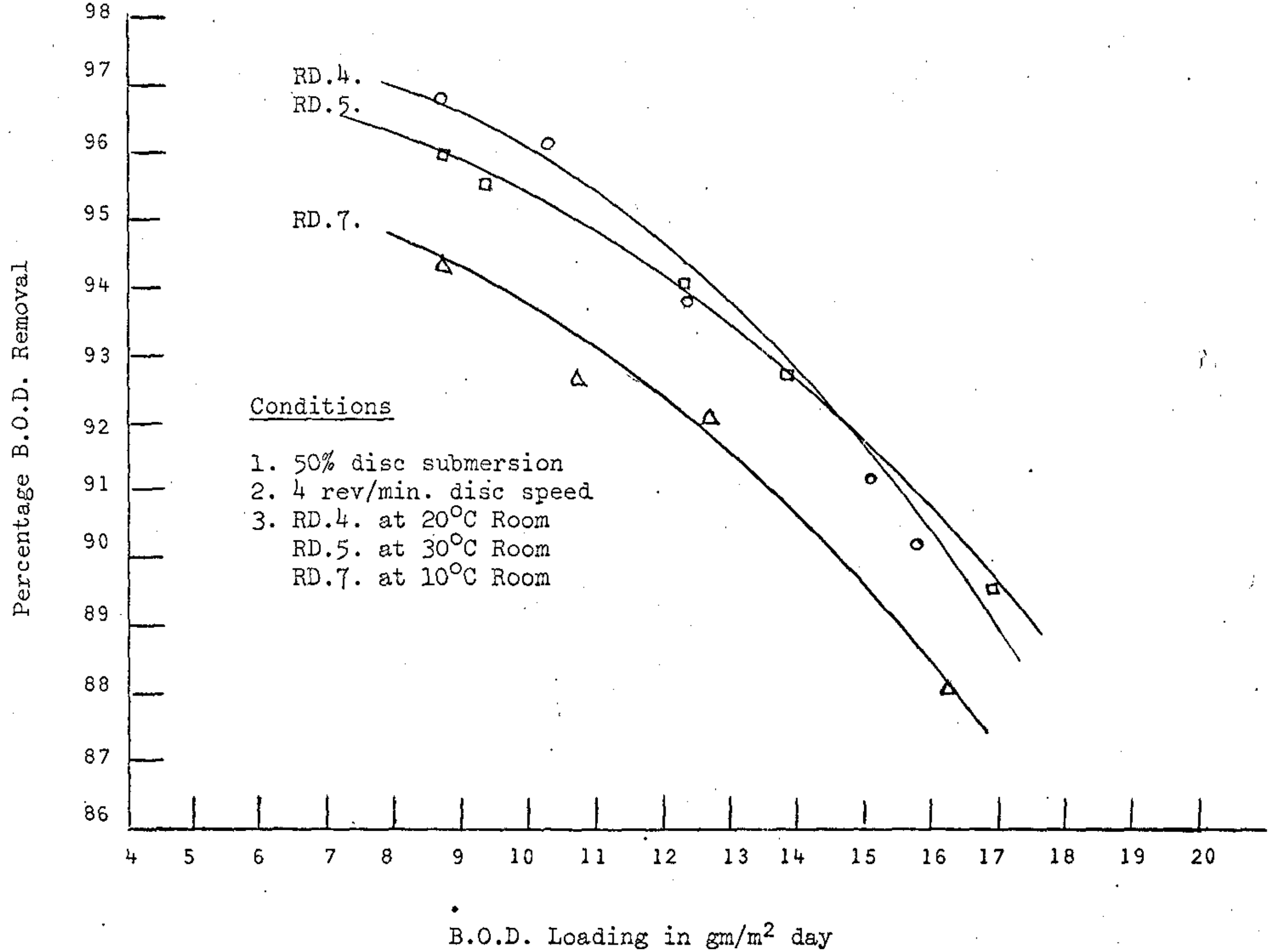
GRAPH NO. 6 : C.O.D. REMOVAL AS A FUNCTION OF RETENTION TIME



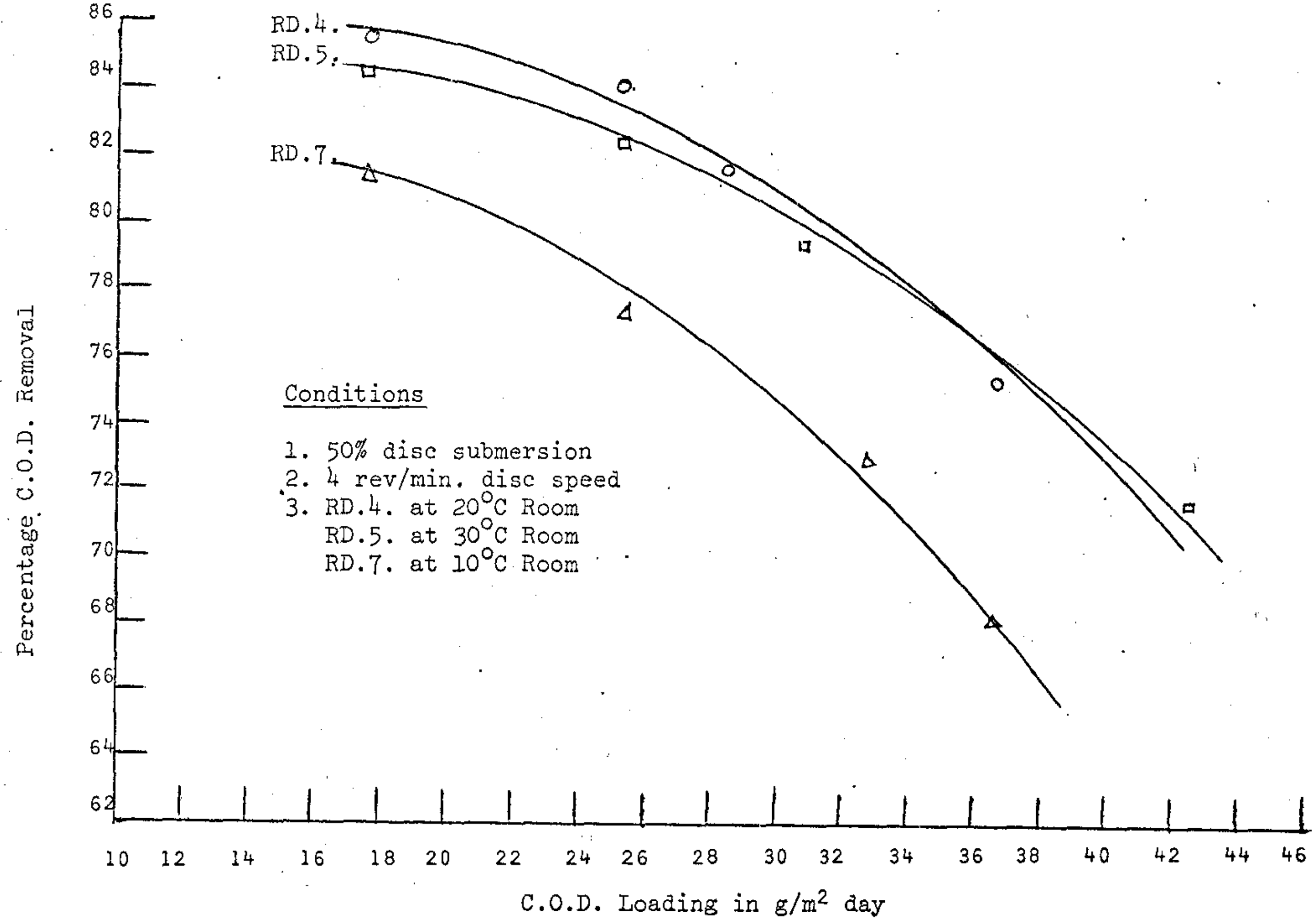
Conditions

1. 50% disc submersion
2. 4 rev/min. disc speed
3. RD.4. at 20°C Room
   RD.5. at 30°C Room
   RD.7. at 10°C Room

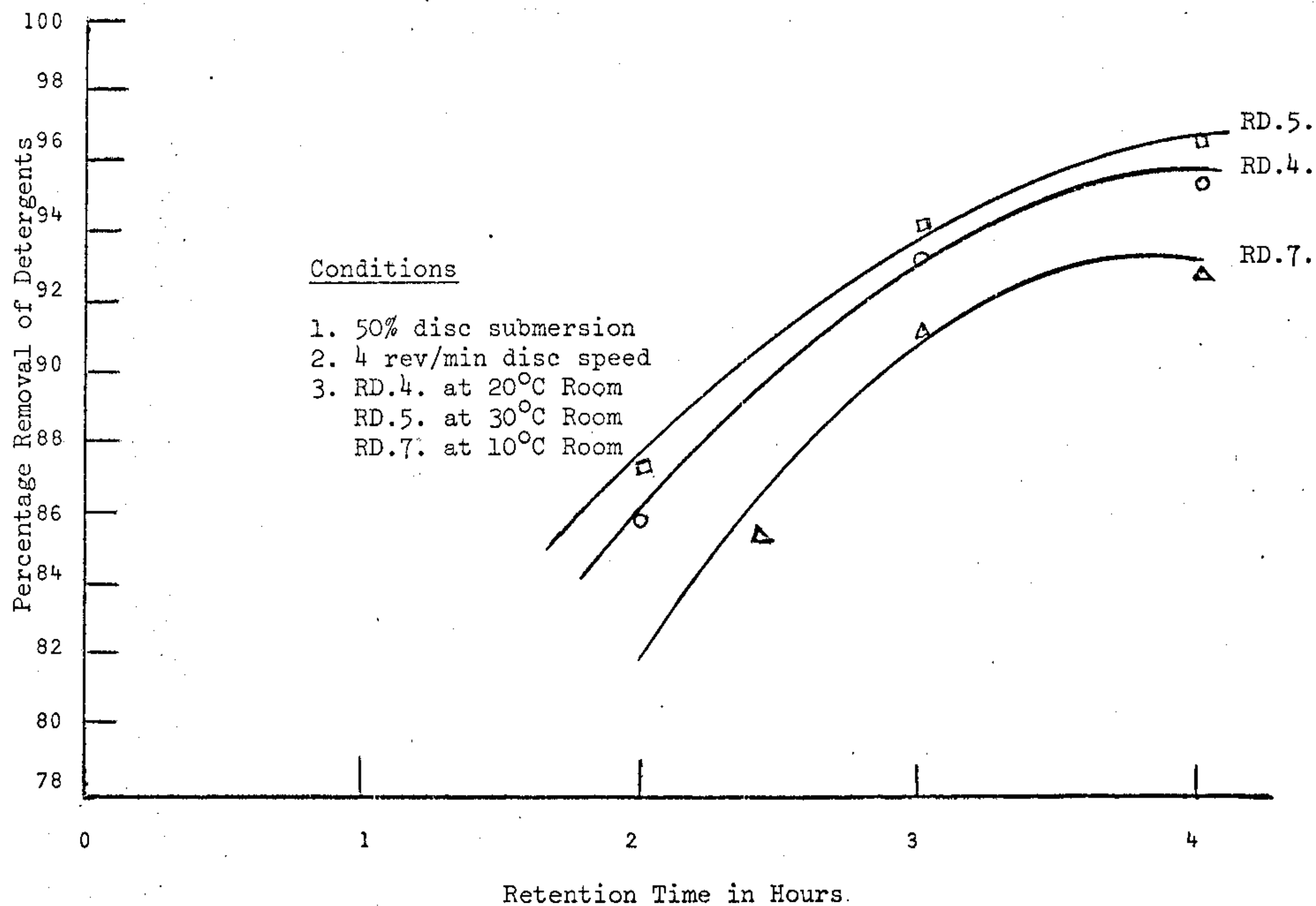
GRAPH NO. 7 : B.O.D. REMOVAL AND B.O.D. LOADING



GRAPH NO. 8 : C.O.D. REMOVAL AND C.O.D. LOADING



GRAPH NO. 9 : DETERGENTS REMOVAL AND RETENTION TIME



Ammonia Oxidation

It seems that the R.D.T. units are capable of achieving high degrees of ammonia oxidation. This can be explained by two properties of the system. One is that the system operates as a fixed film biological reactor in which a captive population of micro-organisms is able to acclimatise itself to the particular waste water it is treating. The other is that by arranging discs in a series of stages, the fixed cultures in the successive stages each adapt to the waste water as it undergoes a progressively increasing degree of treatment. Also, at higher B.O.D. loadings a greater portion of ammonia removal may be attributable to cell synthesis. At lower B.O.D. loadings where nitrifying organisms predominate, a greater proportion of ammonia removal is converted to nitrites and eventually nitrates. This is why ammonia removal proceeds rapidly as the B.O.D. loading is reduced.

Table 3 shows the total oxidized nitrogen as a function of residence time. If $R.D.T.U._4$ is taken as an example, 23.3 mg/L of oxidized nitrogen was formed with a 4 hour retention time while no oxidized nitrogen was formed with two hour retention time.

4.3[1] REACTIONS KINETICS

The first order equation (2),

$$\text{Log} \frac{C}{C_o} = kt$$

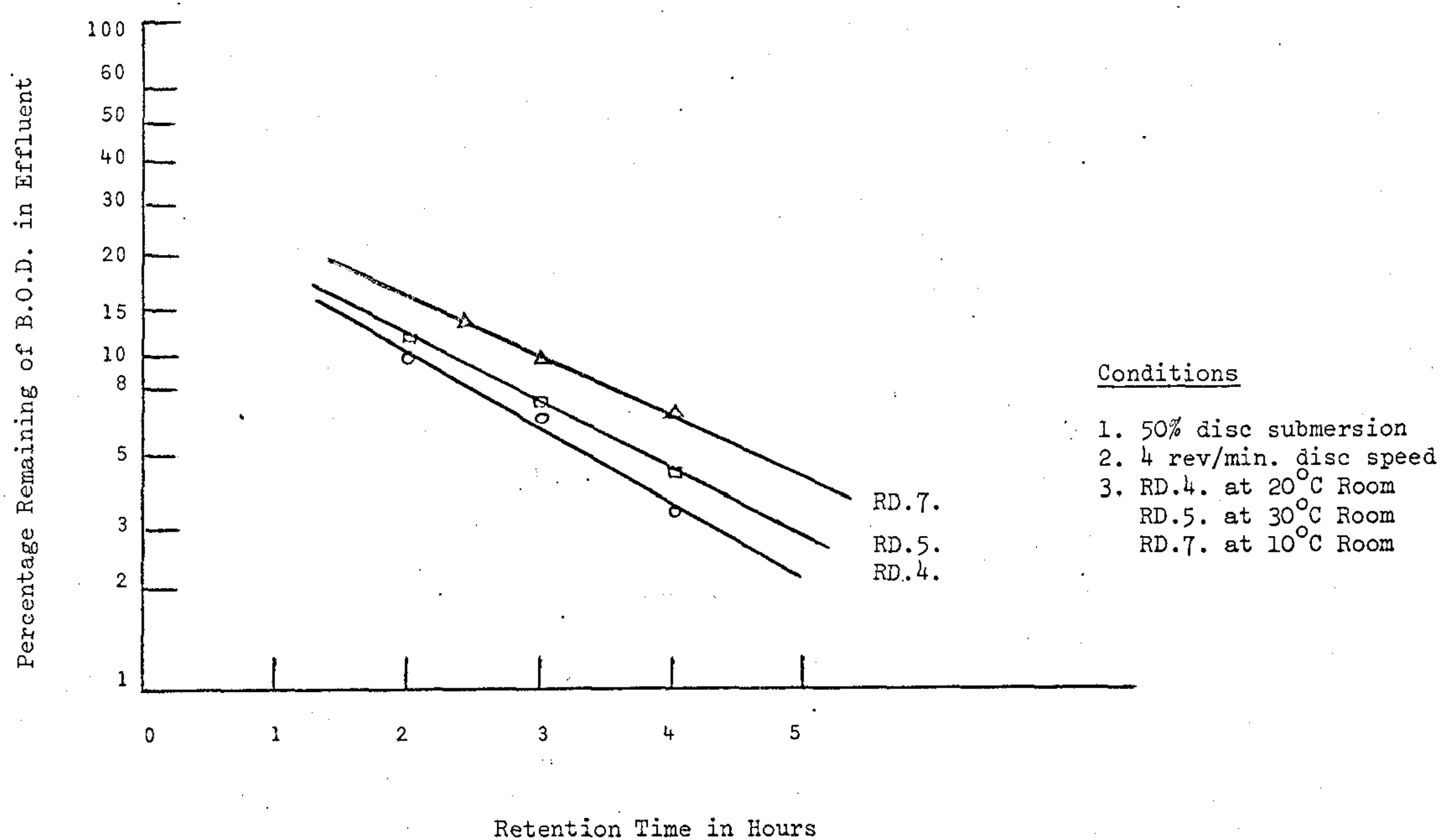
described in section 3 to represent the biochemical oxygen demand kinetics, was used by Streeter and Phelps in 1925.

The graphs 10,28 and 11,29 reveal some aspects of the carbonaceous B.O.D. removal and ammonia kinetics. Graphs 10,28 show the logarithmic percentage remaining of the B.O.D. in the effluent as a function of the residence time. The graphs apparently indicate that for the degrees of treatment conducted during the investigation, the reactions, like other biochemical reactions, are seemingly concentration dependent and appear to follow first order kinetics for the type of sewage used.

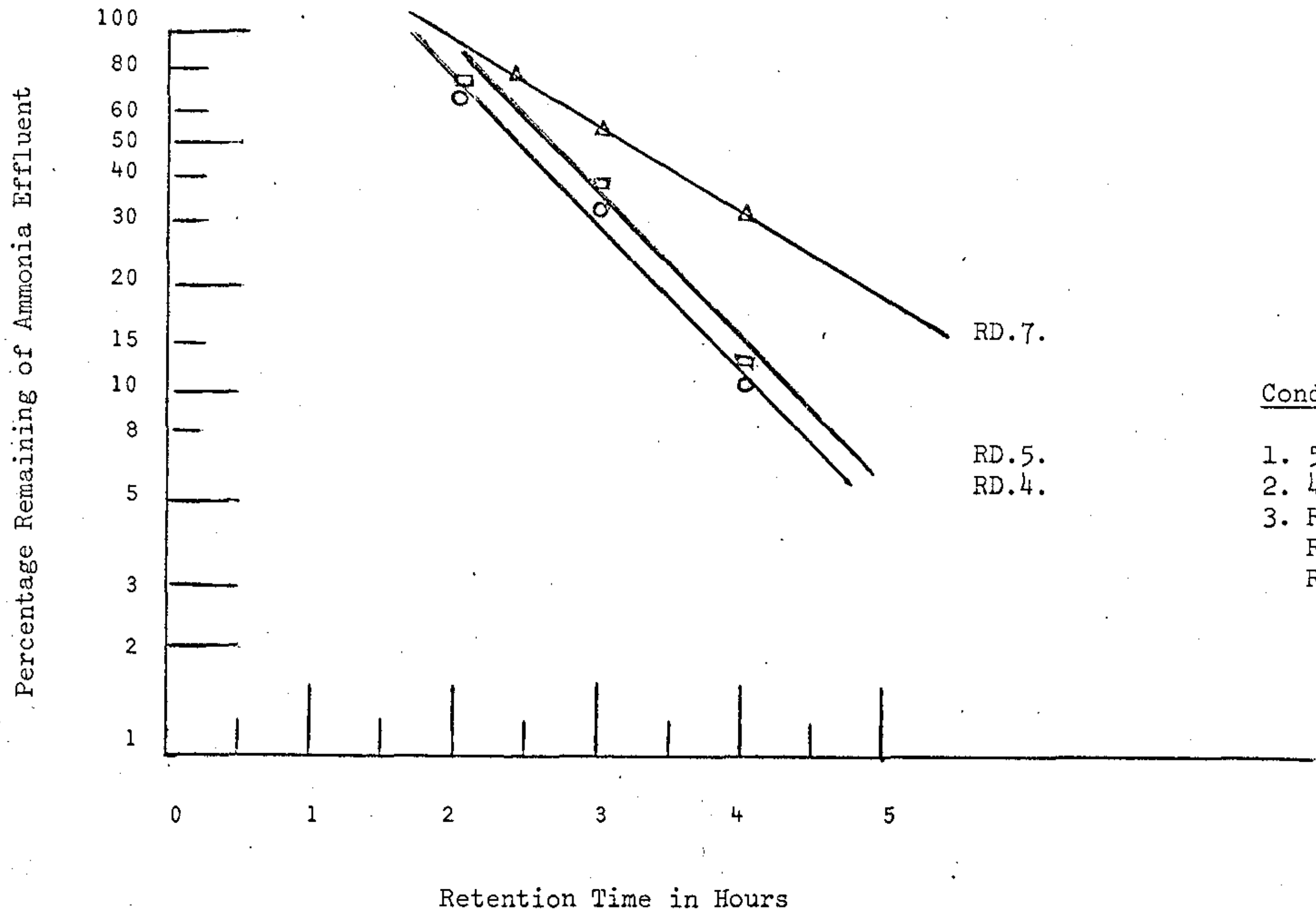
TABLE 3 : TOTAL OXIDIZED NITROGEN FORMED W.R.T. RETENTION TIME

Operational Conditions	R.T. in hours	Total oxidized Nitrogen in mg/l R.D. 4	Total oxidized Nitrogen in mg/l R.D. 5	Total oxidized Nitrogen in mg/l R.D. 7
1. 50% disc sub. 2. 4 Rev./min. disc speed 3. $R.D._4$ at 20°C room $R.D._5$ at 30°C room $R.D._7$ at 10°C room	2	NIL	NIL	NIL
	3	12.2	5.5	1.1
	4	23.3	18.1	8.4

GRAPH NO. 10 : B.O.D. KINETICS



GRAPH NO. 11 : AMMONIA KINETICS



Conditions

1. 50% Disc Submersion
2. 4 rev/min. Disc Speed
3. RD.4. at 20°C Room
   RD.5. at 30°C Room
   RD.7. at 10°C Room

Graphs 11,29 show the logarithmic percentage remaining of ammonia in the effluent as a function of residence time. The graphs approximately indicate that the ammonia kinetics are a first order.

It should be noted that the results shown by the above graphs about the B.O.D. and ammonia kinetics are only applicable for the type of sewage used and the degrees of treatment conducted during this investigation. Also, the kinetics graphs 10 and 11 only have 3-points in each line and hence are not very reliable.

To verify exactly the B.O.D. and ammonia kinetics,further investigation is needed. This can be done by conducting the investigation at higher B.O.D. loadings or lower retention times which were not included in this testing.

4.4 THE DEVELOPMENT OF THE PURIFICATION PROCESS LONGITUDINALLY THROUGH THE REACTOR

The tables (4-9) and the graphs 12, 13 are plotted to illustrate the degree of purification achieved at various stages in the process. The purification achieved is measured by B.O.D. removal, C.O.D. removal and the amount of oxidized nitrogen formed.

All the tables and graphs plotted show that the efficiency of the R.D.T. unit increases with the length of the tank.

The division of the unit into a series of consecutive compartments enhances the natural development of different biological cultures in each stage. In the initial stages the disc develops micro-organisms which oxidize the carbonaceous B.O.D. As the B.O.D. concentration is reduced, subsequent stages of discs develop nitrifying bacteria which oxidize ammonia nitrogen and satisfy the nitrogenous B.O.D.

Tables 4,5 and 6 and graph 12 indicate that more than 60% of the B.O.D. removal is completed, by the first two stages for the three units under the operating conditions stated on each table and graph. The rest of the stages confine their work to the removal of about 35% of the B.O.D. and to the oxidation of the ammonia to nitrite and nitrate.

Tables 7,8 and 9 and graph 13 show that more than 50% of the C.O.D. removal is completed by the first two stages for the three units under the conditions shown on each graph.

Graphs 14 and 15 show the performance through the various stages of the ammonia oxidation under different operating conditions. Graph 14 shows the oxidized nitrogen formed in the stages of $R.D.T.U._4$. At a 4 hour retention time nitrification was observed to begin at Stage 2, while at a 3 hour retention time nitrification was observed to begin at Stage 6.

TABLE 4 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (B.O.D. REMOVAL)

R.D. 4

Conditions	Number of stages	Gram B.O.D./m^2 per day	Percentage B.O.D. removal
1. 25.7% Disc Sub. 2. 4 rev/min. Disc speed	2	25.5	67.2
		55.2	66
	3	17.0	79
		36.8	71
	4	12.8	90.5
		27.6	83.2
	5	10.2	92.1
		22.1	88.5
	6	8.5	93.7
		18.4	93.5
	7	7.3	94.8
		15.8	94.2

TABLE 5 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (B.O.D. REMOVAL)

R.D. 5

Conditions	Number of stages	Gram B.O.D./m^2 per day	Percentage B.O.D. removal
1. 50% Disc Sub. 2. 4 rev/min. Disc speed	2	17.4	61.5
		35.6	60.5
		59	53.3
	3.	11.6	73.1
		23.8	72.5
		39.5	69.8
	4	8.7	80.8
		17.9	79.5
		29.5	78.7
	5	6.95	85.4
		14.3	85.0
		23.6	84.3
	6	5.78	89.3
		11.9	88.0
		19.8	87.6
	7	4.95	92.3
		10.2	90.5
		16.9	90.0

TABLE 6 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (B.O.D. REMOVAL)

R.D. 5

Conditions	Number of stages	Gram B.O.D./m^2 per day	Percentage B.O.D. removal
1. 25.7% Disc Sub. 2. 4 rev/min Disc speed	2	22.8	73.5
		48.2	70
	3	15.2	85.3
		32.2	84
	4	11.4	91.2
		24.1	90.4
	5	9.15	96.5
		19.3	91.1
	6	7.6	97.7
		16.1	94.3
	7	6.52	98.2
		13.8	95.2

GRAPH NO. 12 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (RD.7. B.O.D. REMOVAL)

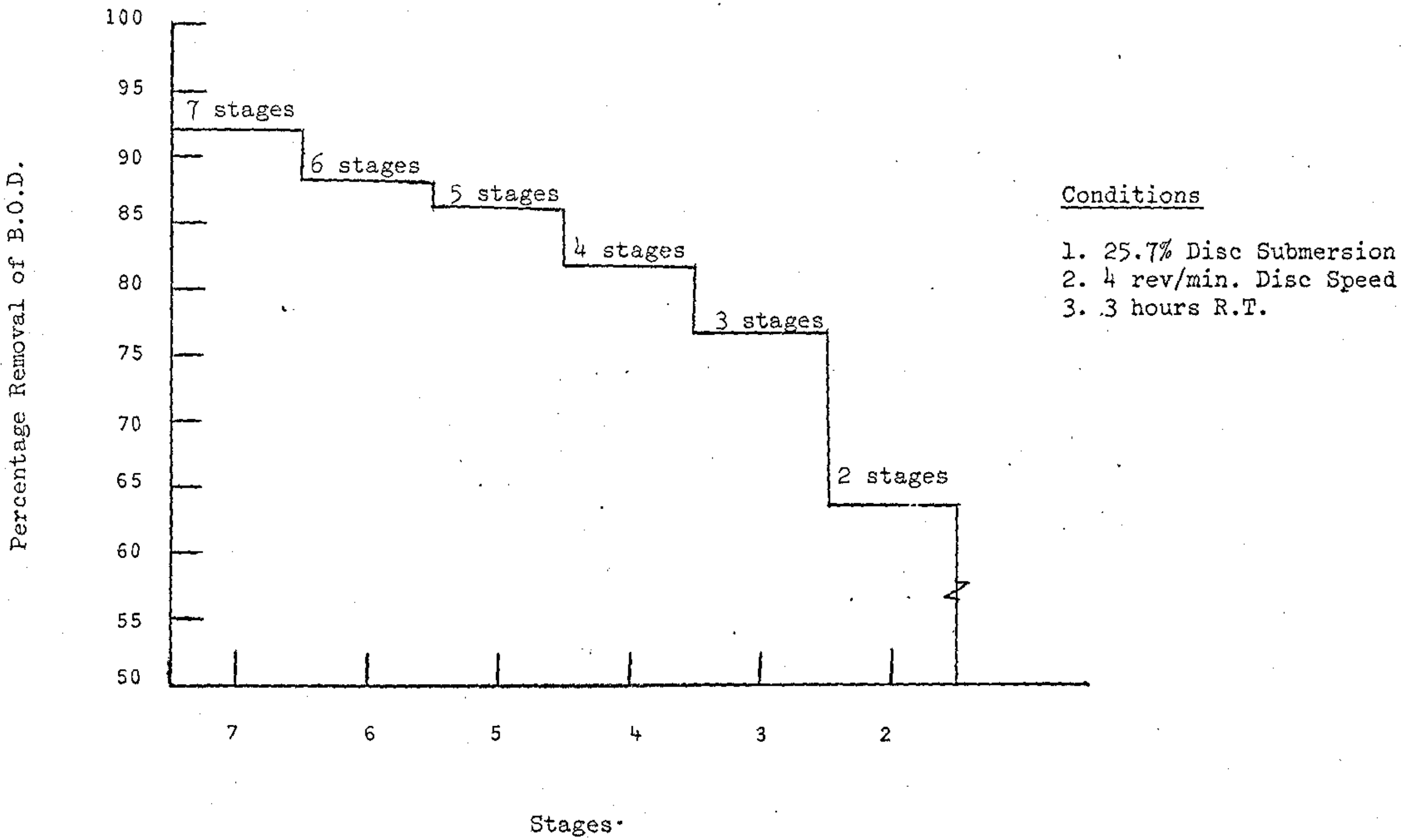


TABLE 7 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (C.O.D. REMOVAL) R.D. 4

Conditions	Number of stages	Gram C.O.D./m^2 per day	Percentage C.O.D. removal
1. 50% Disc Sub. 2. 4 rev/min. Disc speed	2	46.1	62.5
		54.0	52.0
		84	50.2
	3	30.7	67.5
		36	59.4
		56	54.5
	4	23.0	72.5
		27	67.8
		42	61.0
	5	18.4	80.0
		21.6	73.9
		33.6	63.5
	6	15.3	84.1
		18.0	80.8
		28.0	66.1
	7	13.1	87.5
		15.3	85.5
		24.0	69.0

TABLE 8 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (C.O.D. REMOVAL) R.D. 4

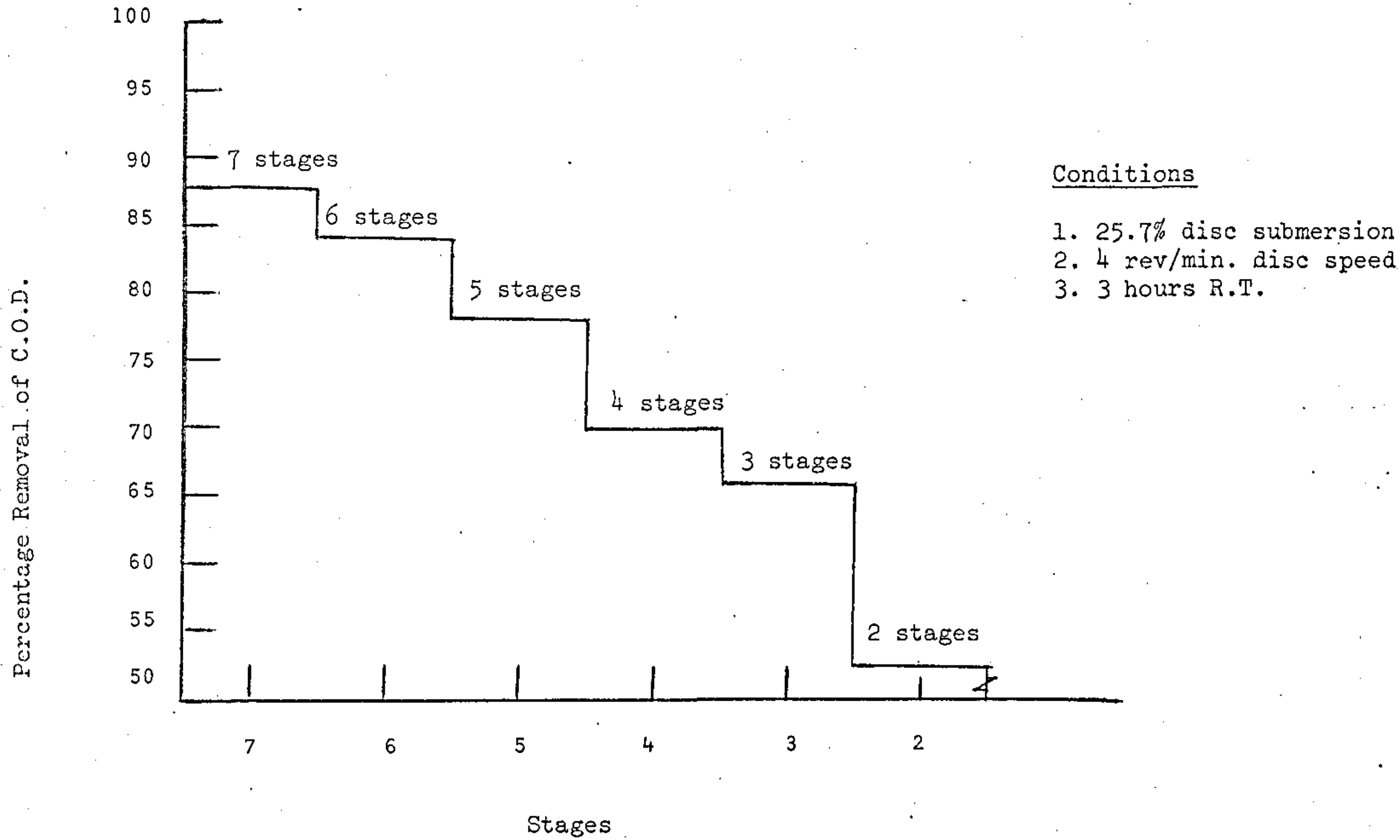
Conditions	Number of stages	Gram C.O.D./m^2 per day	Percentage C.O.D. removal
1. 25.7% Disc Sub. 2. 4 rev/min. Disc speed	2	50.4	54.5
		68.8	50
	3	33.6	64.2
		45.8	56
	4	25.2	73.0
		34.4	71
	5	20.1	83.5
		27.6	78.5
	6	16.8	87.8
		22.9	83.7
	7	14.4	89.7
		19.6	89.2

TABLE 9 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (C.O.D. REMOVAL)

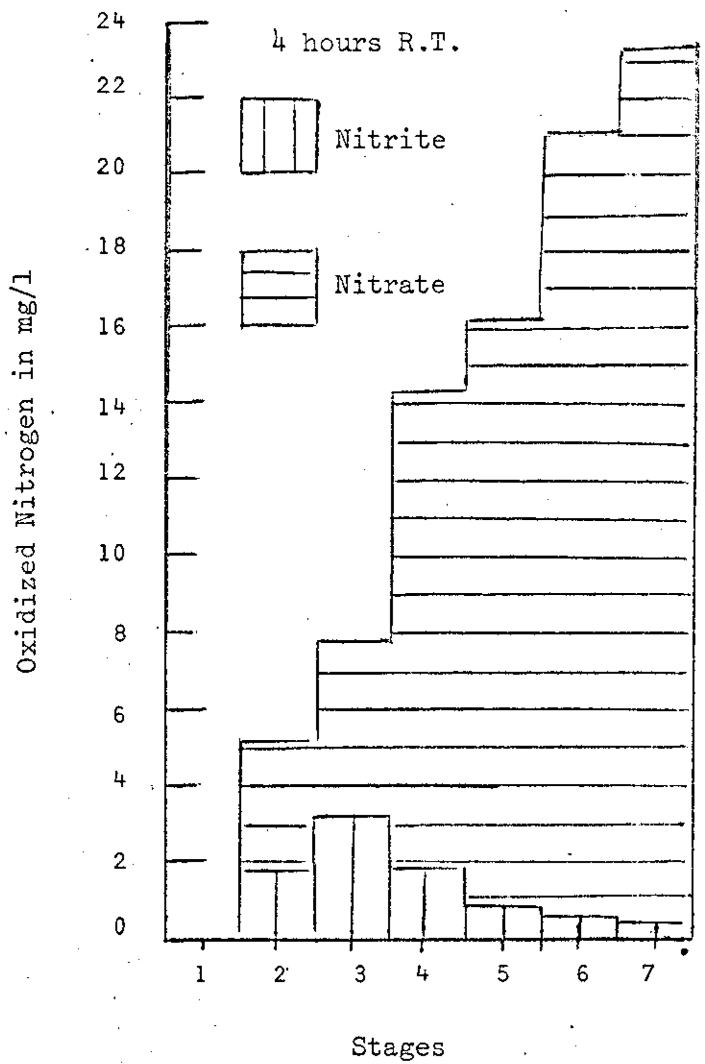
R.D. 5

Conditions	Number of stages	Gram C.O.D./m^2 per day	Percentage C.O.D. removal
1. 25,7% Disc Sub	2	54.4	68
		109	66
	3	36.2	76
		72.8	73
	4	27.2	78
		54.5	74
2. 4 rev/min Disc speed	5	21.7	82
		43.6	77
	6	18.1	85
		36.4	84.7
	7	15.5	89.7
		31.1	88.5

GRAPH NO. 13 : INCREASING EFFICIENCY ALONG LENGTH OF UNIT (RD.7. C.O.D. REMOVAL



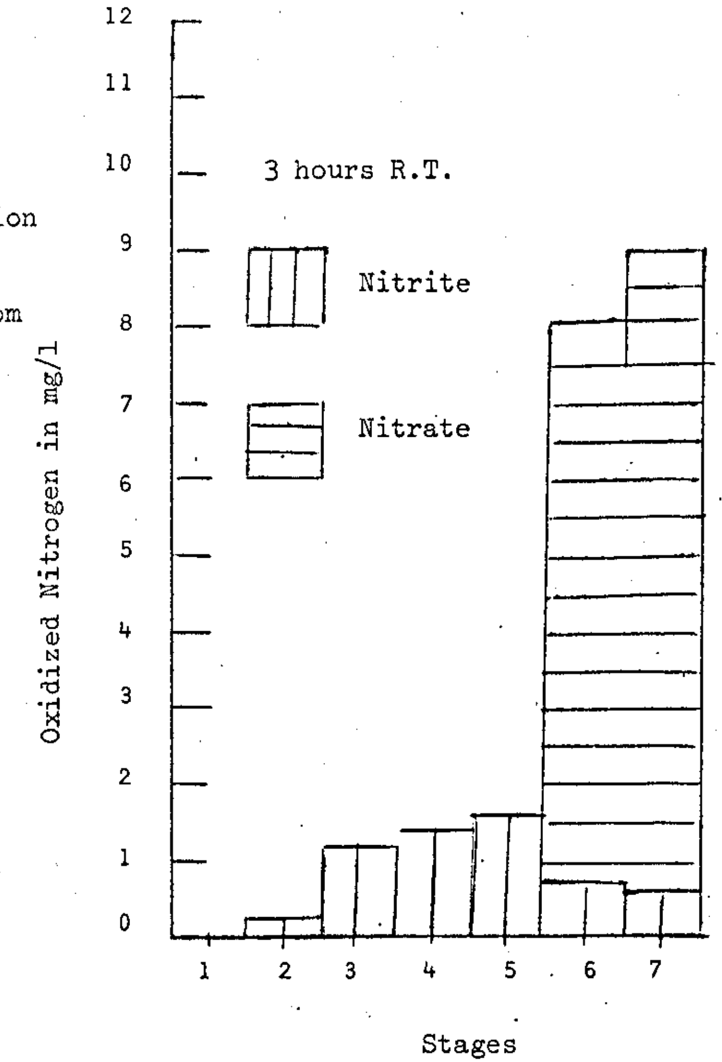
GRAPH NO. 14 : OXIDATION OF AMMONIA ALONG LENGTH OF REACTION VESSEL



RD.4.

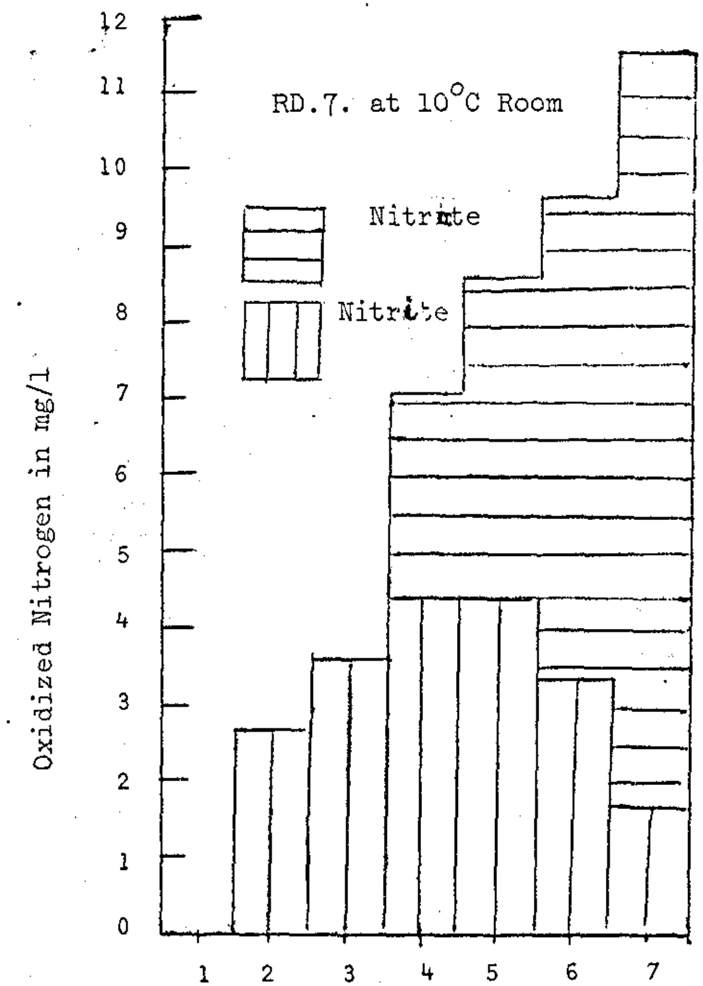
Conditions

1. 50% Disc Submersion
2. 4 rev/min. disc speed
3. RD.4. at 20°C Room



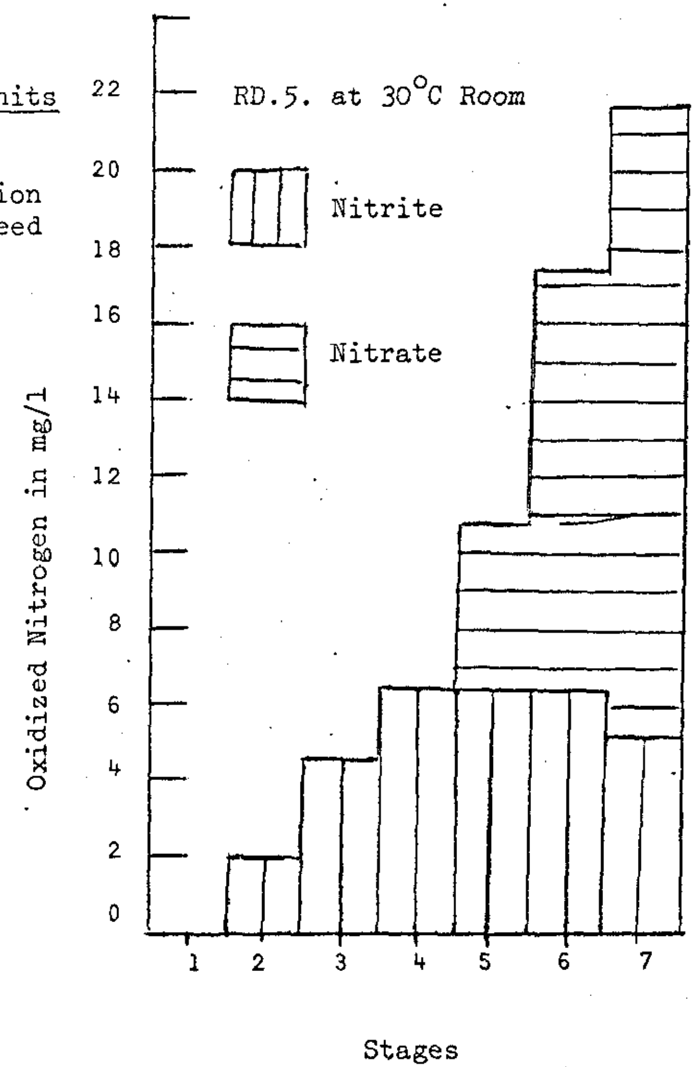
92.

GRAPH NO. 15 : OXIDATION OF AMMONIA ALONG LENGTH OF UNITS RD.7. AND RD.5.



Conditions for both units RD.7. and RD.5.

1. 25.7% disc submersion
2. 4 rev/min. disc speed
3. 3 hours R.T.



The formation of nitrite started in both 4 hours and 3 hours retention times at Stage 2.

Graph 15 shows the oxidized nitrogen formed in the stages of $R.D.T.U._7$ and $R.D.T.U._5$. Although both units were operated under the same conditions of operations, the amount of oxidized nitrogen formed in $R.D.T.U._5$ was much greater than that of $R.D.T.U._7$. Although the quantity of nitrate formed in $R.D.T.U._5$ is greater than that of $R.D.T.U._7$ yet the nitrification in $R.D.T.U._7$ was observed to begin at Stage 4, while that of $R.D.T.U._5$ was observed to begin at Stage 5.

It should be noted that the nitrite appeared to start in Stage 2 for the three units and that the nitrite formed increased from one stage to another until it reached a maximum value and then decreased. The nitrate formed appeared to increase from one stage to another with the maximum nitrate concentration at Stage 7.

4.5 AREA OF DISC SUBMERGED

It was stated above that as the discs rotate through the reaction vessel the biological slime is alternatively exposed to the waste water and to the air.

In both conditions the biological slime picks up the oxygen either from the air or from the oxygen dissolved in water. It is obvious that the biological slime stands a better chance of picking up oxygen directly from the atmosphere and hence the more time the discs are exposed to the air, rather than immersed in the water, the more oxygen is adsorbed by the micro-organisms.

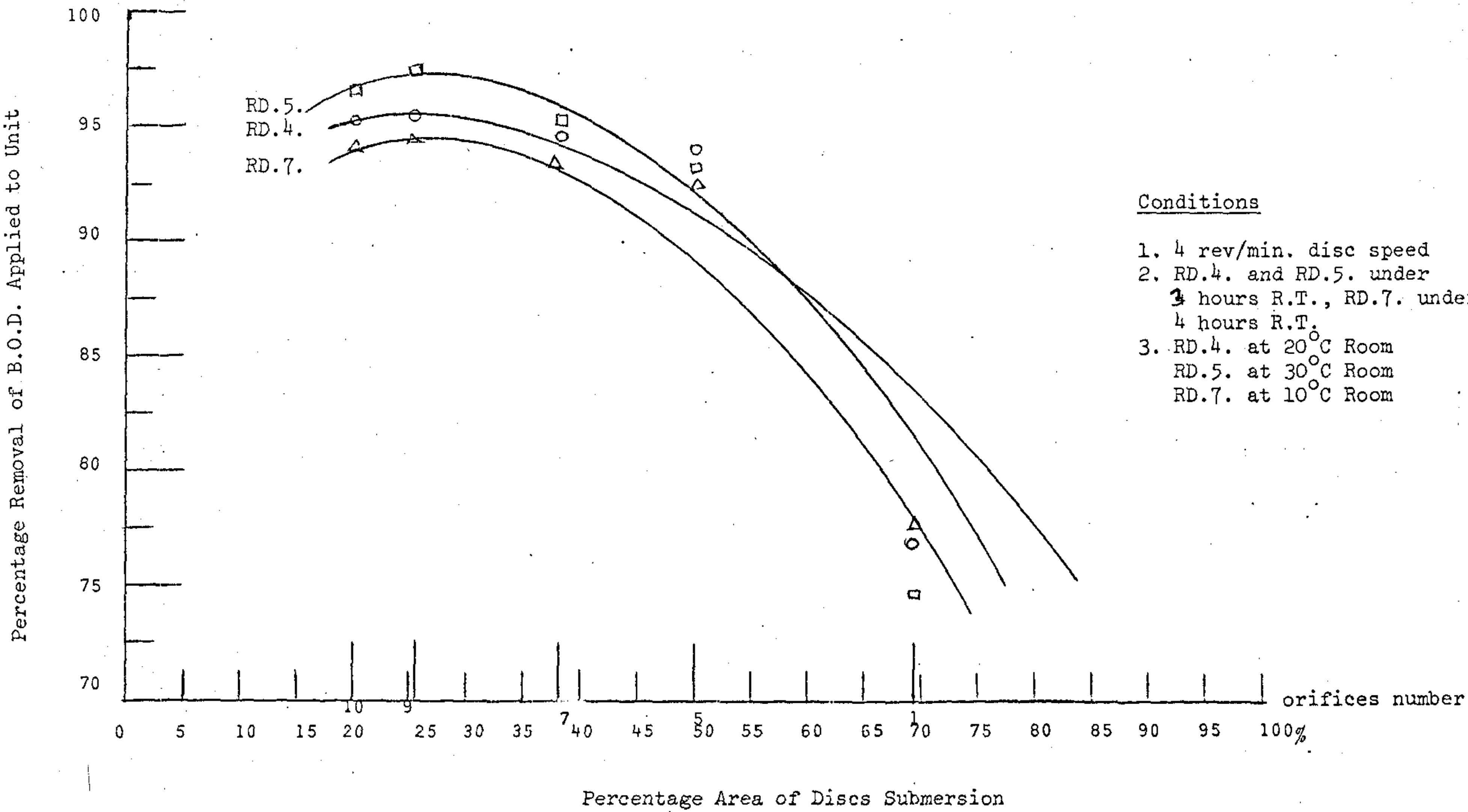
The results collected during the variations of the submerged disc area are plotted in graphs (16-21).

All the graphs show that the efficiency of the unit decreases with the increase in area of disc submersion, above 26% submersion. Also, the efficiency decreases with the increase in area of disc submersion below 26% submersion.

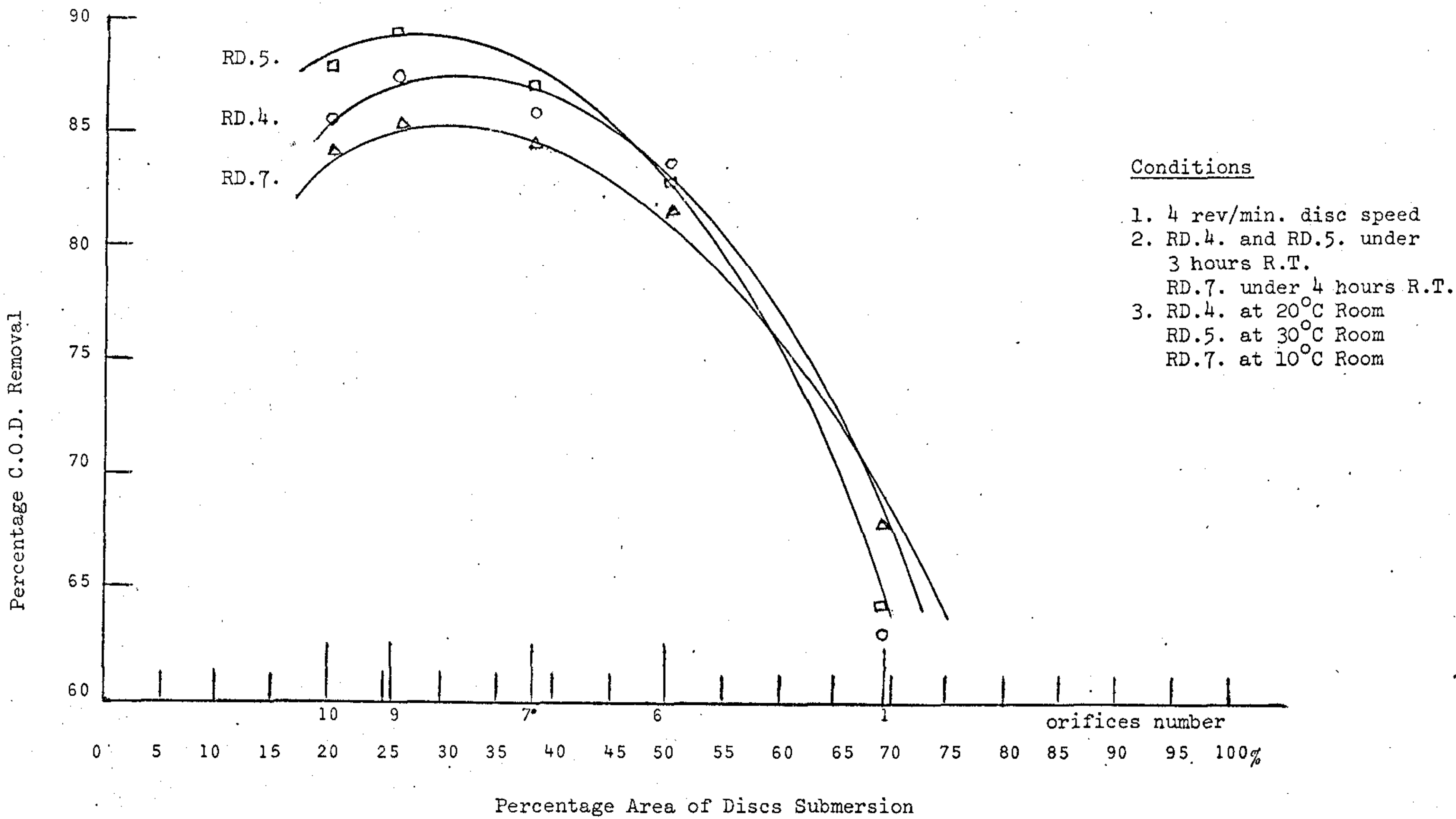
Taking R.D.T.U.$_5$ as an example, in graph 16, 97.4% of B.O.D. was removed under 26% disc submersion, while only 73% of B.O.D. was removed under 70% disc submersion. In graph 17, 89.5% of C.O.D. was removed under 26% of disc submersion, while 64% C.O.D. was removed under 70% of disc submersion. In graph 21 96% of the detergent was removed with 26% disc submersion, while only 62% of the detergent was removed with 70% submersion. If R.D.T.U.$_4$ is taken as an example, 23 mg/L of oxidized nitrogen was formed under 26% submersion, while no oxidized nitrogen was formed at all under 70% submersion. This is observed in graph 19.

Graph 18 shows the percentage ammonia removal with varying areas of disc submersion. Graph 20 shows the suspended solid removal in relation to the area of disc submersion. In both graphs the ammonia and the suspended solids removals are better under the 26% disc submersion.

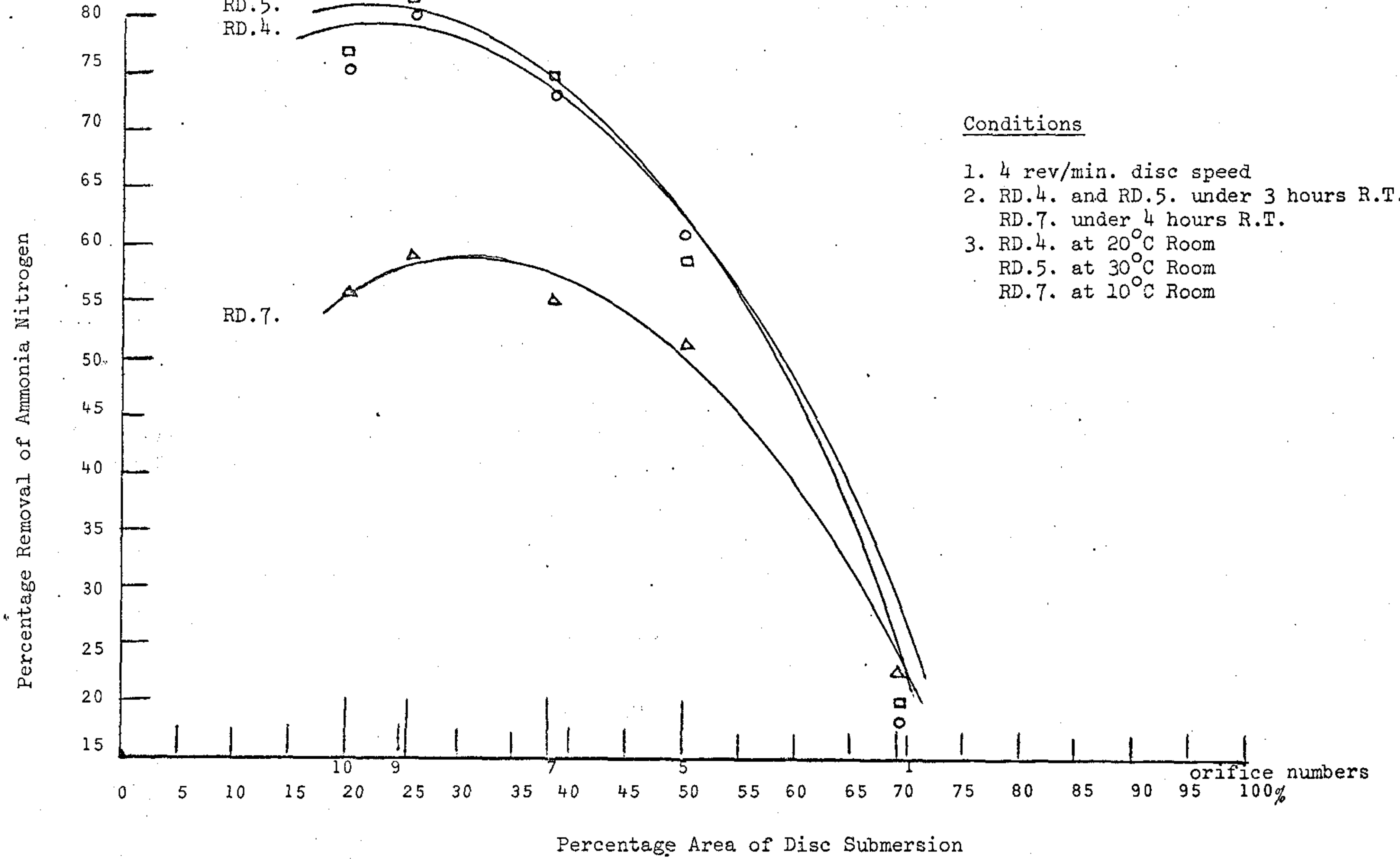
GRAPH NO. 16 : VARIATION OF B.O.D. REMOVAL EFFICIENCY WITH AREA OF DISC SUBMERGED



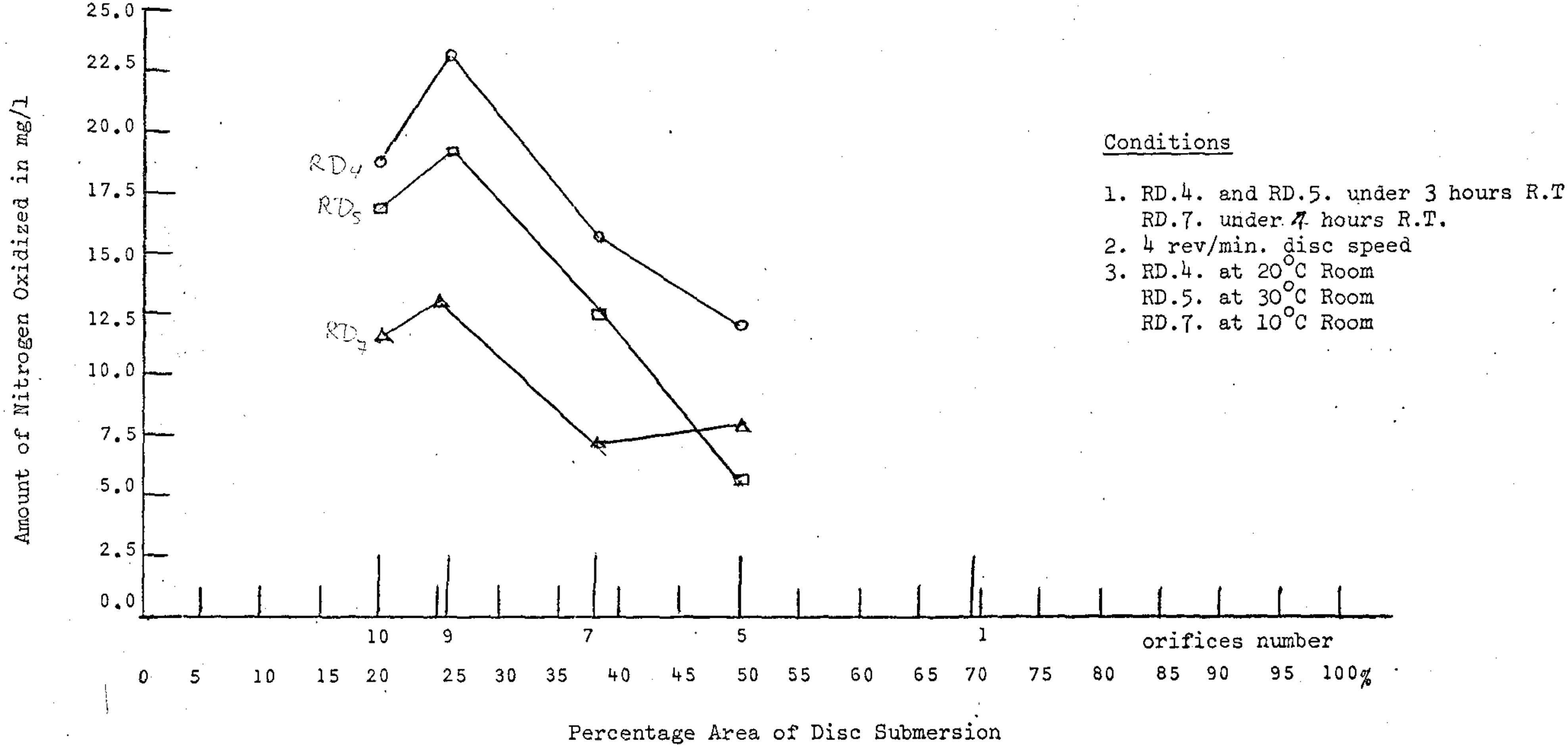
GRAPH NO. 17 : VARIATION OF C.O.D. REMOVAL EFFICIENCY WITH AREA OF DISC SUBMERGED



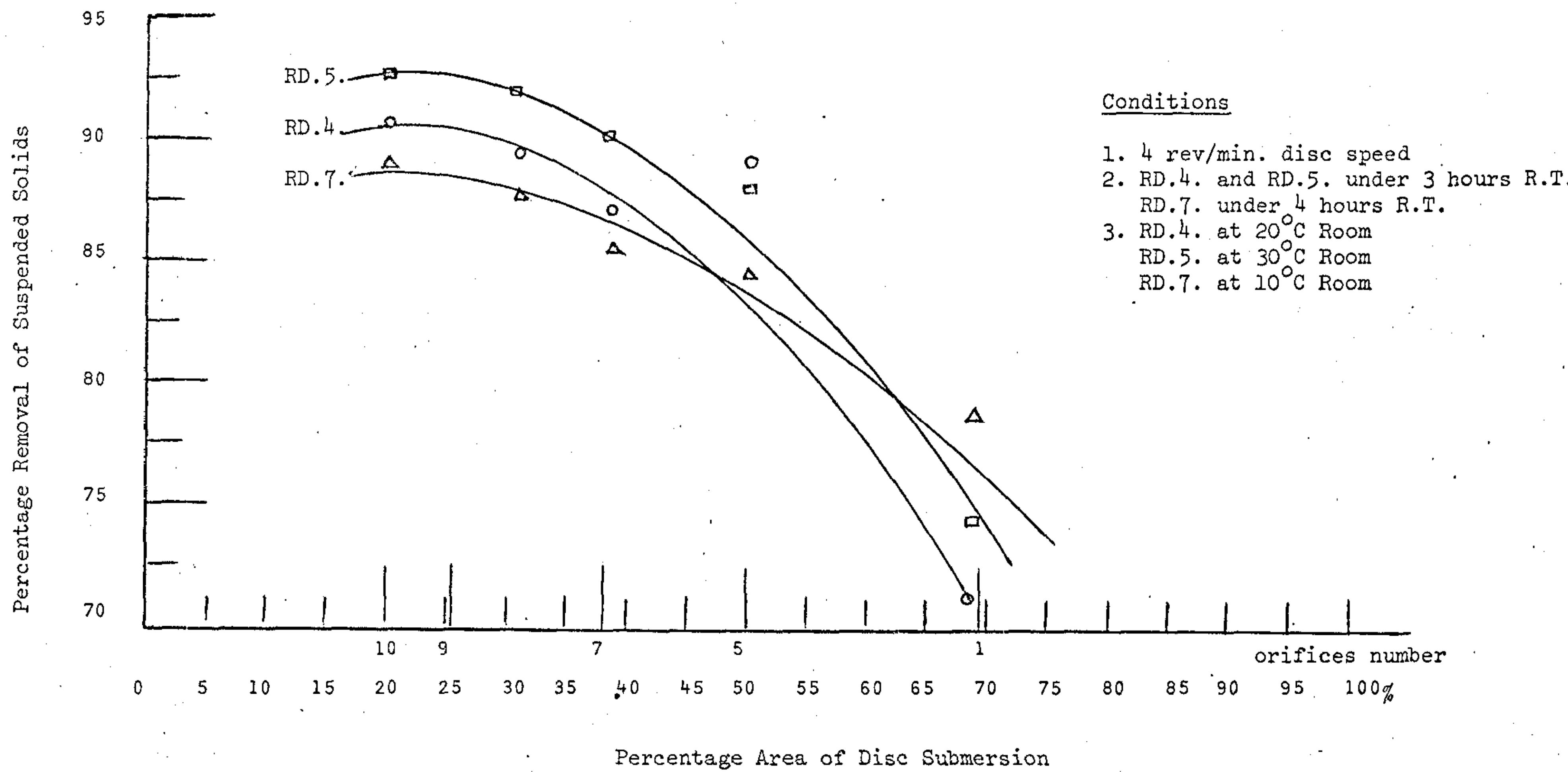
GRAPH NO. 18 : AMMONIA NITROGEN REMOVAL AND AREA OF DISC SUBMERGED



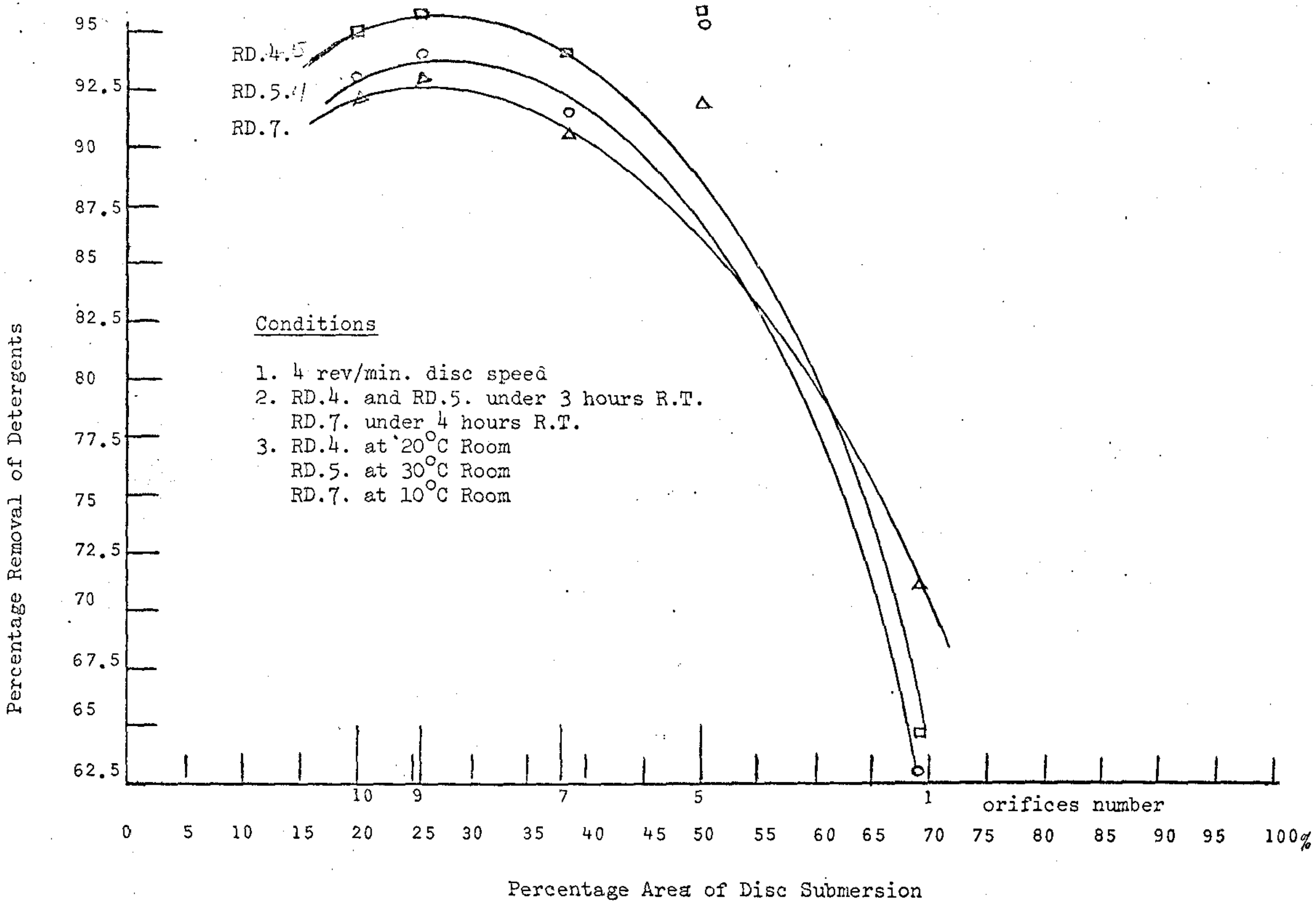
GRAPH NO. 19 : VARIATION OF THE AMOUNT OF OXIDIZED NITROGEN FORMED WITH AREA OF DISCS SUBMERGED.



GRAPH NO. 20 : SUSPENDED SOLIDS REMOVAL AND AREA OF DISCS SUBMERGED



GRAPH NO. 21 : VARIATION OF DETERGENT REMOVAL WITH AREA OF DISC SUBMERGED



The results indicate that efficiency was at a maximum when only 26% of the disc area was submerged under the liquid surface.

It was stated earlier that the maximum population of micro-organisms occurs at the 50% disc submersion, but the later results show that the optimum percentage area of disc submersion is about 26%. This means that the major governing factor is the supply of oxygen, where at low percentage areas of submersion such as 26%, more oxygen is picked up by the micro-organisms directly from the atmosphere.

It should be noted that at this level of submersion the water actually covers more than 26% of the disc area. This is because as the disc rotates the water covers some of the adjacent un-submerged parts of the discs.

Under further, lower percentage areas of submersion more oxygen is picked up, but some of the micro-organisms will lose contact with the waste water.

The reason why the maximum efficiency occurs at 26% of disc submersion is that at this degree of submersion a balance between the absorption of oxygen, as the disc passes through the air, and the contact of the micro-organisms with the basic substrate in the waste water is obtained.

4.6 OPTIMUM OPERATIONAL CONDITIONS

For this period of operation the units were maintained under the optimum operational conditions below:-

1. 26% disc submersion
2. 4 rev/min. disc speed.

The load put to the unit was increased by decreasing the retention period, until a short retention time of 60 minutes was reached. Even at this high loading a fair quality of effluent was obtained.

Graphs (22-29) illustrate the performance of the unit during this period of operation. If $R.D.T.U._5$ is taken as an example, then the graphs 22 and 23 show that the unit is capable of removing 90% of the applied B.O.D. even under 60 minutes retention time and under 23 grams of B.O.D./m^2. day loading respectively.

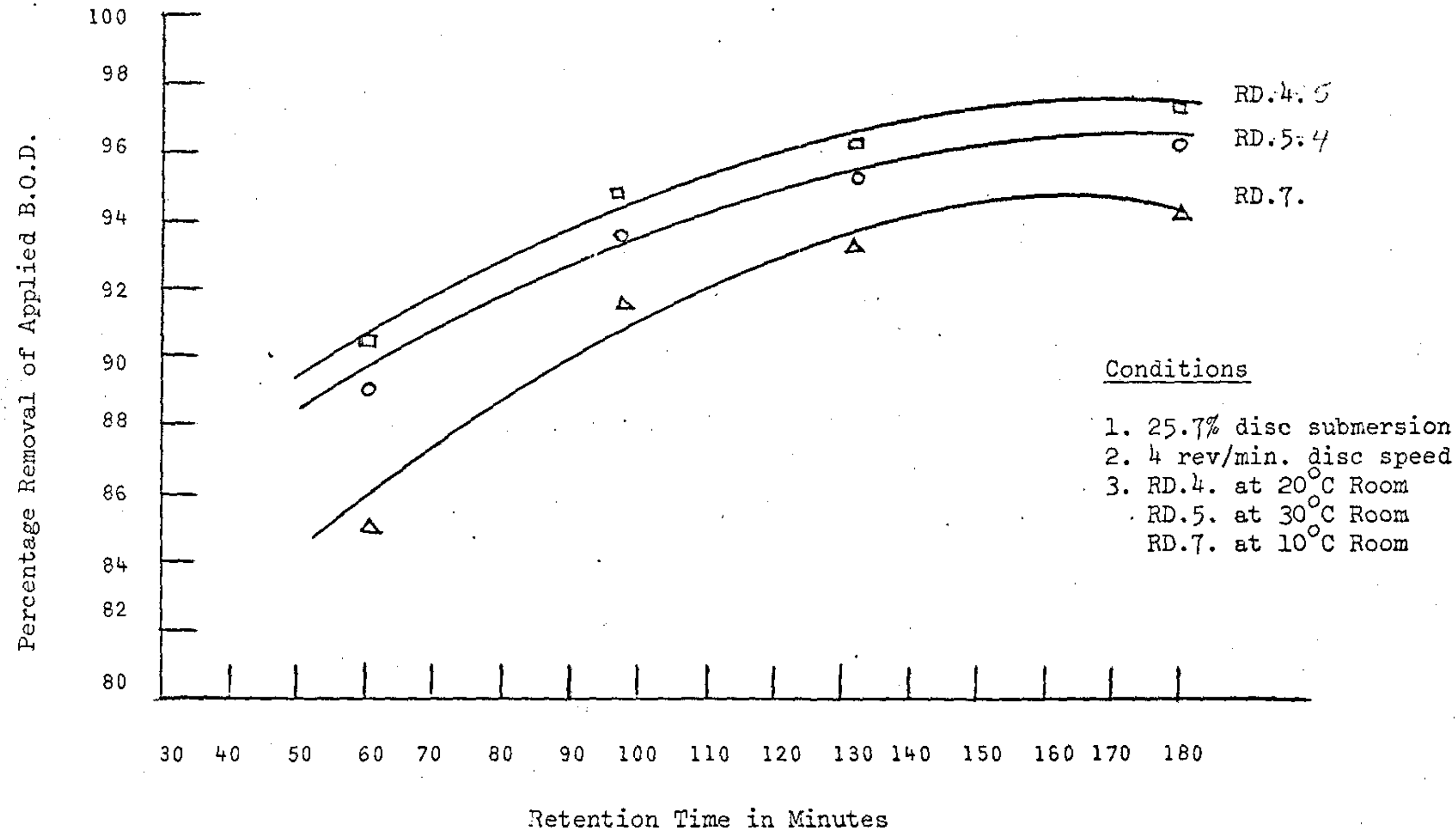
Graphs 24 and 25 illustrate the C.O.D. removal as a function of the retention time and the C.O.D. loading respectively. 73% of the C.O.D. was removed under 60 minutes and 44 grams of C.O.D./m^2. day loading.

Graph 26 shows that more than 70% of the ammonia was removed in 97 minutes retention time. Graph 27 shows the performance of the unit in removing detergents.

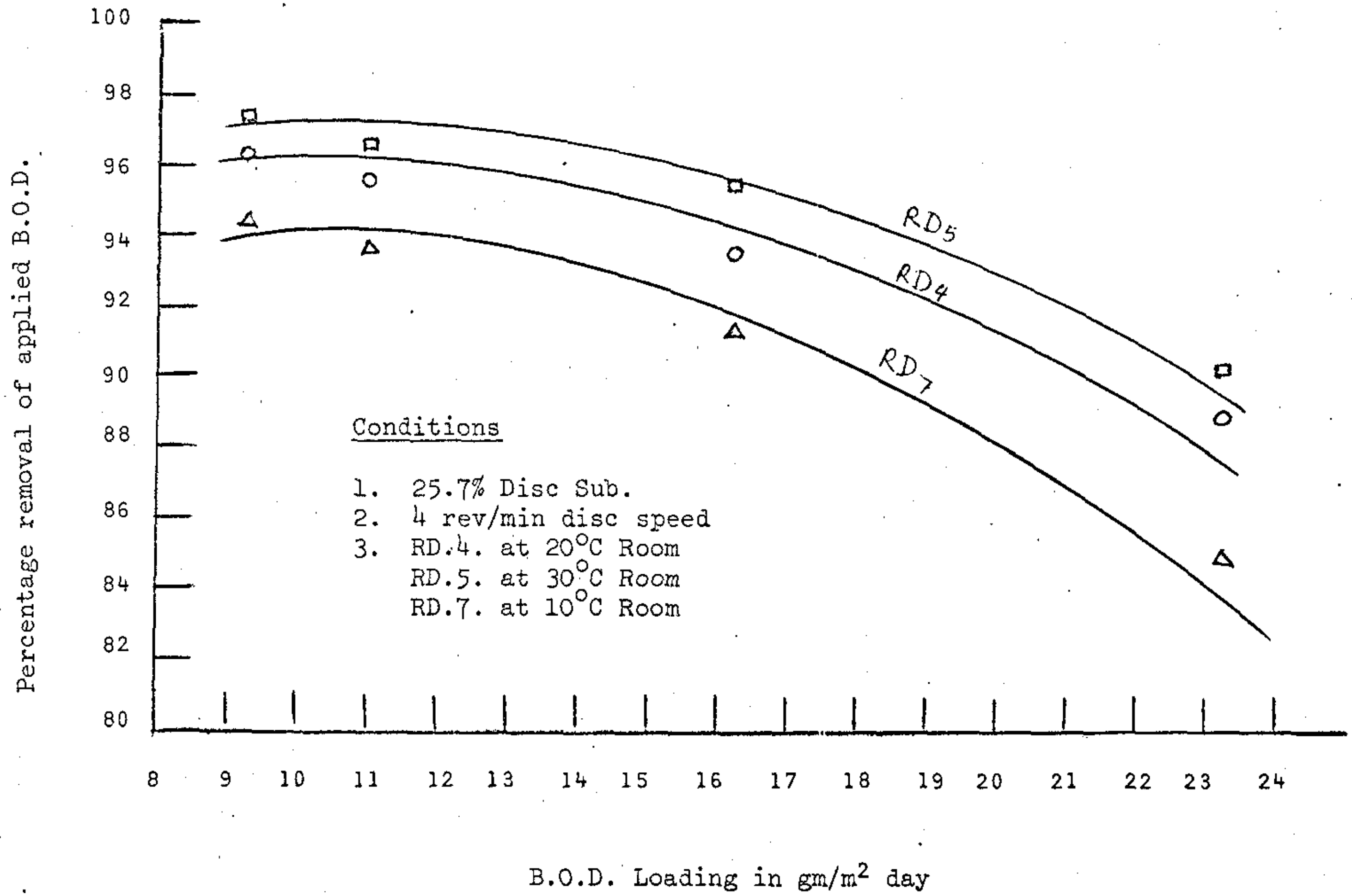
Graphs 28 and 29 were plotted to reveal the kinetics of the carbonaceous B.O.D. and the ammonia. Both graphs were referred to earlier in this section, when discussing the reaction kinetics.

The nitrate and nitrite formed as a result of oxidation of ammonia are shown in Table 10. The oxidized nitrogen was observed to fall rapidly with the decrease in the retention time. No nitrate was formed in 60 minutes retention time but a fair amount of nitrite was formed in case of $R.D.T.U._4$ and $R.D.T.U._5$

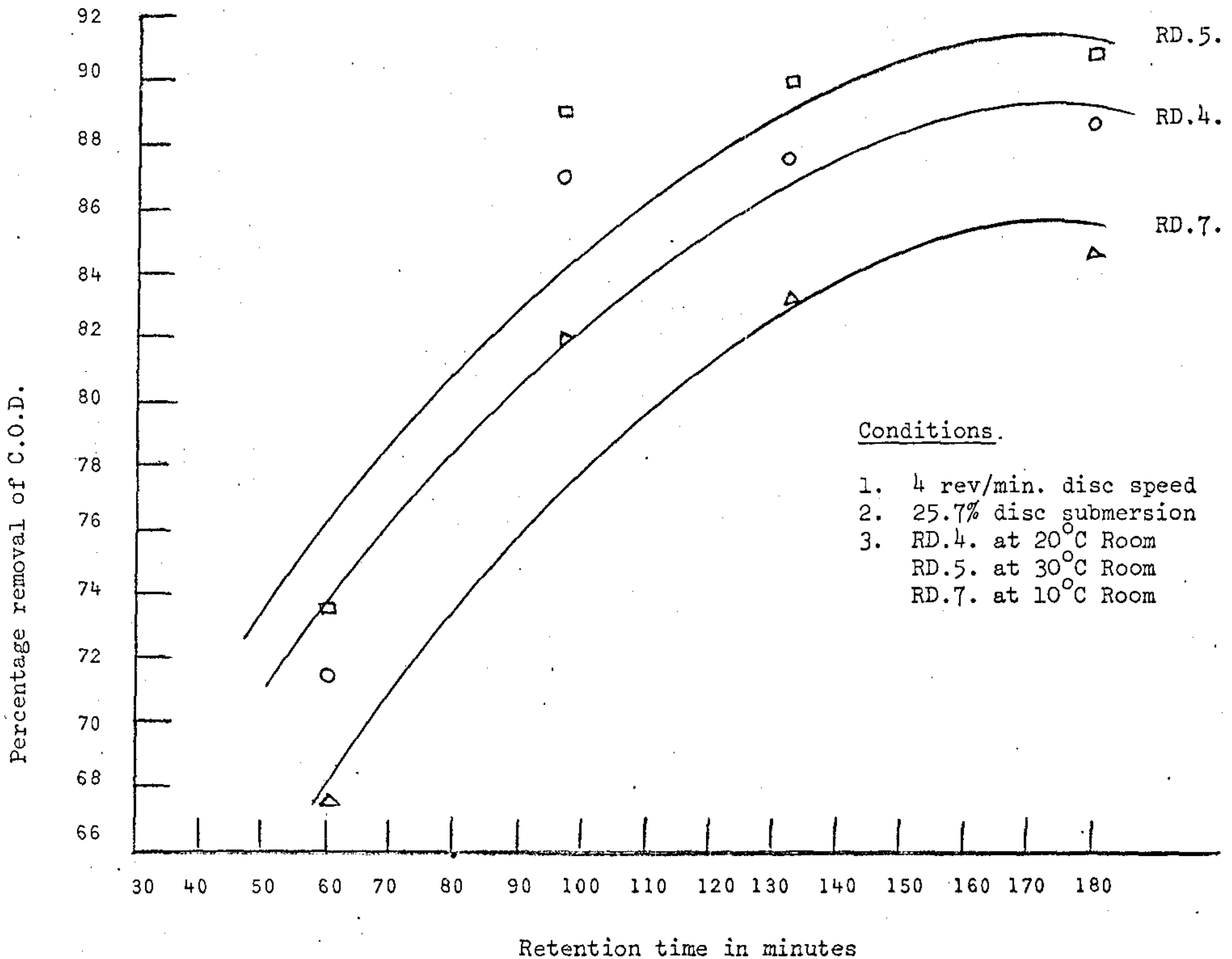
GRAPH NO. 22 : VARIATION OF B.O.D. REMOVAL EFFCIENCY WITH RETENTION TIME



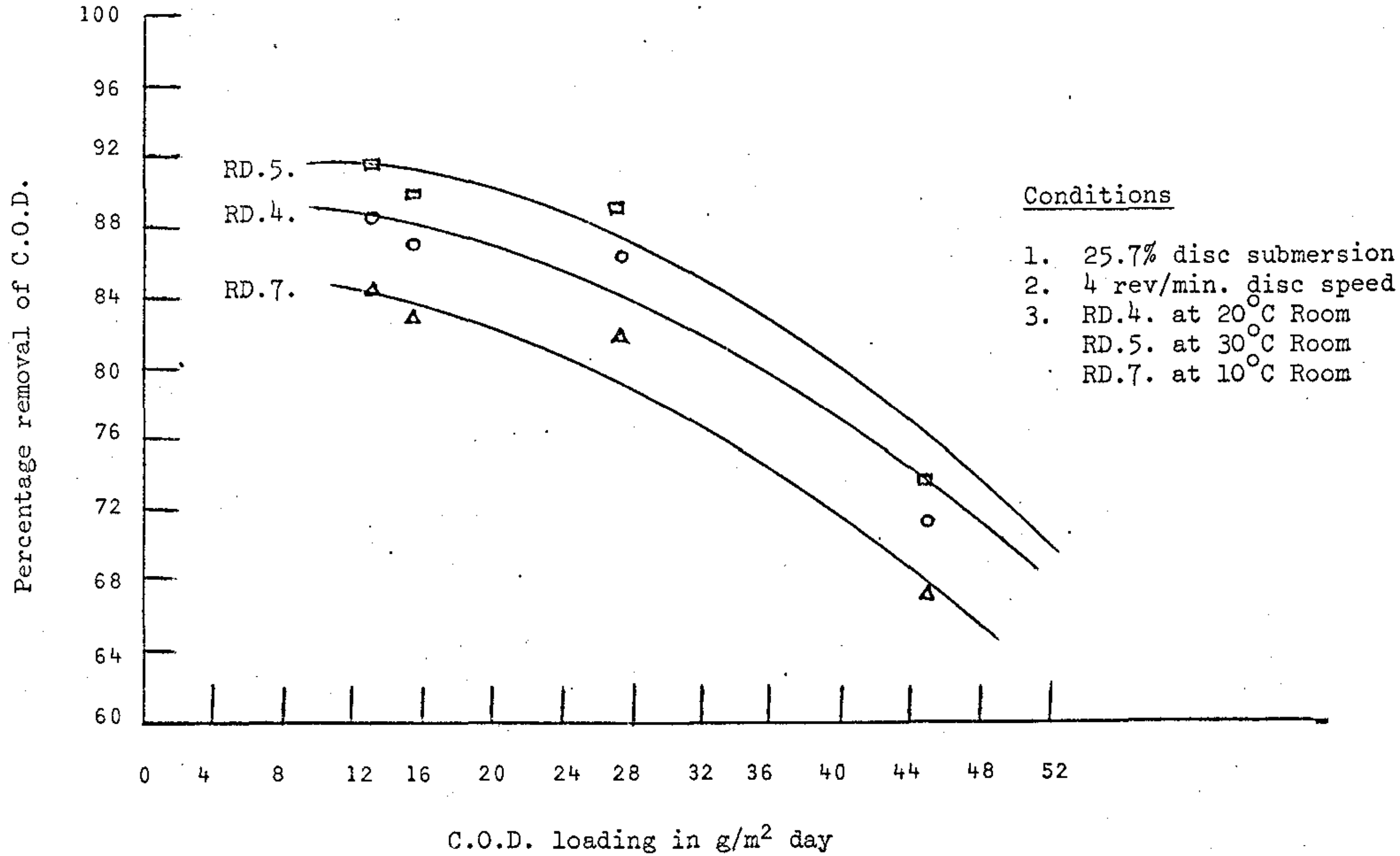
GRAPH NO. 23 : B.O.D. REMOVAL EFFICIENCY AND B.O.D. LOADING



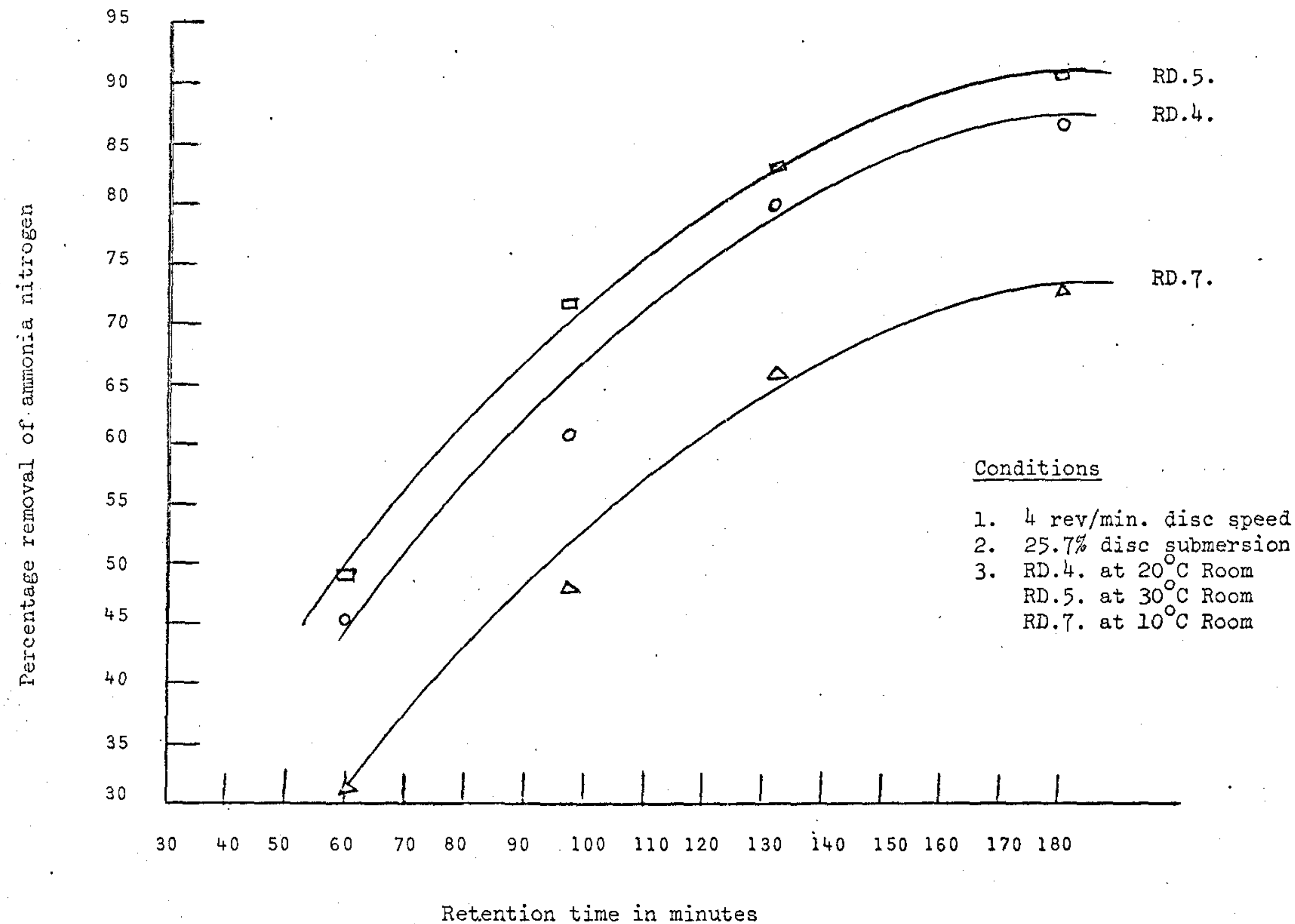
GRAPH NO. 24 : C.O.D. REMOVAL EFFICIENCY AND RETENTION TIME



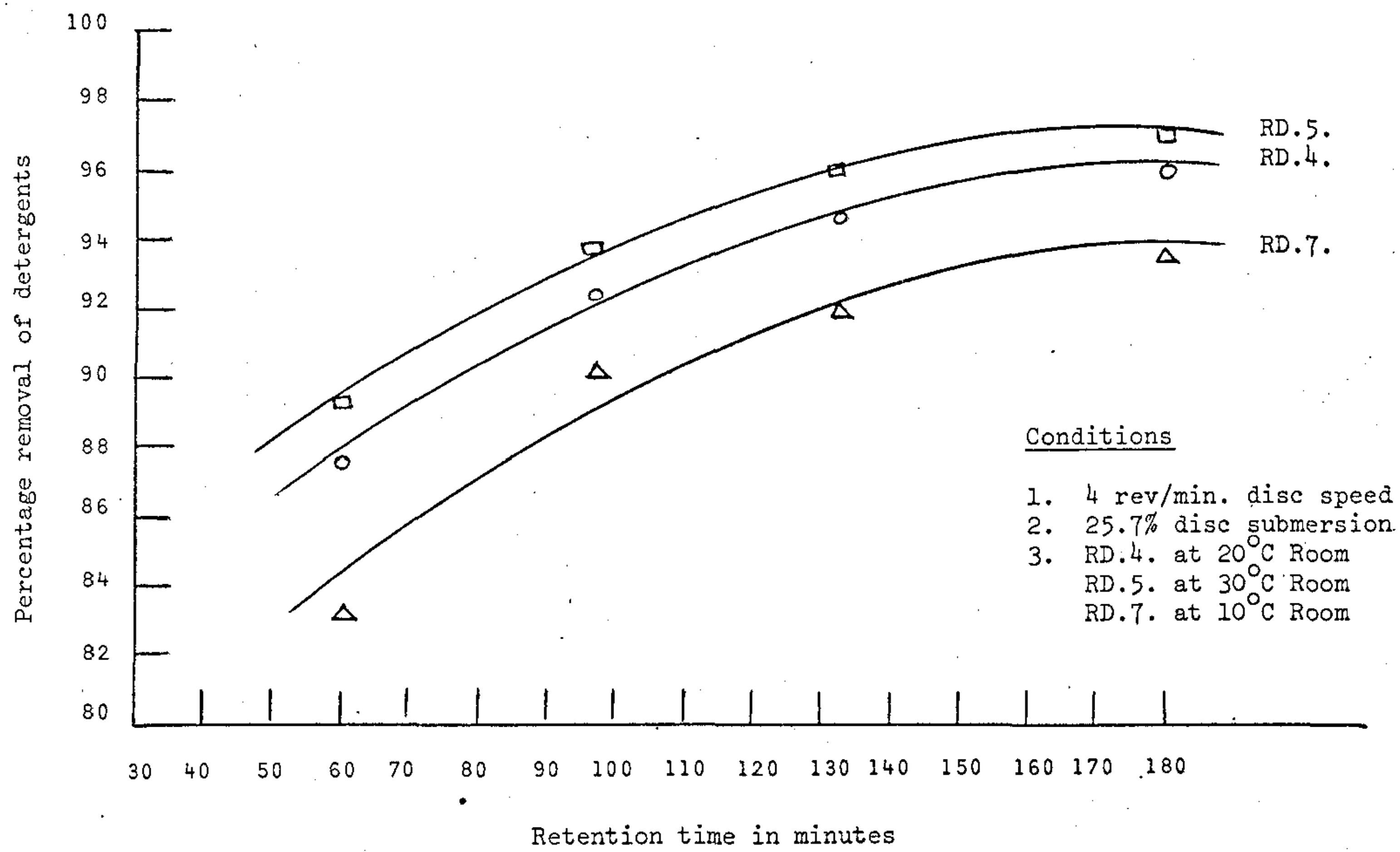
GRAPH NO. 25 : VARIATION OF C.O.D. REMOVAL EFFICIENCY WITH C.O.D. LOADING



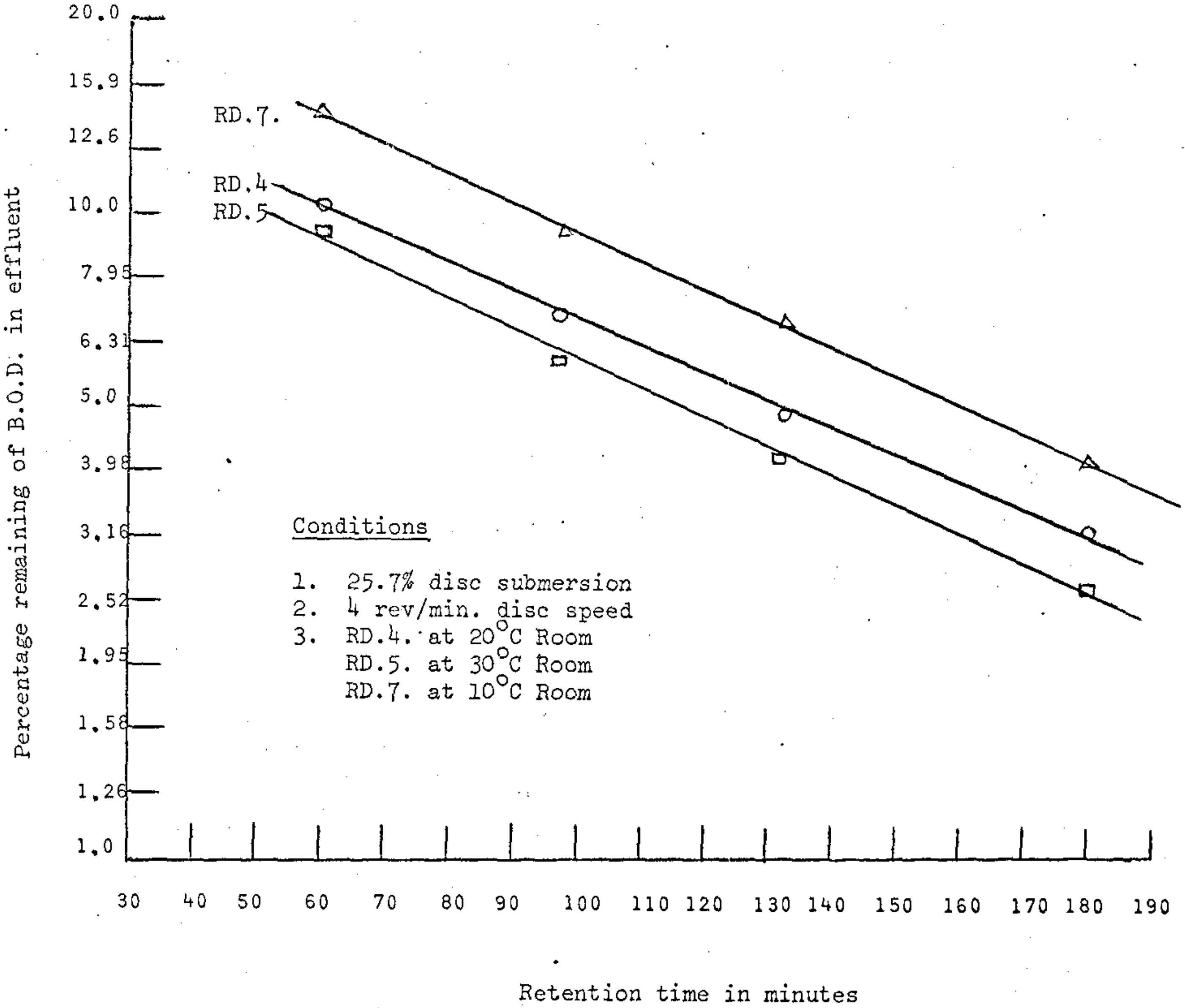
GRAPH NO. 26 : AMMONIA REMOVAL AND RETENTION TIME



GRAPH NO. 27 : VARIATION OF DETERGENT REMOVAL WITH RETENTION TIME



GRAPH NO. 28 : B.O.D. KINETICS



GRAPH NO. 29 : AMMONIA KINETICS

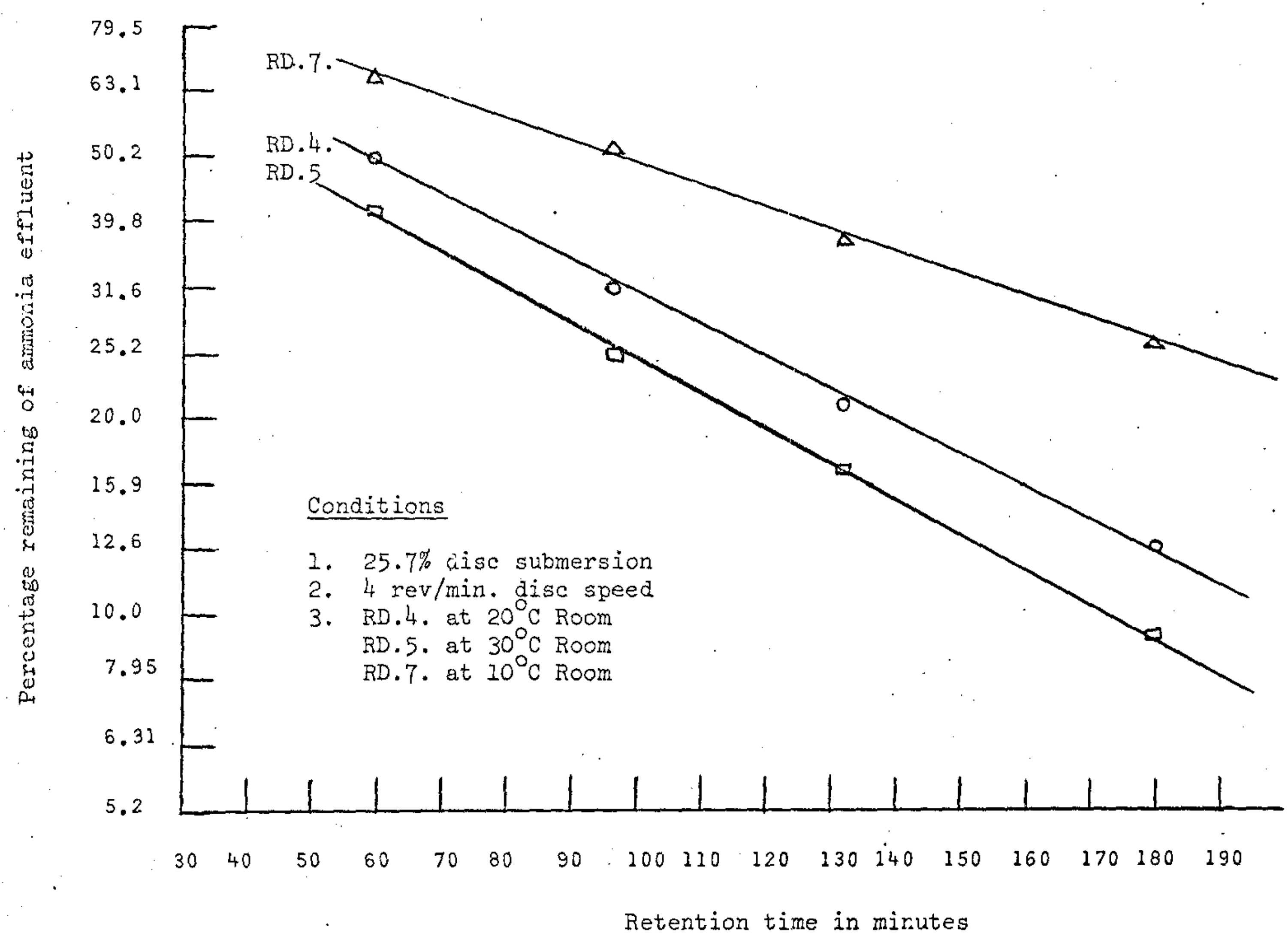


TABLE 10 : TOTAL OXIDIZED NITROGEN AND RETENTION TIME

Conditions	RD.4.			RD.5.			RD.7.			
	NO_2-N mg/l	NO_3-N mg/l	T.O.N. mg/l	NO_2-N mg/l	NO_3-N mg/l	T.O.N. mg/l	NO_2-N mg/l	NO_3-N mg/l	T.O.N. mg/l	R.T. in Minutes
1. 25.7% Disc Submersion	2.15	21.15	23.3	4.3	15.0	19.3	1.1	12.3	13.4	180
	0.8	15.5	16.3	0.95	14.55	15.5	1.2	9.1	10.3	132
2. 4 rev/min disc speed	0.3	8.2	8.5	3.4	7.8	11.2	0.6	5.7	6.3	97
3. Retention Time shown on last column	0.7	NIL	0.7	1.73	NIL	1.73	NIL	NIL	NIL	60

TABLE 11 : EFFLUENTS PROPERTIES

Unit	Temp. °C	Disc Sub.	Disc speed	R.T. minutes	BOD mg/l	SS mg/l	COD mg/l	NH_3-N mg/l	NO_2-N mg/l	NO_3-N mg/l	T.O.N. mg/l	Detergents mg/l
RD.4.	18°C	25.7%	4 rev/ min.	180	7.5	8	32	2.5	2.15	21.15	23.3	0.67
				132	8	8	35	6.0	0.8	15.5	16.3	0.71
				97	13	10	47	15	0.35	8.15	8.5	1.0
				60	22	23	107	18	0.6	NIL	0.6	1.4
RD.5.	27°C	25.7%	4 rev/ min.	180	6.5	8	26	1.0	4.3	15.0	19.3	0.5
				132	7	7	28.5	4.0	0.9	14.55	15.5	0.55
				97	9.5	9	38.5	11	3.5	7.7	11.2	0.8
				6	21	21	100	17	1.6	NIL	1.6	1.26
RD.7.	11°C	25.7%	4 rev/ min.	180	9.5	10	44	4	1.1	12.3	13.4	0.83
				132	10	9	47.5	12	1.2	9.1	10.3	0.98
				97	17	14	65	19	0.6	5.7	6.3	1.27
				60	29	31	121	23	NIL	NIL	NIL	1.75

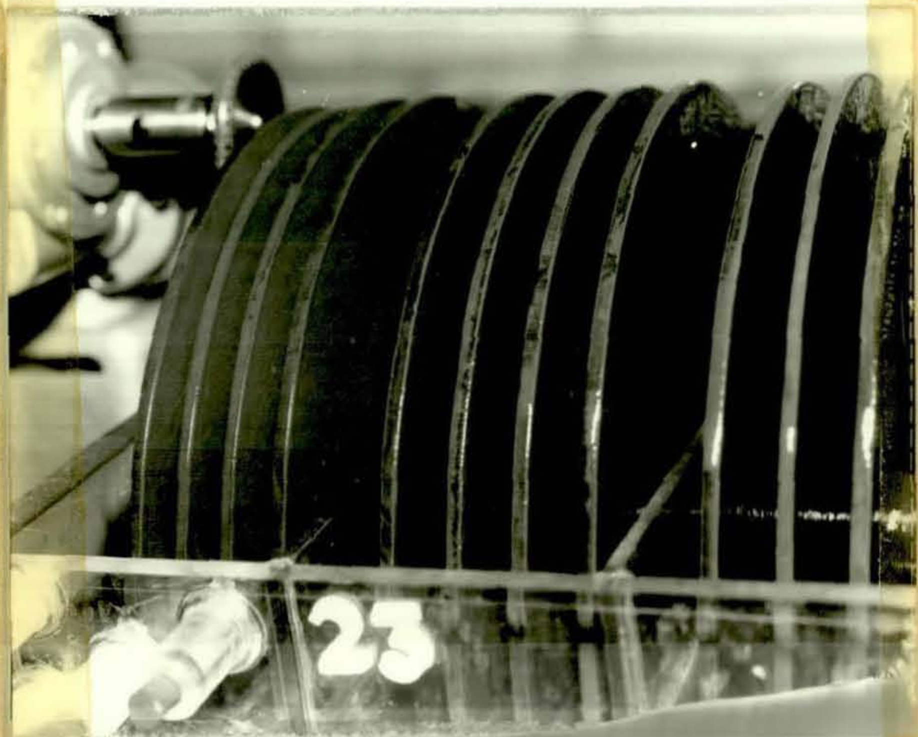
The results described above are the best results recorded during the whole investigation. Table 11 shows some properties of the effluents evolved during this period of operation. If a general assessment is to be made on the quality of effluents evolved, all the effluents produced after being retained in the reaction vessel for 97 minutes or more, can be classified as first class effluents.

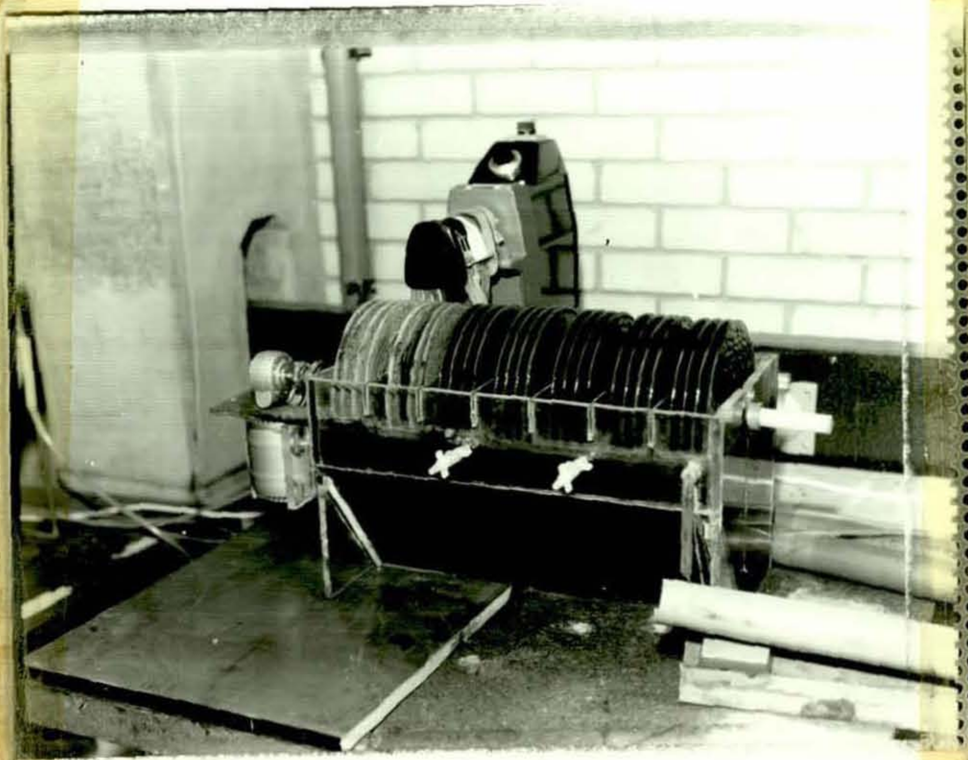
4.7 THE BIOMASS

Further research work is still required to investigate the optimum thickness of the biomass, but in this report it is worth recording some of the observed characteristics of the biomass.

1. There is a large biological growth supported by the discs. This was measured by removing the micro-organisms from the discs and placing them in the mixed liquor. The resulting mixed liquor suspended solids concentration was in excess of 23000 mg/ℓ.
2. Fig. 9 shows how the biological growth develops on each stage of the R.D.T. unit. It is clear that each stage exhibits a substantially different surface feature with a different microbial nature.
3. The thickness of the biomass was observed to be affected by the substrate concentration and the area of disc submersion. The thickness of the biomass was observed to increase with the increased rate of substrate concentration. Also, at higher degrees of disc submersion, the biomass was observed to increase in thickness.
4. The accumulation of the biological growth was rapid in the first two or three stages.
5. The colour of the biological growth changes with the degree of treatment. It was noticed that a white or grey colour on the discs of the first two stages could be correlated with a poor effluent. The dark colour is the sign of satisfactory effluent. The brown colour is the sign of a good effluent with a high degree of nitrate formation.

FIGURE 9 : BIOLOGICAL GROWTH DEVELOPMENT ON DISCS SURFACES





6. The standard of the effluent improved as the thickness of the biomass decreased. This agrees with the model of the structure and metabolism of the nature of biological film community already discussed in Section 3. It follows that the cleaning of the discs is important so that the biomass does not go anaerobic. The efficiency of the unit can be increased if the biomass thickness can be maintained at a minimum in the first two or three stages. Frequent cleaning of the excess biomass can be achieved by gently reversing the direction of the disc rotation. There is no danger of losing the biological culture because the bio-slime is renewed in less than 24 hours.

4.8 TEMPERATURE

4.8.1 General

As stated earlier, the required temperature is extremely important because of its effects on the rate of growth, type and structure of micro-organisms. Since the oxygen is consumed in support of synthesis reactions, it follows that the oxygen consumption in aerobic biological oxidation processes is the fundamental parameter in assessing the rate of these reactions. Furthermore, since quantitative relationships exist between the amount of oxygen required to convert a definite amount of any given organic compound to CO_2 and H_2O, B.O.D. data can be interpreted in terms of the amount of oxygen used during its oxidation.

However, Phelps predicted a first order reaction to represent the B.O.D. during the first stage and according to him, the rate of change in concentration of organic substrate $\frac{dl}{dt}$ is directly proportional to concentration of substrate remaining at that time, l

$$\frac{dl}{dt} = KL$$

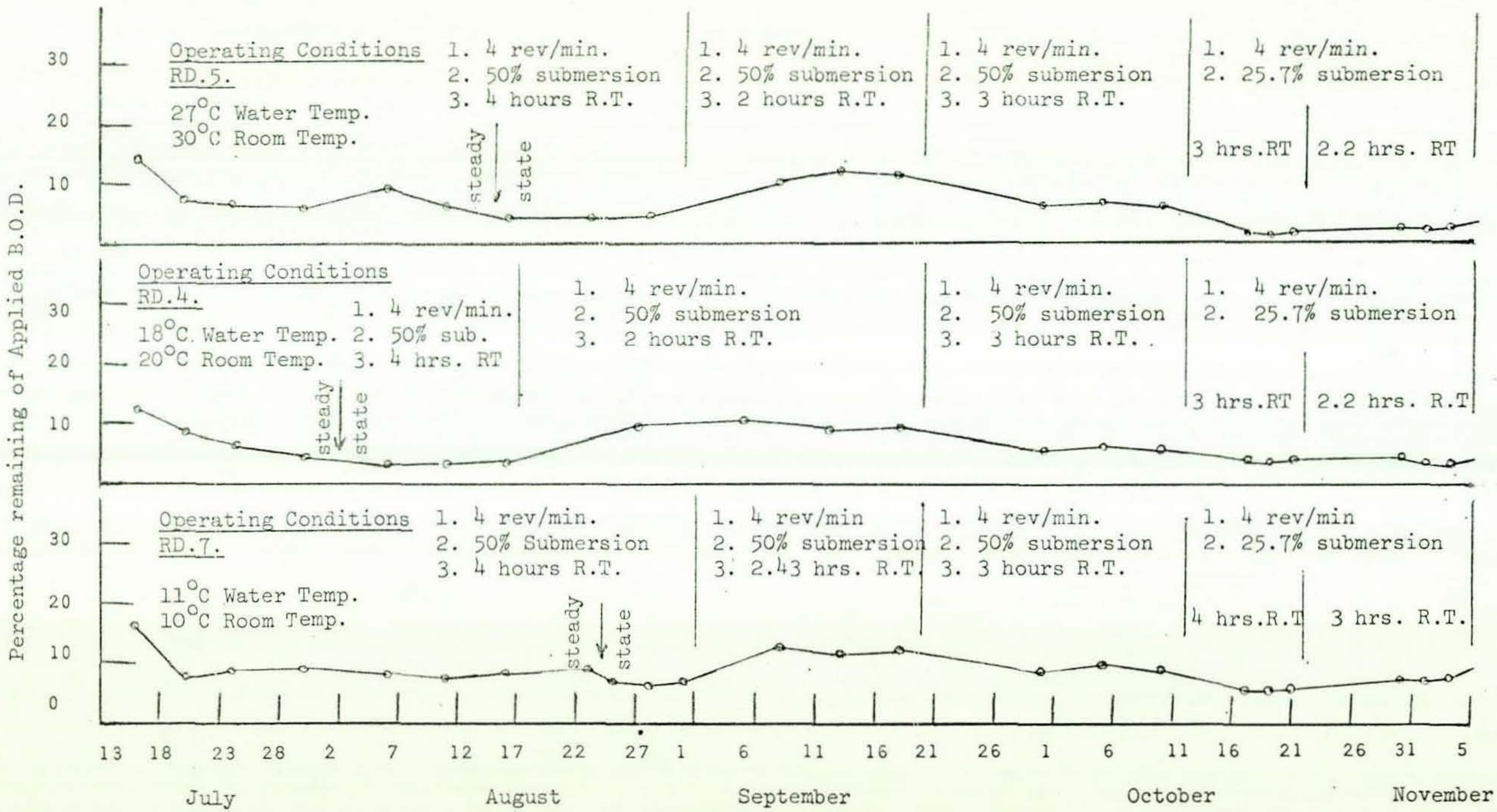
where k is the rate constant for this reaction.
After integration:

$$L = La \{1 - e^{-kt}\}$$

where La is the ultimate oxygen demand. The reaction rate constant k is temperature dependent.

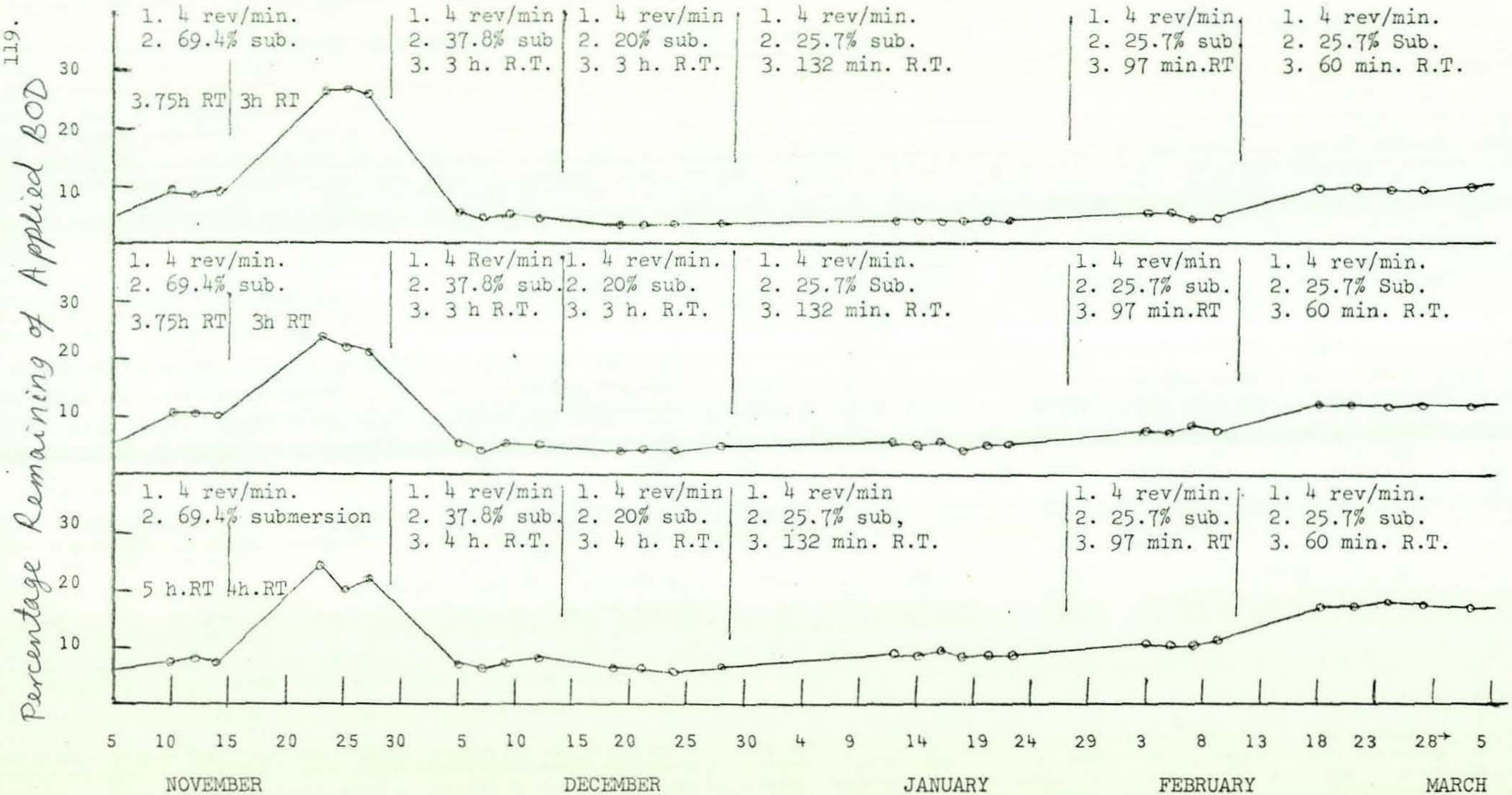
In Section 3 some correlations between the temperature and the rate constant k were described by equations (3-5[11]). The most general equation is equation 5.

GRAPH (B) : CHRONOLOGICAL VARIATIONS IN B.O.D. REMAINING

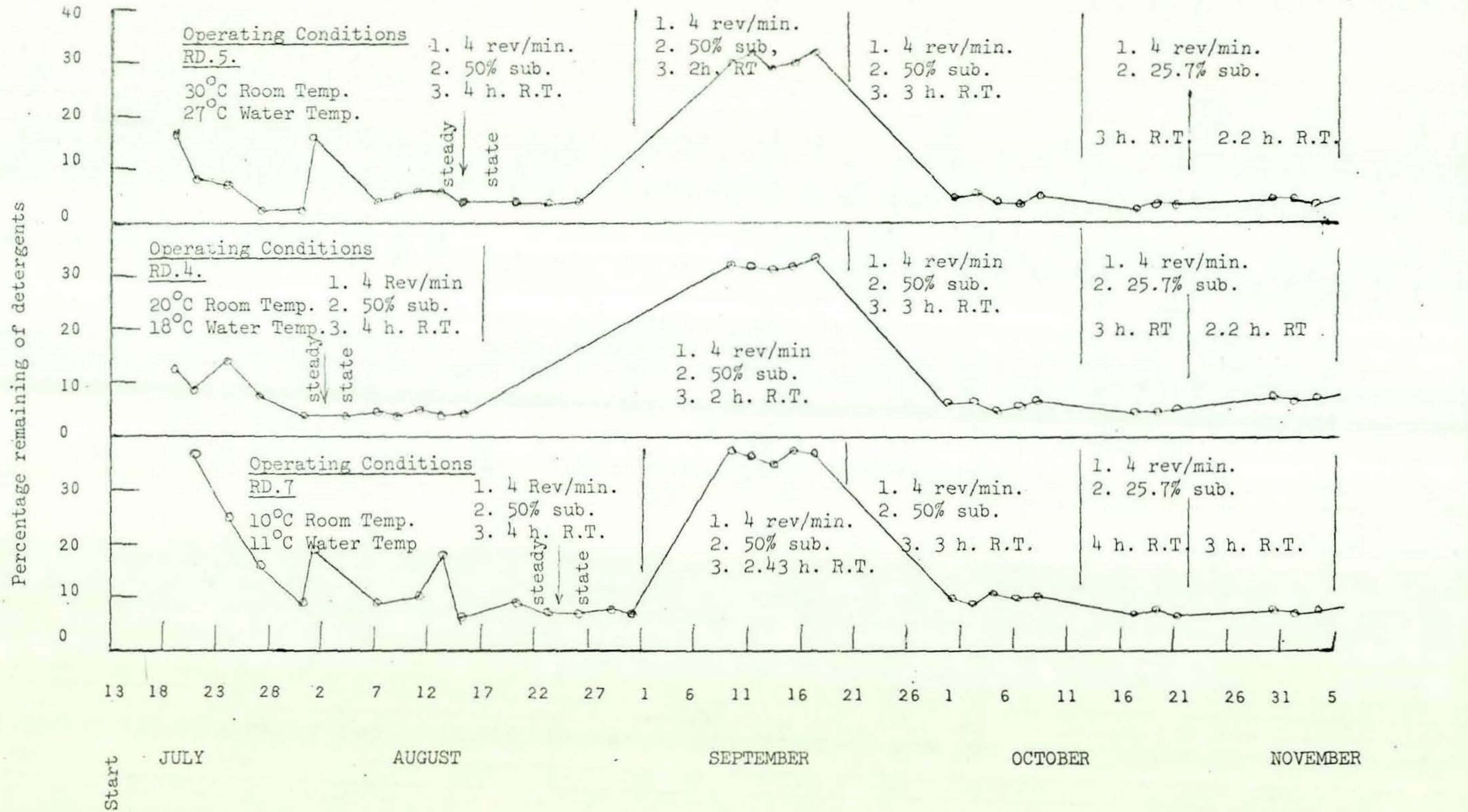


B

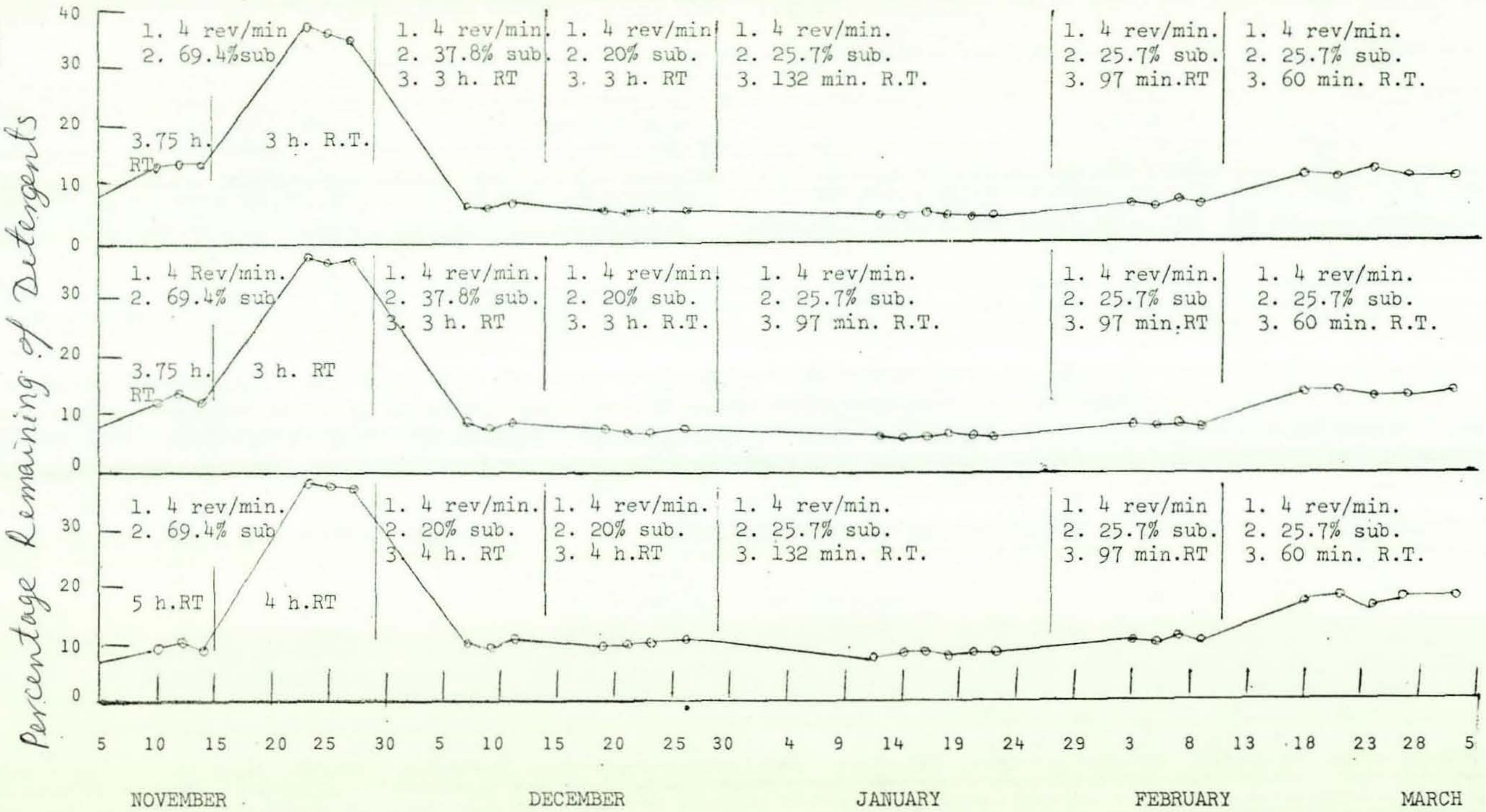
CONTINUATION OF GRAPH (B)



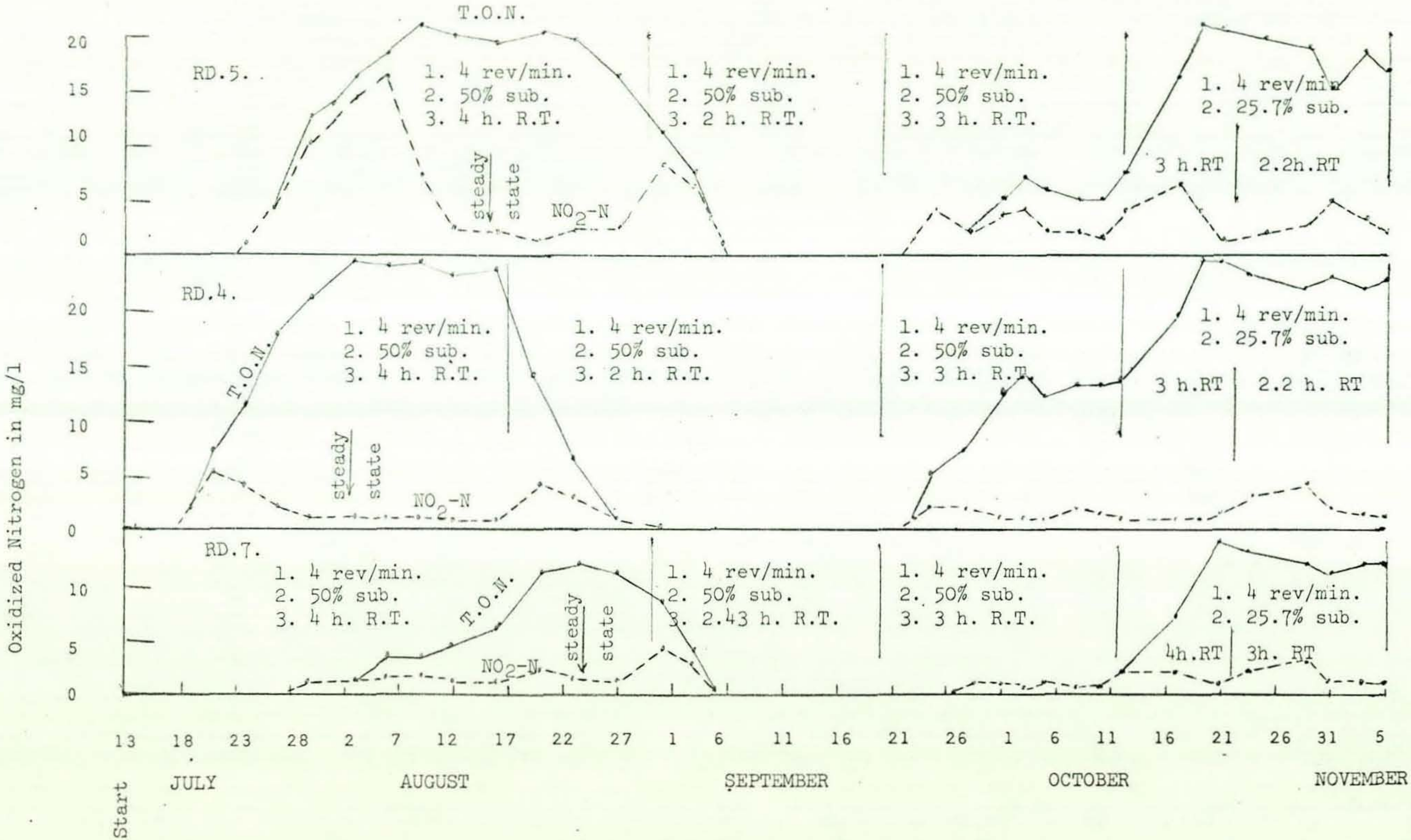
GRAPH (D) : CHRONOLOGICAL VARIATIONS IN DETERGENT REMAINING



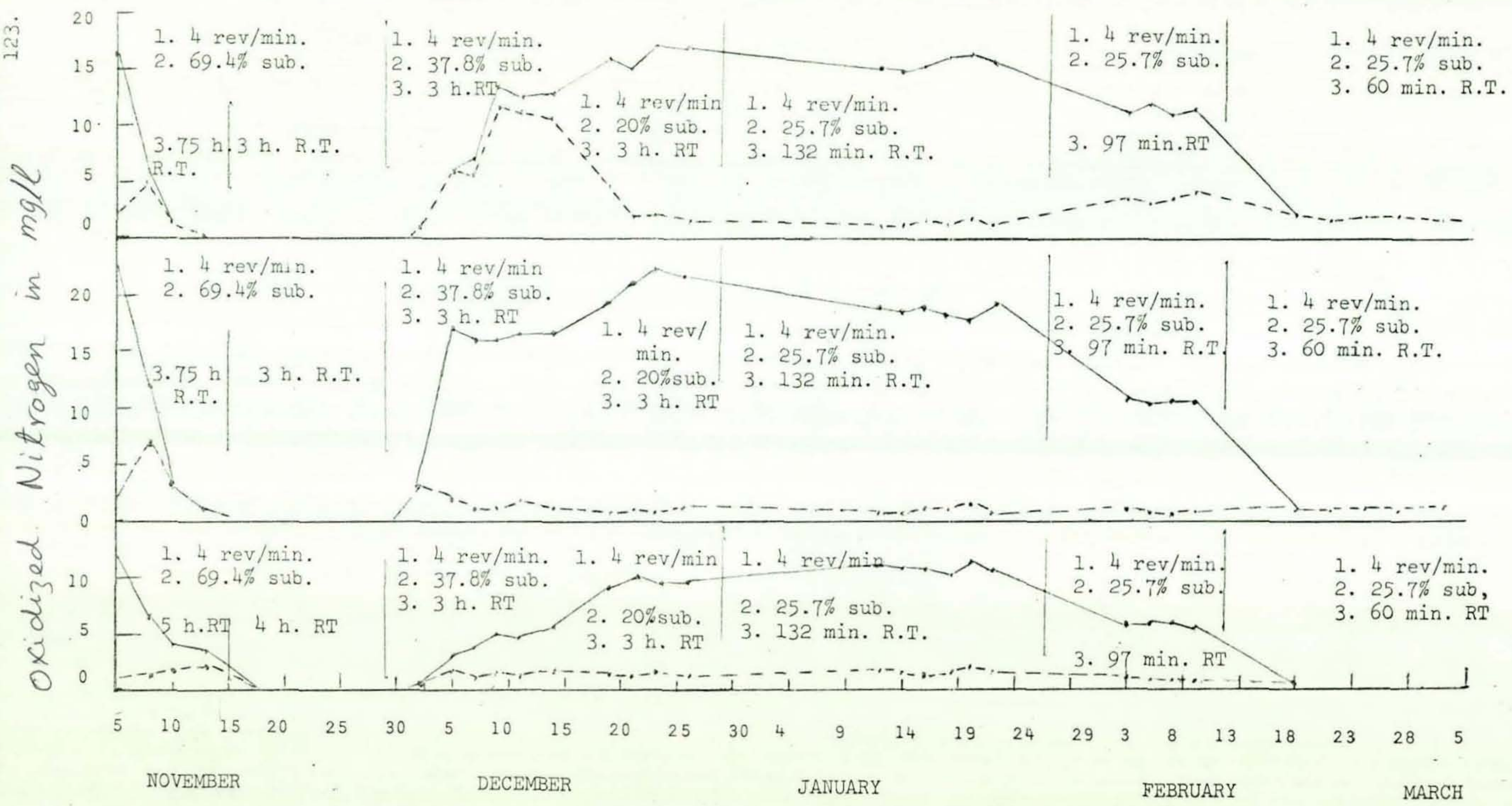
CONTINUATION OF GRAPH (D)



GRAPH (N) CHRONOLOGICAL VARIATIONS OF TOTAL OXIDIZED NITROGEN AND NITRITE NITROGEN



CONTINUATION OF GRAPH (N)



$$\frac{Kt_1}{Kt_2} = \theta^{-t_2+t_1}$$

where θ is the temperature coefficient.

As for this investigation, the performance of the three units under the three different temperature conditions is shown by the long graphs B,D and N. These graphs show the efficiency of each unit in removing B.O.D., and detergent as well as the amount of the total nitrogen oxidized under each condition of operation throughout the period of the investigation.

It is clear from the B.O.D. graph results that under all conditions of operation $R.D.T.U._7$ shows a poorer performance than the other two units. This is why the retention time of $R.D.T.U._7$ was increased with respect to $R.D.T.U._4$ and $R.D.T.U._5$ for most of the installation period.

With 50% of the area of the discs submerged, $R.D.T.U._4$ shows a better performance than $R.D.T.U._5$, but the difference in the results of both units working under these conditions was very small.

$R.D.T.U._5$ shows a better performance than $R.D.T.U._4$ under all conditions of operation when the area of disc submersion is less than 50%.

From the results shown by all the graphs it is clear that there is an increase in the B.O.D. removal efficiency with the increase in temperature. The reason why, under the condition of more than 50% area of disc submersion, no increase in efficiency is noted, is because under this condition most of the work will be done by using the oxygen dissolved in water and the solubility of oxygen in water decreases with the increase in temperature.

If $20^{\circ}C$ is taken as a reference temperature, the decrease in the B.O.D. removal rates below $20^{\circ}C$ is significant,while the increase in the B.O.D. removal rates above $20^{\circ}C$ is small.

TABLE 12 : VARIATION OF B.O.D. REMOVAL WITH TEMPERATURE

Conditions			B.O.D. Loading in gm/m^2 day	RD.7. - 11^{o}C	RD.4. - 18^{o}C	RD.5. - 27^{o}C
Disc Speed	Disc Sub.	R.T. minutes		Percentage B.O.D. Removal	Percentage B.O.D. Removal	Percentage B.O.D. Removal
4 rev/min	25.7%	180	9.4	92.4	95.4	97.4
4 rev/min	25.7%	132	11.0	91.4	94.3	96.0
4 rev/min	25.7%	97	16.2	89.2	92.6	94.8
4 rev/min	25.7%	60	23.1	82.9	88.0	90.3

If the period of investigation between the 29th December, 1973 and the 15th March, 1974 is taken as an example, then the relationship of temperature to B.O.D. removal efficiency for this period is represented by Table 12 for each retention time or B.O.D. loading. For the four loadings or retention times as a whole, a temperature reduction from 18°C to 11°C resulted in a drop of B.O.D. removal efficiency.

from 95.4% to 92.4% at 180 minutes retention time and

from 94.3% to 91.4% at 132 minutes retention time and

from 92.6% to 89.2% at 97 minutes retention time and

from 88.0% to 82.9% at 60 minutes retention time.

A temperature increase from 18°C to 27°C resulted in an increase,

from 95.4% to 97.4% at 180 minutes retention time and

from 94.3% to 96.0% at 132 minutes retention time and

from 92.6% to 94½8% at 97 minutes retention time and

from 88.0% to 90.3% at 60 minutes retention time.

4.8.2 Evaluation of the Temperature Coefficient Θ using Eckenfelder equation.

The study made use of the data above to calculate the temperature coefficient using Eckenfelder equation, equation 6 for biological filters.

$$\frac{E_{T1}}{E_{T2}} = \Theta^{T_1 - T_2}$$

where,

E = filter efficiency

T = temperature, °C

The B.O.D. removal shown on Table 12 can be taken to represent the filter efficiency and hence the temperature coefficient Θ can be calculated accordingly.

The average value of Θ for each temperature range can be calculated from the values of Θ at the four retention times stated above.

As for temperature range $11^{o}C$ to $18^{o}C$.

$$\Theta_1^{18-11} = \frac{95.4}{92.4}, \quad \Theta_2^{18-11} = \frac{94.3}{91.4}, \quad \Theta_3^{18-11} = \frac{92.6}{89.2}$$

and $\Theta_4^{18-11} = \frac{88}{82.9}$

The average value of Θ for this range of temperature equals 1.006.

Similarly, for the temperature range of 18 to $27^{o}C$

$$\Theta_1^{27-18} = \frac{97.4}{95.4}, \quad \Theta_2^{27-18} = \frac{96.0}{94.3}, \quad \Theta_3^{27-18} = \frac{94.8}{92.6}$$

and $\Theta_4^{27-18} = \frac{90.3}{88.0}$

The average value of Θ for the temperature range of 18 to $27^{o}C$ is equal to 1.0025.

If $20^{o}C$ is to be introduced as a reference temperature then the temperature coefficient Θ of the range $10^{o}C$ to $20^{o}C$ is 1.006 and that for the temperature range of $20^{o}C$ to $30^{o}C$ is 1.0025, or:

$$\frac{E_T}{E_{20}} = 1.006^{T-20}$$ for temperature range of 10 to $20^{o}C$

and $$\frac{E_T}{E_{20}} = 1.0025^{T-20}$$ for the temperature range of 20 to $30^{o}C$

Although the temperature variations seem to have little effect on the carbonaceous B.O.D. removal efficiency, they do show that the temperature coefficient Θ increases with increase in temperature, but at a decreasing rate of increase. An average temperature coefficient for the temperature range of 10 to 30°C can be calculated in the same manner.

If the average temperature coefficient Θ is known for the normal range of temperature 10°C to 30°C, as in the case of this investigation, then equation 6 can be slightly modified to read the value of Θ at any desired temperature within the specified range of temperature (10 - 30°C) i.e.

$$\frac{E_T}{E_{20}} = \{\Theta_a - a\,(T-20)\}^{T-20}$$ where

Θ_a = average temperature coefficient for the temperature range of 10 to 30°C

a = a constant

E_T = efficiency of the filter at temperature, T°C

E_{20} = efficiency of the filter at 20°C

The variation of Θ with temperature was also noticed previously by some of the research workers in this area. Bewta and Charan[9] in their study of B.O.D. tests conducted on raw sewage at Okhla Sewage Works, gave the following temperature coefficient values.

Θ = 1.07 for temperature range of 12 to 20°C and

Θ = 1.048 for temperature range of 20°C to 37°C

Zanoni[40] reported that for the carbonaceous phase of deoxygenation, the best values for Θ were found to be

Θ = 1.077 for temperature range 10°C to 20°C

and Θ = 1.048 for temperature range 20°C to 30°C

However, Antonie reported that:

"The Bio-Disc process is unaffected by waste water temperature above 55°F. For waste water temperature below 55°F, the treatment efficiency of the Bio-Disc decreases just as it does for all biological waste water treatment processes."

From the above values presented by this investigation and the other research workers, it is clear that for the carbonaceous stage the coefficient of temperature θ increases with rise in temperature but with a decreasing rate of increase.

4.8.3 Effect of Temperature on Nitrification

Nitrification results from the oxidation of ammonia by nitrosomonas to nitrite and subsequent oxidation of nitrite to nitrate by nitrobacter. Under suitable conditions favouring the development of nitrifying bacteria the bacteria increases in number and further oxidation of ammonia occurs. Reduction in number of nitrifying bacteria is most likely to occur when the retention period is low, dissolved oxygen concentration is little and the carbonaceous B.O.D. is high.

The effect of temperature on nitrification has been reported by many writers. Hary Wild[36] reported that the temperature affects the rate of nitrification and that the rate increases through the range 5°C to 30°C in reasonable agreement with van't Hoff-Arhenius Law

In this investigation the rate of nitrification is represented by the long graph (N). In all the period of operation the total oxidized nitrogen was observed to increase rapidly between the temperature range of 11°C to 18°C, while it decreases slowly between the temperature range of 18°C to 27°C. Excess nitrite was formed at the higher temperature of 27°C

Table 13 shows the degree of nitrification evolved under different conditions of operation.

TABLE 13 : VARIATION OF TOTAL OXIDIZED NITROGEN WITH TEMPERATURE

Operational Conditions			R.D.$_7$ 11°C			R.D.$_4$ 18°C			R.D.$_5$ 27°C		
Disc Sub.	Disc Speed	R.T. minutes	NO_2-N	NO_3-N	T.O.N.	NO_2-N	NO_3-N	T.O.N.	NO_2-N	NO_3-N	T.O.N.
25.7%	4 rev/ min	180	1.1	12.3	13.4	2.15	21.15	23.3	4.3	15.0	19.3
25.7%	4 rev/ min.	132	1.2	9.1	10.3	0.8	15.5	16.3	0.95	14.55	15.5
37.8%	4 rev/ min.	180	2.82	4.43	7.25	1.5	14.3	15.8	12.6	NIL	12.6
20%	4 rev/ min.	180	1.1	8.0	9.1	1.1	17.6	18.7	2.8	14.2	17.0

Under the operating conditions stated on the table, a temperature increase from 11°C to 18°C resulted in an increase of total oxidized nitrogen in mg/L

from 13.4 to 23.3 and

from 10.3 to 16.3 and

from 7.2 to 15.8 and

from 9.1 to 18.7

or an average increase of 8.5 mg/ℓ of the total oxidized nitrogen. A temperature increase from 18°C to 27°C resulted in a drop of total oxidized nitrogen in mg/L.

from 23.3 to 19.3 and

from 16.3 to 15.5 and

from 15.8 to 12.6 and

from 18.7 to 17.0

or an average drop of 2.4 mg/ℓ of total oxidized nitrogen accomplished under the operational conditions shown on the table.

This indicates that there is an optimum temperature at which a maximum degree of nitrification is expected. Unfortunately, with the three temperatures used in this investigation, it is difficult to predict this optimum temperature. The results show that the rate of nitrification increases rapidly from 11°C to 18°C while the drop in nitrification rate from 18°C to 27°C is very small. The results of this investigation may agree with Zanoni's[39] report about the effect of temperature on nitrification rate. Zanoni reported that the optimum temperature for nitrification is at 22°C and that the relationship between the rate constant k and the temperature for the nitrogen range is represented by two equations.

1. $K_T = K_{20} (1.92)^{T-20}$ temperature range 10°C to 22°C

2. $K_T = K_{20} (1.203) (0.877)^{T-22}$ temperature range 22°C to 30°C

However, Jenkins[22] reported that the rate of nitrification increases with the increase in temperature and that bacteria will only oxidize ammonia above a certain critical temperature, provided that the dissolved oxygen concentration remains above the critical minimum value of that required for nitrification, while Borchardt[11] reported that the temperature had little effect on nitrification in the range of 15°C to 30°C

4.8.4 Formation of Excess Nitrite at Worm Unit

The results illustrated by the long graph (N) indicate that an excess formation of nitrite occurs in the case of R.D.T.U.$_5$ (27°C). These high concentrations of nitrite in samples taken from the worm unit R.D.T.U.$_5$ are relatively uncommon because the oxygen requirements for the oxidation of nitrite is much less than that for the oxidation of ammonia.

This excess formation of nitrite in R.D.T.U.$_5$ indicates that at this temperature the nitrosomonas may predominate while the nitrobacter multiply at a slow rate. Dr. Southgate[31] reported that the growth constant k increases with temperature up to 30°C in a rate 9.5% per °C for nitrosomonas and 5.9% per °C for nitrobacter.

If the combined effects of temperature on the unit efficiency (in removing organic pollutants) in terms of carbonaceous B.O.D. and nitrogenous B.O.D. is to be considered, there is a significant increase of efficiency for the temperature range of 11°C to 18°C and there is a little increase in efficiency for the temperature range of 18°C to 27°C .

4.9 SOME SLUDGE CHARACTERISTICS

Sludge is a major by-product of domestic and industrial waste water treatment. Its disposal is a problem comparable in importance and magnitude to the liquid waste water treatment problem.

4.9.1 Sludge Production

The determination of the sludge production rate is essential for the design of sludge handling facilities and disposal systems.

In any biological process, volatile solids are produced when soluble organic substrates(B.O.D., C.O.D. etc.) are assimilated by micro-organisms. These volatile solids are a measure of the micro-organisms produced by the process. Micro-organisms can continuously remove organic matter from liquid wastes. Since a definite quantity of organic matter is required to form the energy necessary for synthesis, a relationship should exist between the organic matter utilized, the cell synthesized (biological mass) together with the oxygen consumed. As well as micro-organism production, there is also some destruction of the micro-organisms. This destruction is known as the endogenous respiration or auto-oxidation. The net solids production is therefore the difference between the volatile solids produced and the volatile solids destroyed.

Kormanik[24] formulated the following material balance for the substrate and cell material.

$$\Delta X_{\nu} = aS_r - bX_m \qquad \text{———————} \qquad 1.$$

where

S_r	=	soluble B.O.D. removed by the biological process lb/day
a	=	rate of solid production $\frac{\text{lb of V.S.S. produced}}{\text{lb of B.O.D.}_5 \text{ removed}}$
b	=	endogenous respiration rate, day^{-1}
X_m	=	mixed liquor volatile suspended solids M.L.S.S.
ΔX_{ν}	=	net secondary volatile solids produced lb/day.

Eckenfelder gave a slight modification for equation (1) when volatile suspended solids are present in the influent waste.

$$\Delta X_{v} = (f + aS_{r}) - bX_{m} \qquad \text{———} \qquad 2.$$

where f, the coefficient fraction, is that fraction of the volatile suspended solids (in lb/day) present in influent waste which are not bio-degradable during the aeration process.

It must be noted that the solids production is only associated with the soluble B.O.D. B.O.D. measurements on filtered effluents give the soluble B.O.D. of the organic matter remaining in the effluents after the treatment.

The use of V.S.S. as a measure of cell concentration also has some limitations. Since it is a mass measurement it includes both live organisms and dead cells. Thus the measurement of V.S.S. takes no account of the activity of the micro-organisms and it is possible to have identical weight with widely different activities (Jenkins, D. and Garrison)[221]. A V.S.S. measurement will include also organic matter stored in the cell or absorbed on the surface of the sludge. When a V.S.S. measurement is made on a cell containing a large amount of adsorbed organic matter, an erroneously high estimate of cell material will be obtained.

However, McKinney presented the equation below to include the measurement of the increase in active mass plus the decrease in active mass due to endogenous metabolism.

$$\Delta M_{a} = \frac{F}{2.13} - \frac{0.0129}{2.13} M_{a} \cdot t \qquad \text{———} \qquad 3.$$

where F = organic matter removed in mg/L in terms of B.O.D.

M_a = active microbial mass mg/L in terms of V.S.S.

t = time in hours.

In this investigation an effort was made to evaluate approximately the coefficient a, the rate of solid production. Two factors were measured:

1. Solid Production

   Daily sludge production was calculated as solids removed from reaction vessel (g) + solids in effluent (g) minus solids in substrate (g) i.e. solids produced (g/day) = Total solids removed from the reaction vessel (g/day) - (influent S.S. - effluent S.S.) (g/day).

2. Total B.O.D. removed

   The total B.O.D. removed (g/day) was calculated by subtracting the effluent (unfortunately, not filtered) B.O.D. (g/day) from the influent B.O.D. (g/day) or

   Total B.O.D. removed (g/day) = influent B.O.D. (g/day) - effluent B.O.D. (g/day).

   Diving the solid produced (g/day) by the B.O.D. removed (g/day) yielded an approximate value for the sludge production rate, a

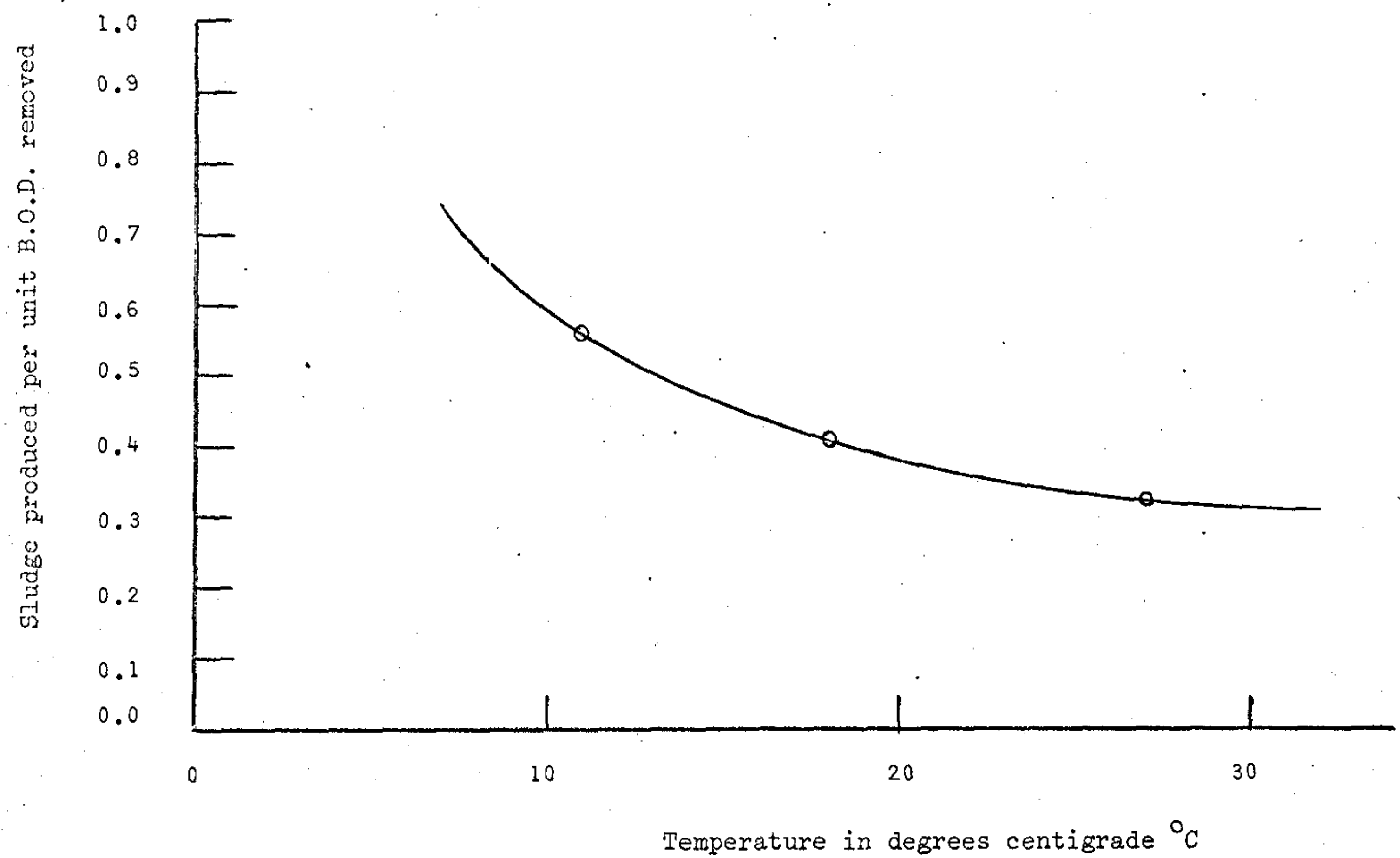
   $$\frac{\text{gram solid produced}}{\text{gram B.O.D. removed}}$$

The measurement of the volatile solids were approximated by the measurement of the solids (normal solids are 80% volatile).

The results obtained were meaningful, because besides the values of the rate of sludge production obtained, the significant effect of temperature on sludge production rates was observed.

Graph 30 shows the sludge production rate for the three units under the specified temperature of operation. The sludge production rate appears to be in the range of 0.3 to 0.6 kg. of solids produced per kg. of B.O.D. removed, for the temperature range used in the investigation. Hartmann reported that the sludge production for the rotating discs process is greater than the other biological processes.

GRAPH NO. 30 : VARIATION OF SLUDGE PRODUCTION RATE WITH TEMPERATURE



Jenkins and Garrison found the sludge production rate for an activated sludge to be 0.33 kg. of solids produced per kg. of C.O.D. removed. However, Kormanik reported that "Depending on the type of waste and the type of biological process employed, the overall ratio has a value of 0.3 to 0.6 kg. of V.S.S. produced per kg. of soluble B.O.D. removed."

In order to get accurate results for the sludge production rate that can be relied upon, a close examination should be carried out.

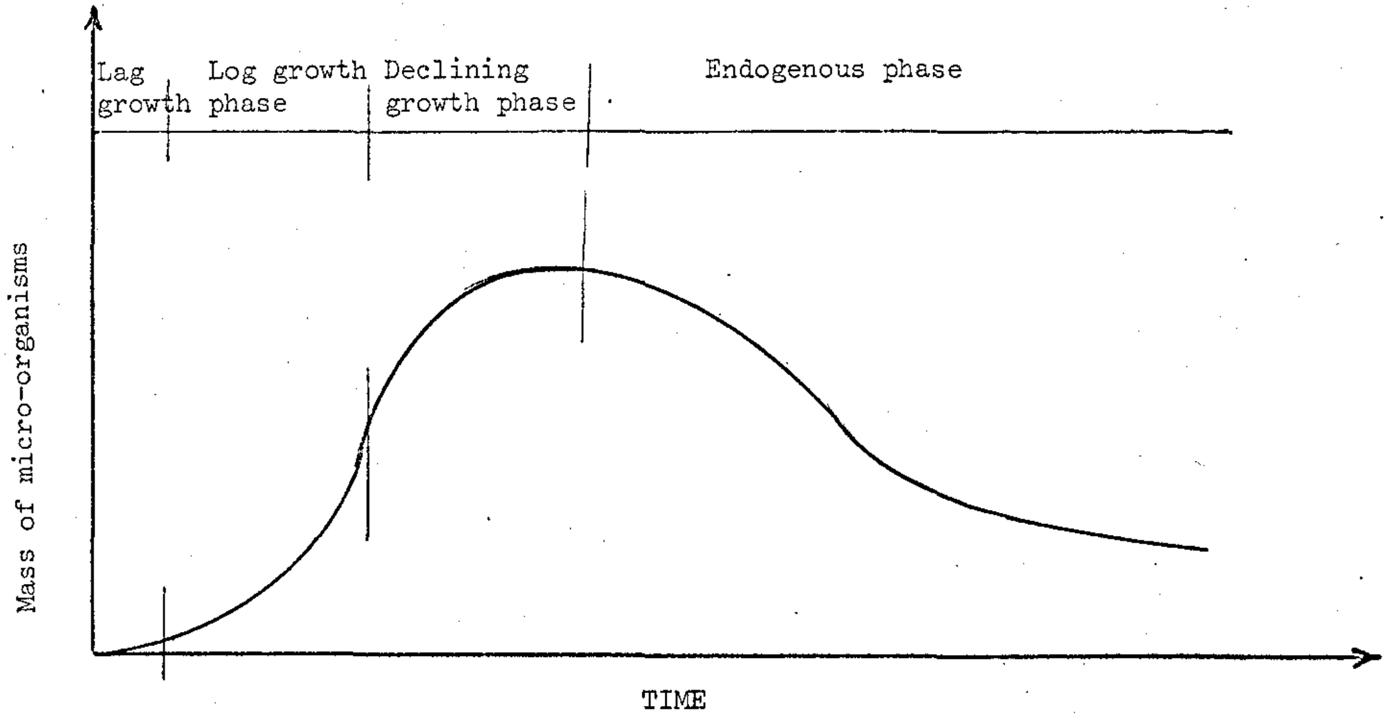
The results revealed by the graph indicate that a significant variation of sludge production appears to occur with temperature. The sludge production rate appears to be much higher under low temperatures of operation. This may be due to the following reason:-

At low temperatures the degree of treatment decreases and the effluent may be high in unstabilized organic matter which suggests that the treatment system at this stage has a relatively high food:micro-organisms ratio. With high F:M ratios the system may not reach the endogenous phase and hence little loss of microbial mass is expected.. The system at this stage will be expected to operate between the log growth and the declining growth phases (refer to Fig. 10).

On the other hand, the operation at higher temperatures increases the degree of treatment and hence the effluent may contain low concentrations of organic matter. With low F:M ratios the system may reach the endogenous phase, where the concentration of organic matter becomes a limiting factor for the growth of new cells. The growth at this stage may be exceeded by the rate of cellular degradation and eventually a decrease in microbial mass occurs.

The sludge production rate was observed, by other research workers in this area, to vary with temperature.

FIGURE 10 : VARIATION OF MASS OF MICRO-ORGANISMS WITH TREATMENT TIME



The U.S. Environmental Protection Agency[34] reported that the sludge production is much higher when waste water was treated below $10^{o}C$. Karl Wuhrmann[38] reported that the sludge production rate in terms of organic carbon is consistently decreased with increasing temperature.

4.9.2 Sludge Settleability

The sludge produced by the R.D.T. system has quite good settling characteristics. If the sludge is left to settle by gravity the sludge will be thickened to concentrations of 3.0 to 3.5% as solids.

4.9.3 Sludge De-watering Characteristics

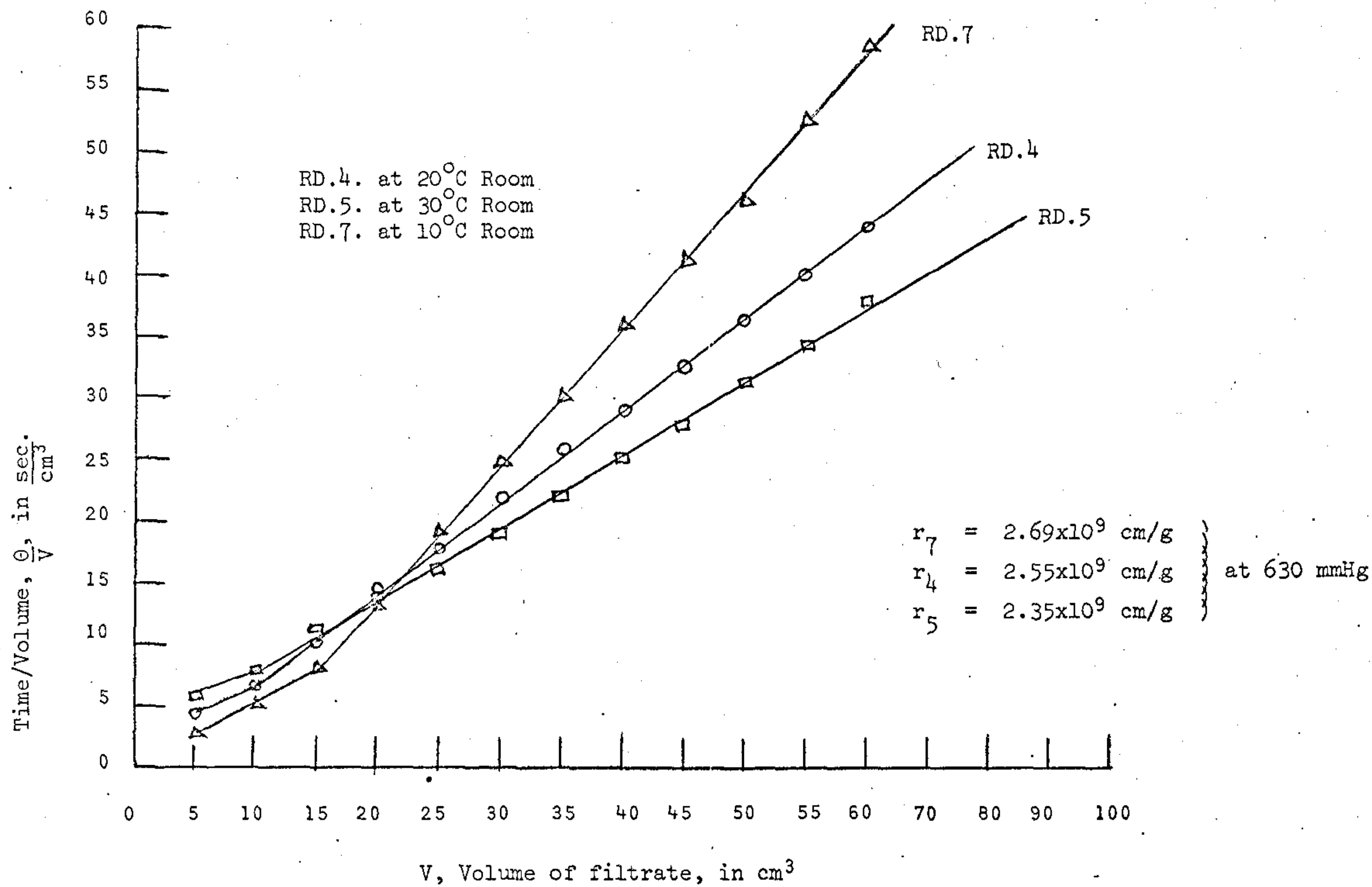
One of the most commonly used methods for determining the filterability of sewage sludge is to filter the sludge through a filter paper using a Buchner funnel and measure either the time to obtain a given volume of filtrate or the time until the cake residue begins to crack, the shorter the time is, the better is the filterability of the sludge. Now the parameter known as the specific resistance to filtration is widely used to characterize the de-watering properties of sewage sludges.

In this investigation the specific resistance was calculated for the sludge of the three units using the known formula.

$$r = \left(\frac{2B}{\eta C}\right) . P$$

where P is the filtration pressure, C is the mass of dry suspended solids deposited on filter cake per unit volume of filtrate obtained.
B is the slope of plot $\frac{\theta}{\nu}$ against ν where ν is the volume of filtrate obtained from unit area of filter surface. η is the viscosity of water.

GRAPH NO. 31 : TIME/VOLUME V VOLUME OF FILTRATE ($\frac{\Theta}{V}$ AGAINST V)



Graph 31 shows the plot Θ/ν against ν .

The specific resistance was then calculated for the three units under the filtration pressure P of 63 cm. Hg. was as follows:-

R.D.T.U.$_7$	-	11°C	r_7	=	2.69×10^9	cm/g.
R.D.T.U.$_4$	=	18°C	r_4	=	2.55×10^9	cm/g.
R.D.T.U.$_5$	=	27°C	r_5	=	2.35×10^9	cm/g.

The results show no practical difference of specific resistance with temperature.

The value of the specific resistance of the R.D.T. process indicates that the de-watering of the secondary sludge generated by this system can be accomplished by vacuum filtration.

4.10 RECIRCULATION

The recirculation system adopted in this investigation was the return of the effluent coming from the R.D.T. unit outlet to the inlet of the same unit.

The effect of recirculation is quite pronounced in percolating filters. Recirculation of the effluent serves to increase the efficiency of the filter. The factors favouring increased treatment by recirculation include:-

1. Recirculation dilutes strong sewage and supplements weak sewage. This helps to maintain the filter in good condition during periods of fluctuation in loading.
2. Recirculation serves to reduce the thickness of growth of film, by producing a better flushing action for the removal of loose film. It also promotes more effective contact with the available surface area of the medium and ensures a more uniform distribution of biological activity with depth.
3. The beneficial presence of dissolved oxygen in the recirculate or diluent.
4. The effect of continuous seeding of the bed with aerobic organisms and beneficial enzymes.

Recirculation was not expected to increase the efficiency of the R.D.T. unit much because the major problems occurring in the percolating filter operation, which are partially solved by recirculation, are already solved in the R.D.T. unit process:-

Continuous wetting of the biological growth in the R.D.T. system occurs because of the intimate contact between the waste water and the biological growth held by the discs, occurs as a result of the continuous rotation of the discs.

The clogging which occurs in the percolating filter process is prevented by the sloughing action of the excess biomass from the discs caused by shearing forces developed as the discs rotate.

The recirculation in the R.D.T. unit is not expected to reduce the thickness of the biological growth, because in the R.D.T. system the biological growth is passed through the waste water and not the waste water which is passed over the biological growth, as in the case of the percolating filter.

The recirculation effect was investigated by operating two R.D.T. units for about nine weeks. One unit was operated with recirculation, the other was operated, as a reference, without recirculation. Both the unit with recirculation and the unit without recirculation ($R.D._R$ and $R.D._S$) were operated under identical conditions of operation, i.e. the area of disc submersion, the disc rotational speed and the waste water temperature were the same for both. The rate of flow of the re-cycled effluent was maintained at 100% of settled sewage rate. The concentration of the combined influent to the unit with recirculation was calculated by the formula

$$\frac{La + Le}{2}$$

La = influent concentration, Le = effluent concentration.

The efficiency of each unit was measured by its ability to remove the B.O.D. load applied to it.

Table 14 shows the average results of the $R.D.T.U._R$ and $R.D.T.U._S$ for about nine weeks of operation.

The recirculation of the effluent to the unit was observed to increase slightly the degree of treatment. Below is the increase in efficiency caused by effluent recirculation and measured by B.O.D., C.O.D., S.S., and ammonia nitrogen efficiency, as well as the increase in the amount of oxidized nitrogen formed.

TABLE 14 : EFFECT OF EFFLUENT RECIRCULATION ON UNIT EFFICIENCY

Unit	R.T. in hours	Inf. mg/l	Eff. mg/l	Load put in unit g/day	Load removed g/day	Removal of load in %	Inf. mg/l	Eff. mg/l	Load put in unit g/day	Load removed g/day	Removal of load in %
		B.O.D. Results					C.O.D. Results				
RD.S.	2	277	21	30.4	28	92.4	458	66	53.5	46	85.6
RDR	1	148	19	30.4	28.4	93.5	259	59	53.5	47	87.7
		Ammonia Nitrogen Results					Suspended Solids Results				
RD.S.	2	29.6	19.2	3.250	1.05	35	218	46	23.9	19	79
RDR	1	22.6	15.5	3.250	1.54	47.5	130	42	23.9	19.4	81
		NO_2-N mg/l	NO_3-N mg/l	T.O.N. mg/l							
RD.S.	2	1.2	NIL	1.2							
RDR	1	1.8	0.8	2.6							

These are average results for 9 weeks of operation
RD.S. = Standard Unit or reference unit
RDR = Unit with recirculation

1.1% as B.O.D. removal

2.1% as C.O.D. removal

2.0% as S.S. removal

12.5% as ammonia nitrogen removal

1.4 mg/l as oxidized nitrogen formed.

The increase in efficiency is so little that it can be neglected. It can be concluded that the recirculation of the effluent to the R.D.T. system will not increase the degree of treatment of the process.

SECTION FIVE

DISCUSSIONS III (COMPARISONS)

5.1 COMPARISON TO PREVIOUS ROTATING DISC TREATMENT PROCESS EXPERIENCE

The rotating disc process was developed initially in Europe in the mid 1950's. Further development of the process began in the United States in 1965 and has continued to the present time.

Previous testing of a rotating disc system on municipal waste water has been carried out by Hans Hartmann, who conducted his investigation in Bavaria, and Ronald Antonie, who conducted his investigation at the village of Milwaukee, Wis., U.S.A.

Table 15 is a comparison of Hartmann and Antonie's test units and operating conditions with those for this investigation.

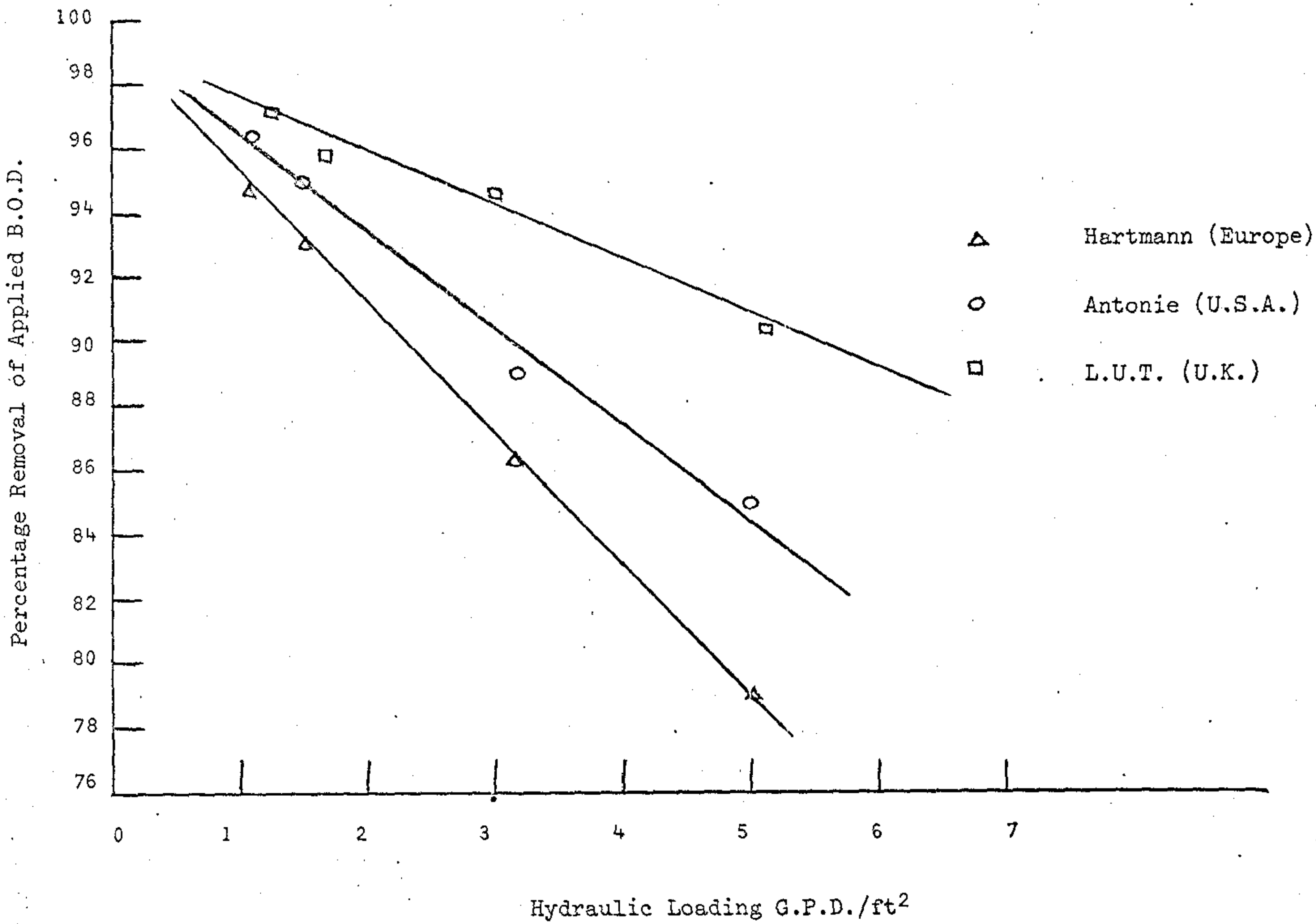
Graph 32 compares the hydraulic loading curve determined from best operational conditions at 25.7% submersion, 4 rev/min., disc speed and $18^{\circ}C$ as waste water temperature, with the results obtained by Hartmann and Antonie. This current investigation yielded a better percentage of B.O.D. removal at all hydraulic loadings tested, even though the organic loading was considerably higher.

The Antonie and the current investigation test units showed better performance at all hydraulic loadings tested, than the Hartmann test unit. This may be because the liquid-holding capacity per unit disc surface area available in the test unit used by Hartmann, was much less than those available in the test units used by Antonie and Loughborough University ($0.12\ gal/ft^2 > 0.115\ gal/ft^2 > 0.085\ gal/ft^2$). Another factor which may contribute to the better performance of the Antonie and the current investigation test units was the larger number of stages of discs.

TABLE 15 : SPECIFICATIONS OF UNITS USED IN PREVIOUS EXPERIENCE

Specifications of Units used for Test	H. Hartmann (Europe)	R.L. Antonie (U.S.A.)	Author (L.U.T., U.K.)
Diameter of disc measured in feet	10	1.92	0.66
Disc spacing centre to centre in feet	0.07	-	0.035
Disc thickness in feet	0.0254	0.031	0.01
Ratio of $\frac{\text{Tank Volume}}{\text{Area of Discs}}$ in Gal/ft^2	0.085	0.12	0.115
Disc material	Expanded Polystyrene	Expanded Polystyrene	Perspex
Some operation conditions:-			
1. Disc speed in rev/min.	-	11	4
2. Area of disc submersion in per cent	≈50	≈50	≈26
3. Average waste water temperature ^{o}C	≈15	≈15	18
4. Average influent (B.O.D.) Concentration mg/l	-	147	240

GRAPH 32 : B.O.D. REMOVAL COMPARED TO PREVIOUS TESTING IN THE UNITED STATES AND EUROPE



The test unit of the current investigation showed a better performance than the Antonie test unit, although both units had nearly the same liquid-holding capacity per unit disc surface area (0.12 gal/ft^2 and 0.115 gal/ft^2) and both units received uniform rates of substrate supply. Also, the organic loading applied to the test unit in this investigation was considerably higher than in Antonie's investigation. The only difference between the two units was that the Antonie test unit is bigger in size. (The disc used by Antonie is 1.92 ft. dia. and that of Loughborough University is 0.66 ft. dia.)

The reason why the test unit of the current investigation achieved higher efficiency than the Antonie test unit can be attributed to the following factors:-

a). The design of the current investigation test unit has two advantages over that of the Antonie test unit.

(1) The provision of gradually increasing compartments volume was an advantage because most of the work was still carried out in the first two compartments.

(2) The design of the current investigation test unit included a rotating screw (Archimedian-Type). The secondary sludge produced was removed frequently by this rotating screw and hence the aerobic conditions inside the reaction vessel can be maintained.

b). The investigation conducted by Antonie did not include the performance of the R.D.T. unit with respect to different degrees of disc submersion. The results presented by the current investigation showed that the R.D.T. unit is greatly affected by the percentage area of disc submerged.

It is believed that the major factor contributing to the higher performance of the test unit used in the current investigation, is due to the operation of this unit under a lower percentage area of disc submerged, such as 26%.

5.2 THE COMPARISON OF THE R.D.T. PROCESS WITH THE PERCOLATING FILTER AND THE ACTIVATED SLUDGE PROCESSES

A complete comparison of the R.D.T. process with the other conventional biological processes such as the activated sludge and the percolating filter, should include the capital and running costs, but since this is beyond the scope of this investigation, the comparison will be confined to the operational characteristics of this process.

5.2.1 Comparison of the R.D.T. Process with the Percolating Filter Process.

Both the R.D.T. process and the percolating filter process are fixed film biological reactors. The growth in both units is supported by solid surfaces, the discs in the R.D.T. unit and the medium in the percolating filter.

The difference between the two biological processes is that the microbial mass in the R.D.T. system is passed through the waste water, while in the percolating filter the waste water is passed over the microbial mass.

A factor contributing to the advantage of the R.D.T. process is that the rotating discs provide an intimate contact between the biological slime and the waste water. The rotating discs also increase the degree of mixing, agitation and turbulence in the reaction vessel and in doing so, the organic pollutants in the waste water will stand better chances of diffusing into the biological film.

The clogging that occurs in the percolating filter system is prevented with the R.D.T. unit by the sloughing action of the excess biomass from the discs caused by the shearing forces developed as the discs rotate.

The dissolved oxygen content of the waste water is increased by the rotating discs in the R.D.T. unit. This may prevent the development of anaerobic conditions.

Both the percolating filter and the R.D.T. systems are simple to maintain and have a relatively low running cost. Although the percolating filter set-up may not require power under some situations, it requires a substantial hydraulic head. On the other hand, the R.D.T. process requires little power.

Ronald Antonie and Karen Van Aacken, C., reported that there were no nuisances, no objectionable odors and no flies present while they were operating a Bio-Disc plant at the village of Millwaukee, Wis., U.S.A. James Simpson also reported from his prototype unit that odours had not been detected and there had been no fly nuisance.

This is because the development of flies, which are often associated with the percolating filter operation, is prevented in the R.D.T. unit operation by the continuous wetting of their biological growth.

The Water Pollution Research Laboratory[35] at Stevenage reported the following:-

"As with the Bio-Disc plant, it would appear that a settled sewage B.O.D. loading of about 5-6 g/m^2 surface of medium is suitable for fairly complete purification. For comparison, the appropriate B.O.D. loading on a low-rate single pass percolating filter containing a medium of 50 mm nominal size would only be 1-2 g/m^2."

However, in this investigation the R.D.T. unit demonstrated that a settled sewage B.O.D. loading of more than 15 g/m^2 could be accepted. This indicates that the area required by a percolating filter to purify the same amount of settled sewage is much greater. This investigation may agree with Jack Borchardt who reported that the actual area occupied by the Bio-Disc unit was about 1/10 of that required by a percolating filter.

As stated earlier, it is unnecessary to recycle the effluent to achieve maximum wetting and flushing action. The necessity for recirculation increases the capital cost and the running costs of a percolating filter plant in comparison to an R.D.T. unit.

5.2.2. Comparison of the R.D.T. Process with the Activated Sludge Process

The Rotating D.T. process is somewhat similar to the activated sludge process in that it has a suspended culture of biomass in its mixed liquor and both processes possess aeration devices. However, the part of the biomass that is in suspension in the mixed liquor is too small to compare with the total amount of the biological growth supported by the surfaces of the discs and would therefore contribute only marginally to the treatment.

The R.D.T. process retains a large fixed biological film and a great micro-organism population and because of this, the R.D.T. process is less upset by the variation in hydraulic loading than the activated sludge process.

The R.D.T. process requires little maintenance and minimal operator attention when compared with the activated sludge process, which requires careful supervision. This is because of the mechanical simplicity of the R.D.T. unit.

The power requirements for the R.D.T. system are considerably less than an activated sludge system, because power is required only to rotate the discs. Also, there is no need to recycle the solids in the R.D.T. system as is necessary in the activated sludge system. Consequently, piping, pumping and operational requirements are minimized in the R.D.T. system when compared with the activated sludge system.

Ainsworth[1] reported that a settled sewage B.O.D. loading of about (0.48 - 1.28) kg/m^3 of tank capacity is suitable for fairly good purification by an activated sludge process. For comparison, the appropriate B.O.D. loading, on an R.D.T. unit used in this investigation, would be more than 3 kg/m^3 of tank capacity. This indicates that the treatment capabilities of the R.D.T. process are much greater than those of the activated sludge process.

It was stated earlier that the de-watering of the secondary sludge generated by the R.D.T. unit can be accomplished by vacuum filtration. Quirk[27] reported that waste water sludge solids from an activated sludge process were not amenable to de-watering by vacuum filters.

The only disadvantage to the R.D.T. process is the need for covering the unit to protect the biological growth from freezing temperatures and to protect the discs from wind damage.

SECTION SIX

CONCLUSIONS AND RECOMMENDATIONS

1. The R.D. method of waste water treatment achieves a high level of organic removal. More than 90% of the applied B.O.D. is removed in the short retention time of only one hour.

2. The actual area needed by the R.D.T. unit is moderately small. This is because of the large surface of the discs rotating in the vertical plane, which creates a large reaction surface per unit area of plant. Also, the entire film surface is effectively utilized.

3. The rotating discs provide an intimate contact between the waste water and the biological growth. They increase the degree of mixing and agitation in the reaction vessel and control the aeration rate to a satisfactory degree.

4. The R.D.T. system requires a very short time to mature. After only two weeks operation a quite good effluent can be achieved.

5. The discs hold a high concentration of microbiological growth and there is a rapid growth in the first two or three stages. The cleaning of the discs of those stages is important so that the microbial mass does not go anaerobic.

6. The R.D.T. process is time dependent. For the domestic sewage used and under the range of 1-4 hours retention time, the carbonaceous B.O.D. kinetics appear to be first order.

7. The R.D.T. system is greatly affected by the disc submersion. The optimum percentage area of disc submersion was found to be 26%

8. The optimum disc rotational speed was found to be in the range of 1-5 rev/min.

9. The R.D.T. process, like the other biological processes, is affected by temperature. The carbonaceous B.O.D. removal was increased with increase in temperature. The oxidized nitrogen increased considerably with the increase in temperature from 11°C to 18°C, while a further

9. (Contd.) increase in temperature from 18°C to 27°C led to a small decrease in the oxidized nitrogen.

10. In spite of the large biological growth, the R.D.T. unit is less susceptible to clogging than the percolating filter.

11. The operational costs of the R.D.T. unit will be low, as will maintenance costs.

12. Because of the slow rotation speed a separate settling tank is unnecessary.

13. The increase of the R.D.T. unit efficiency was very little when the effluent was recycled to the unit.

14. The B.O.D. removal efficiency during this investigation was discovered to be higher than that achieved by other investigators.

15. During the course of investigation, it was felt that time should be devoted to studying the rest of the parameters, which were not included in this investigation, which affected the performance of the R.D.T. process.

    Additional testing at various disc spacing is required to determine the optimum disc spacing that will maximize the effectiveness of the disc surface area.

16. Close attention should be given to investigating the type, structure and thickness of the biological film. The determination of an optimum thickness of the biomass and the means for its control, are required.

17. All the work in this investigation was carried out under constant flow rates of domestic or synthetic sewages. The treatment capabilities of the R.D.T. unit towards trade effluents, flow variations, shock loads etc., should be explored.

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APPENDIX

Diary

Event	Date
1. Start of $R.D.T.U._4$ in the Preliminary Operation	5.4.1973
2. Start of $R.D.T.U._5$ in the Preliminary Operation	4.5.1973
3. Change of the speed of $R.D.T.U._4$ from 5 to 10 rev/min.	22.5.1973
4. Breakdown of the nylon chain of $R.D.T.U._5$	3.6.1973
5. Start of $R.D.T.U._7$ in the Preliminary Operation	16.6.1973
6. Change of the speed of $R.D.T.U._4$ from 10 to 2 rev/min.	17.6.1973
7. Manufacturing of polythene lids to loosely cover the apparatus.	27.6.1973
8. Second breakdown of the nylon chain of $R.D.T.U._5$	7.7.1973
9. Alteration of the drive mechanism on the apparatus operating at 30°C from chain drive to direct gear arrangement.	9.7.1973
10. Start of the three units operated at 4 rev/min, 50% disc submersion and 4 hours retention time.	13.7.1973
11. $R.D.T.U._4$ reached steady state	2.8.1973
12. $R.D.T.U._5$ reached steady state.	15.8.1973
13. $R.D.T.U._4$ retention time was changed from 4 to 2 hours	17.8.1973
14. $R.D.T.U._7$ reached steady state	24.8.1973
15. $R.D.T.U._5$ retention time was changed from 4 to 2 hours	31.8.1973
16. $R.D.T.U._7$ retention time was changed from 4 to 2.43 hours	1.9.1973
17. Bridging of Biomass across the discs of the first compartment of $R.D.T.U._7$	14.9.1973
18. The three units retention times were changed from 2 to 3 hours.	20.9.1973
19. Changing of the fuses of the peristaltic pump	11.10.1973

Event	Date
20. The outlets of the three units were changed from orifice 5 to orifice 9	12.10.1973
21. R.D.T.U.$_4$ and R.D.U.$_4$ retention times were changed from 3 to 2.2 hours while R.D.T.U.$_7$ retention time was changed from 4 to 3 hours.	22.10.1973
22. The three units outlets were changed from orifice 9 to orifice 1	5.11.1973
23. R.D.T.U.$_4$ and R.D.T.U.$_5$ retention times were changed to 3 hours and R.D.T.U.$_7$ retention time was changed to 4 hours.	15.11.1973
24. The three units outlets were changed from orifice 1 to orifice 7.	29.11.1973
25. Changing the fuses of the peristaltic pump.	29.11.1973
26. Passing of the sewage feed through an electric heater before entering R.D.T.U.$_5$	9.12.1973
27. The three units outlets were changed from orifice 7 to orifice 10.	14.12.1973
28. The units retention time was changed to 2.2 hours	29.12.1973
29. The units retention time was lowered to 97 minutes	22.1.1974
30. Changing the fuses of the peristaltic pump	24.1.1974
31. The units retention time was lowered to 60 minutes	11.2.1974
32. Changing the fuses of the peristaltic pump	11.2.1974
33. Changing the fuses of the peristaltic pump	18.2.1974
34. Servicing the peristaltic pump	18.2.1974
35. The three units were stopped	15.3.1974

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LIST OF ABBREVIATIONS

R.D.T.U.	=	Rotating Disc Treatment Unit
RD_4 , RD_5 , RD_7	=	$R.D.T.U._4$, $R.D.T.U._5$, $R.D.T.U._7$
rev/min.	=	Revolution per Minute
h.	=	Hour
R.T.	=	Retention Time
Sub.	=	Submersion
B.O.D.	=	Biochemical Oxygen Demand
C.O.D.	=	Chemical Oxygen Demand
D.O.	=	Dissolved Oxygen
D.V.	=	Dichromate Value
P.V.	=	Permangate Value
S.S.	=	Suspended Solids
$NH_3 - N$	=	Ammonia Nitrogen
$NO_2 - N$	=	Nitrite Nitrogen
$NO_3 - N$	=	Nitrate Nitrogen
r	=	Specific Resistance
Θ	=	Temperature Coefficient