PART - II

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"HYDRAULIC LOADING AND STABILIZATION OF AHMEDABAD SEWAGE BY PHOTOSYNTHETIC OXYGENATION."

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HYDRAULIC LOADING AND STABILIZATION OF AHMEDABAD SEWAGE BY PHOTOSYNTHETIC OXYGENATION

1. INTRODUCTION

" There is a dearth of general performance information based upon experimental data" relating to oxidation ponds (Oswald 1964). In this system of sewage treatment algae and bacteria are cultured simultaneously, the former utilising the solar energy synthesis fresh organic matter in the form of algal cells from hydrogen liberated from water, carbondioxide from sewage and atmosphere and nutrients from the waste by bacterial action. Oxygen, so badly needed by bacteria for biolysis of decomposing organic matter entering the system, is released from water by algae after absorption of light. Thus natural light energy is used to produce oxygen to stabilise sewage. The two basic types of reactions taking place together in the pond are oxygenation by algal photosynthesis or photosynthetic-reduction and bacterial oxidation.

In addition, Oswald and Gotaas(1957) state that there are two sets of factors operating in oxidation ponds. They are:(a) controllable factors & (b)uncontrollable factors. The former relates to design criteria and are sub-divided into (i) independent variables such as ....

as " size, shape, depth, detention time, surface area, B.O.D. loading, inlet and outlet structures, soil composition, site selection, methods of operation etc., which are subject to engineering control"; and (ii) dependent variables such as " oxygen production, algae produced, energy stored in algae, nutrients in waste, B.O.D. Stabilization, pond condition and effluent stability". The uncontrollable factors are solar radiation, temperature, wind velocity and other climatological characteristics that equally affect the efficiency of the purification process.

For developing criteria for design of the process of controlled photosynthetic oxygenation of sewage, it is necessary to establish relationships between controllable and uncontrollable factors. The two general categories of factors are vitally linked, for, the basic consideration in the design of oxidation ponds is the organic loading based on surface area with controlled depth, which is strongly influenced by the climatic conditions especially solar radiation and temperature of the locality or latitude and elevation in which the lagoon is situated. The possibilities of oxygenation of sewage by algal photosynthesis have not been adequately investigated although sufficient light energy is normally

Fig 1.

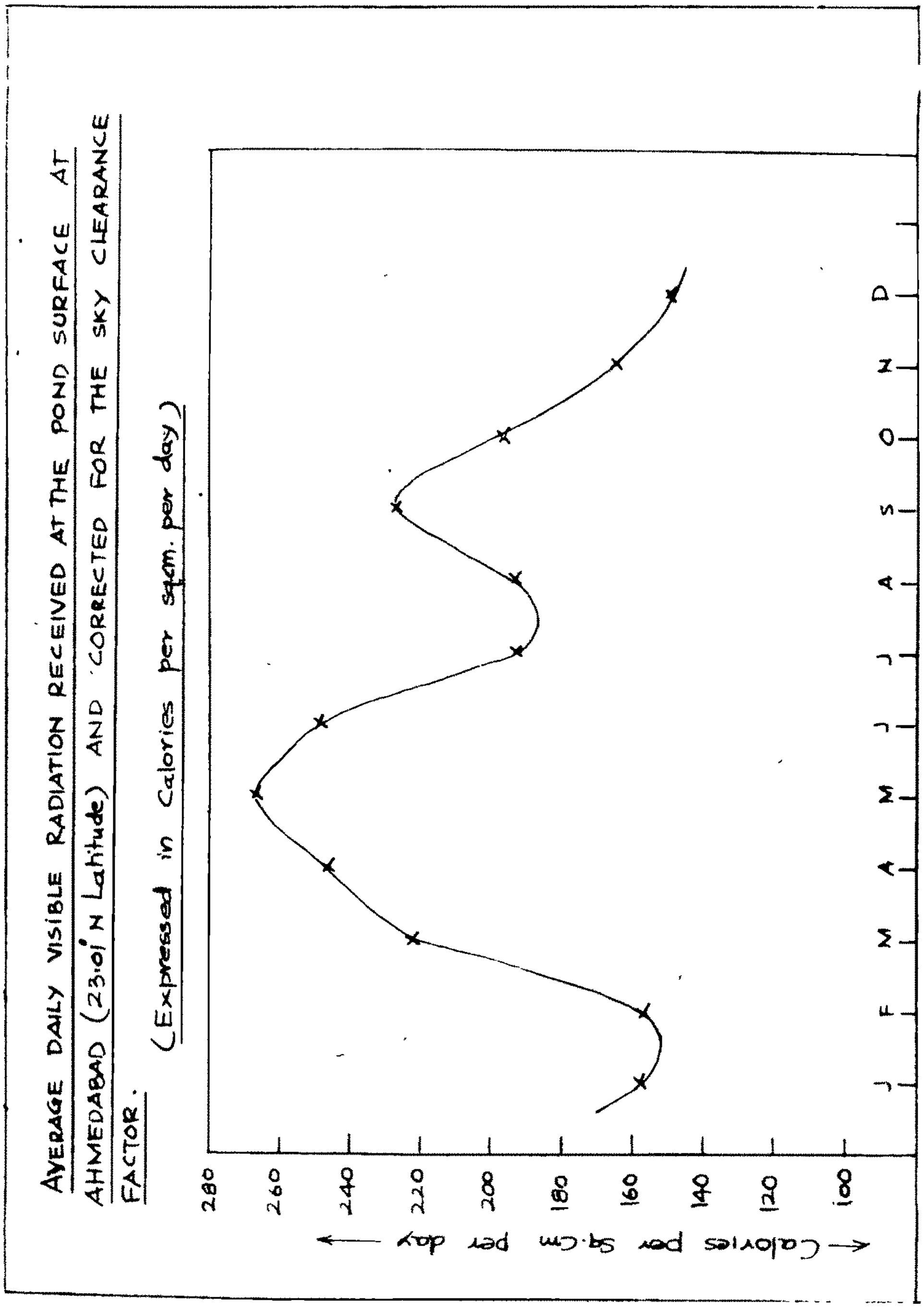

Fig. 38. Graph showing the average visible radiation received at the pond surface at Ahmedabad.

available anywhere in India. An attempt was, therefore, made to develop design criteria and criteria for operation of oxidation ponds trapping the energy of the sun at Ahmedabad through photosynthesis as the principal synthetic force, on the lines followed by Oswald et al (1953,1957), Oswald and Gotaas (1957) and Gotaas and Oswald (1955).

In the first place, Oswald and Gotaas (1957) have published "information concerning the amounts of visible light energy penetrating a smooth water surface at sea-level in relation to latitude and month of the year" from which the values for Ahmedabad have been taken for the north latitude 23.01 and shown in Fig.3B and in Table I (Appendix) for ready reference.

The utilization of this solar energy by the algae present, in the presence of nutrients from sewage, results in the proliferation of new algal cells and the concomitant production of molecular oxygen. A relationship has been established by the Western workers between new algal cell material synthesised and the oxygen released on account of photosynthesis. The ratio of the weight of oxygen released to the weight of algae synthesised has been termed "p" and this value has been reported to vary from 1.25 to 1.75 for algae produced in oxidation ponds. In other words the formation of one unit of chlorophyll containing algal cell material is associated with the production 1.25 to 1.75 units of oxygen. This is termed " photosynthetic oxygen " which is different from the dissolved oxygen estimated by Winkler method. So, if an oxidation pond is producing enough oxygen for satisfying its BOD of, say 350 mg/l, then the concentration (Cc) of algae that is likely to develop in it will be :

$$= \frac{350}{p} = \frac{350}{1.25} = 280 \text{ mg/l}$$

Again, the concentration of algae Cc (in mg/l,) divided by the detention time, say "t" days, will give the quantity of algal cell material in mg/litre/day. Therefore, for a given yield of algae, the amount of photosynthetic oxygen produced can easily be calculated.

Next, the visible portion of sunlight is the energy source of the photosynthetic oxygenation, and therefore, the data on the amount of available light energy together with the data on algal cell growth are used for predicting the quantities of oxygen which may be produced through light energy fixation by algal cells. The amount of energy associated with oxygen liberation by algae is well established. In the case of sewage grown algae like Chlorella, Scenedesmus and other similar organisms, the amount of energy associated with oxygen liberation is stated to be 3.68 calories per milligram of oxygen produced.

Also, the efficiency of light energy conversion by algae grown in sewage under a wide variety of environmental conditions has been studied and it is found that the energy conversion seldom exceeds 10 or 12% of the available light energy. Since the probable values for the amount of available light energy can be predicted and photosynthetic efficiencies may be assumed, the quantity of oxygen that will be produced for a given efficiency may be calculated from the equation:

$$Wo_2(\text{ mg/l/day}) = \frac{F.S.}{3.68} \text{ ; or } 89\left\{\frac{F.S.}{3.68}\right\} = 24.2\ F.S.,$$

where " Wo_2 is the weight of oxygen, S, is the amount of visible solar energy which penetrates a smooth water surface in calories per sq. cm per day; F, is the efficiency of light energy conversion to chemical energy expressed as a decimal; 3.68, is the energy required to produce 1 mg of oxygen through photosynthesis and the factor 89 converts mg per sq. cm. to pounds per acre". So, from the available light energy at a particular locality like Ahmedabad the theoritical quantity of oxygen that is likely to be produced through photosynthesis can be calculated for various efficiencies from

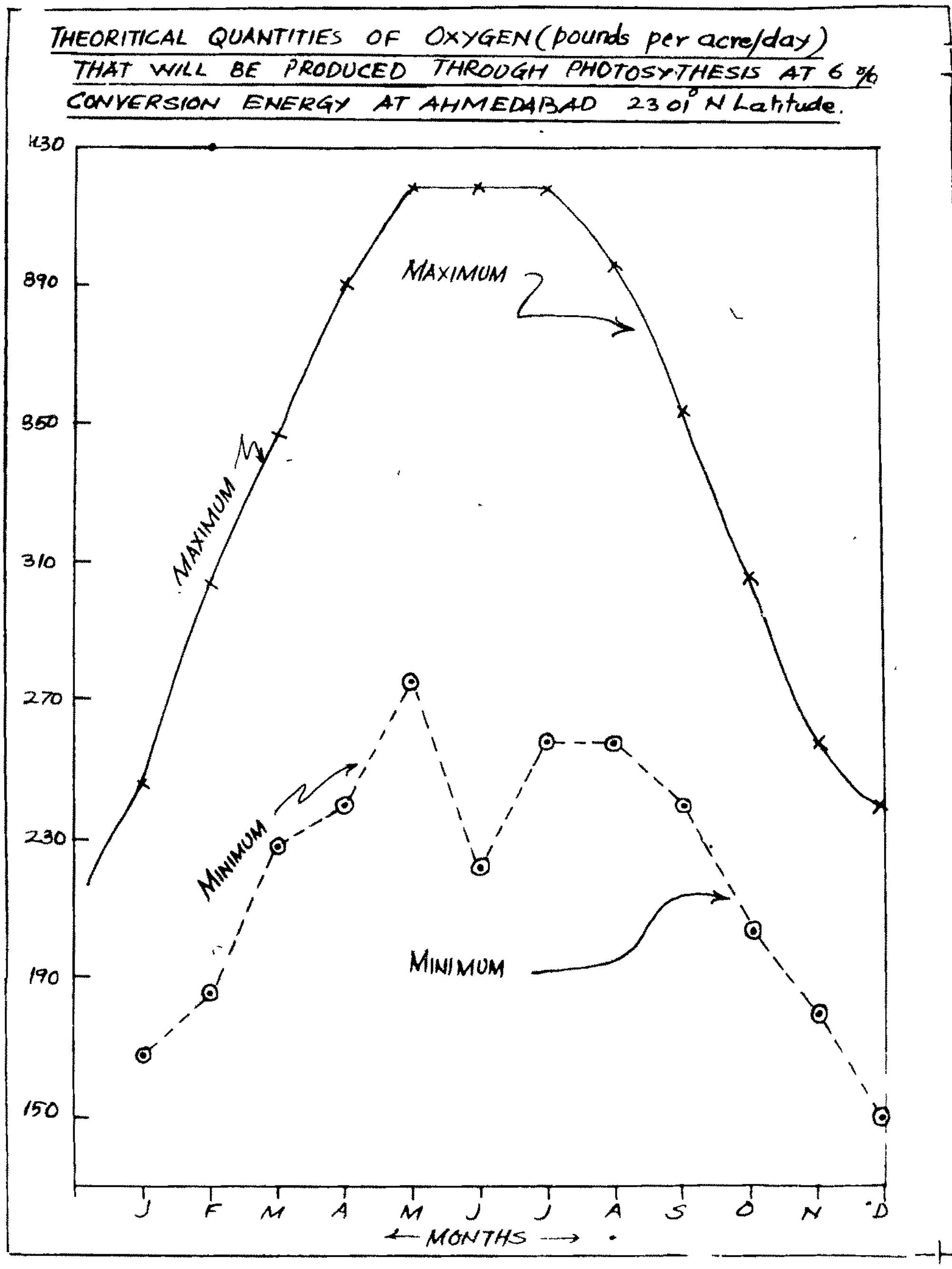

Fig. 39. Graph showing the theoritical quantities of oxygen that will be produced through photosynthesis at 6% conversion energy at Ahmedabad.

1 to 10%. This has been calculated for Ahmedabad and is shown in Table No.II (Appendix)and in Fig.39.

2. <u>Climatic conditions of Ahmedabad during 1962-63</u>.

The climatic conditions of the locality in which a pond is situated plays a very important role in the purification of sewage by photosynthetic oxygenation. The two important climatic factors concerned are temperature and the number of hours of bright sunshine. The range of variations of maximum and minimum temperature and hours of bright sunshine for each of the four seasons of 1962 and 1963 are summarised below from Table No. III (Appendix).

TABLE No. 1

Season & Year	Temperature (^{o}C)		Bright Sunshine (Monthly average)		
	Maximum	Minimum	Maximum	Minimum	Average
<u>Cold Weather:</u>					
1962	27.8-31.5	9.5-14.6	307.8	273.2	290.2
1963	26.3-33.6	12.3-15.1	292.0	273.2	283.9
<u>Hot Weather:</u>					
1962	35.3-42.3	18.3-26.8	339.5	286.0	290.4
1963	31.3-41.2	18.6-27.1	293.4	257.7	281.3
<u>Monsoon Season:</u>					
1962	33.0-33.5	24.0-25.7	215.9	138.7	249.2
1963	30.1-33.0	21.6-25.8	202.1	119.8	157.7
<u>Post-monsoon:</u>					
1962	33.1-34.6	15.9-17.5	304.8	277.5	291.1
1963	32.1-35.6	18.5-21.1	286.2	268.1	277.1

It will be seen from the above that the range of temperature is highest during summer (18.3-42.3°C) and lowest during the cold weather (9.5 to 33.6°C). The range of monthly hours of bright sunshine is highest (257.7-339.5 hours) during the hot weather and lowest (119.8-215.9 hours) during the monsoon season. During the cold weather the range of monthly hours of bright sunshine is comparatively higher than in the monsoon and post-monsoon seasons although the temperature range is comparatively lower. In the post-monsoon season the temperature and the hours of bright sunshine are comparatively higher than the respective minimum ranges. Therefore, it would appear that all the year round favourable conditions for the growth of algae for photosynthetic oxygen production seem to exist at Ahmedabad.

3. PILOT-PLANT EXPERIMENTS

Observations of the experimental pilot plant operations using depths varying between 3 and 4 feet, varying detention periods and organic loadings under the ambient climatic conditions have been made in the Pirana Sewage Farm at Ahmedabad in order to gather data relating to performance attainable for maximum efficiency during the different seasons of 1962-63. The sewage used in these experiments was the mixed sewage from the Jamalpur and new Suburban Pumping Stations. A measured quantity of

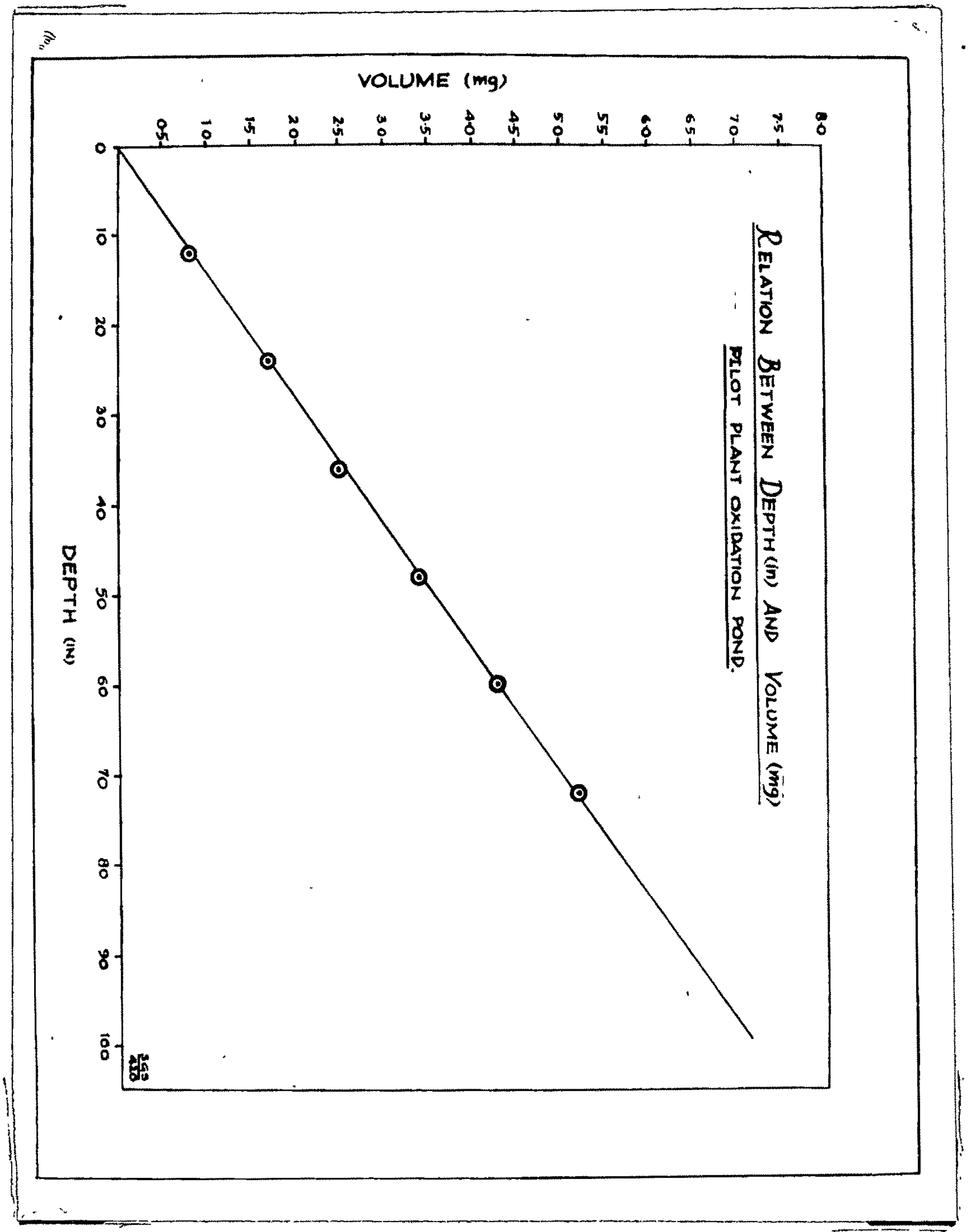

Fig. 40. Graph showing the relation between depth and pond volume in the single cell unit at the Pirana Sewage Farm in Ahmedabad.

sewage, (say ½", 1", 1½", 2", 3" or 4") was allowed to flow over the weir into the single pond (already described in Part II, Paper I), for a definite period during each season. The depth was actually measured everyday at 250', 500', 750' and 1000' length of the pond and the average depth was recorded for each hydraulic loading. The theoritical detention time was later calculated from the volume of sewage in the pond determined from Fig.40, and from the average rate of flow of sewage during the period. Every alternate day either at 11.00 a.m. or 3.00 p.m. grab samples were taken at the inlet, 250', 500', 750' and 1000' for physical, chemical, bacteriological and biological tests. In the absence of a pyrheliometer the the visible light energy per sq. cm. per day received at the pond surface was taken from Oswald & Gotaas' Paper (1957) for the latitude of Ahmedabad and is shown in Table I (Appendix and in Fig.3B.) The size of the algal population, its weight and chlorophyll content were also taken and determined on each occasion. The heat combustion of the harvested algae was assumed at 6000 calories per gram (Gotaas and Oswald 1955). Also, the weight of oxygen produced by algae during photosynthesis has been assumed as 1.64 times the weight of algae synthesised in the pond (Gotaas and Oswald 1955).

4. Analysis of Results: Loadings & Performance.

The results of our observations and analysis for

Fig·1

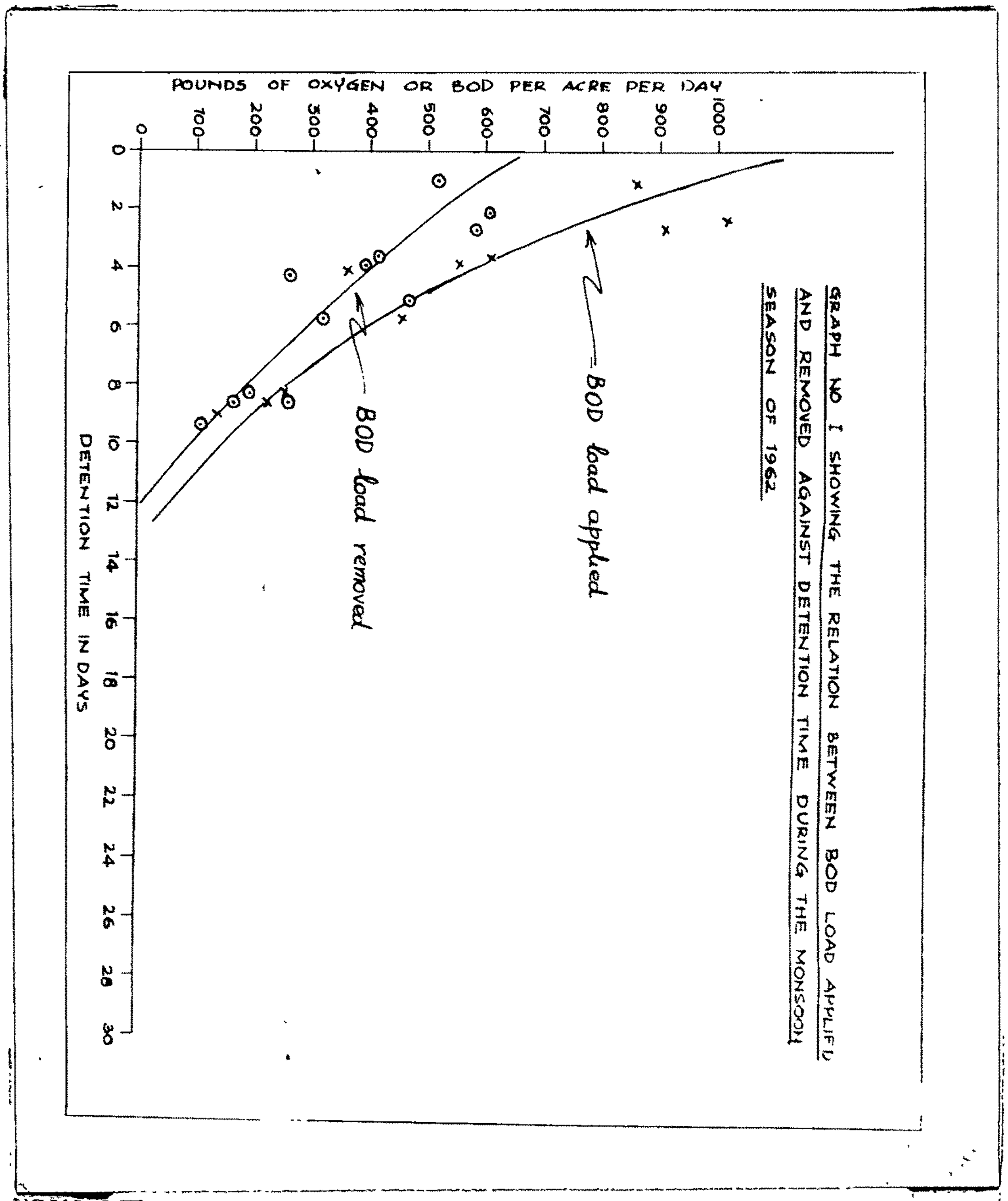

Fig. 41. Graph showing the relation between BOD load applied and removed as against detention time during the monsoon season.

each of the four seasons of 1962-63 with reference to hydraulic loading, depth, detention time, dry weight of algae and the amount of photosynthetic oxygen determined from algal cell weight, are shown in Tables IV, V, VI and VII (Appendix) and the seasonal averages for the hydraulic loading in Table VIII (Appendix). The calculated values for ultimate BOD and reaction velocity constant "K" for the average seasonal temperatures are shown in Table IX (Appendix) and the dominant algae found growing during different seasons of 1962-63 are shown in Paper I, Part II.

(a) BOD load applied and removed

The relation existing between the BOD load applied and the load removed for each of the four seasons of 1962-63 are shown in Tables IV, V, VI and VII (Appendix) and in Figures 41, 42, 43 and 44 from which the following observations are made.

A load beginning from 87 lbs upto 1000 lbs was tried during the monsoon season (Fig.41). A maximum reduction of 91% was obtained when the organic loading was only 87 lbs per acre per day and a minimum reduction of 59% was obtained when the loading was 1016 lbs per acre per day.

During the post-monsoon season (Fig.42) a load beginning from 178 lbs per acre per day upto 605 lbs was

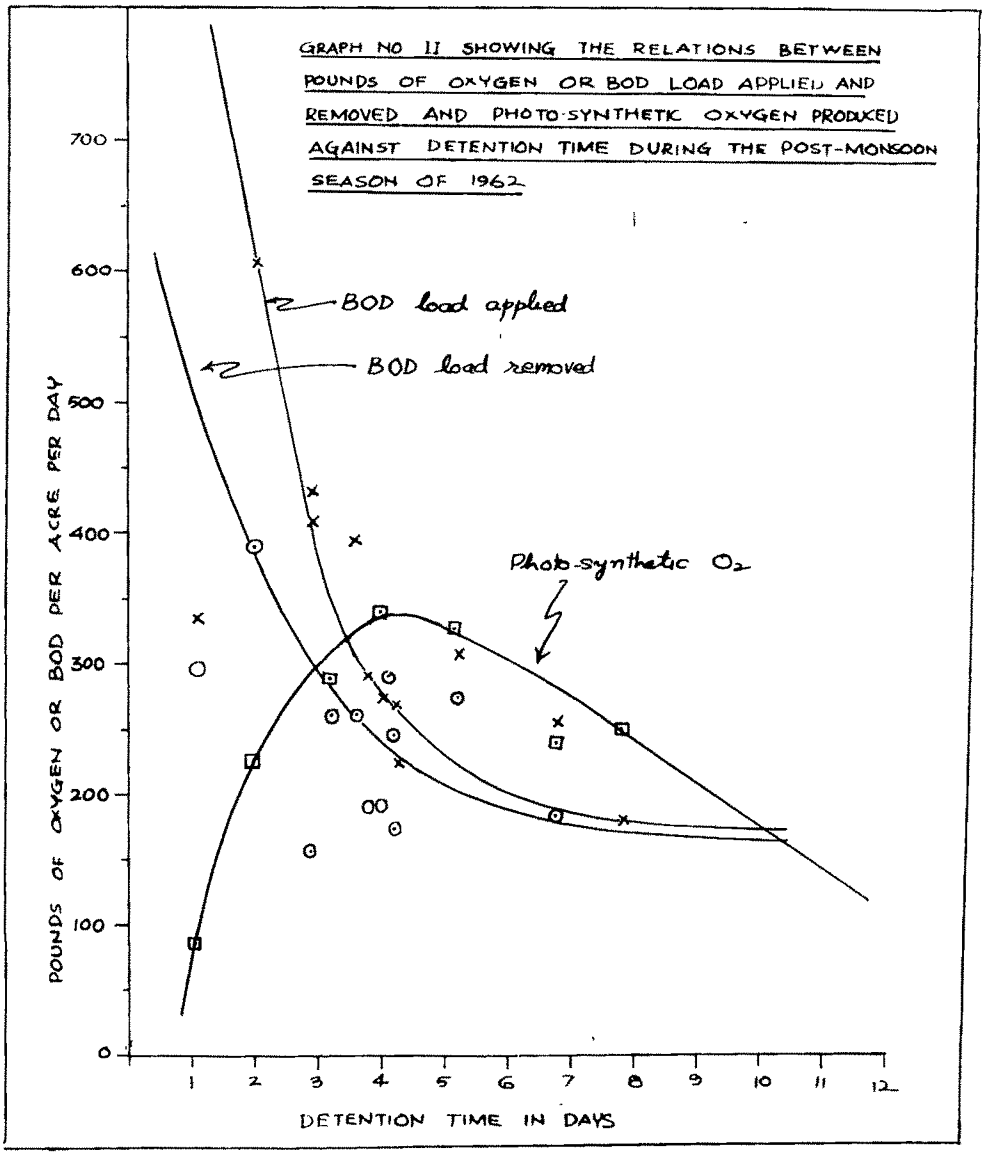

Fig. 42. Graph showing the relation between the pounds of oxygen or BOD load applied and removed and photosynthetic oxygen produced against the detention time during the post-monsoon season.

tried. A maximum reduction of about 88% and a minimum reduction of about 64% were obtained.

During the cold weather period (Fig.43) a load beginning from 75 lbs upto 1200 lbs per acre per day was tried. A maximum reduction of 81% and a minimum reduction of 41% were obtained.

The range of loading was varied between 41 lbs and 590 lbs per acre per day and the reduction obtained was found to vary between 51% and 93% during the hot weather period (Fig.44).

A comparative statement of the organic loading both applied and removed for the four different seasons of 1962-63 as indicated by the Figs 41 to 44 is shown below:

TABLE NO. 2

Load applied in lbs per acre per day	Per centage of BOD removal			
	Monsoon	Post-monsoon	Cold-weather	Hot-weather
100	87.0	95.0	78.0	87.8
150	81.0	95.0	73.5	82.0
200	77.0	82.5	69.5	78.0
250	74.0	74.0	66.5	74.0
300	73.0	71.0	62.5	70.0
350	72.0	68.0	59.0	66.0
400	70.5	65.0	56.0	64.0
450	70.0	64.0	53.5	61.5
500	69.0	63.0	51.5	60.0
550	68.0	62.0	50.0	58.5
600	67.0	61.0	48.5	57.0
650	66.5	60.5	47.0	56.0
700	65.5	60.0	46.0	55.0
800	64.0	59.0	45.0	54.0
Average 429	71.8	68.1	57.6	65.3

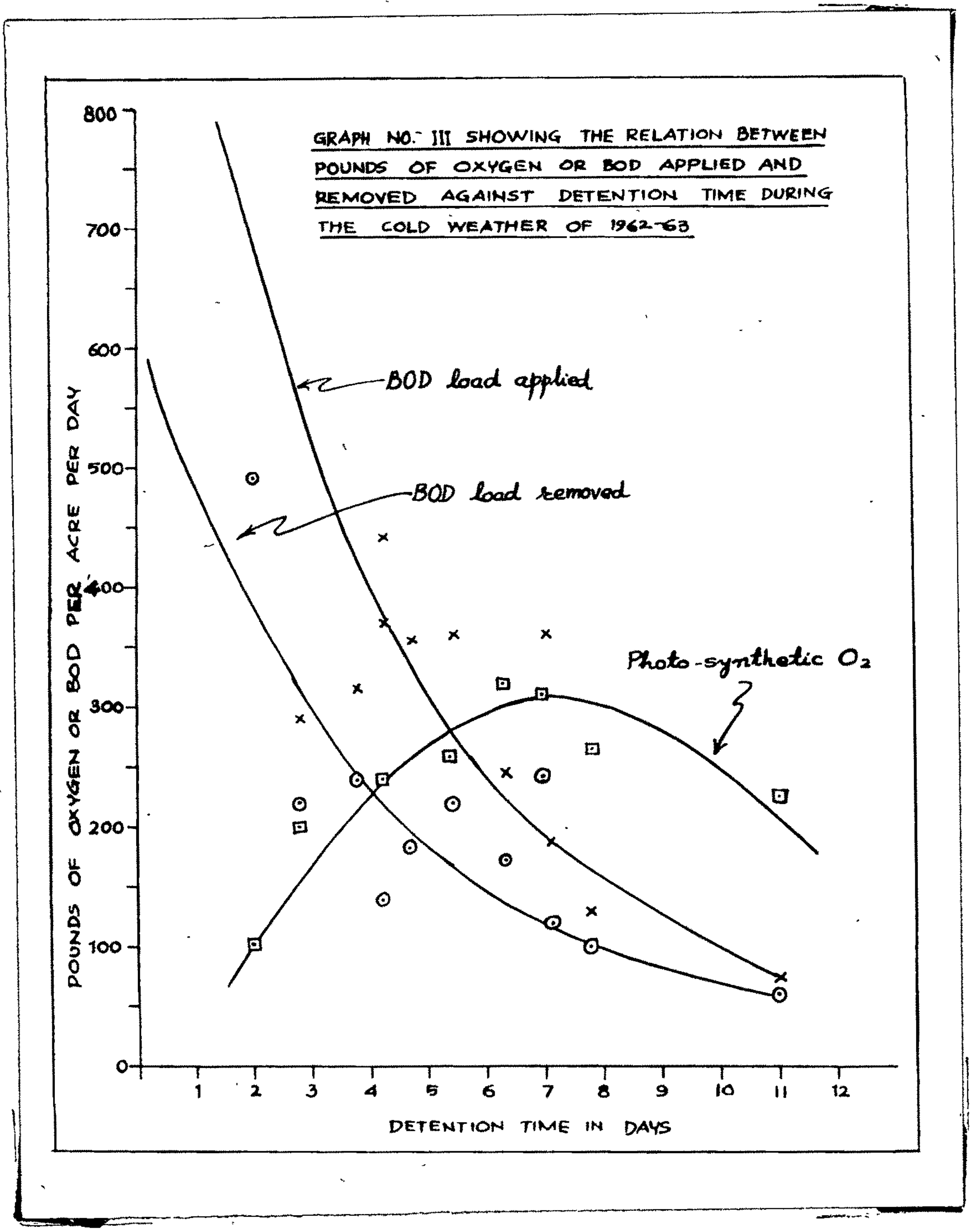

Fig. 43. Graph showing the relation between the pounds of oxygen or BOD load applied and removed as against detention time during the cold weather.

From the above it will be seen that the annual average loading of about 400 lbs BOD per acre per day and an average reduction of about 66% may be reached in Ahmedabad.

(b) Relation between detention period (in days) and BOD loading and BOD removal.

This relationship also is shown in Figures 41, 42, 43 and 44 from which a comparative statement showing the BOD loading applied and removed for the corresponding detention periods from 1 to 11 days is given in the next page in Table No.4.

It will be seen from a study of the table that the optimum conditions are reached as detailed below:

TABLE NO. 3

Season	Detention time (in days)	Applied	Removed	%Removal
		(BOD lbs per acre per day)		
Monsoon	7	330	245	74.2
Post-Monsoon	7	185	180	97.3
Cold Weather	6	240	150	62.5
Hot Weather	6	360	300	83.3

TABLE NO. 4.

Detention time (days)	B. O. D. IN LBS. PER ACRE PER DAY											
	Monsoon-Season			Post-Monsoon			Cold-weather			Hot-weather		
	Applied	Removed	% Removal	Applied	Removed	% Removal	Applied	Removed	%Removal	Applied	Removed	% Removal
1	960	580	60.4	830	540	65.0	840	485	57.8	700	525	75.0
2	820	515	62.8	605	380	62.8	685	380	55.5	620	475	76.6
3	700	460	65.7	375	285	76.0	515	300	58.2	545	425	77.9
4	580	400	70.0	275	235	85.5	395	325	57.0	475	380	80.0
5	490	350	71.4	230	207	90.0	305	180	59.0	415	335	80.7
6	400	290	72.5	202	190	94.0	240	150	62.5	360	300	83.3
7	330	245	74.2.	185	180	97.3	195	120	62.0	315	265	84.1
8	270	190	70.3	185	175	94.5	160	100	62.5	275	235	85.4
9	200	145	72.5	185	175	94.5	130	80	61.5	235	200	85.1
10	150	95	63.3	185	175	94.5	100	70	70.0	200	170	85.0
11	100	50	50.0	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-

(c) Relation between photosynthetic oxygen production, BOD loading and removal and the detention period.

Unfortunately the quantitative determination of algal cell material produced during the the monsoon season was not made but it was done in the other three seasons, which are discussed below:

Post-monsoon season: (Fig. 42) At a detention period of one day, although the BOD removal is at a maximum, it would seem to represent only about 50% of the applied BOD. Therefore, in this short detention period, sedimentation, was perhaps, responsible for the apparent BOD removal. At a detention period of 4 days photosynthetic oxygen production was equal to the BOD loading. With the detention periods of 5 and 6 days, the photosynthetic efficiency attained was above that required. In fact oxygen production exceeded BOD loading. After a detention period of 6 days, the difference between the BOD load applied and BOD removed was nearly constant.

Cold weather period: In Fig. 43 which represents the conditions of existence during this season, it is seen that the maximum photosynthetic oxygen production takes place at a detention period of 7.0 days. In fact the oxygen production at a detention period of 5 days was equal to the BOD loading and thereafter the photosynthetic efficiency attained was above that required. After a detention period,

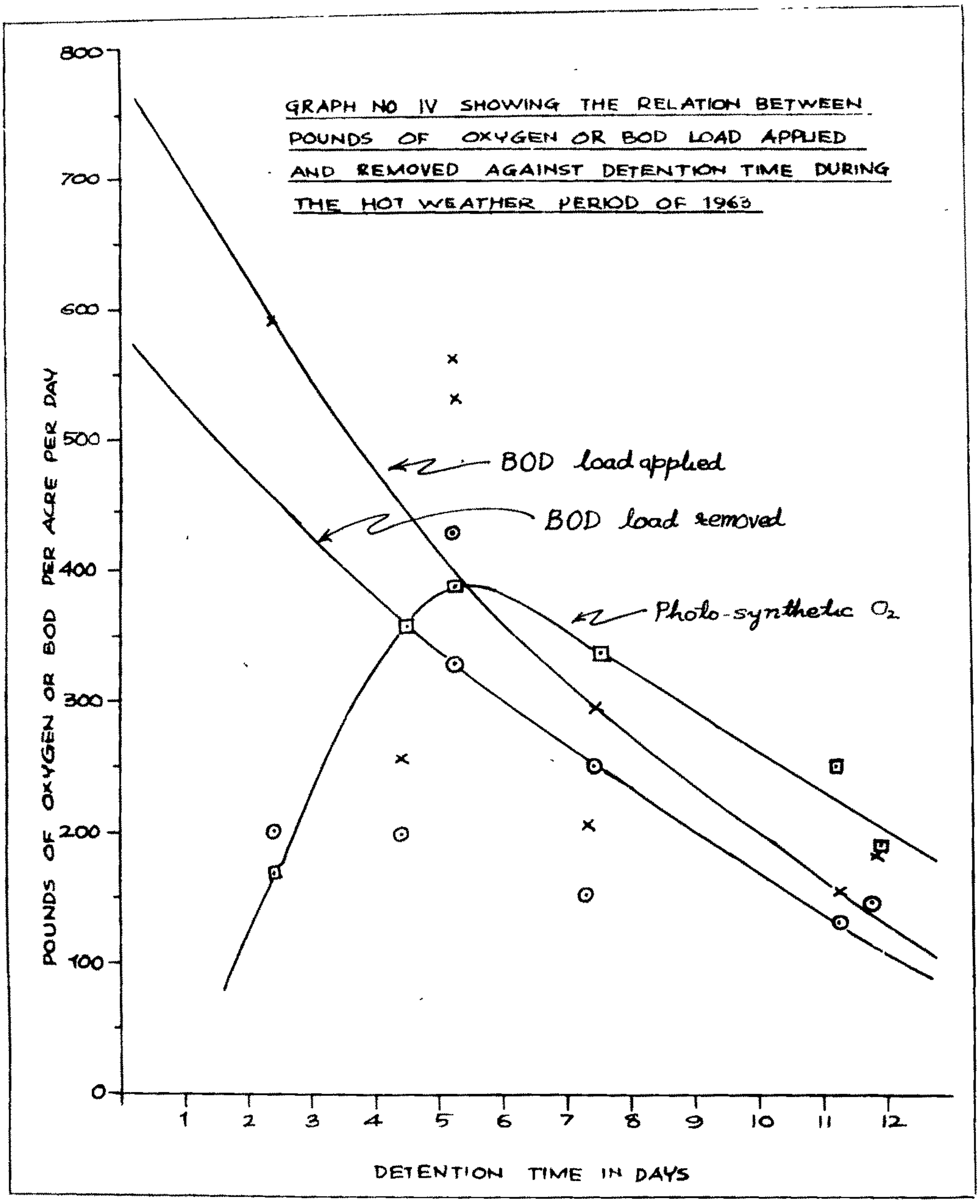

Fig. 44. Graph showing the relation between the pounds of oxygen or BOD load applied and removed as against detention time during the hot weather period.

of 11 days the difference between BOD load applied and BOD removed appears to be approximately constant. At a detention period of 1 day, although the BOD removal is highest it represents only about 50% of the applied BOD. Sedimentation appears to have contributed to apparent BOD removal during this very short detention period.

<u>Hot-weather period</u>: (Fig.74): At a detention period of 1 day BOD removal is maximum and this has to be attributed only to sedimentation. At a detention period of 5.5 days photosynthetic oxygen production was not only maximum but was also equal to BOD loading. With the detention period of 6 and 7 days the photosynthetic efficiency reached was above that required to meet the BOD requirements. After a detention period of 7 days the difference between the BOD load applied and BOD removed was nearly constant.

(d) <u>Determination of rational criteria as design parameters.</u>

(i) <u>Estimation of the average quantity of oxygen required for stabilization of sewage for the four seasons of 1962-1963.</u>

Applying the formula $y = £(1-10^{-kt})$ the ultimate BOD values of the influent and effluent for the four seasons are shown below(Vide Table IX, Appendix).

TABLE NO. 5

Season	Influent	Effluent	Difference
1. Monsoon season (ppm)	546.1	140.4	405.7
2. Post-monsoon season	340.1	79.6	260.5
3. Cold weather period	343.1	103.0	240.1
4. Hot weather	472.0	111.0	361.0

(ii) The net weight of oxygen that must be produced for B.O.D. satisfaction through photosynthesis of algae (Gotaas and Oswald 1955, p. 106) for the four seasons is given below:-

TABLE No. 6

Season	Net Weight
Monsoon season	$\frac{405.7 \times 10 \times 2.48 \times 454}{2.9}$ $= 15.6 \times 10^5$ grams per acre per day
Post-monsoon	$454 \times 260.5 \times 10 \times 2.34/2.88$ $= 9.6 \times 10^5$ grams per acre per day
Cold weather	$240.1 \times 10 \times 2.34 \times 454/2.89$ $= 9.2 \times 10^5$ grams per acre per day
Hot weather	$361.0 \times 10 \times 2.32 \times 454/2.8$ $= 13.7 \times 10^5$ grams per acre per day

The quantity of algae that is necessary to produce that amount of oxygen mentioned in (ii) has been calculated in two ways: (i) from the formula of Oswald and Gotaas (1957) i.e., Weight of algae=$\frac{\text{weight of oxygen produced}}{1.64}$

and (ii) from the actual seasonal average quantities of algae developed in our pond (vide Table VIII Appendix).

TABLE No.7

Seasons	Theoritical	Actual
Monsoon season	$15.6 x 10^5/1.64$ $= 9.51 x 10^5$	-------------
Post-monsoon	$9.6 x 10^5/1.64$ $= 5.85 x 10^5$	$169.3 x 10 x 2.34 x 454/4.2$ $= 4.3 x 10^5$
Cold weather	$9.2 x 10^5/1.64$ $= 5.61 x 10^5$	$212.2 x 10 x 2.45 x 454/5.64$ $= 4.26 x 10^5$
Hot weather	$13.7 x 10^5/1.64$ $= 8.35 x 10^5$	$260.04 x 2.32 x 454/11$ $= 2.5 x 10^5$

"Normally the weight of algae estimated in this manner is less than that actually grown because some CO_2 from the atmosphere dissolves in the liquid providing an additional source of Carbon" (Gotaas and Oswald 1955 p.106). But it is the contrary in our case.

Total energy required per day for sustaining algal growth during the four seasons on the assumption that the unit heat of combustion of sewage-grown algae is 6000 calories per gram (Gotaas and Oswald 1955, p.105) has been calculated below.

TABLE No. 8

Season	Calories per day	
Monsoon season	$9.51 \times 10^5 \times 6000$ or 5706×10^6	------------
Post monsoon season	$5.85 \times 10^5 \times 6000$ or or 3510×10^6	$4.3 \times 10^5 \times 6000$ or 2580×10^6
Cold weather season	$5.61 \times 10^5 \times 6000$ or 3366×10^6	$4.26 \times 10^5 \times 6000$ or 2556×10^6
Hot weather period	$8.35 \times 10^5 \times 6000$ or 5010×10^6	$2.5 \times 10^5 \times 6000$ or 1500×10^6

(iv) Visible daily average solar radiation available at Ahmedabad (vide Table 1, Appendix) is expressed in terms of seasonal averages below:

TABLE No. 9

	Calories/sq/cm/day	Calories/acre/day
Monsoon season	204.1	$204.1 \times 40.5 \times 10^6$
Post-monsoon season	181.3	$181.3 \times 40.5 \times 10^6$
Cold weather period	155.0	$155.0 \times 40.5 \times 10^6$
Hot weather period	246.2	$246.2 \times 40.5 \times 10^6$

The most important factor to reckon with in connection with solar radiation is the rate of conversion of light energy into chemical energy by the algal cells. " Published efficiencies for out-door ponds have generally been found to range between 1% and 10% with most values in the narrow range of 3% to 7%", (Oswald et al 1957). " However values of about 3.5% to 4.0% efficiency appear conservative for use in the digestion of ponds to operate under average environmental conditions"(Oswald 1963, p.71). " Photosynthetic efficiencies of 5% to 8% may be attainable with algal cell concentrations dense to utilize the nutrients and permit harvesting of cells" (Gotaas and Oswald 1955 p.111). Rabinowithch (1955) has stated that Miss Meffert obtained in algal ponds, an average eight percent utilization of total incident light and this for several months. So, a value of 6% has been assumed by us in this paper.

So, the quantum of energy that will be stored in the algal cells at 6% conversion energy during the four seasons of 1962-63 is given below:

TABLE No. 10

Monsoon season	$=204.1 \times 40.5 \times 10^6 \times 0.06$	calories/acre/day.
Post-monsoon	$=181.3 \times 40.5 \times 10^6 \times 0.06$	" " "
Cold weather	$=155.0 \times 40.5 \times 10^6 \times 0.06$	" " "
Hot weather	$=246.2 \times 40.5 \times 10^6 \times 0.06$	" " "

(V) Calculation of the design data:

(a) Surface area is one of the basic considerations for design criteria. So, the area of the pond required to produce definite quantities of photosynthetic oxygen according to theoritical and actual algal production is given below:

TABLE NO. 11

Season	Theoritical algal production	Actual algal production
Monsoon season	$\frac{5706x10^6}{204.1x40.5x10^6x0.06}$ = 11.5 acres	---------
Post monsoon	$\frac{3510x10^6}{181.3x40.5x10^6x0.06}$ = 8.0 acres	$\frac{2580x10^6}{181.3x40.5x10^6x0.06}$ = 5.9 acres
Cold weather	$\frac{3366x10^6}{155.0x40.5x10^6x0.06}$ = 9.0 acres	$\frac{2556x10^6}{155x40.5x10^6x 0.06}$ = 6.8 acres
Hot weather	$\frac{5010x10^6}{246.2x40.5x10^6x0.06}$ = 8.3 acres	$\frac{1500x10^6}{246.2x40.5x10^6x0.06}$ = 2.5 acres

(VI) Calculation of 5 day BOD loading at 20°C. in pounds per acre per day.

Having known the surface area required per million gallons of sewage, the 5 day BOD loading at 20 $^{\circ}$C is calculated below for both aspects.

TABLE No. 12

Season	Theoritical Loading		Actual Loading	
Monsoon season	$\frac{2550}{11.5}$ =	222	--	--
Post-monsoon season	$\frac{1620}{8.0}$ =	203	$\frac{1620}{5.9}$ =	275
Cold weather	$\frac{1760}{9.0}$ =	196	$\frac{1760}{6.8}$ =	259
Hot weather	$\frac{2200}{8.3}$ =	222	$\frac{2200}{2.5}$ =	880

(VII) Next, Detention time (t) in days is calculated using the well known equation for BOD exertion.

$$Y = £ (1-10^{-kt}); \therefore t = \frac{1}{k} \log \left(\frac{£}{(£ - Y)} \right)$$

Where K = reaction velocity constant

£ = BOD of the influent

Y = BOD to be satisfied in the pond.(This is found by deducting the effluent BOD from the influent BOD)

"K" has been experimentally determined for Ahmedabad sewage to be 0.074 at 20°C. Also it is known that "K" varies with temperature as follows:

$$KT = \left[K \quad X\ 1.047^{(T-20)} \right]$$

The values of "K" for the average seasonal temperature of 1962-63 have been calculated and are shown in Table IX from which the detention time "t" in days is calculated below:

TABLE NO. 13

Season	Average temperature
Monsoon season	$= 1/.12 \log \frac{(546.1)}{(140.4)} = 5.0$ days
Post-monsoon	$= 1/.096 \log \frac{(340.1)}{(79.6)} = 6.6$ days
Cold weather	$= 1/.084 \log \frac{(343.1)}{(103.0)} = 6.2$ days
Hot weather	$= 1/.112 \log \frac{(472)}{(111.0)} = 5.5$ days

(VIII) Depth of the pond: The average rate of flow through the pond for the four seasons are shown in Table VIII (Appendix) 1MG = 3.68 acre/ft.

TABLE NO. 14

Season				
Monsoon	=	$\frac{3.68 \text{ acre ft. x } .607 \text{x} 5.0}{11.5}$	=	1.0 ft.
Post-monsoon	=	$\frac{3.68 \text{ acre ft. x} .572 \text{x} 6.6}{8.0}$	=	1.7 ft.
Cold weather	=	$\frac{3.68 \text{ acre ft. x} .530 \text{x} 6.2}{9.0}$	=	1.346 ft.
Hot weather	=	$\frac{3.68 \text{ acre ft.x } .319 \text{x} 5.5}{8.3}$	=	0.8 ft.

The depths obtained are too low and at least 3-4 feet will be required for preventing growth of a aquatic vegetation at Ahmedabad.

5. DISCUSSION

The design data for the oxidation ponds of Ahmedabad have been worked out from two angles. In the first place, the quantity of algae required to produce enough oxygen for BOD satisfaction was theoritically calculated assuming that the weight of algae required was equal to the quotient obtained by dividing by 1.64 the weight of oxygen required (which was the difference between the ultimate BOD value of the influent and effluent) according to Oswald and Gotaas (1957). The values thus obtained for the four seasons are theoritical and are compared below with the design data obtained from similar calculations made with the actual algal quantitative determinations made for three seasons:

TABLE No. 15

Seasons	Surface area Theori-tical	Surface area Actual	BOD loading Theori-tical	BOD loading Actu-al	Detention time	Depth feet
Monsoon season	11.5	--	222	--	5.0	1.00
Post-mon-soon	8.0	5.9	203	275	6.0	1.70
Cold weather	9.0	6.8	196	259	6.2	1.34
Hot weather	8.3	2.5	265	880	5.5	0.80
Average	9.2	5.1	222	471	5.8	1.21

The values for the surface area and BOD loading alone differ in the two cases. In the case when the algae were actually estimated, the surface area required is much less than that obtained from theoritical considerations but the hydraulic loading is far greater, especially for the summer season i.e., 880 lbs per acre per day. There are certain fallacies in our basic assumptions which will have to be next considered for explaining the discrepancies in values between the theoritical and practical approach to the problem. The oxygen donating capacity of algae may vary from genera to genera and even from species to species. The chemical composition of the algae similarity may differ and also the unit of heat combustion as it depends upon the composition of the algae. Oswald (1963) found that different species of green algae exhibited varying over-all photosynthetic efficiencies or light energy conversion efficiencies. He found *Chlamydomonas agloiformis* to possess the highest over-all photosynthetic efficiency, while *Chlorella pyrenoidosa*, *Scenedesmus obliquus*, and *Euglena gracilis* to exhibit lesser efficiencies. It is a well known fact that the light conversion efficiency of algae affect the loading considerably.

In the pilot plant oxidation pond under study, 19 species of algae belonging to three groups, were either dominant or sub-dominant. Even weekly changes in dominance of the algal species were recorded. Under such circumstances it will be very difficult to determine the over-all light conversion efficiency since not one but several species and types of algae are dominant during a season. So, it is necessary to study the chemical composition, the heat combustion, the light conversion efficiency and the oxygen donating capacity of all the algae found growing in the pond for a more correct apprisal of the design data. Till then the empirical values suggested by Oswald and Gotaas will have to be adopted. The dominant and sub-dominant algae occurring during the different seasons of 1962-63 are shown in Table 3 of Paper I, Part II.

Another interesting point to be noted is the comparatively less surface area (30%) but greater BOD loading (3.3 times) than the corresponding values obtained for theoritical estimations of algae during the summer season when the dominant algal flora was Arthrospira Khannae Dr. and Strickl of the blue-green group. But " There is little evidence of any tendency for blue-green algae to grow in fresh domestic sewage. In two years of open air pilot plant operation blue-greens have appeared only in negligible concentration" (Oswald and Gotaas 1957). The development of blue-green algae is not encouraged in oxidation ponds of the States as they are reported to form thick floating scums and to develop pigpen odour. So, Johnson (1960) and Smith (1960) have suggested the addition of Phygon at the rate of 1.0 ppm in the lagoon influent and around water edge or the use of an out-board motor boat for stirring up the water surface in order to break the mat surface".

In our case the entire pond became a thick green soup with the formation of a floating coalescing scum in certain corners but with no bad odour at all. The first welcome reference about the occurrence of Oscillatoria from Gotaas (1963) who states " The use of other types of algae, their relationship to light conversion and growth efficiency, harvesting and reclaiming the algae, mixing and recirculation are important factors in the further development. For example, it has been thought that small unicellular algae that are relatively free floating are most effective for photosynthetic oxygenation. However, recent studies by Gaur, Pipes and Gotaas (1960) show that *Oscillatoria*, a filamentous alga grows well and produces approximately as high yields in organic wastes as do *Chlorella* or *Scenedesmus*".

Our observations also confirm the fact that *Oscillatoria* spp. and *Arthrospira khannae*, two filamentous forms of blue-green algae which were either dominant or sub-dominant and grew well in summer months of 1963 in our pilot plant oxidation pond effected good improvement and also gave high yields. They can be more easily harvested than other green algal forms. About one ton of impure dry algae mixed with sand per million gallons of effluent was harvested from our algae-drying beds during the summer season of 1963.

6. RATIONAL SOLUTION FOR AHMEDABAD

The cheapest and the best method of purification of Ahmedabad sewage is no doubt the oxidation pond method. The area required for treating one million gallons of sewage is 7acres, the average 5 day at 20° C BOD loading is 350 lbs per acre per day (the averages between the theoritical and actual values), the detention period is

6 days and the depth should be between 3 & 4 feet. So, for treating 57 mgd. of Ahmedabad sewage in admixture with about 18 mgd., of textile mill wastes the acreage of land required will be 57 x 7 or 399 or 400 acres plus an addition 50 acres as a margin of further safety. Therefore, 450 acres of land will be required for treating 57 mgd. of sewage originating from 12 laks of population. This will work out to one acre of land for nearly every 3000 people as against 100 people in Dakotas, U.S.A., and 1000 people in Europe (Fitzgerald and Rohilish 1958).

7. SUMMARY

1. Photosynthesis is a key process in natural economy and it is the basic mechanism by which oxygen is released from water for stabilisation. The theoritical amounts of oxygen which may be produced through photosynthetic oxygenation at a latitude of 23.01 North latitude for Ahmedabad are shown for various efficiencies for each of the 12 months of the year.

2. The different variables in stabilization of sewage by photosynthetic oxygenation have been considered in arriving at the design criteria for operation of oxidation ponds at Ahmedabad. The area required for treating one million gallons of sewage is 7 acres or one acre for nearly 3000 population, the

2.(Contd.)

hydraulic loading is 450 lbs per acre per day, the theoritical detention time is six days, for a depth of between 3 and 4 feet at Ahmedabad.

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TABLE NO. I

Average Daily Visible Radiation received at the pond surface at Ahmedabad and (Corrected for the sky clearance factor (S. C. F.)

(Formula applied = Min. +(Max - Min.) x S.C.F.)

Season	Month	Visible solar Radiation Langleys/Sq.Cm./day Max.	Min.	Max-Min.	Sky Clearance Factor (S.C.F.) %	Average daily radiation received at pond Surface expressed in Calories per Sq. Cm. per day		Calories per acre per day
Cold Weather	December	166.5	105.5	61.0	75	151.2	x	40.5 x 10
"	January	170.0	117.0	53.0	75	156.7	x	"
"	February	203.0	127.5	75.5	75	156.1	x	"
Average	-	-	-	-	75	155.0	x	"
Hot Weather	March	238.5	158.0	79.5	79	221.8	x	"
"	April	269.0	165.5	103.5	79	247.3	x	"
"	May	287.0	192.0	95.0	79	267.0	x	"
"	June	288.0	153.5	134.5	79	248.9	x	"
Average	-	-	-	-	79	246.2	x	"
Monsoon	July	286.0	174.5	111.5	17	193.4	X	"
"	August	273.0	175.0	98.0	17	191.7	x	"
"	September	246.0	167.5	78.5	76	227.2	x	"
Average	-	-	-	-	-	204.1	x	"
Post-monsoon	October	215.0	139.5	75.5	76	196.9	x	"
"	November	179.0	123.5	55.5	76	165.7	x	"
Average	-	-	-	-	-	181.3	x	"

TABLE NO. II

THEORITICAL QUANTITIES OF OXYGEN *(in pounds per acre per day) THAT WILL BE PRODUCED THROUGH PHOTOSYNTHESIS IN PONDS OPERATING AT VARIOUS CONVERSION EFFICIENCIES AT NORTH LATITUDE 23.01 FOR AHMEDABAD.

Month	Max. / Min.	VISIBLE LIGHT ENERGY CONVERSION - percentage									
		1	2	3	4	5	6	7	8	9	10
Jan.	Max.	41	82	123	164	205	246	287	328	369	410
	Min.	28	56	84	112	140	168	196	224	252	280
Feb.	Max.	49	98	147	196	245	294	343	392	441	490
	Min.	31	66	93	124	155	186	217	248	279	310
Mar.	Max.	58	116	174	232	290	348	406	464	522	580
	Min.	38	76	114	152	190	228	266	304	342	380
Apr.	Max.	65	130	195	260	325	390	455	520	585	650
	Min.	40	80	120	160	200	240	280	320	360	400
May.	Max.	69	138	207	276	345	414	483	452	621	690
	Min.	46	92	138	184	230	276	322	368	414	460
June	Max.	69	138	207	276	345	414	483	552	621	690
	Min.	37	74	111	148	185	222	259	259	333	370
July	Max.	69	138	207	276	345	414	483	552	621	690
	Min.	43	86	129	172	215	258	301	341	387	430
Aug.	Max.	66	132	198	264	330	396	462	528	594	660
	Min.	42	84	126	168	210	258	294	336	378	420
Sept.	Max.	59	118	177	236	295	354	413	472	531	590
	Min.	40	80	120	160	200	240	280	320	360	400
Oct.	Max.	51	102	153	204	255	306	357	408	459	510
	Min.	34	88	102	136	170	204	238	272	306	340
Nov.	Max.	43	86	129	172	215	258	301	344	387	430
	Min.	30	60	90	120	150	180	210	240	270	300
Dec.	Max.	40	80	120	120	200	240	280	320	360	400
	Min.	25	50	75	100	125	150	175	200	225	250

* Formula applied $WO_2 = 24.2 \times F \times S$; where F is the visible light energy conversion percentage and S is the solar radiation for Ahmedabad.

TABLE NO. III

CLIMATOLOGICAL DATA FOR AHMEDABAD FOR 1962 & 1963

Season	Month	Temperature C" mean				Monthly hours of bright sunshine	
		Maximum		Minimum			
		1962	1963	1962	1963	1962	1963
Cold Weather	Dec.	29.2	29.5	13.4	15.1	289.7	273.2
-do-	Jan.	27.8	26.3	9.5	12.3	307.8	292.0
-do-	Feb.	31.5	33.6	14.6	14.7	273.2	286.5
Average		29.5	29.8	12.5	14.0	290.2	283.9
Hot Weather	Mar.	35.3	31.3	18.3	18.6	286.0	289.8
-do-	Apr.	39.8	38.7	23.2	23.4	304.8	293.4
-do-	May	42.3	41.2	26.7	25.9	339.5	357.7
-do-	June	38.4	39.3	26.8	27.1	290.4	281.3
Average		38.9	37.6	23.7	23.7	305.2	305.5
Monsoon period	July	38.3	33.0	25.7	25.8	143.9	151.3
-do-	Aug.	33.5	30.5	25.2	24.8	138.7	119.8
-do-	Sept.	33.0	30.1	24.0	21.6	215.9	202.1
Average		32.9	31.2	25.0	24.1	249.2	157.7
Post Monsoon	Oct.	34.6	35.6	17.5	21.1	304.8	286.2
-do-	Nov.	33.1	32.2	15.9	18.5	277.5	268.1
Average		33.8	33.9	16.9	19.8	291.1	277.1

TABLE NO. IV

SHOWING THE AVERAGE HYDRAULIC LOADINGS ARRANGED IN INCREASING ORDER OF MAGNITUDE DURING THE MONSOON SEASON OF JUNE TO SEPTEMBER 1963.

S. No.	B.O.D in PPM			% BOD Removed	Load: Lbs/acre/day		Inflow		Volume		Depth in inches	Area in acres	Detention period in days	Ratio of Depth/D.period	Algae Wt mg/1	Photosynthetic Oxygen lb/acr/day
	Influent	Effluent	Removed		Applied	Removed	Inches	m.g.d.	m. g.	m.c.ft.						
1.	250	23	227	91	86.8	78.8	1.00	0.099	2.61	0.418	40.0	2.87	26.4	1.53	-	-
2.	450	50	400	89	106.4	94.3	0.75	0.070	2.33	0.373	35.2	2.92	33.3	1.06	-	-
3.	215	47	168	78	141.0	110.2	1.50	0.149	1.90	0.304	28.1	2.98	9.5	2.96	-	-
4.	202	49	153	76	220.2	166.8	2.00	0.312	2.69	0.430	41.2	2.87	8.6	4.79	-	-
5.	230	60	170	74	251.2	194.4	2.00	0.312	2.62	0.420	40.0	2.89	8.3	4.82	-	-
6.	170	46	124	73	359.0	261.9	3.00	0.689	2.50	0.400	38.2	2.88	4.1	9.33	-	-
7.	350	102	248	71	378.7	268.3	2.00	0.312	2.68	0.429	41.0	2.88	8.6	4.77	-	-
8.	290	87	203	70	455.5	318.8	2.50	0.451	2.57	0.411	39.5	2.87	5.7	6.93	-	-
9.	270	84	186	69	564.9	389.1	3.00	0.689	2.35	0.376	36.0	2.88	3.9	9.23	-	-
10.	250	83	167	67	610.2	407.6	3.50	0.735	2.68	0.429	39.7	2.98	3.6	10.90	-	-
11.	280	98	182	65	906.5	589.2	4.00	0.930	2.57	0.411	38.5	2.94	2.7	14.31	-	-
12.	130	51	79	61	853.1	518.4	6.50	1.880	1.91	0.306	29.0	2.91	1.0	28.43	-	-
13.	290	94	136	59	1016.0	600.8	5.00	1.260	2.68	0.429	40.8	2.89	2.1	19.41	-	-
Average	260	67	188	71	380.7	315.3	2.83	0.607	2.48	0.387	37.5	2.90	9.1	9.11	-	-

TABLE NO. V

SHOWING THE AVERAGE HYDRAULIC LOADINGS ARRANGED IN INCREASING ORDER OF MAGNITUDE DURING THE POST MONSOON SEASON OF OCTOBER AND NOVEMBER 1962

S. No.	B.O.D. in PPM Influent	B.O.D. in PPM Effluent	B.O.D. in PPM Removed	% BOD Removed	Load: Lbs/acre/day Applied	Load: Lbs/acre/day Removed	Inflow Inches	Inflow m.g.d.	Volume m.g.	Volume m.c.ft	Depth in inches	Area in acres	Detention period in days	Ratio of Depth in period	Algae weight Mg/1	Photosynthetic oxygen Lbs/acre/day
1.	165	20	145	87.9	177.8	156.4	2.00	0.312	2.43	0.389	37.25	2.89	7.80	4.80	259	487.1
2.	110	24	86	78.0	224.6	175.2	3.00	0.689	2.49	0.389	38.00	2.89	4.22	9.01	204	688.8
3.	230	60	170	74.0	256.0	189.4	2.00	0.312	2.11	0.338	32.00	2.80	6.77	4.72	242	440.0
4.	130	13	117	90.0	266.7	246.0	3.00	0.689	2.49	0.398	38.00	2.89	4.20	9.10	180	606.8
5.	135	42	93	69.0	276.5	190.8	3.00	0.689	2.36	0.378	36.20	2.88	4.00	9.10	160	537.7
6.	140	46	94	67.0	282.8	189.5	3.50	0.735	2.23	0.357	34.00	2.89	3.82	8.99	150	496.9
7.	100	10	90	90.0	305.9	275.3	2.75	0.470	2.44	0.330	37.33	2.88	5.20	7.12	242	634.7
8.	235	30	205	87.2	338.5	295.8	1.50	0.149	2.29	0.366	35.00	2.88	1.15	30.44	44	499.0
9.	175	60	115	66.0	396.4	261.6	3.25	0.701	2.36	0.378	36.30	2.87	3.63	10.00	150	557.6
0.	160	56	104	65.0	408.8	265.7	3.50	0.735	2.34	0.374	35.70	2.88	3.18	11.22	184	754.4
1.	210	74	136	65.0	428.9	278.8	3.00	0.689	2.43	0.389	37.25	2.88	4.13	9.21	198	663.5
2.	160	58	102	64.0	604.9	387.1	4.50	1.090	2.17	0.347	33.00	2.87	2.00	16.28	20	124.0
Verge	162.5	41.0	121.5	75.3	331.6	243.1	2.92	0.572	2.34	0.375	35.84	2.88	4.20	10.83	169.3	535.9

TABLE NO. VI

SHOWING THE AVERAGE HYDRAULIC LOADINGS ARRANGED IN INCREASING ORDER OF MAGNITUDE DURING THE COLD WEATHER PERIOD OF DECEMBER '62 JANUARY AND FEBRUARY 1963.

. o.	B.O.D. in PPM In-flu-ent	Eff-lue-nt	Re-mov-ed	BOD % Remo-ved	Load: lbs/acre/day App-lied	Remo-ved	Inflow In-ches	m.g.d.	Volume m.g.	m.c.ft.	Depth in inche es	Area in acres	Deten-tion period in days	Ratio of Depth/Detn. period	Algae weight mg / 1	Photosyn-thetic oxygen lbs/acre / day
1.	105	20	85	81	75.0	60.7	1.2	0.120	2.20	0.352	34.7	2.80	11.0	3.2	341	399.5
2.	120	25	95	79	128.0	100.1	2.0	0.312	2.23	0.389	36.7	2.92	7.8	4.7	367	641.2
3.	175	61	114	65	188.0	122.7	2.0	0.312	2.23	0.357	33.8	2.91	7.1	4.8	369	653.2
4.	180	65	115	64	193.4	124.0	2.0	0.312	2.23	0.357	33.8	2.91	7.1	4.8	365	628.2
5.	110	44	66	60	234.0	140.4	3.0	0.689	2.51	0.402	38.3	2.89	4.2	9.1	171	579.7
6.	180	50	130	72	244.5	176.0	2.5	0.451	2.48	0.397	37.7	2.90	6.3	6.0	320	712.4
7.	130	30	100	77	315.0	240.6	3.0	0.689	2.29	0.366	35.0	2.88	3.8	9.2	120	412.0
8.	90	30	60	67	286.7	217.9	4.0	0.930	2.57	0.411	39.3	2.88	2.8	14.0	68	355.5
9.	295	94	201	68	362.6	243.4	2.0	0.312	2.51	0.402	38.3	2.89	7.0	5.5	326	421.4
0.	170	80	90	53	353.0	187.1	3.0	0.689	2.80	0.448	43.0	2.87	4.7	9.1	206	691.3
1.	235	89	146	62	362.1	224.5	2.5	0.451	2.43	0.389	36.7	2.92	5.4	6.8	258	548.1
2.	180	70	110	61	367.9	224.4	3.0	0.689	2.49	0.398	38.0	2.89	4.2	9.1	176	592.0
3.	215	64	157	54	441.1	238.2	3.0	0.689	2.49	0.398	38.0	2.89	4.2	9.1	210	706.3
4.	274	59	211	41	1201.0	492.4	5.0	1.260	2.55	0.408	38.8	2.90	2.0	19.4	69	497.6
ve-age	115.4	55.7	119.6	65.3	332.4	192.4	2.8	0.530	2.45	0.319	37.9	2.89	5.54	8.2	204.4	398.5

TABLE NO. VII

SHOWING THE AVERAGE HYDRAULIC LOADINGS ARRANGED IN INCREASING ORDER OF MAGNITUDE DURING THE HOT WEATHER PERIOD OF MARCH, APRIL, MAY & JUNE 1963

S. No.	B.O.D. in PPM			% BOD Removed	Load : Lbs/acre / day		Inflow		Volume		Depth in inches	Area in Acres	Detention period in days	Ratio of Depth/Deten period	Algae weight mg/l.	Photosynthetic O_2 lbs/acre/day
	Influent	Effluent	Removed		Applied	Removed	Inches	m.g.d.	m.g.	m.c.ft.						
1.	120	6	114	93	41.4	39.3	1.0	0.099	2.28	0.365	34.7	2.90	22.8	1.5	376	212.5
2.	190	25	165	87	65.4	56.9	1.0	0.099	2.40	0.384	36.7	2.88	24.2	1.5	386	218.1
3.	135	11	124	92	98.6	90.7	1.5	0.149	2.50	0.400	38.0	2.90	11.8	3.2	336	397.7
4.	310	40	270	87	105.5	91.8	1.0	0.099	2.20	0.352	33.0	2.94	22.0	1.5	356	198.0
5.	210	27	183	87	154.2	134.2	1.5	0.149	2.36	0.378	36.3	2.87	11.2	3.2	250	310.6
6.	250	50	200	80	183.3	146.6	1.5	0.149	2.50	0.400	38.1	2.89	11.8	3.2	360	432.8
7.	190	49	141	74	206.5	152.8	2.0	0.312	2.29	0.366	35.0	2.88	7.3	5.0	279	498.4
8.	160	37	123	77	256.4	197.4	2.5	0.451	2.01	0.321	31.0	2.85	4.4	7.0	290	762.6
9.	270	81	189	70	298.4	208.9	2.0	0.312	2.33	0.373	36.0	2.85	7.4	5.0	326	590.6
10.	335	117	218	65	370.1	250.6	2.0	0.312	2.33	0.373	36.0	2.85	7.4	5.0	310	561.7
11.	140	18	112	80	537.6	430.1	2.5	0.451	2.35	0.376	36.3	2.86	5.2	7.0	168	435.4
12.	360	151	209	58	564.9	327.6	2.5	0.451	2.35	0.376	36.0	2.88	5.2	7.0	159	410.0
13.	190	93	97	51	591.4	301.6	4.0	0.930	2.20	0.352	36.0	2.94	2.4	13.8	79	403.9
Average	220	55	165	77	252	183.0	1.92	0.319	2.32	0.363	35.4	2.80	11.0	4.92	282.5	417.9

TABLE NO. VIII

HYDRAULIC LOADINGS OF THE PILOT PLANT OXIDATION POND
IN THE PIRANA SEWAGE FARM, AHMEDABAD

(Seasonal Averages for 1962-1963)

No.	Description	Monsoon season July to Sept.'62	Post-monsoon season Oct. & Nov.'62	Cold Weather Dec.'62 to Jan. Feb.'63	Hot weather March to June '63
1.	5Day at 20 C BOD (ppm)				
	(a) Influent	260	162.5	175.4	220
	(b) Effluent	67	41.0	55.7	55
	(c) Removed	188	121.5	119.6	165
	(d) % Removed	71	75.3	65.3	77
2.	Load applied in lbs/acre/day.				
	(a) Applied	380.7	331.6	332.4	252.0
	(b) Removed	315.3	246.1	192.4	183.0
	(c)				
3.	Inflow:				
	(a) Inches	2.83	2.92	2.8	1.92
	(b) mgd.	0.603	0.572	0.530	0.319
4.	Volume				
	(a) m.g.	2.47	2.34	2.45	2.32
	(b) m. c. ft.	0.387	0.375	37.4	0.369
5.	Depth (inches)	37.50	35.84	37.4	35.4
6.	Area (acres)	2.90	2.88	2.89	2.8
7.	Detention period (days)	9.10	4.20	5.54	11.0
8.	Algal Weight (mg/l.)	-	169.30	240.4	282.5

TABLE NO. IX

SHOWING THE CALCULATED VALUES OF THE REACTION RATE CONSTANT (K) AND THE ULTIMATE B.O.D. FOR THE AVERAGE SEASONAL TEMPERATURES DURING 1962 TO 1963 K AT 20°C BEING 0.074

Description	Monsoon	Post-Monsoon	Cold Weather	Hot Weather
A. <u>INFLUENT</u>				
(a) Water Temperature °C	31.4	30.2	25.9	31.5
(b) 5 day 20°C BOD	255.0	162.5	175.4	220.0
(c) K value at the seasonal average temp.	0.13	0.12	0.09	0.13
(d) BOD ultimate 20°C	444.60	282.50	306.90	383.70
(e) BOD ultimate at the seasonal average Temperature(L).	546.1	340.10	343.10	472.00
B. <u>EFFLUENT</u>				
(a) Water Temperature °C	30.1	25.7	22.7	29.0
(b) 5-day BOD at 20°C	67.0	41.0	56.0	54.0
(c) K-value at the seasonal average temperature	0.120	0.096	0.084	0.112
(d) BOD ultimate 20°C	116.90	71.50	97.70	94.70
(e) BOD ultimate at the seasonal average temperature.	140.4	79.60	103.00	111.00
(f) Ultimate BOD removed (Y)	546.1-140.4 = 405.7	340.1-79.6 = 260.5	434.1-103.0 = 240.1	472.0-111.0 = 361.0