Determination of the Rate of Biodegradation in Some Polluted Tropical Waters and in Some Types of Liquid Wastes Common in Puerto Rico

by

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September, 1972

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Introduction

In the fight to control water pollution two things are of utmost importance: one, the kind and degree of treatment that a pollutant must undergo in order to become inocuous in natural ecosystems and, two, the fate of a pollutant when discharged into a natural water body, such as a stream, a bay or a lake.

In the case of liquid organic wastes, the degree to which it may be rendered harmless depends on its chemical complexity and its susceptibility to degradation, which usually is accomplished by biochemical means for practical and economic reasons. On the other hand, when a liquid organic waste is discharged into a natural body of water, its effect upon it, and its persistence, will depend not only on physical dispersive phenomena, but also on its continued natural decomposition.[4]

Natural degradation of organic wastes occur at definite rates and is induced by the action of heterotrophic bacteria. There is ample information in the scientific and technical literature* with regard to methodology to evaluate biodegradation rates of liquid wastewaters as well as the mathematical approach to apply these rates to a multiplicity of practical

* See References.

problems. Nevertheless, most of the available information refers to organic wastes of domestic origin (such as, domestic sewage) and very little with regard to industrial wastewaters. Because of its nature, domestic sewage is rather easily biodegraded with no acclimation of microbial populations needed, while industrial wastewaters, usually lacking in essential nutrients, pose a more complicated problem both in their treatment and their disposal.

A careful survey of the literature reveals that the information with regard to biodegradation rates for specific wastes is seriously lacking. In the mathematical formulations available to compute standard Biochemical Oxygen Demand (BOD) curves no attempt has been made to incorporate a much needed acclimation factor to take into account acclimation periods that usually occur in many industrial wastewaters. As a result, design of treatment processes for industrial wastewaters are plagued with uncertainty and with an undesirable degree of empiricism which, in most cases, must be accompanied by tedious and lengthy pilot plant studies.

It is the opinion of this writer that the availability of the information related to biodegradation rates of industrial wastewaters can put the solution of this problem on a more scientific, rational, and sound basis.

Nature and Scope of this Study

In any water pollution control program, it is necessary to define certain parameters in order to establish conventional critera of pollution levels in natural water bodies and to express the pollution potential of a certain waste. Biochemical Oxygen Demand (that is, the amount of oxygen that microorganisms consume in the biodegradation of a certain amount of a particular waste, under specified conditions) has become a very important "pollution measure". In practice, a high BOD accompanied by a low dissolved oxygen concentration in a body of water is usually conducive to anaerobic conditions which certaintly result in a change of the natural biota of the body of water and other undesirable conditions.[1]

In treatment plant design, the "strength" of a waste is usually measured in terms of its BOD and the efficiency of the treatment process is computed on the basis of BOD removal, among other things. A high BOD removal in the treatment plant results in a lower BOD loading into the receiving water body, which in turn represents less pollution.

Frankland (2) was the first person to use the BOD test, which he did to evaluate the pollution load on the Thames River. Aderney (3) improved on it by developing the dilution technic which made it possible to apply the BOD to any waste regardless of its strength. The dilution technic was incorporated into the seventh edition of "Standard Methods" published in 1933 after Theriault's work "Oxygen Demand of Polluted Waters" (5).

The BOD curve, as presented in any standard textbook of sanitary engineering, results from plotting values of oxygen consumed by bacteria, in the process of biodegrading a certain waste, against time elapsed from the beginning of the process. The curve is mathematically approximated by an exponential function as follows:

$$y = L(1 - 10^{-kt}) \qquad (1)$$

where:

y = total oxygen consumed by bacteria in t days

L = ultimate BOD, total amount of oxygen required for the complete aerobic stabilization of the waste. (theoretically $y = L$ at $t = \infty$)

k = temperature dependent deoxygenation (biodegradation) constant

In theory, each organic constituent of a mixed waste has its own particular value of "K", but due to the complexity and heterogeneous nature of most wastes practical "K" values usually represent the average effect of all constituents in the wastes.

Based on the aforegoing considerations, this project was undertaken to try to accomplish the following goals:

1- To make an evaluation of the several methods quoted in the literature for the determination of biodegradation rates in wastewaters and polluted natural waters, in order to select one method to be applied further on this study.

2- To determine de biodegradation rates for certain selected sanitary and industrial wastewaters.

3- Observe and evaluate the effect, if any, of dilution with natural fresh and salt water on the biodegradation coefficient "K".

4- To apply modern computer technics to an area in which available methods have not developed beyond the "graph-and-sliderule" stage.

<u>Evaluation of Available Methods for the Determination of "K" and "L".</u>

A number of methods have been developed to determine the values of "K" and "L" in the BOD relationship , but the related lengthy computations have scared many investigators from this field. Among those who have made significant contributions are Theriault (5) , Fair (6), and Thomas (7) with his slope method.

Variations of the older methods have been developed recently, which reduce appreciably many of the time-consuming computations, such as the Method of Moments developed by Moore, Thomas, and Snow (8), which does not require for its application a detailed knowledge of its mathematical derivation, Theriault's method (5) based on certain tables developed by him, the logarithmic equation derived by Oxford and Ingram (9), and the arithmetic method by Rhame (10).

Other significant studies have been made with regard to the behavior of the "K" and "L" parameters. Ruchhoft et al (11) found them to vary widely in diluted sewage. Variations from the traditionally accepted value of 0.1 at 20 °C for the "K" of domestic sewage were observed by Mukherjee et al (12), who made the first research work about the effect of pH on the BOD values of domestic sewage for the climatic conditions of India. Sawyer (13) demonstrated the discrepancies between theoretical and actual values of "K" and "L" in mixed wastes due to the differences in biodegradability of the different components of the waste.

As previously stated, no significant information is reported in the literature with regard to similar work accomplished on industrial wastewaters.

Selection of a Method to be Applied in this Study for the Evaluation of "K" and "L".

The first part of this study was devoted to make an evaluation of the methods quoted in the literature for the determination of deoxynation (biodegradation) rates in polluted waters and in wastewaters. The following methods were preliminarily selected for further study and evaluation:

1- The Method of Moments by Moore et al (8).

2- The Arithmetic Method by Rhame (10).

3- The Graphical Method by Thomas (14).

After careful consideration, Moore's method was discarded because the evaluation of "K" and "L" depended in this method on a series of graphs developed by the authors based on certain wastes, and we could not be certain of their undiscriminate application to other wastes.

The method by Rhame was considered too simplistic and did not lend well to sophisticated computer technics. The method lacks in accuracy and, therefore, was also eliminated.

Thomas method was selected because, although graphical in nature, it lends itself to computerized mathematical treatment, thus increasing its already acceptable precision. This method is based on the standard BOD formulation

$$Y = L(1 - 10^{-kt})$$

The author of the method discovered the similarity between the following two functions:

a) $(1 - 10^{-kt})$ b) $(2.3\ kt)\left[1 + \left(\frac{2.3}{6}\right)kt\right]^{-3}$

When both functions are expanded through the proper selection of known series, they become identical for the first three terms of the series, as follows:

a) $(1 - 10^{-kt}) = 2.3\ kt\left[1 - 1/2\ (2.3\ kt) + 1/6\ (2.3kt)^2 \ldots\right]$

b) $2.3\ kt\left[1 + \left(\frac{2.3}{6}\right)kt\right]^{-3} = 2.3kt\left[1 - 1/2\ (2.3\ kt) + 1/6\ (2.3\ kt)^2 \ldots\right]$

After the third term of the series, the rest of the terms diverge, but they are too small in magnitude to have any significant influence in the total value of both functions.

Therefore, Thomas substituted function (b) for its equivalent in the BOD equation:

$$Y = L\,(2.3\ kt)\left[1 = (\tfrac{2.3}{6})kt\right]^{-3}$$

Rearranging terms and extracting the cube root to both sides of the expression he obtained a lineal equation in $(t/_y)^{1/3}$ and t as follows:

$$(t/_y)^{1/3} = \frac{1}{(2.3\ KL)^{1/3}} + \frac{(2.3\ K)^{2/3}}{6\ L^{1/3}}\ t \qquad (2)$$

This is an equation of the form:

$$Y = A = B\ X$$

Where

$$A = \text{vertical axis intercept} = \frac{1}{(2.3\ KL)^{1/3}} \qquad (3)$$

$$B = \text{slope of the straight line} = \frac{(2.3K)^{2/3}}{6L^{1/3}} \qquad (4)$$

Thomas graphical method consists then in plotting the above straight-line equation in rectangular-coordinate paper by using values of $(t/y)^{1/3}$ for the vertical axis versus values of t for the horizontal axis. The values of "t" and "y" are obtained experimentally by running a set of BOD tests on the sample to be analyzed, from which sequential values of "y" are obtained for a cronological sequence of days. The best fitting straight line is drawn and the values of vertical-axis intercept and slope of the curve are measured graphically, from which equations (3) and (4) above may be solved simultaneously for "K" and "L".

In order to increase the precision of Thomas method, the process of curve-fitting to the experimental values was improved by applying statistical analysis to the data. Values of A and B (equations 3 and 4) were obtained mathematically rather than graphically. The entire process was programmed to be solved by means of a computer, as shown in the appendix of this report.

Selection of Wastes to be Studied

It was deemed necessary to have both domestic and industrial wastes for this study. Since most work done in this area has been on domestic sewage, it would serve as control for the study; but in addition, this would afford a good oportunity to study domestic wastewater from Puerto Rico and to see if there was any difference between sewage from different size communities. The following wastewaters were selected:

a) From India Brewery, which contains high residuals of yeast and a very high BOD.

b) From Caribe Feed Mills; this industry ellaborates cattlefeed based on certain raw material obtained from India brewery, containing high malt concentrations.

c) From Integrated Industries, which produces animal feed from stickwater residues of nearby tuna-fish industries. This industry uses in its process sulfuric acid to prevent the decomposition of the stickwater; yeast and molasses are added as nutritive supplement. All these materials are present in the wastewater effluent from this industry.

d) From IBEC Packing Co., a tuna-fish industry. Unfortunately, this last one had to be eliminated because, out of unsound fears, the administrators did not want their wastes to be studied. We tried to get permission from neighbor plants, Del Monte and Starkist, with similar results. This was rather unfortunate because the tuna-fish waste was of particular interest to us since these are among the largest tuna plants in the world, suppling most of the tuna consumed in the U.S.A.

e) Sanitary sewage from Hormigueros, a town of 9,900 citizens.

f) Sanitary sewage from the city of Mayaguez, a community of 93,000 inhabitants.

Experimental Methods and Technics

Sampling points were carefully selected so that the samples would be representative of the waste, and sampling was done as prescribed in Standard Methods (16). Dissolved oxygen and temperature measurements were performed *in situ*. All tests for the study were performed following Standard Methods (16).

The experimental part of this study was divided in three phases. The first phase consisted in working with the waste as it came from the particular source to determine its value of "K" in its original state. The second and third phases of the study consisted in diluting the waste with natural river and sea water to simulate the condition of the waste when discharged into a natural body of water.

In order to exclude any extraneous effect from other contaminants that might be present in the waters used for dilution, these were taken from places known to be free from pollution. The river water was obtained from the Cain Alto River, at a point way upstream from any source of pollution. The sea water was taken at a point about five miles off the coast of Mayaguez which, through previous analyses, was known to be clean.

In order to observe any effect due to different degrees of dilution on the value of "K" of the waste, two dilution factors were used: 2 and 10.

Mathematical Treatment of the Data

Following Thomas method, as explained elsewhere in this report, all data was analyzed and plotted in rectangular-coordinates paper.

It was immediately observed that the wastewater of domestic origin produced BOD curves of normal appearance. In the case of the industrial wastewaters, irreal negative values were obtained for both "K" and "L". This was found to be due to the acclimation period required by the bacteria to develop their enzymatic systems in order to degrade the more difficult industrial wastes. The standard BOD formulation does not take this phenomenon into account.

Since there is no report in the literature with regard to the existence of any mathematical model to deal with this situation, it was necessary to develop our own methodology. It was found that if a standard BOD curve was drawn approximately through the experimental points it would be shifted to the right along the horizontal axis by an interval of time "a" representing the acclimation period. The factor "a" was named "acclimation factor" and was introduced into the standard BOD function as follows:

$$y = L\left(1 - 10^{-k(t-a)}\right)$$

With this modification it was then possible to use Thomas method, as modified for this project, to determine "K" and "L" values for the industrial wastewaters under the conditions of the study. Nevertheless, this technic introduced a trial-and-error element in the methodology, which must be dealt with in future research projects, this being outside of the scope of this study.

Results

The following table and graphs are used to present the results of this study. Because of the trial-and-error method used to apply the acclimation factor "a",as previously stated, the graphs for the industrial wastewaters do not always fit precisely over the experimental points.

Table I - Values of K and L of the Wastewaters Studied

TYPE OF WASTEWATER	SOURCE	RAW WASTE		DILUTED WASTE							
				SWEET WATER				SEA WATER			
				F. D = 2		F. D = 10		F. D = 2		F. D = 10	
		K	L (P.P.M.)	K	L (P.P.M.)	K	L (P.P.M.)	K	L (P.P.M.)	K	L (P.P.M.)
MUNICIPAL	MAYAGÜEZ	0.042	263	0.247	45	0.286	17	0.312	58	0.319	12
		0.144	171	0.278	12	0.277	12	0.332	45	0.329	12
		0.145	123								
	ARITHMETIC MEAN =	0.111	186	0.263	29	0.282	15	0.322	52	0.324	12
	HORMIGUEROS	0.082	183	0.183	58	0.127	20	0.166	21	0.042	23
		0.139	60	0.209	15	0.155	15	0.222	51	0.276	16
		0.195	50								
	ARITHMETIC MEAN =	0.138	98	0.181	37	0.141	18	0.194	36	0.159	20
INDUSTRIAL	INTEGRATED INDUSTRIES	0.186	105970	0.329	41327	0.420	3136	0.339	40903	0.064	29280
		0.260	104938	0.479	14773	0.653	6022	0.351	39760	0.101	9193
		0.447	40218								
	ARITHMETIC MEAN =	0.297	83700	0.404	28000	0.538	5000	0.345	40300	0.583	19200
	CARIBE FEED MILLS	0.141	191115	0.281	8400	0.067	5707	0.213	4742	0.140	2725
		0.273	19409	0.454	6933	0.135	2434	0.294	1771	0.353	1051
		0.428	20016								
	ARITHMETIC MEAN =	0.281	19500	0.368	7670	0.101	4070	0.254	3260	0.247	2000
	INDIA BREWERY	0.005	363754	0.240	8672	0.002	84483	0.054	11876	0.069	3338
		0.054	45076	0.782	8168	0.148	3368	0.187	2594	0.249	714
		0.080	59840								
	ARITHMETIC MEAN =	0.040	156000	0.511	8420	0.075	43900	0.121	7240	0.159	2050

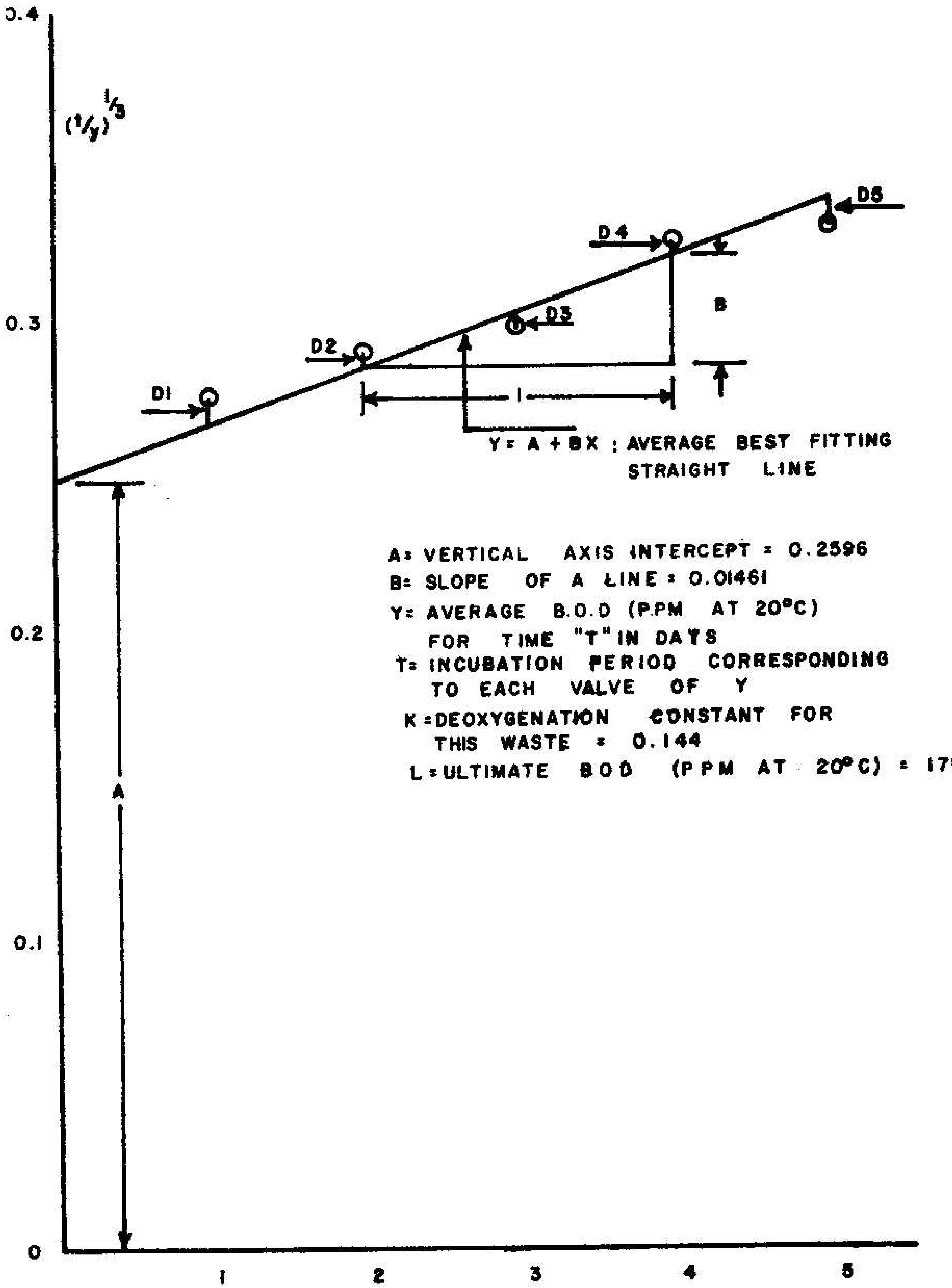

FIG I Lineal form of B.O.D. Curve for a sample of municipal wastewater from the city of Mayagüez.

Table 2 - Computation of K and L for the example shown in Fig 1. by means of the modified Thomas Method.

t (DAYS)	y(P.P.M)	$(t/y)^{1/3}$	$\left[(t/y)^{1/3} - \overline{(t/y)^{1/3}}\right]$	$\left[t - \bar{t}\right]$	$\left[(t/y)^{1/3} - \overline{(t/y)^{1/3}}\right]\left[t - \bar{t}\right]$	$\left[(t/y)^{1/3} - \overline{(t/y)^{1/3}}\right]^2$	$\left[t - \bar{t}\right]^2$
1	48	0.275	-0.029	-2	0.058	0.003360	4
2	82	0.288	-0.016	-1	0.016	0.000256	1
3	111	0.300	-0.004	0	0.000	0.000016	0
4	118	0.324	0.020	1	0.020	0.000400	1
5	139	0.330	0.026	2	0.052	0.002700	4
$\sum$=15		1.517			0.146	0.006732	10

$\overline{(t/y)^{1/3}} = \frac{1}{5}(1.517) = 0.3034$

$\bar{t} = \frac{1}{5}(15) = 3.0$

$C_{xy} = \frac{1}{5}(0.145) = 0.0292$

$(s_{x1})^2 = \frac{1}{5}(10) = 2.0 \quad , s_{x1} = 1.414$

$(s_{y1})^2 = \frac{1}{5}(0.006732) = 0.001346 \quad , s_{y1} = 0.001346$

$R = \frac{0.0292}{(1.414)(0.0367)} = 0.563$

$B = \frac{(0.563)(0.0367)}{1.414} = 0.01461$

$A = 0.3034 - (0.01461)(3) = 0.2596$

$K = \frac{(2.61)(0.01461)}{0.2596} = 0.144$

$L = \frac{1}{\left[2.3 \times 0.144 \times (0.2596)^3\right]} = 171 \text{ P.P.M.}$

Table 3 — Determination of the error of taking a straight line through to experimental points.

+(DAYS)	MEASURED B.O.D. P.P.M.	COMPUTED BOD P.P.M.	DEVIATION	DEVIATION^2
1	48	48	0	0
2	82	83	-1	1
3	111	110	1	1
4	118	123	-7	49
5	139	139	0	0
				$\sum = 51$

$$E = \pm\sqrt{\frac{51}{5}} = \pm 3.19$$

$\pm$ 3.19 = MOST PROBABLE ERROR

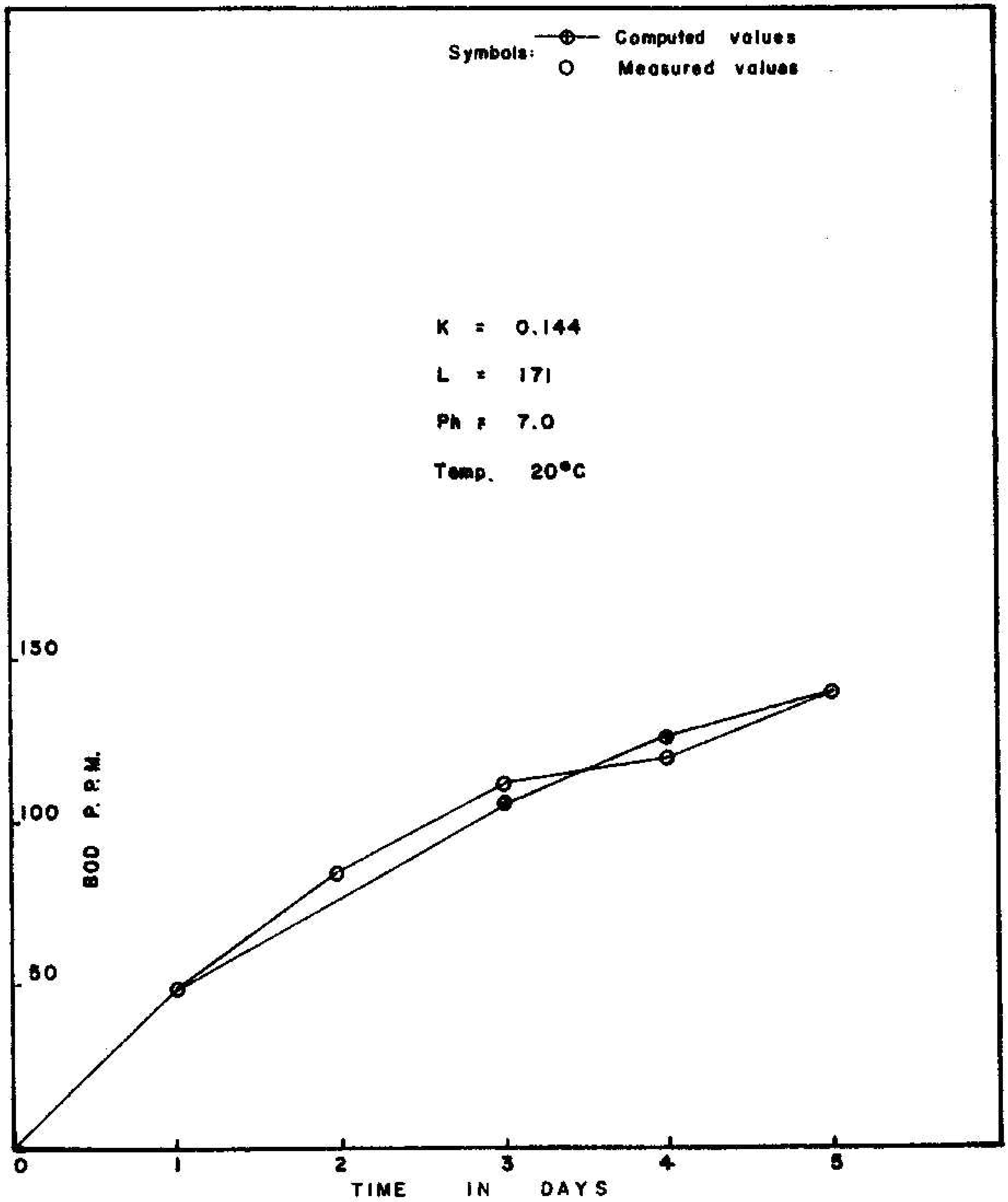

Fig I-I B.O.D curves City of Mayagüez, Raw Seweage Undiluted.

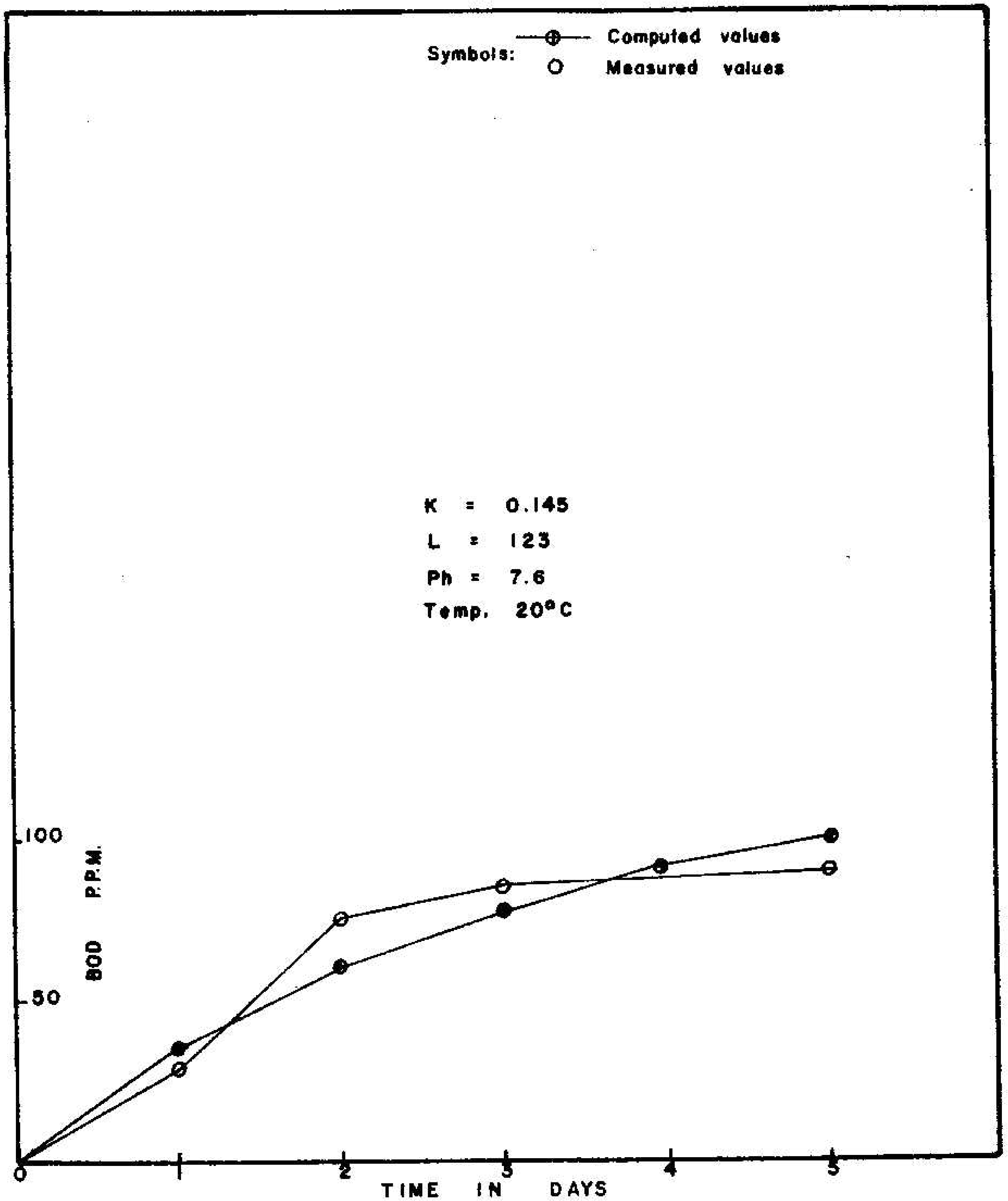

Fig I-2 B.O.D. curves. City of Mayagüez, Raw Seweage Undiluted.

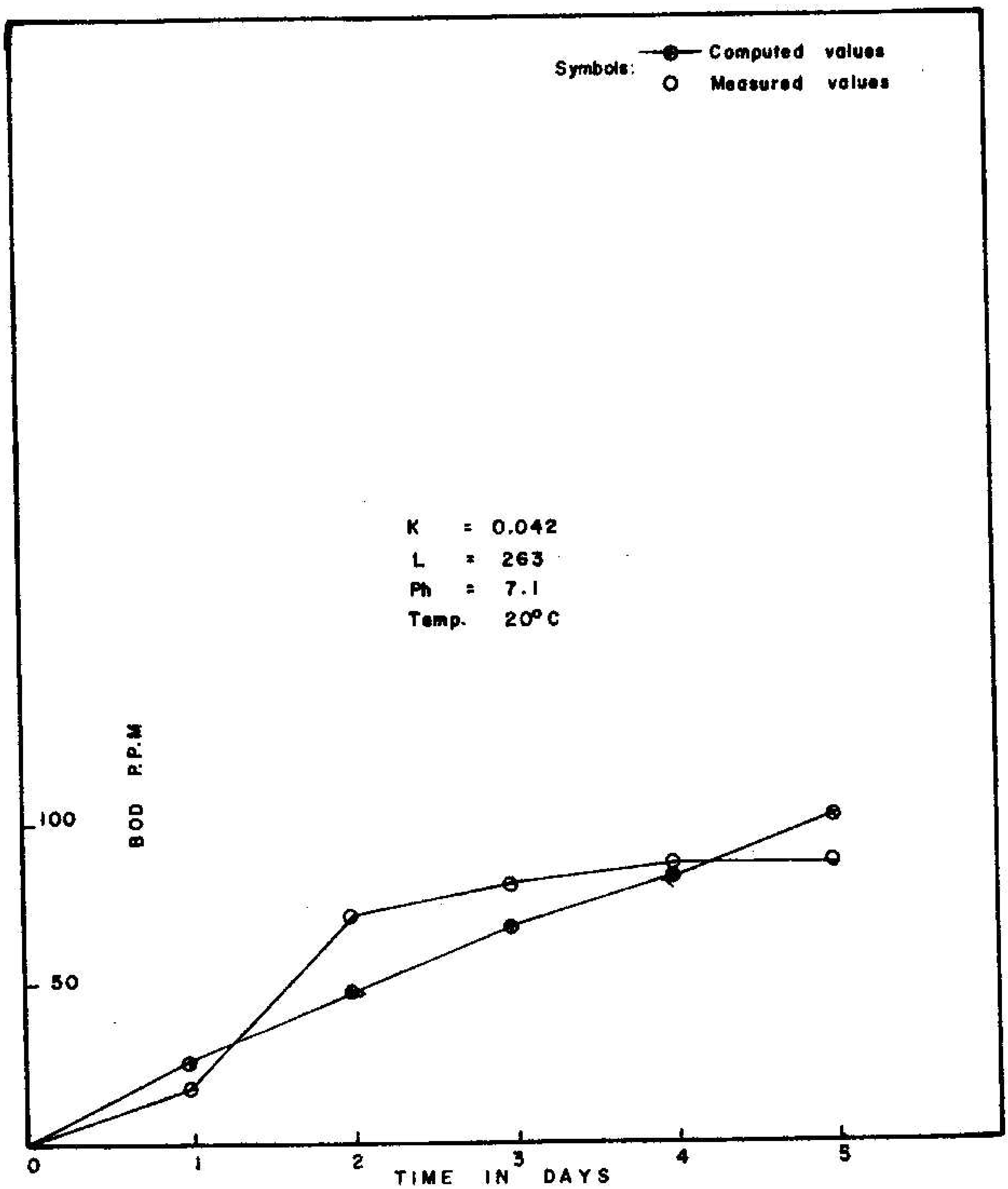

Fig I-3 B.O.D. Curves. City of Mayagüez, Raw Seweage Undiluted.

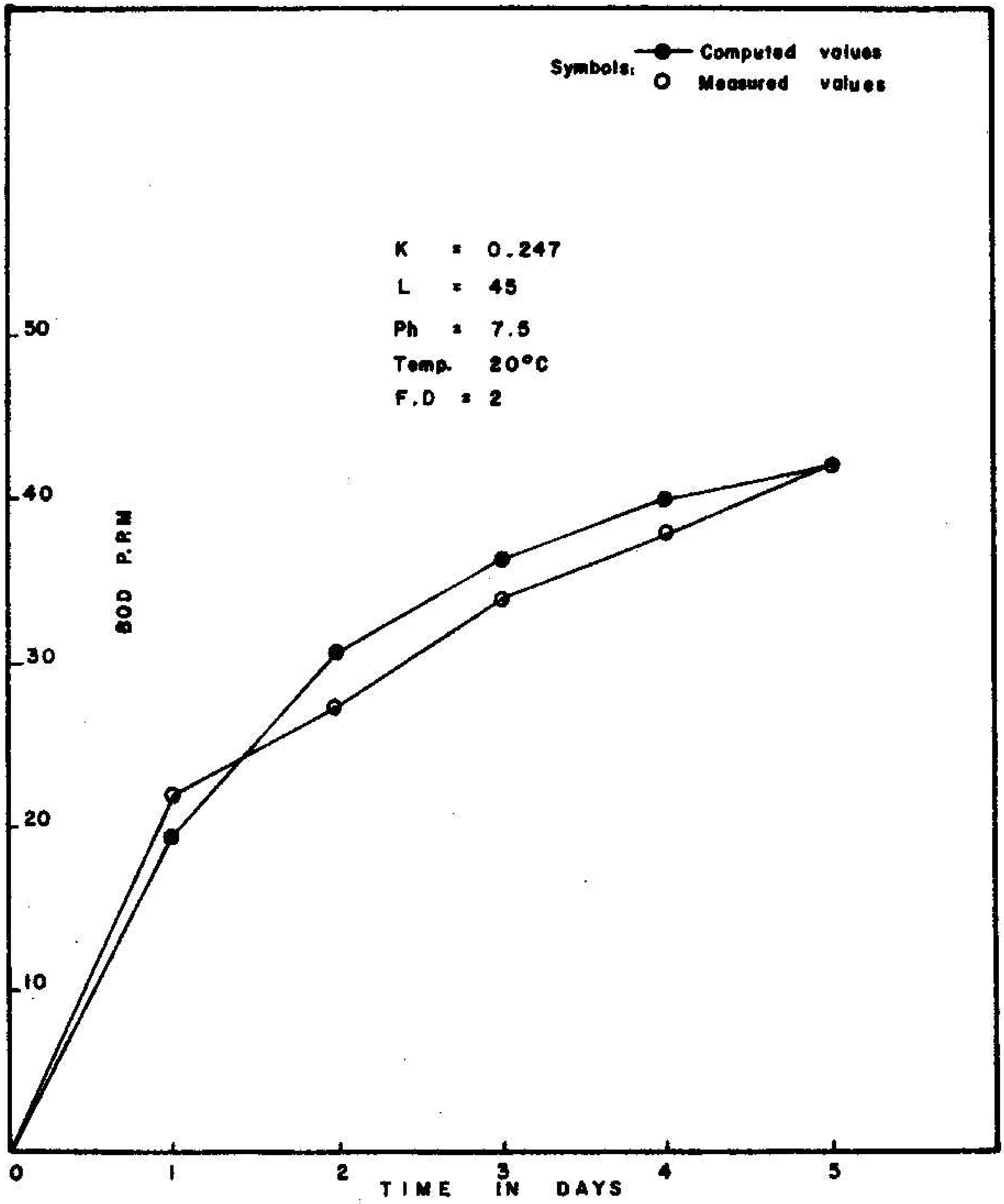

Fig. 2-1 B.O.D. Curves. City of Mayagüez. Raw Sewage. Diluted With Sweet Water by a Factor of 2

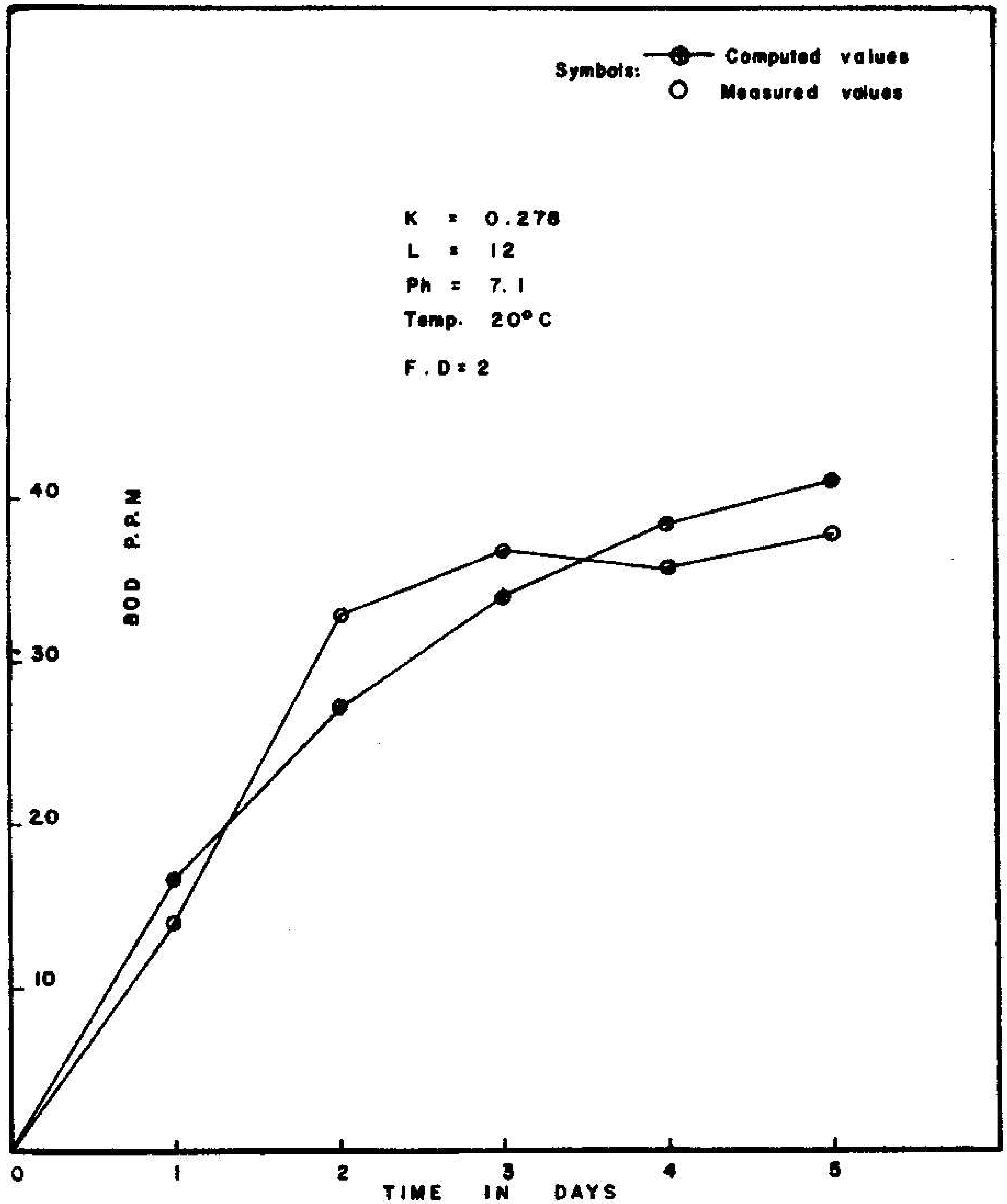

Fig 2-2 B.O.D Curves. City of Mayagüez. Raw Sewage, Diluted With Sweet Water by a Factor of 2

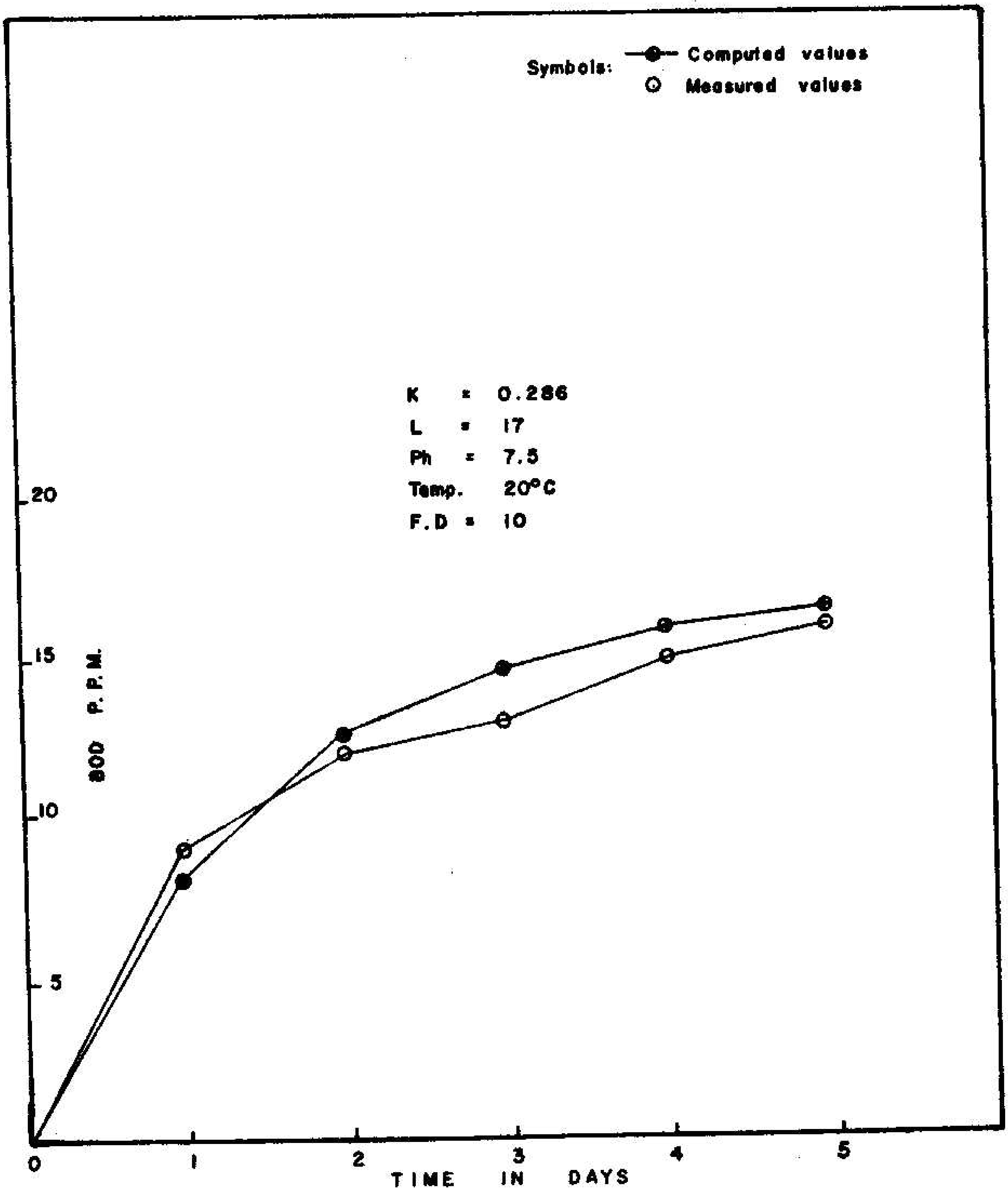

Fig 3-1 B.O.D. Curves. City of Mayagüez. Raw Sewage, Diluted With Sweet Water by a Factor of 10

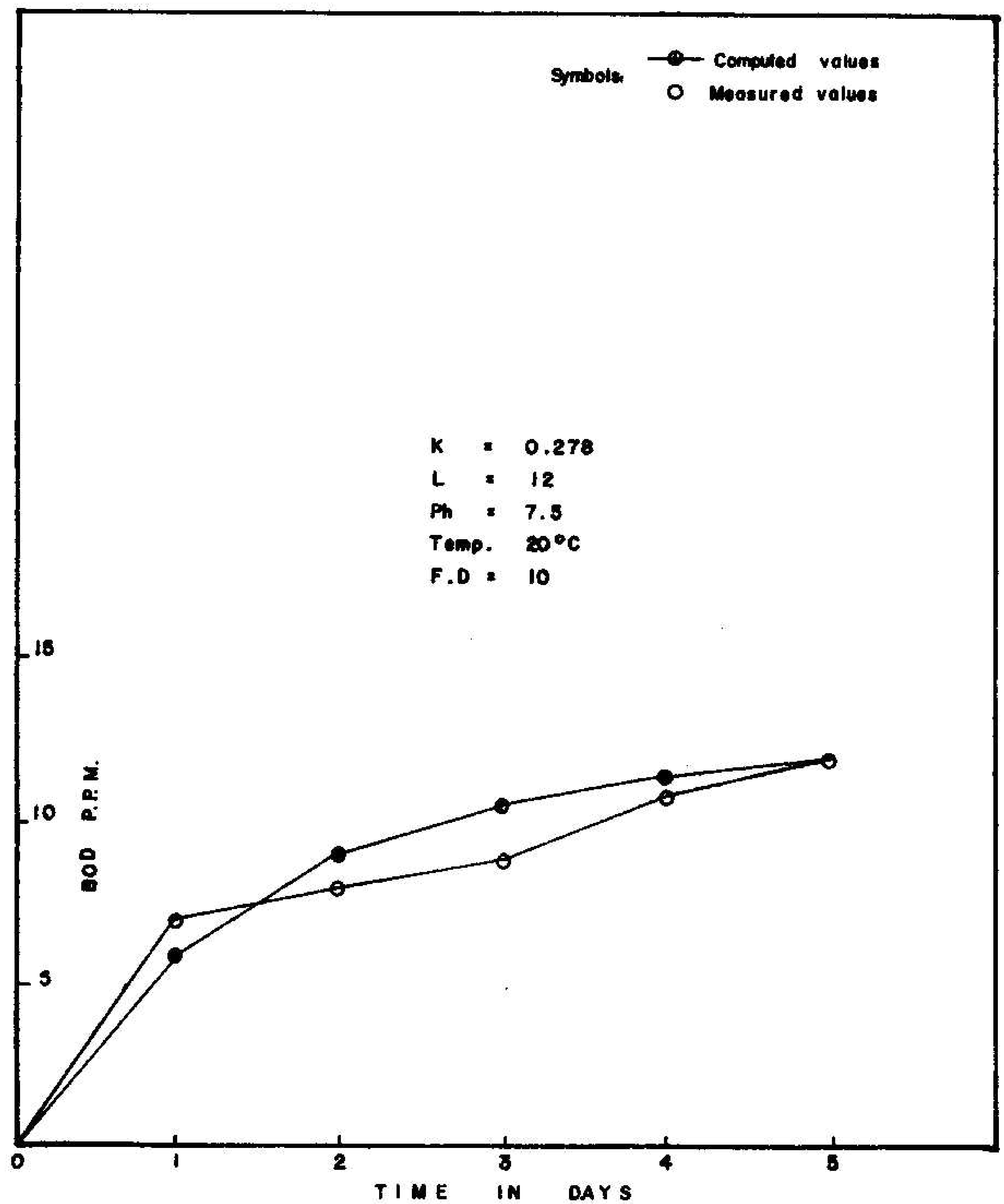

Fig 3-2 B.O.D. Curves. City of Mayagüez. Raw Sewage, Diluted With Sweet Water by a Factor of 10

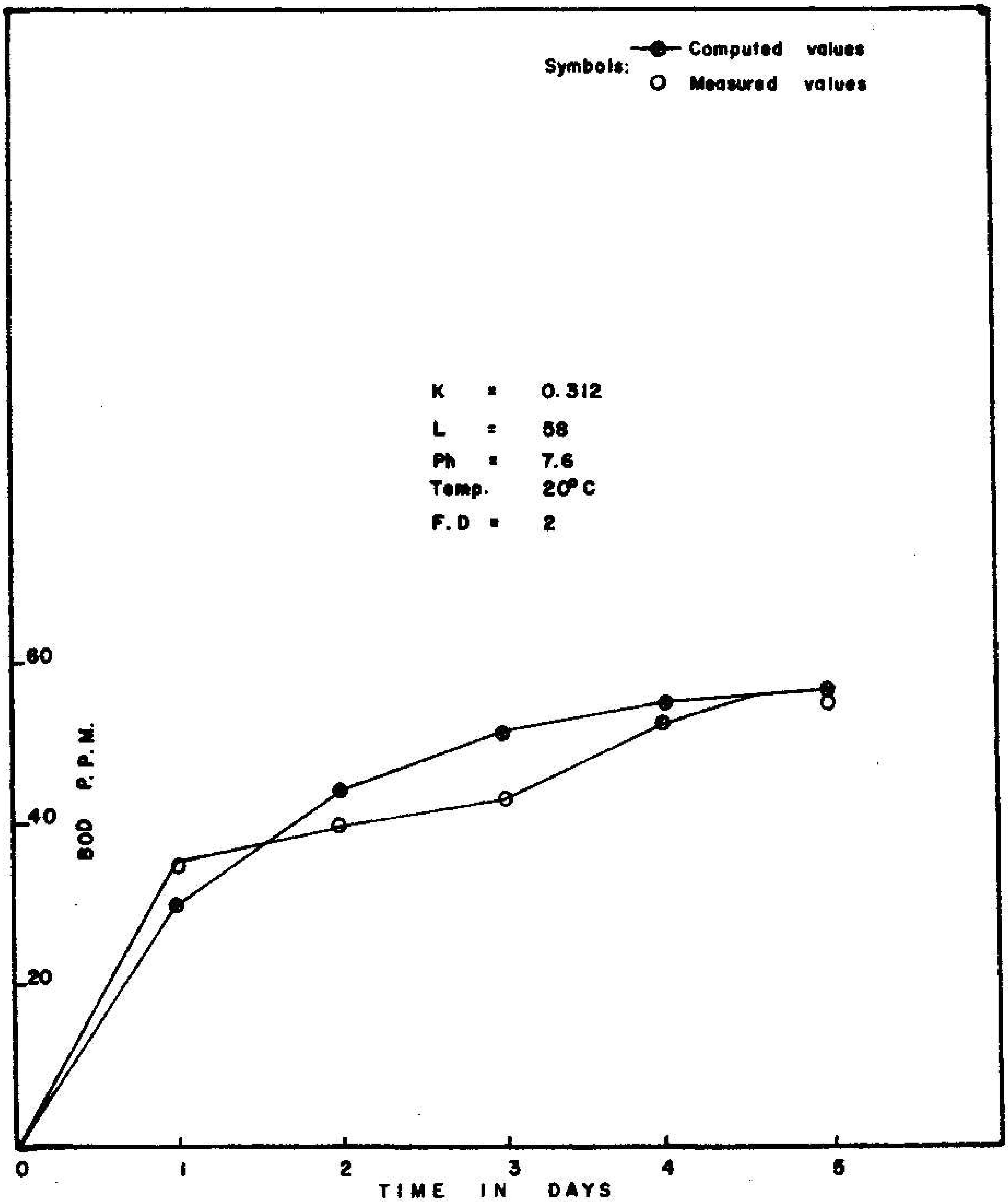

Fig 4-1 B.O.D. Curves. City of Mayagüez. Raw Sewage, Diluted in Sea Water by a Factor of 2

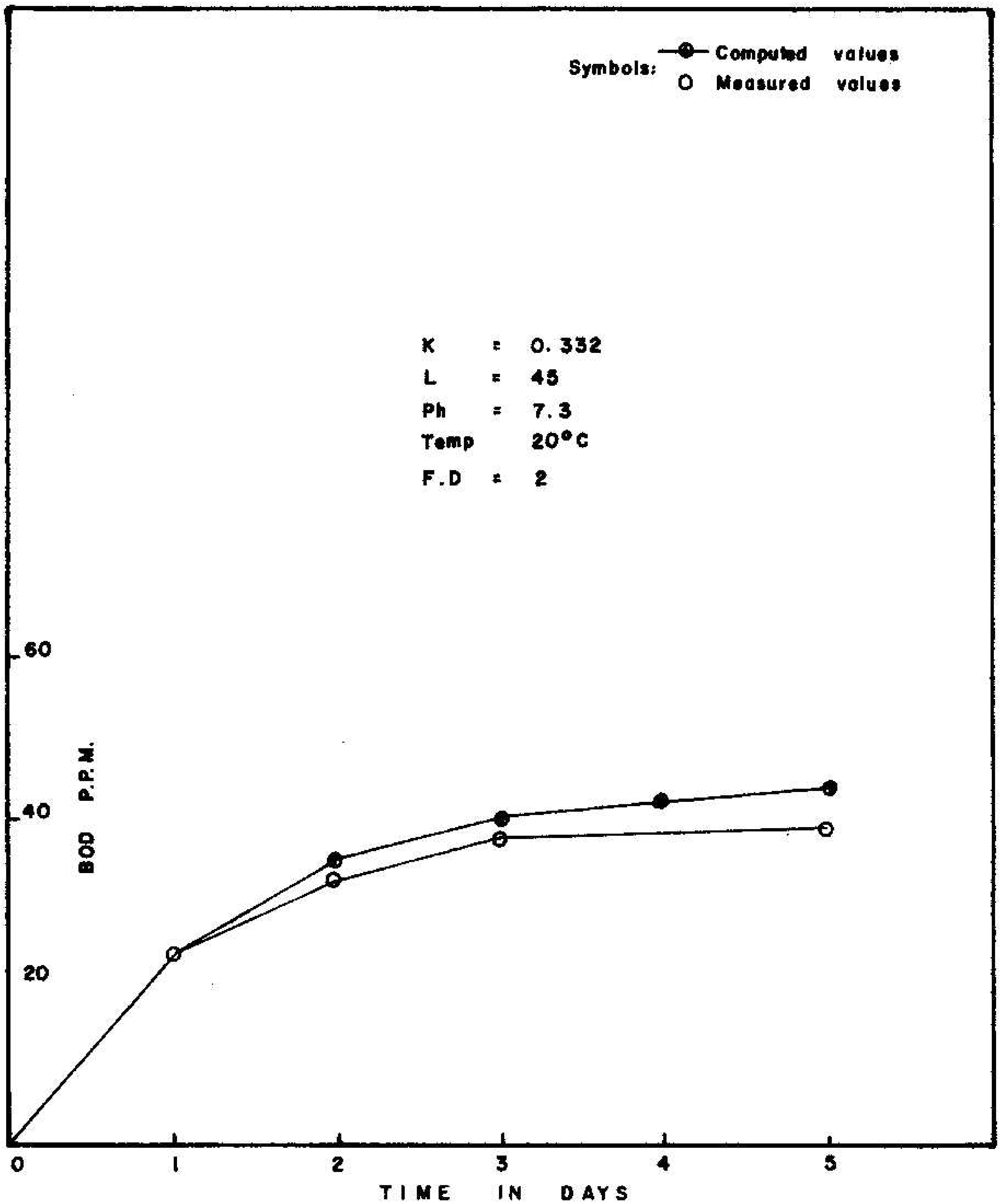

Fig 4-2 B.O.D. Curves. City of Mayagüez. Raw Sewage Diluted in Sea Water by a Factor of 2

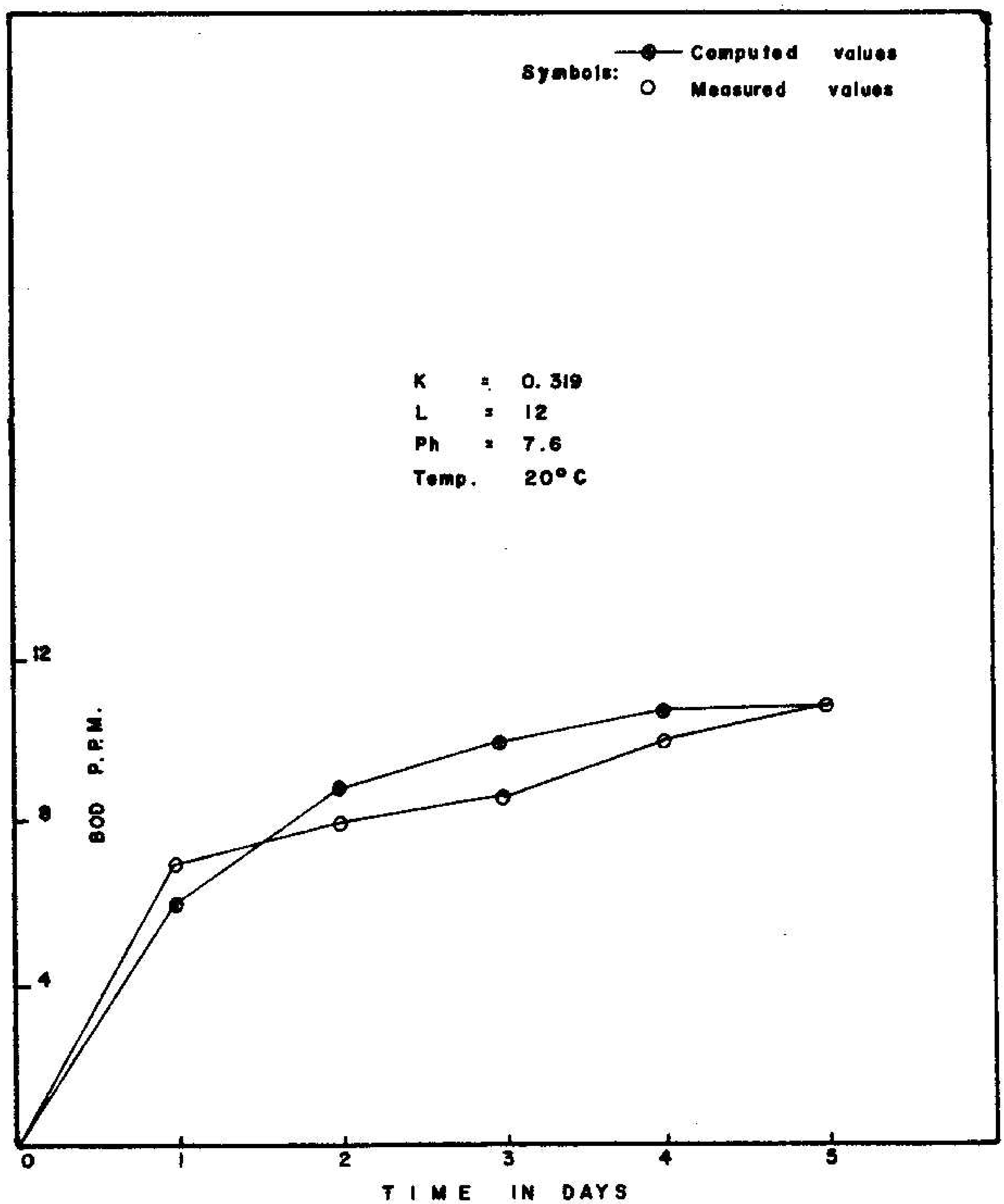

Fig 5—1 B.O.D. Curves. City of Mayagüez. Raw Sewage Diluted in Sea Water by a Factor of 10

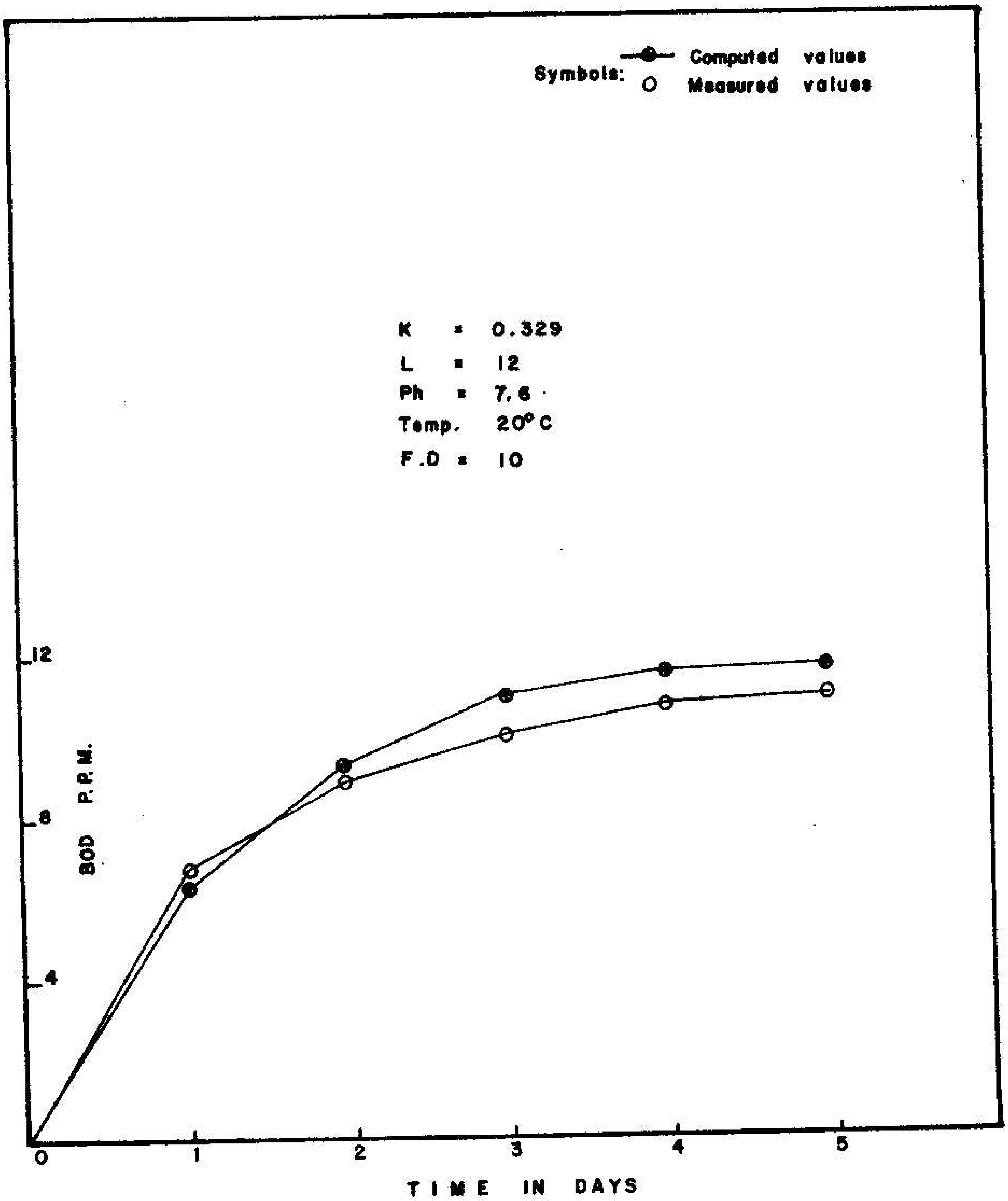

Fig 5-2 B.O.D. Curves. City of Mayagüez. Raw Sewage Diluted in Sea Water by a Factor of 10

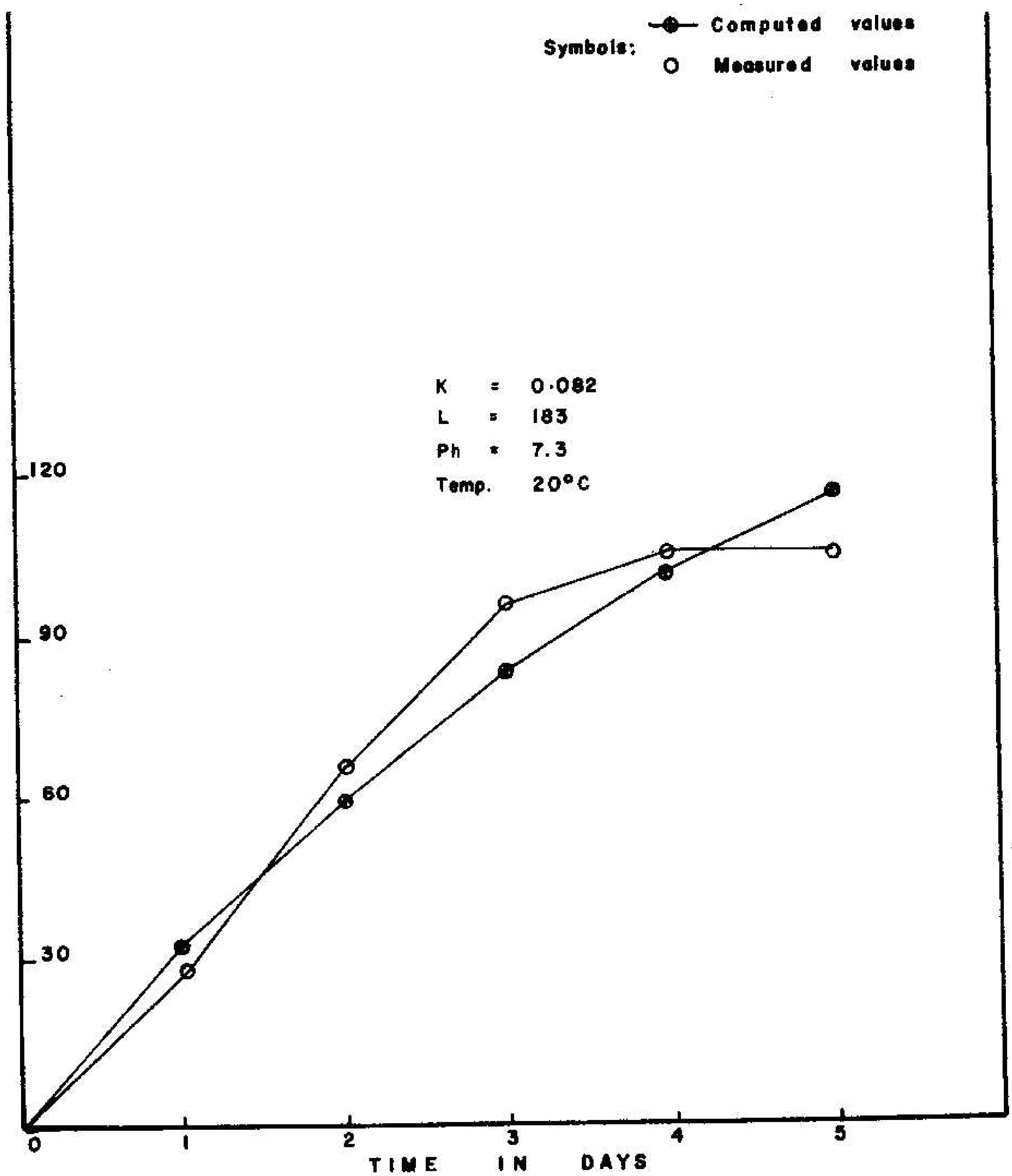

Fig 6-1 B.O.D. Curves. Town of Hormigueros.

Raw Sewage Undiluted.

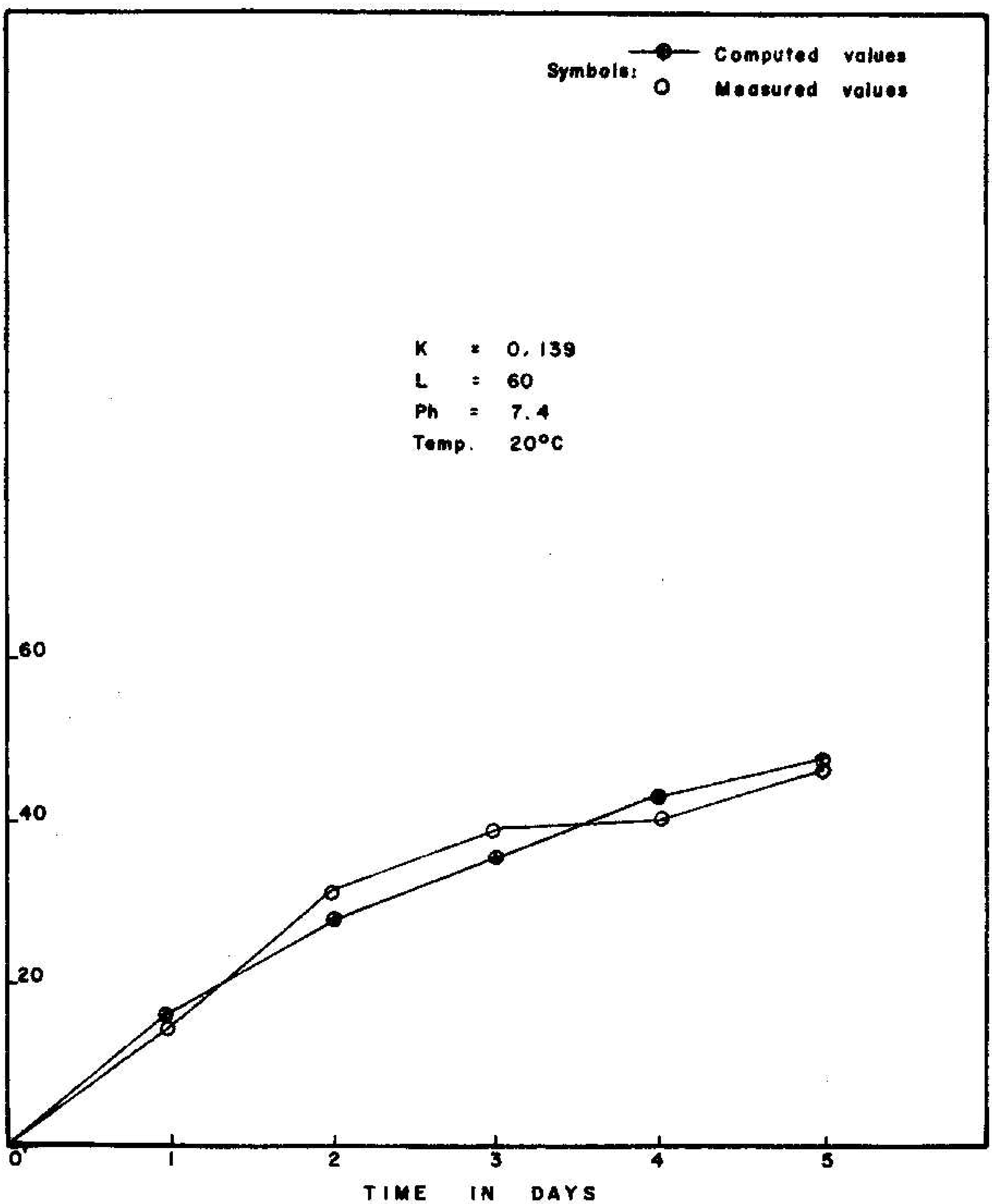

Fig 6-2 B.O.D. Curves. Town of Hormigueros.

Raw Sewage Undiluted.

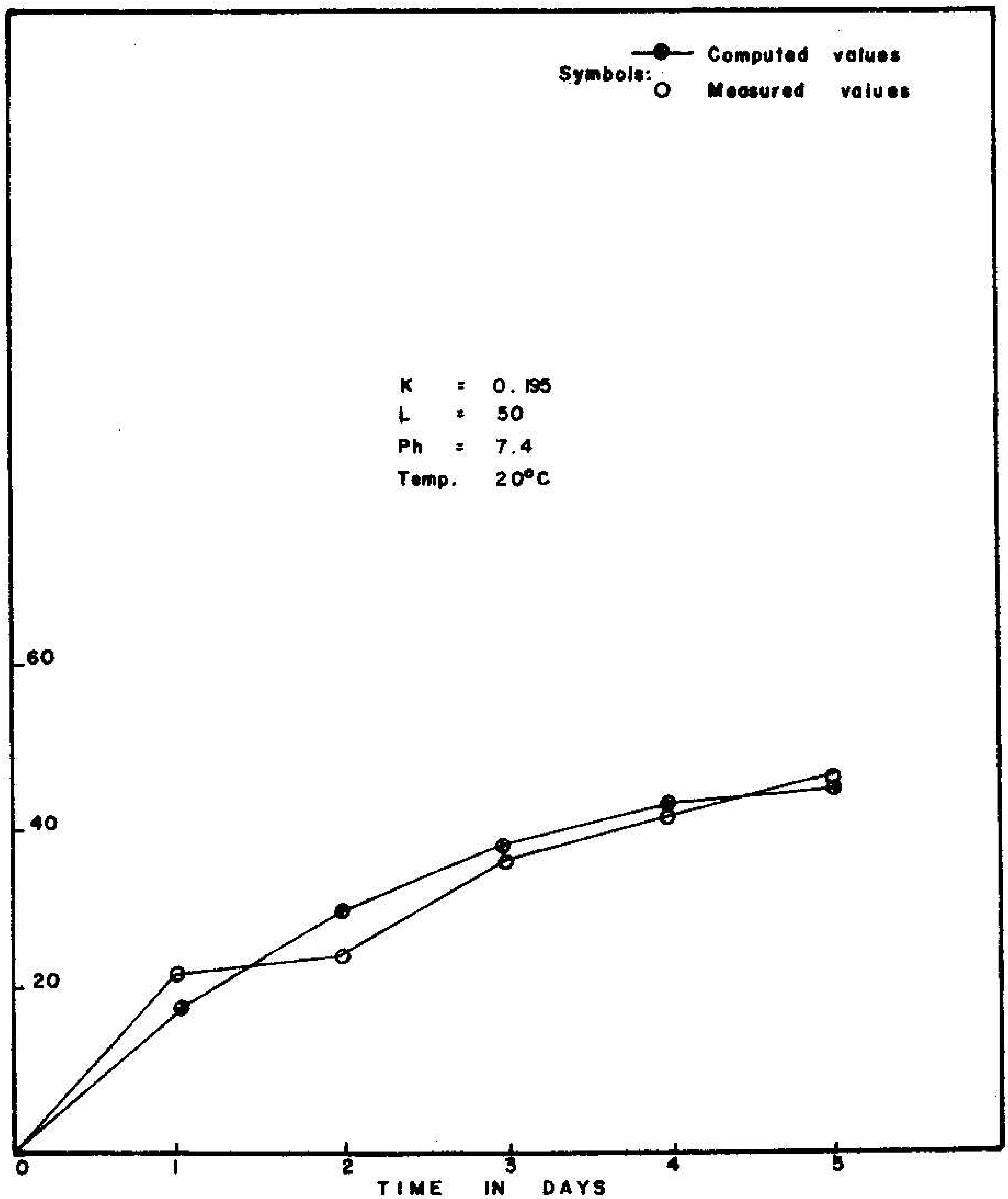

Fig 6-3 B.O.D Curves. Town of Hormigueros.

Raw Sewage Undiluted.

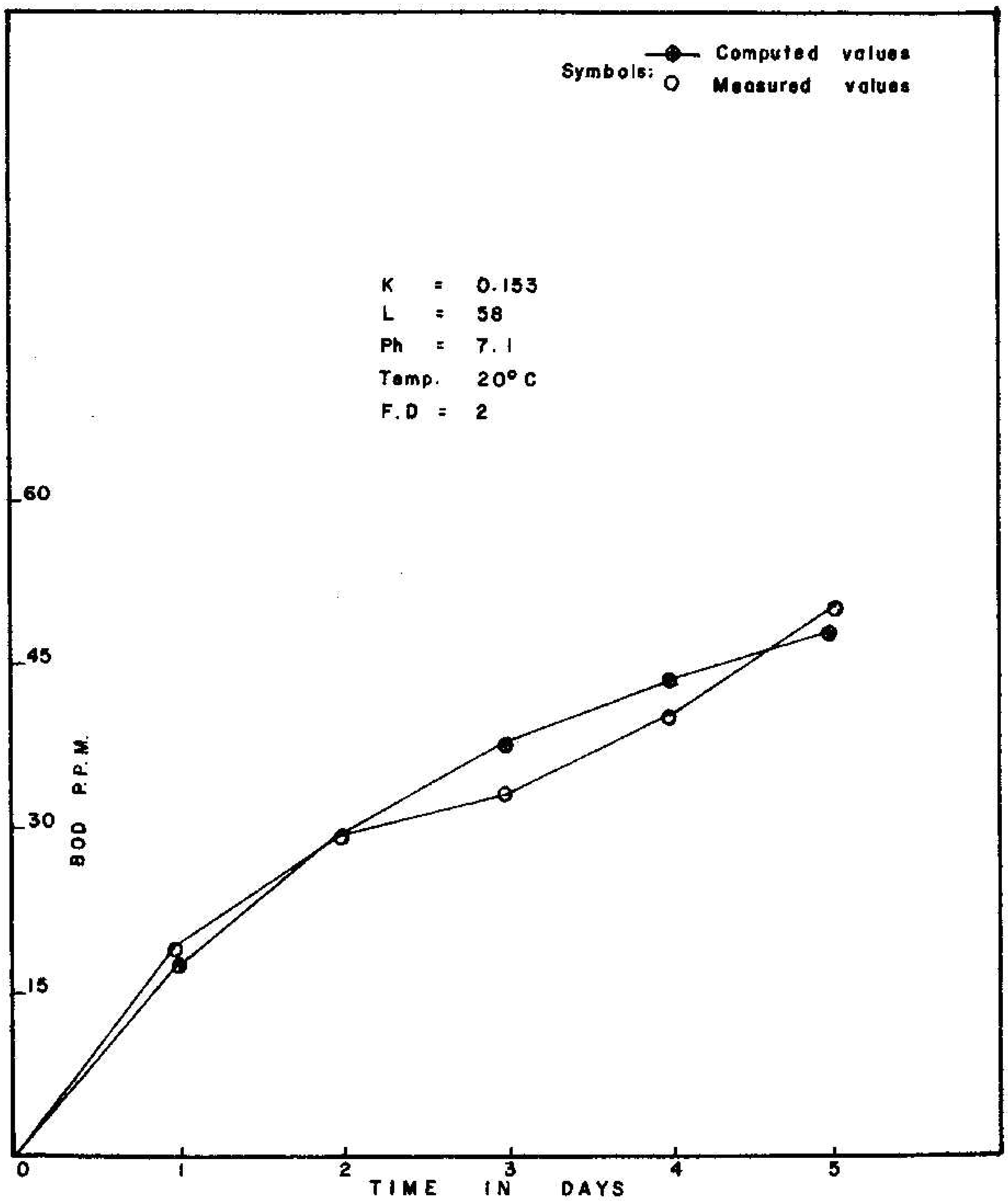

Fig 7-1 B.O.D. Curves. Town of Hormiguros. Raw Sewage Diluted in Sweet Water by a Factor of 2

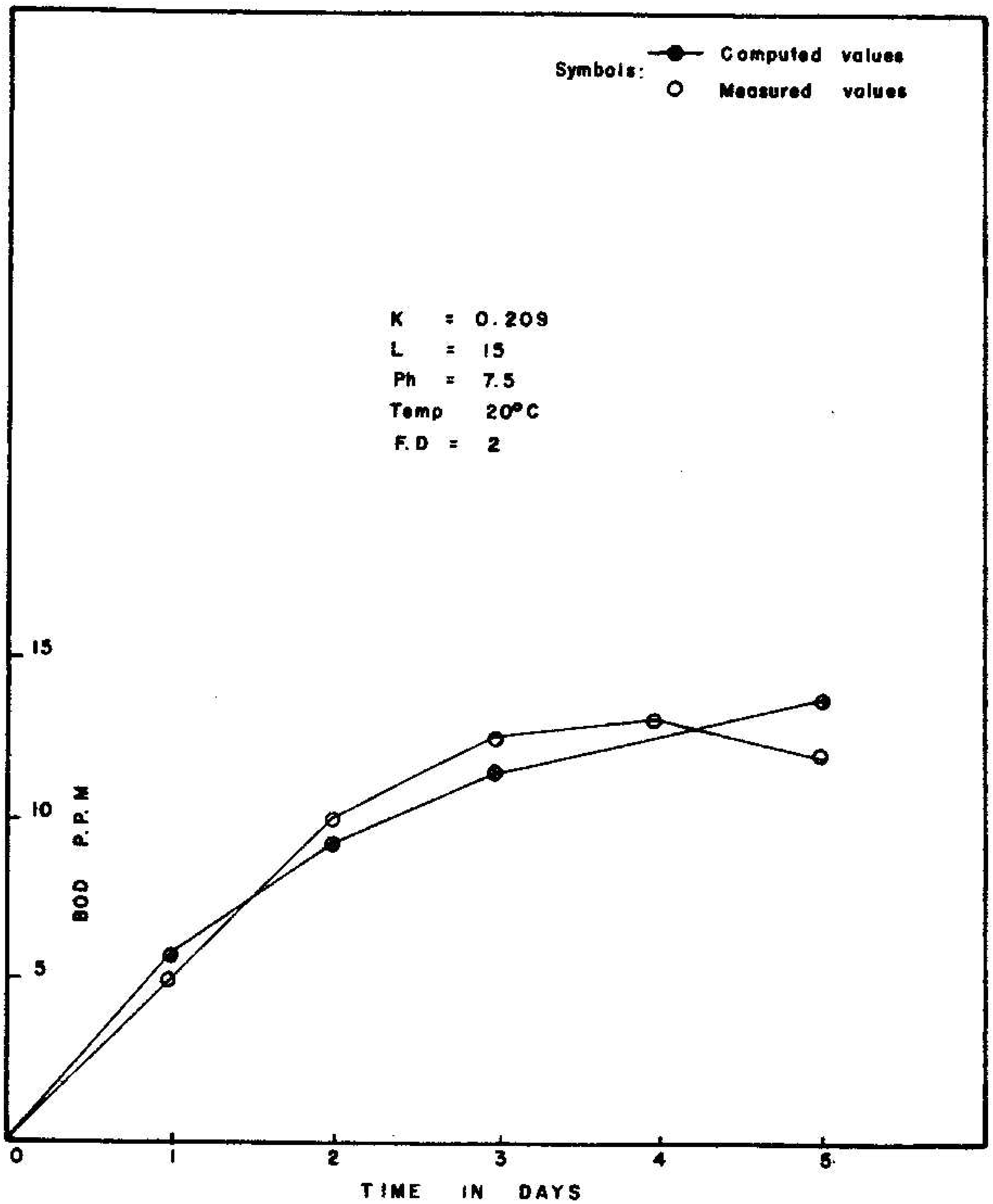

Fig 7-2 B.O.D Curves. Town of Hormigueros. Raw Sewage Diluted in Sweet Water by Factor of 2

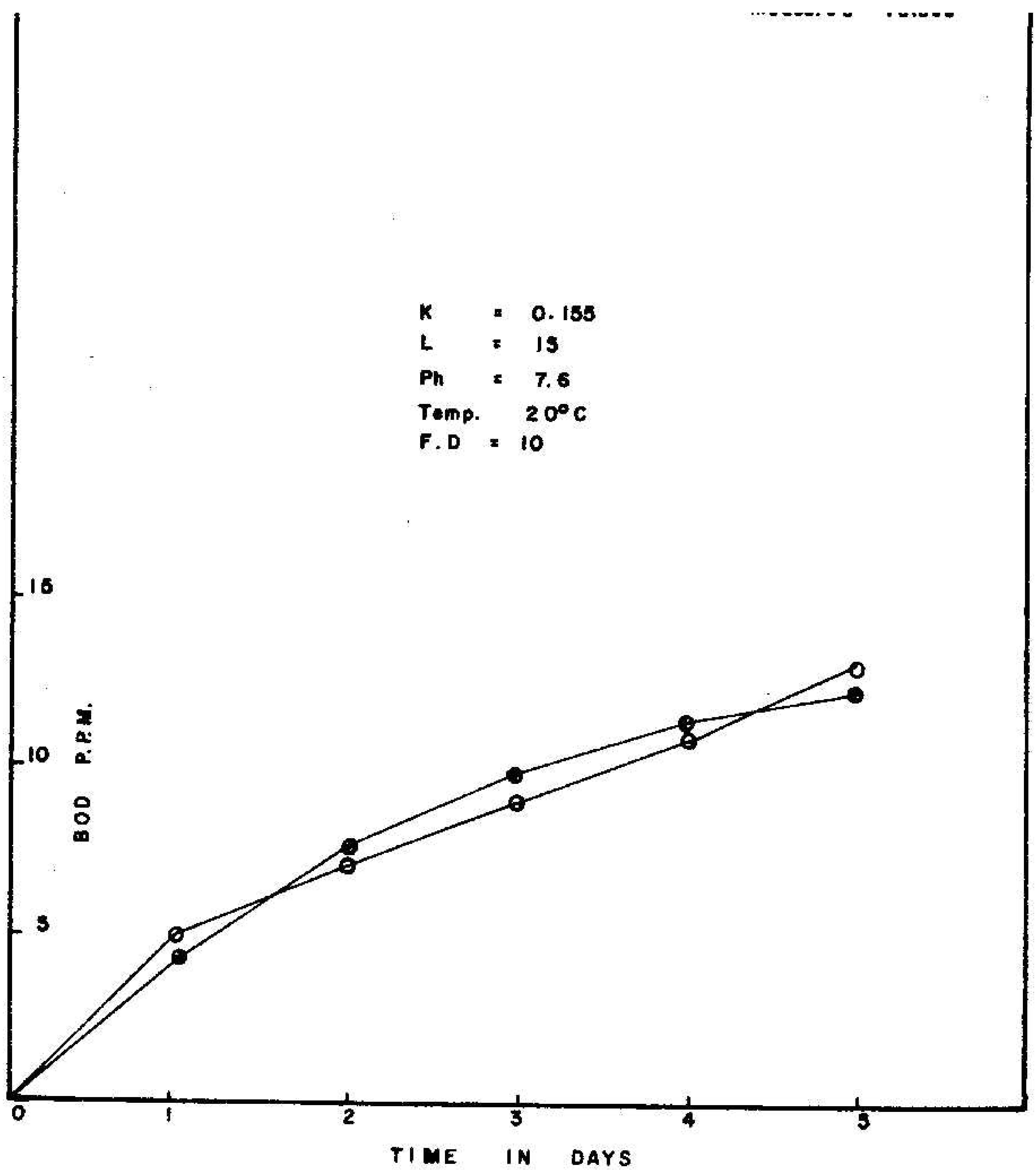

Fig 8—1 B.O.D. Curves. Town of Hormigueros. Raw Sewage Diluted in Sweet Water by a Factor of 10

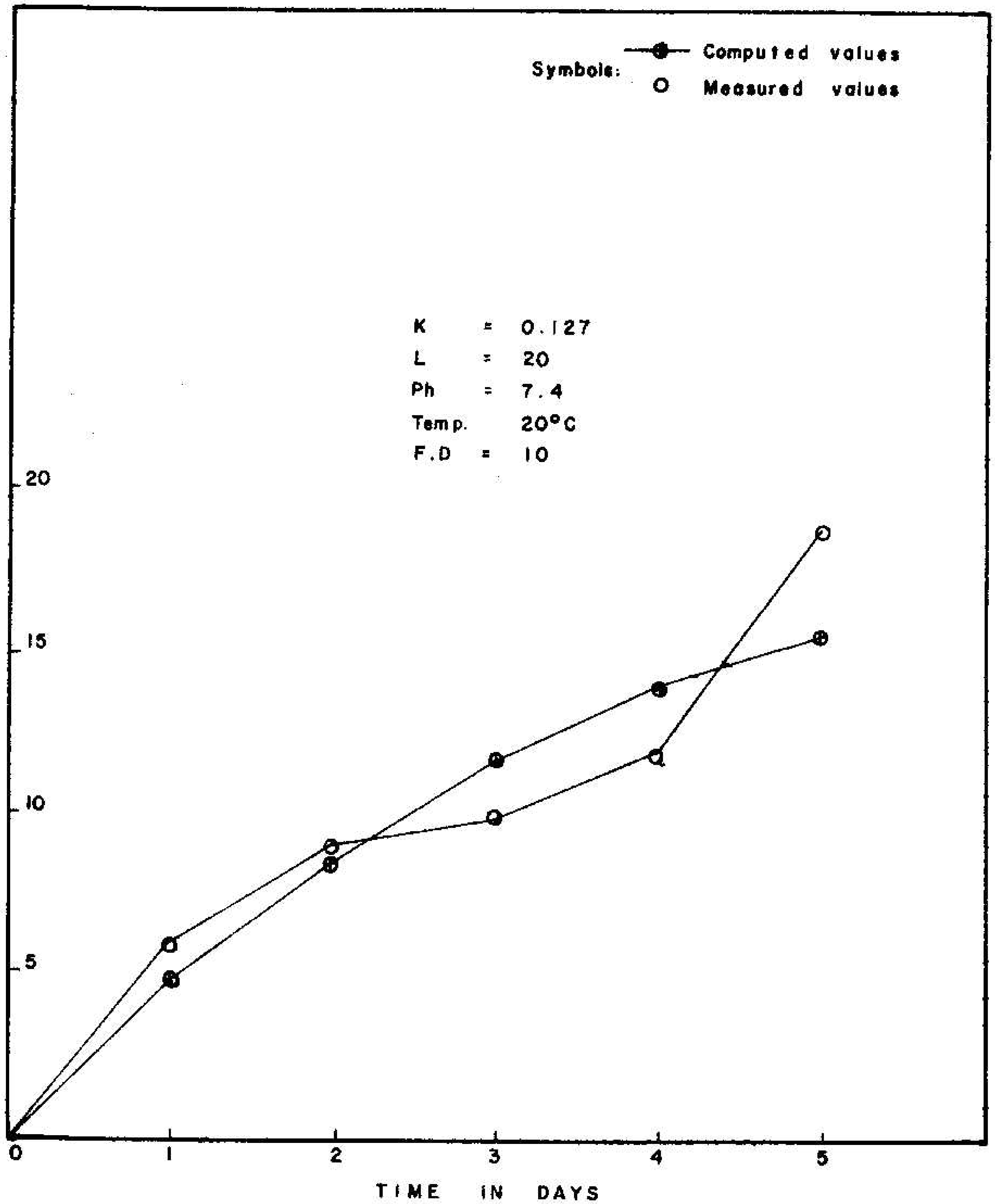

Fig 8—2 B.O.D. Curves. Town of Hormigueros. Raw Sewage Diluted in Sweet Water by a Factor of 10

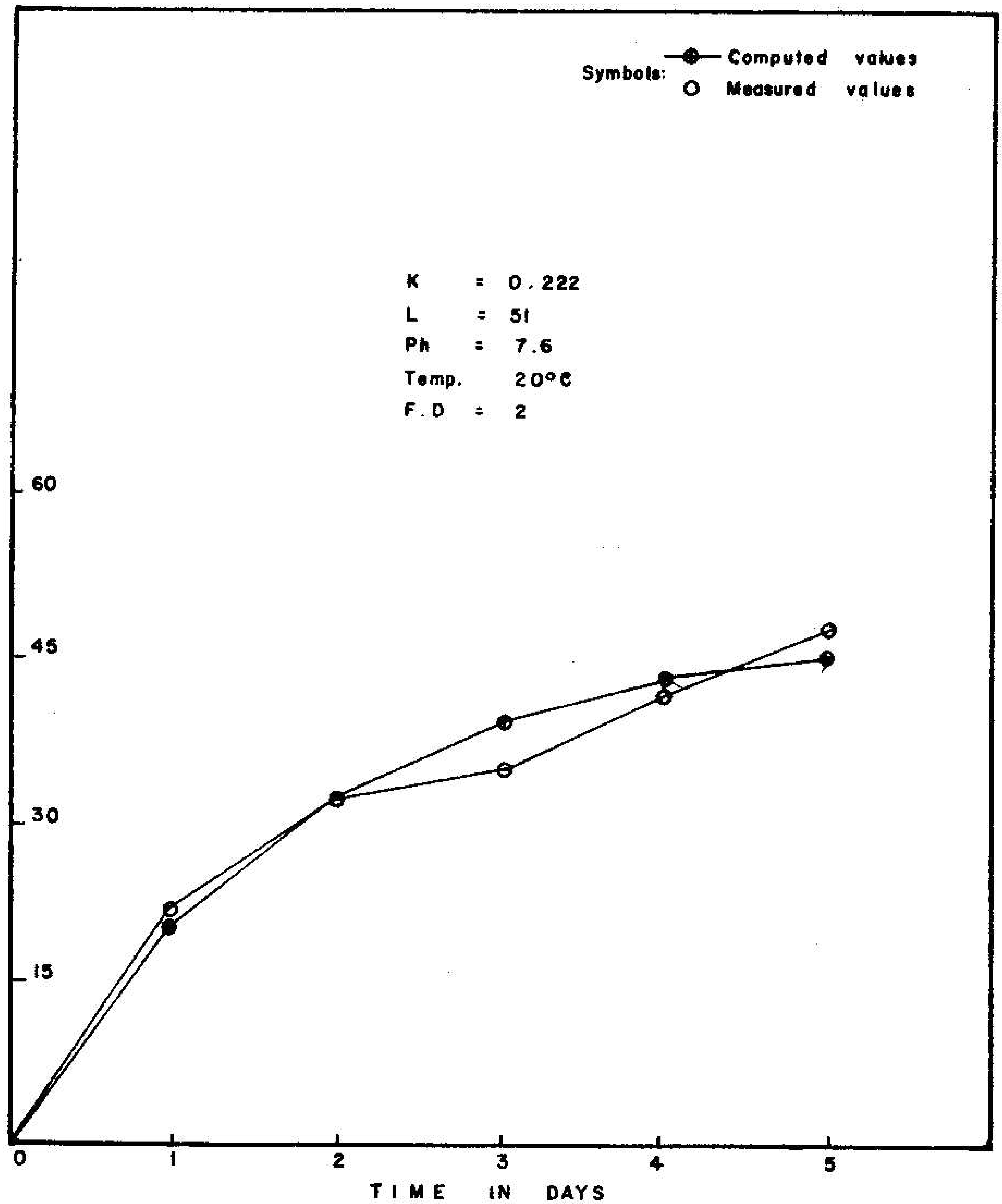

Fig 9-1 B.O.D Curves. Town of Hormigueros. Raw Sewage Diluted in Sea Water by a Factor of 2

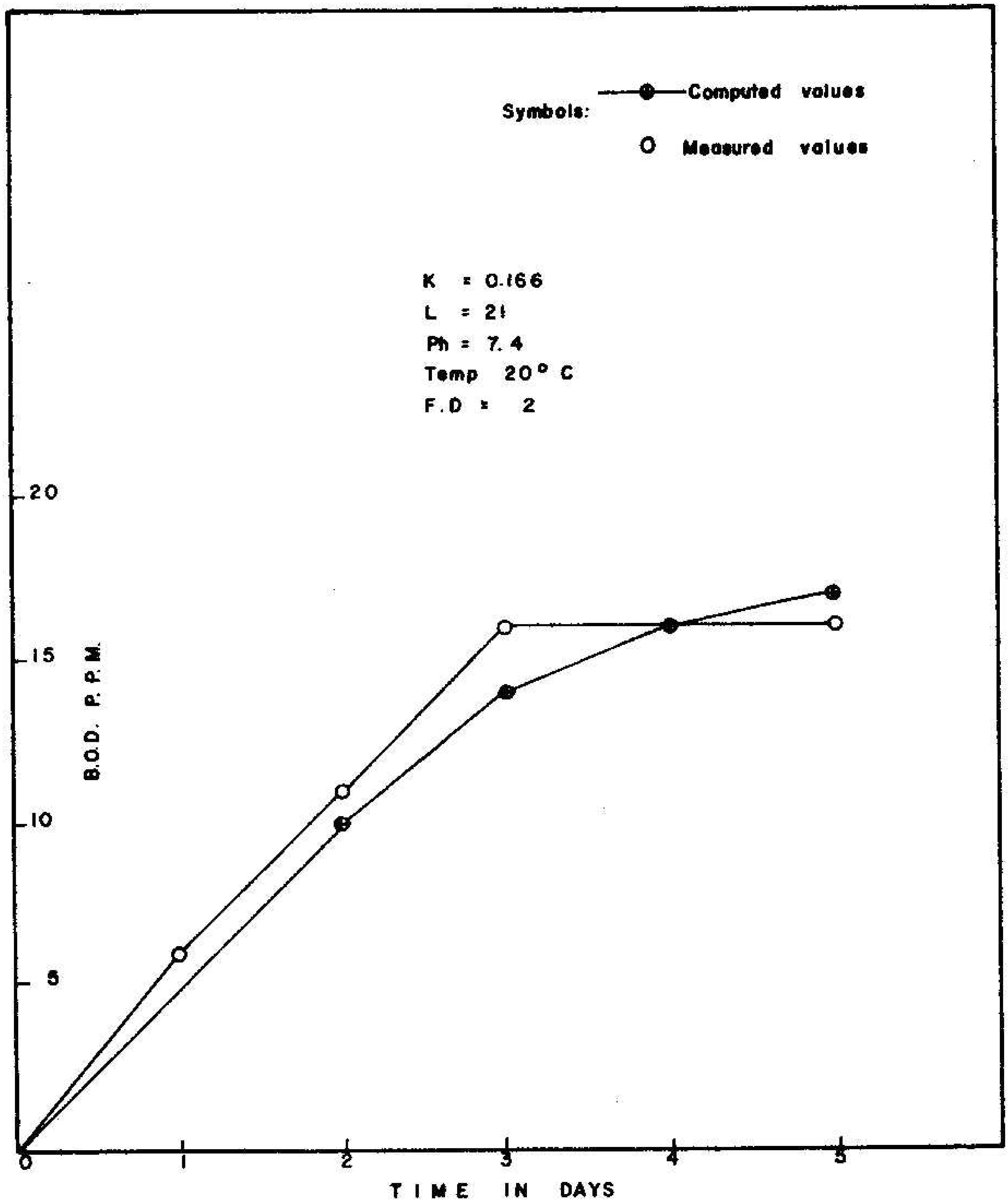

FIG 9-2 B.O.D. Curves. Town of Hormigueros. Raw Sewage Diluted in Sea Water by a Factor of 2

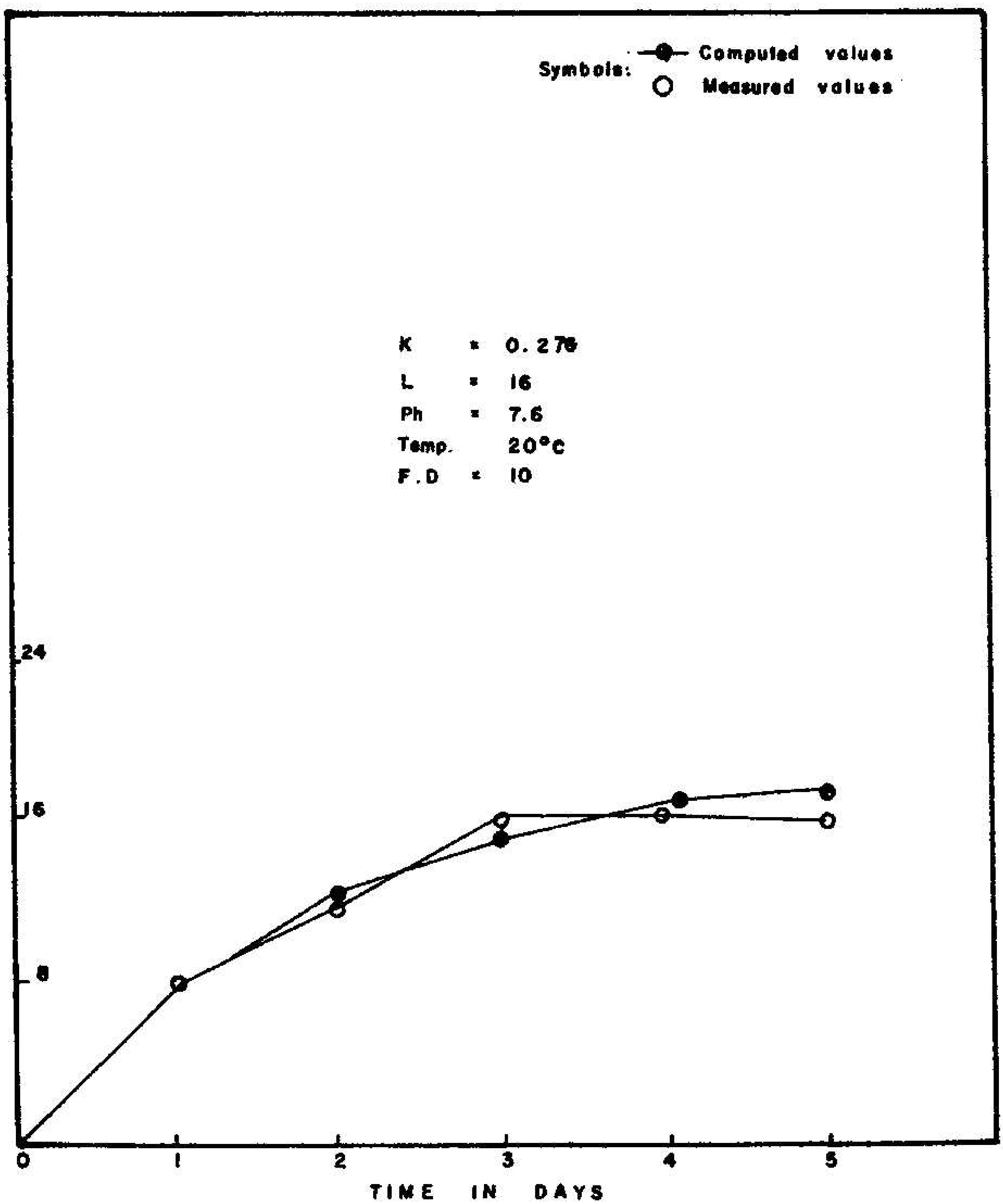

Fig 10-1 B.O.D Curves. Town of Hormigueros. Raw Sewage Diluted in Sea Water by a Factor of 10

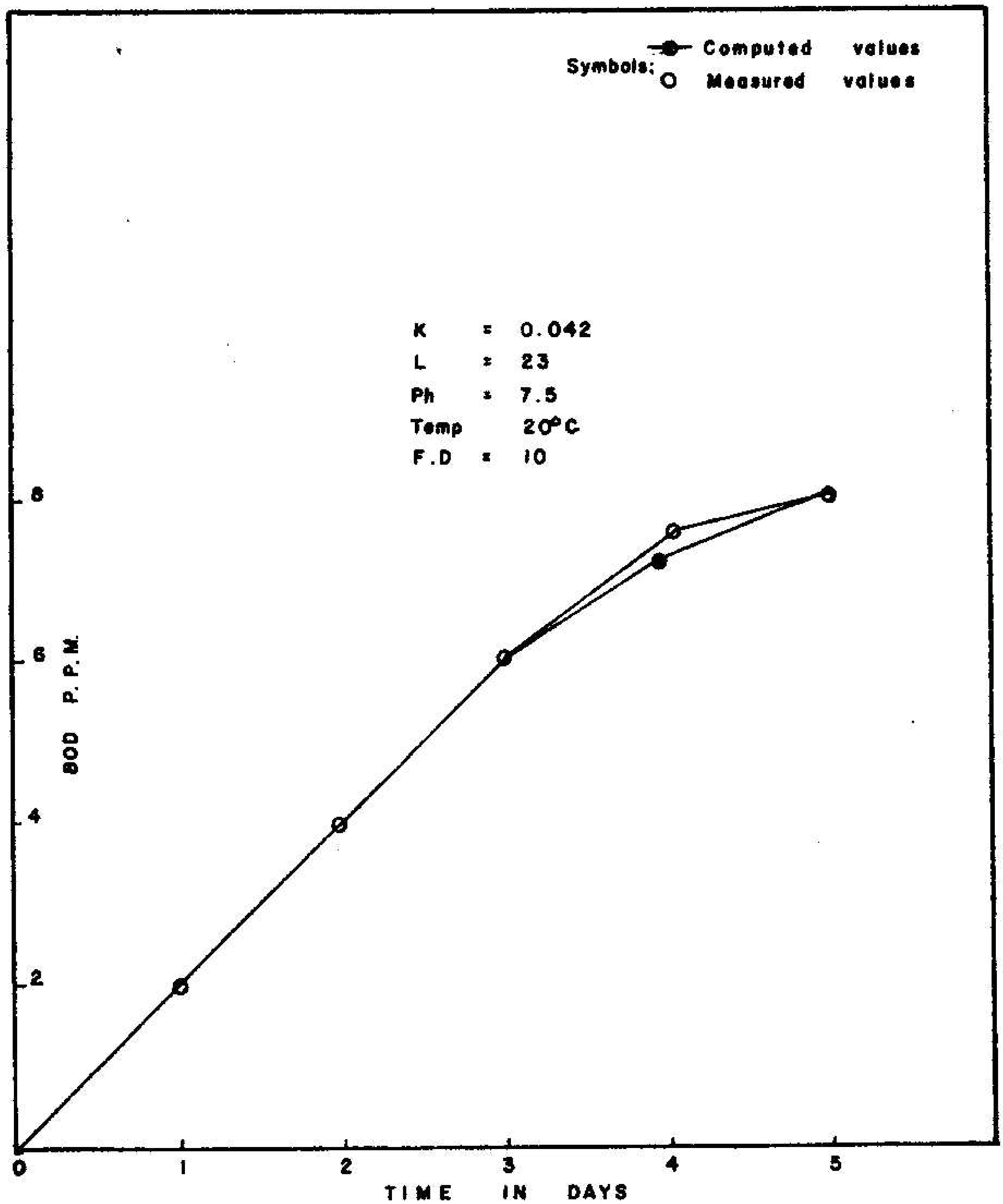

Fig 10-2 B.O.D Curves. Town of Hormigueros. Raw Sewage Diluted in Sea Water by a Factor of 10

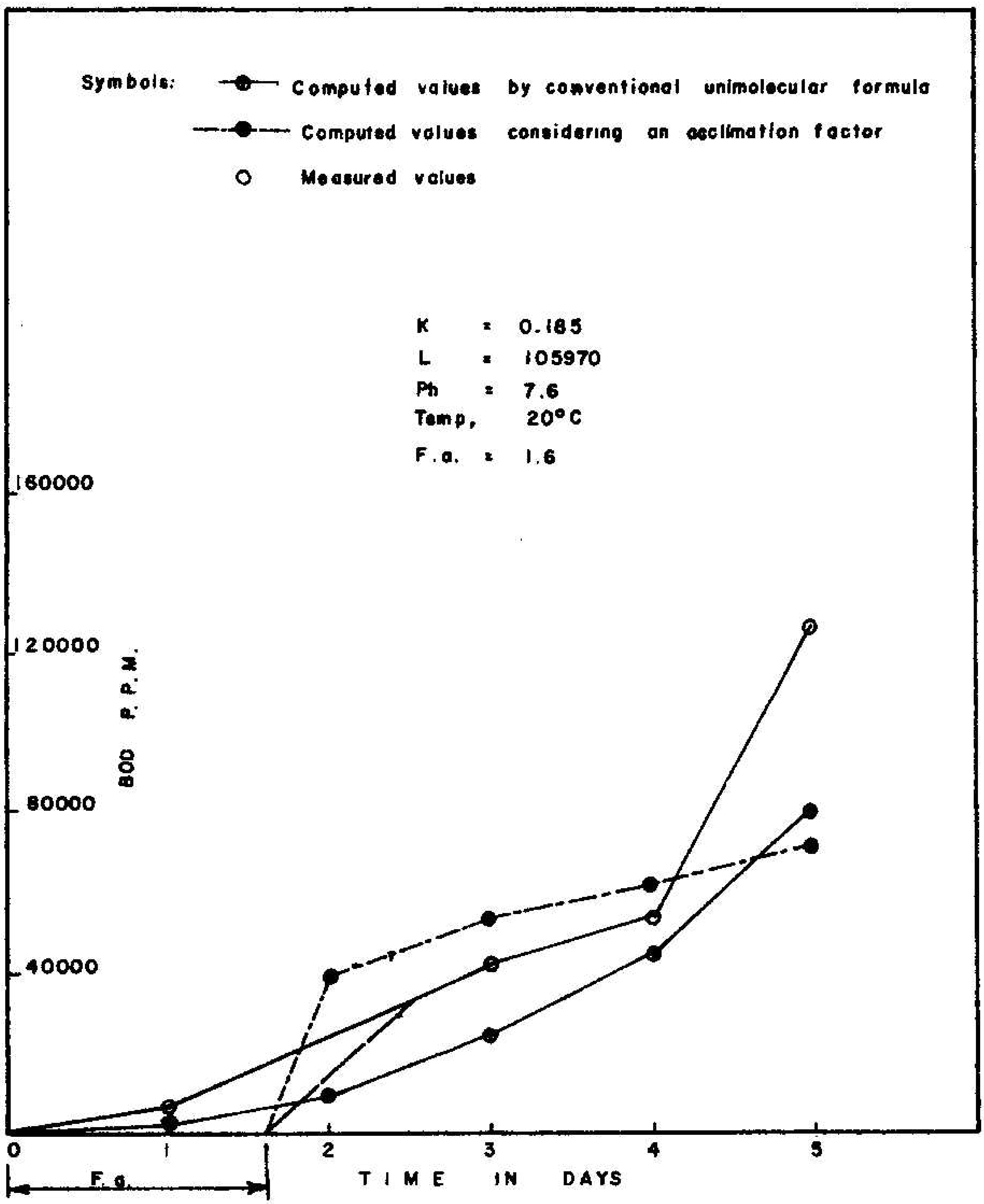

Fig II — I B.O.D. Curves. Integrated Industries Raw Waste, Undiluted.

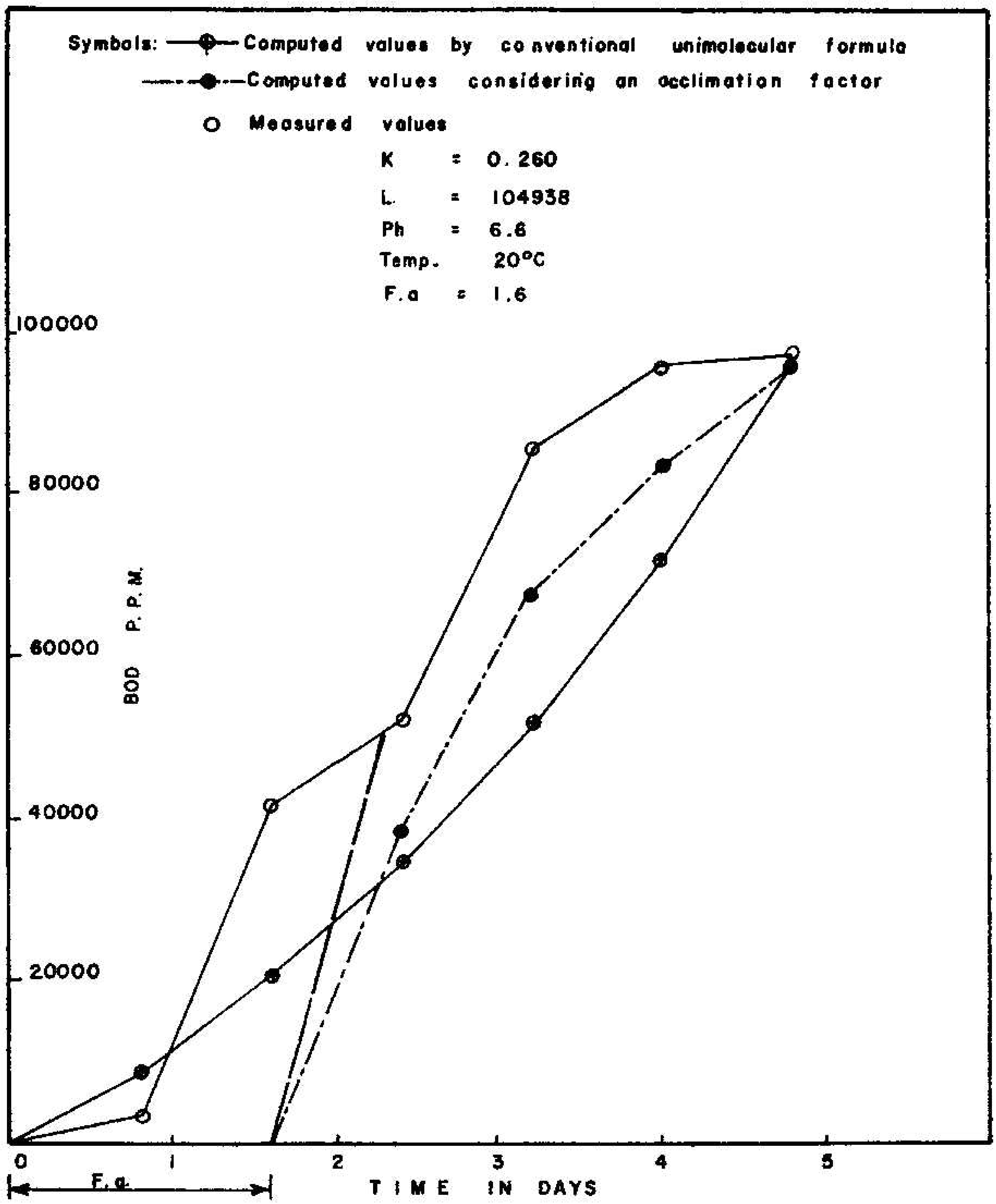

Fig II-2 B.O.D. Curves. Integrated Industries. Raw Waste, Undiluted

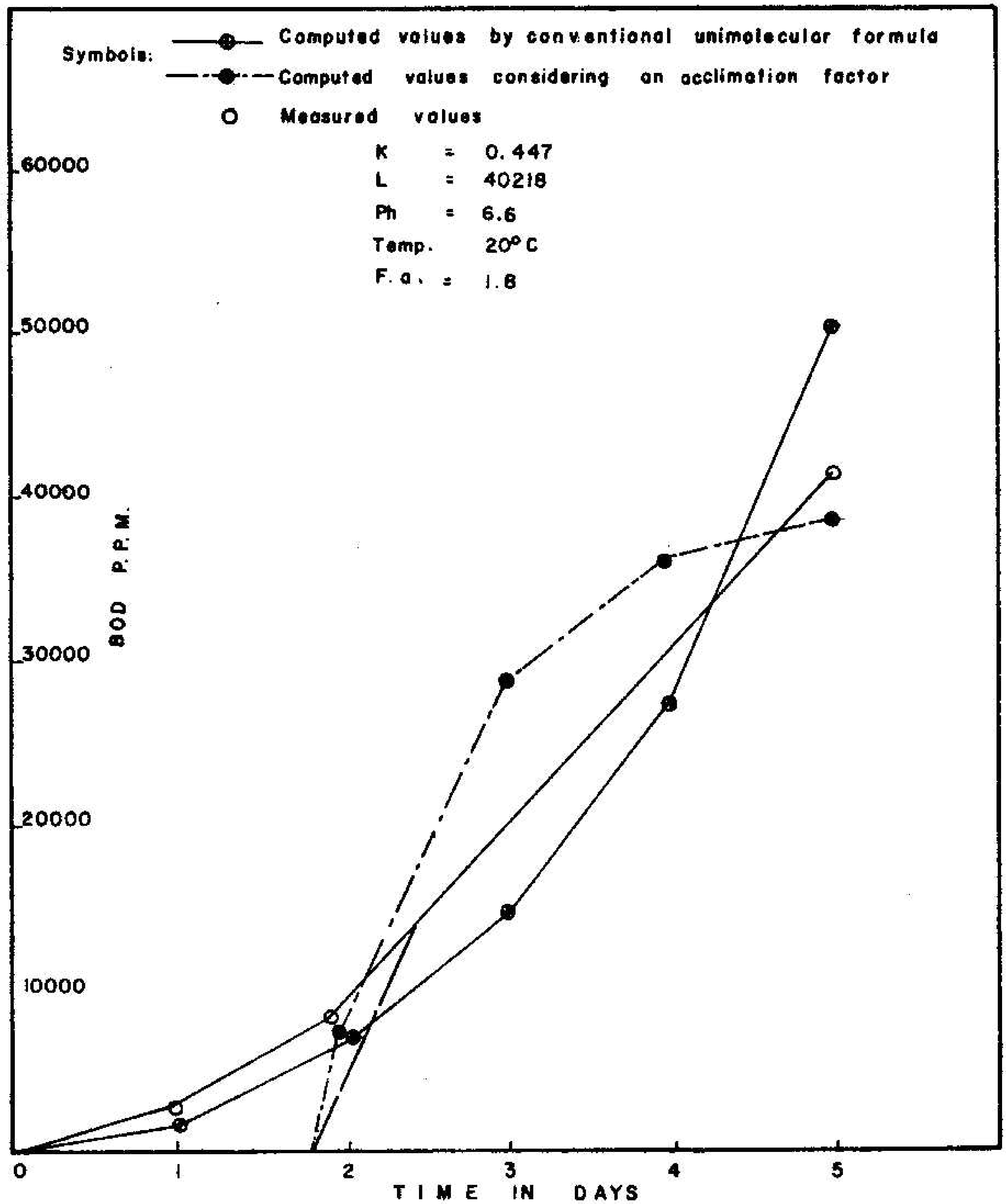

Fig II-3 B.O.D. Curves. Integrated Industries
Raw Waste, Undiluted

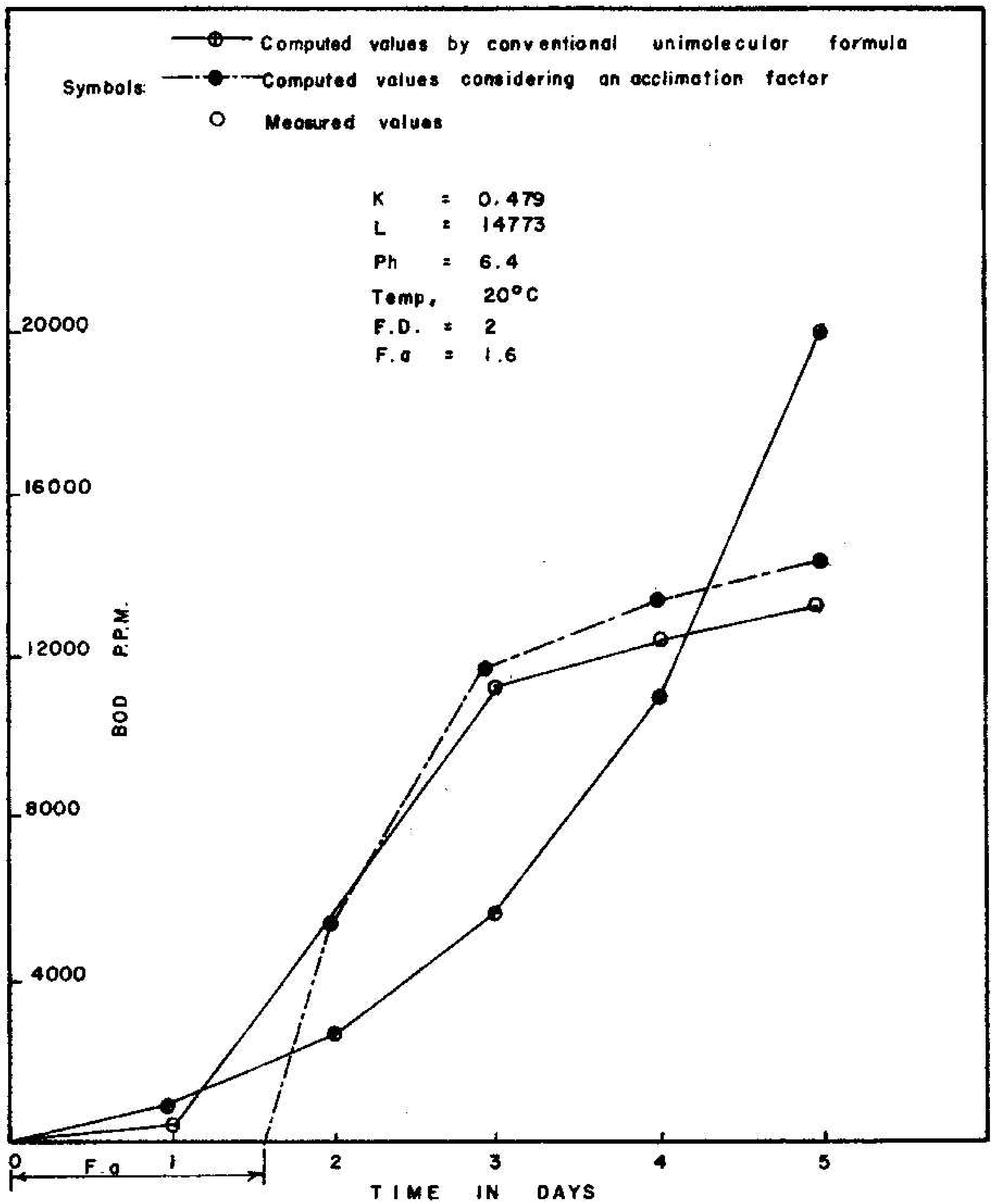

Fig 12-1 B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sweet Water by a Factor of 2

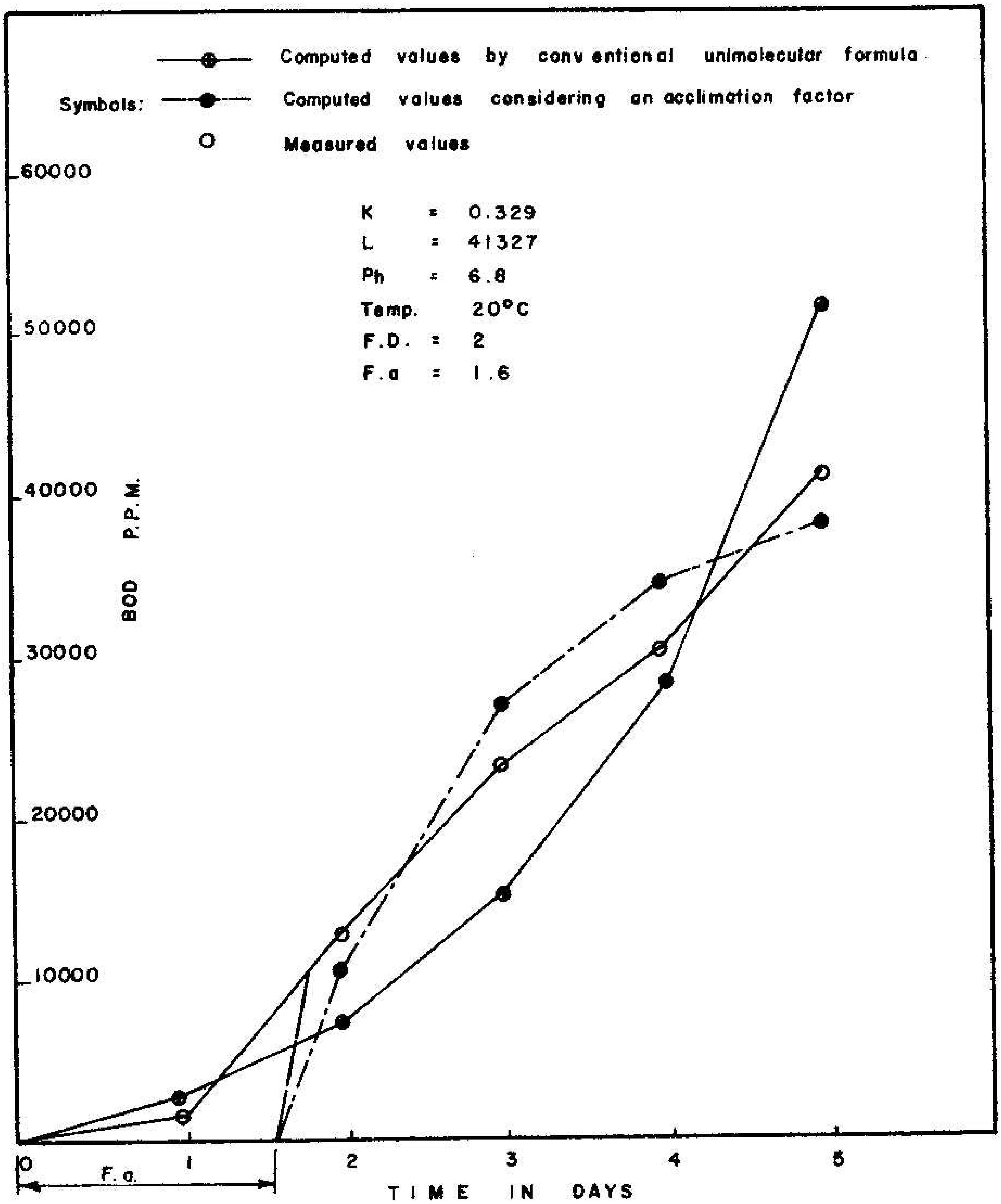

Fig 12 - 2 B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sweet Water by a Factor of 2

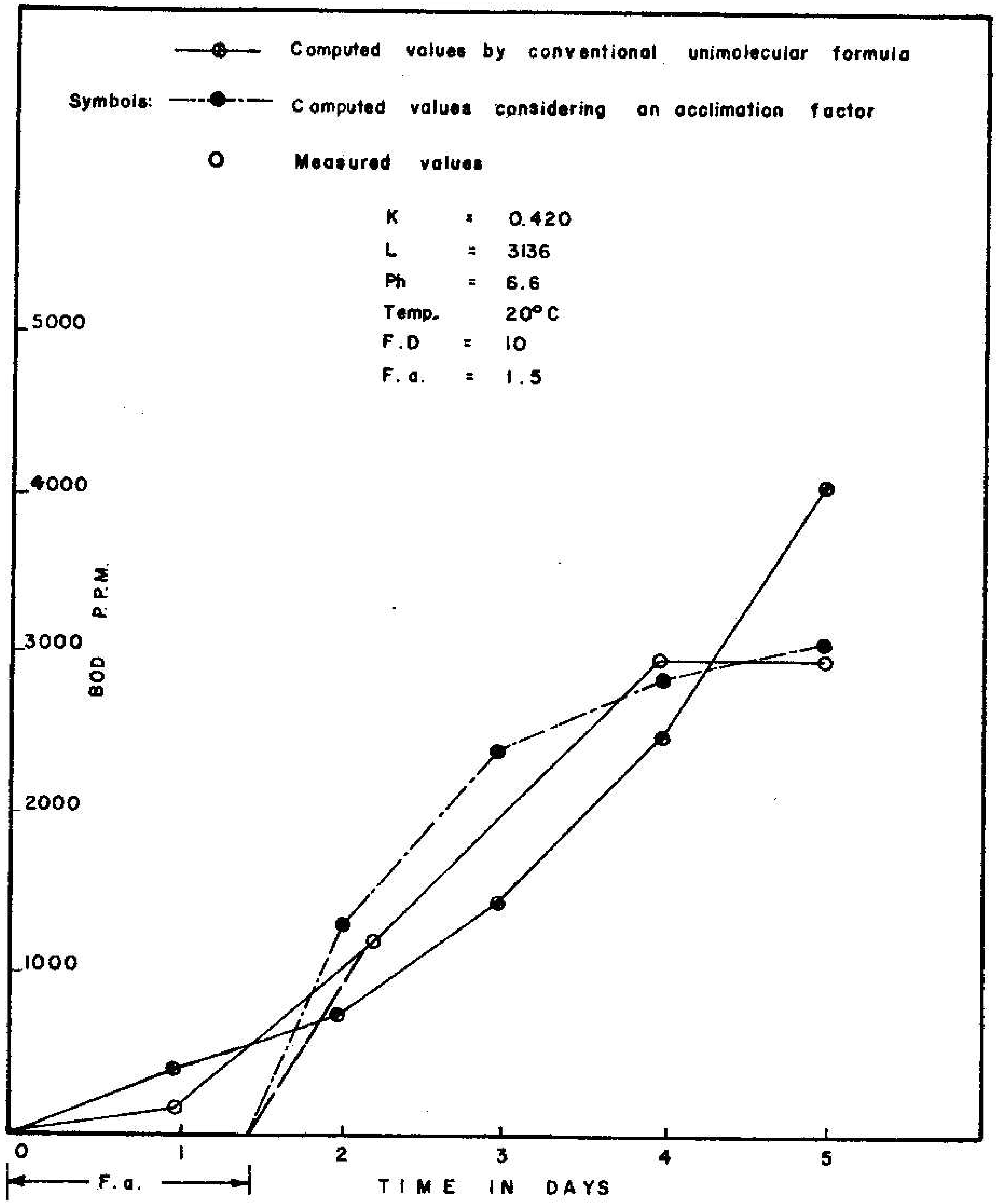

Fig 13 – I B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sweet Water by a Factor of 10

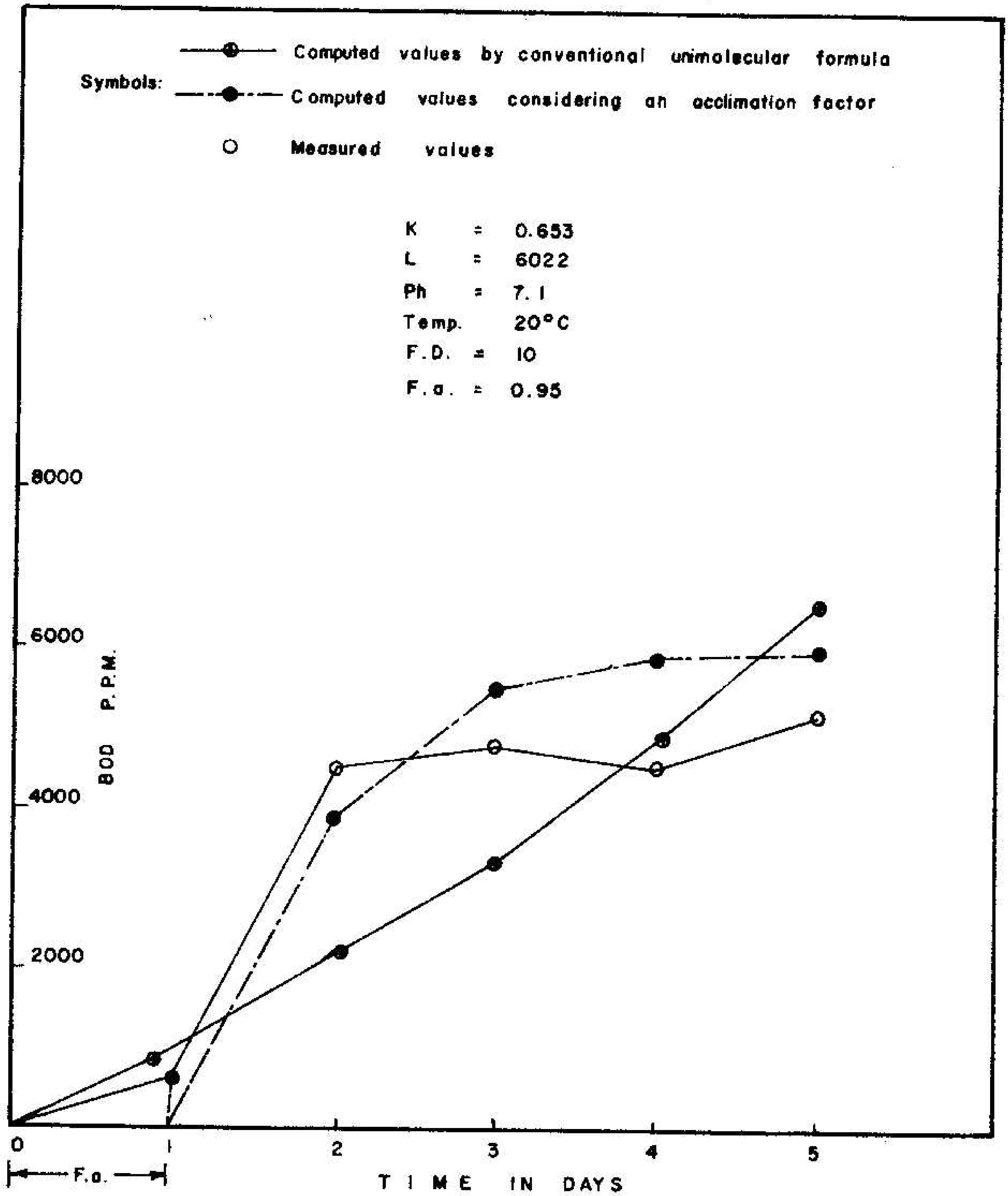

Fig 13 - 2 B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sweet Water by a Factor of 10

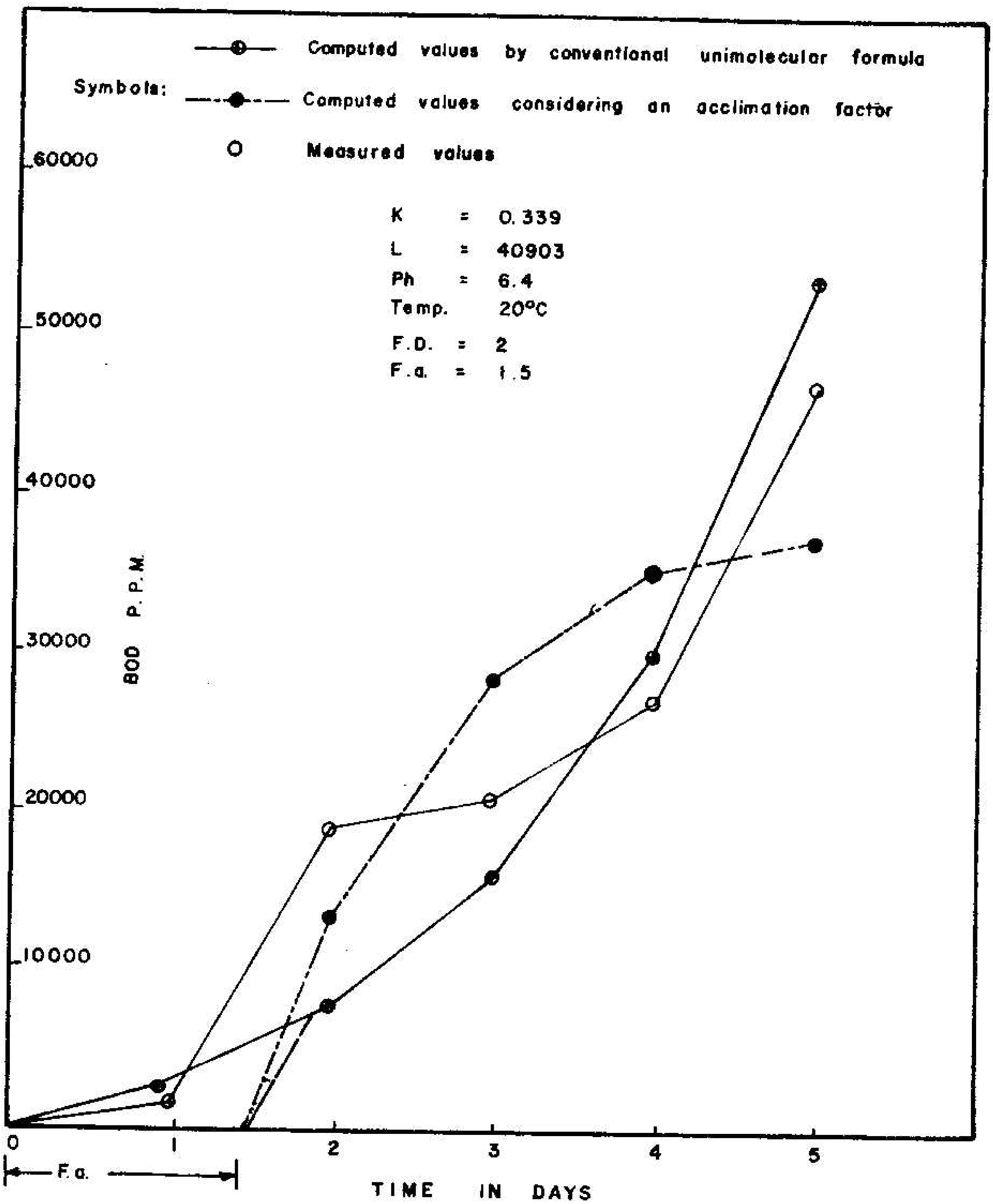

Fig 14-1 B.O.D Curves. Integrated Industries. Raw Waste Diluted in Sea Water by a Factor of 2

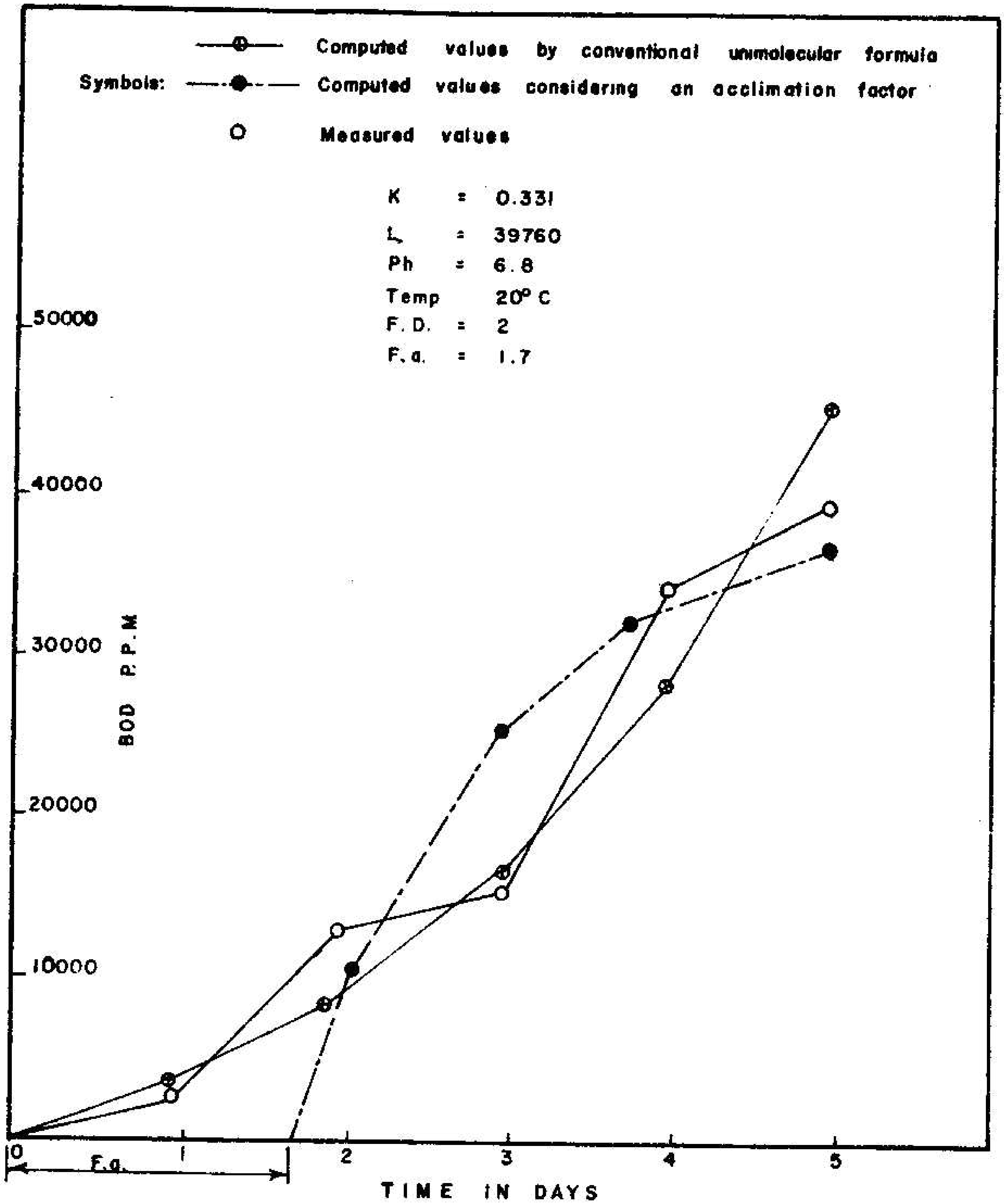

Fig 14 — 2 B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sea Water by a Factor 2

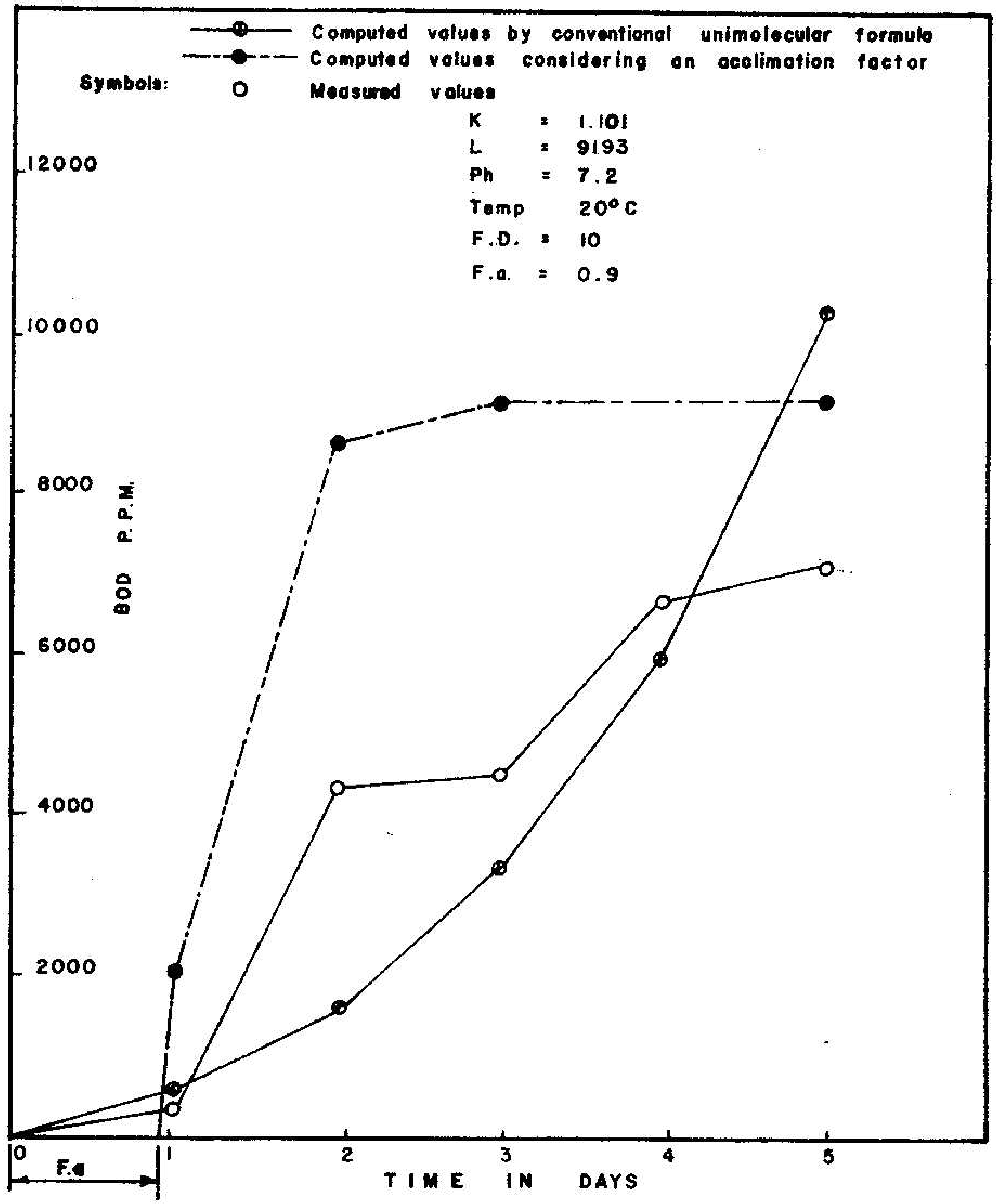

Fig 15-1 B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sea Water by a Factor of 10

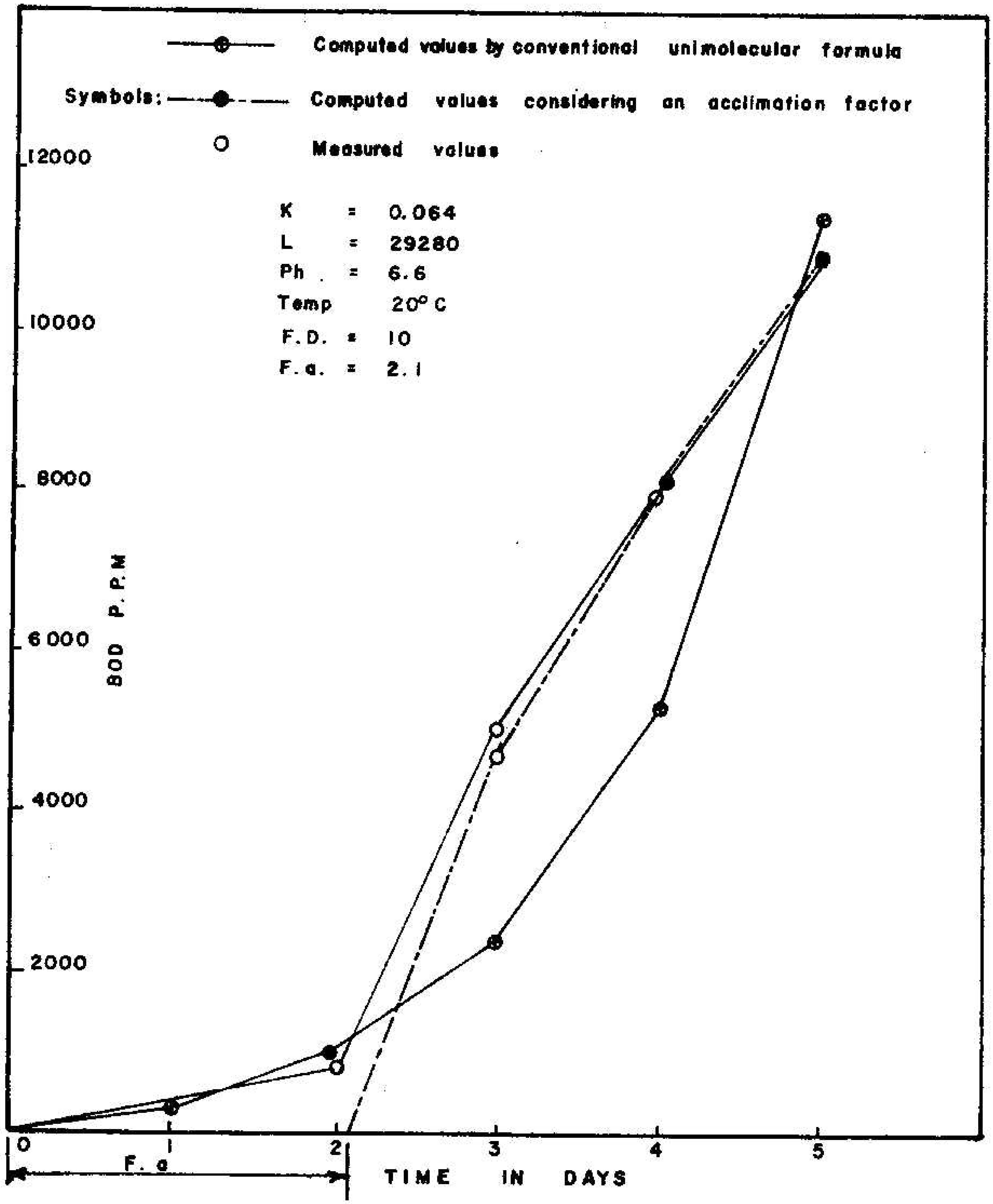

Fig 15- 2 B.O.D. Curves. Integrated Industries. Raw Waste Diluted in Sea Water by a Factor of 10

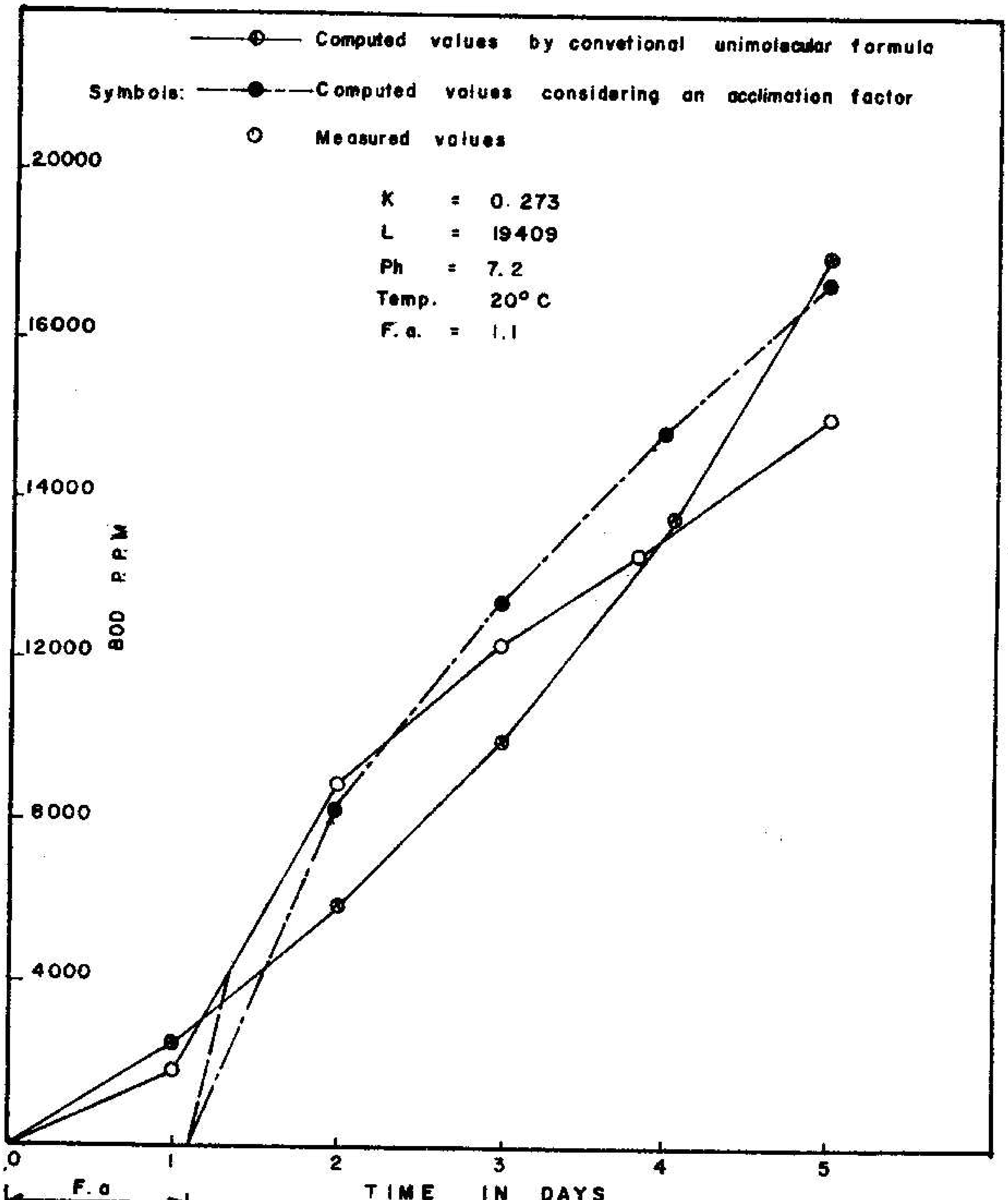

Fig 16-1 B.O.D. Curves. Caribe Feed. Raw Waste, Undiluted.

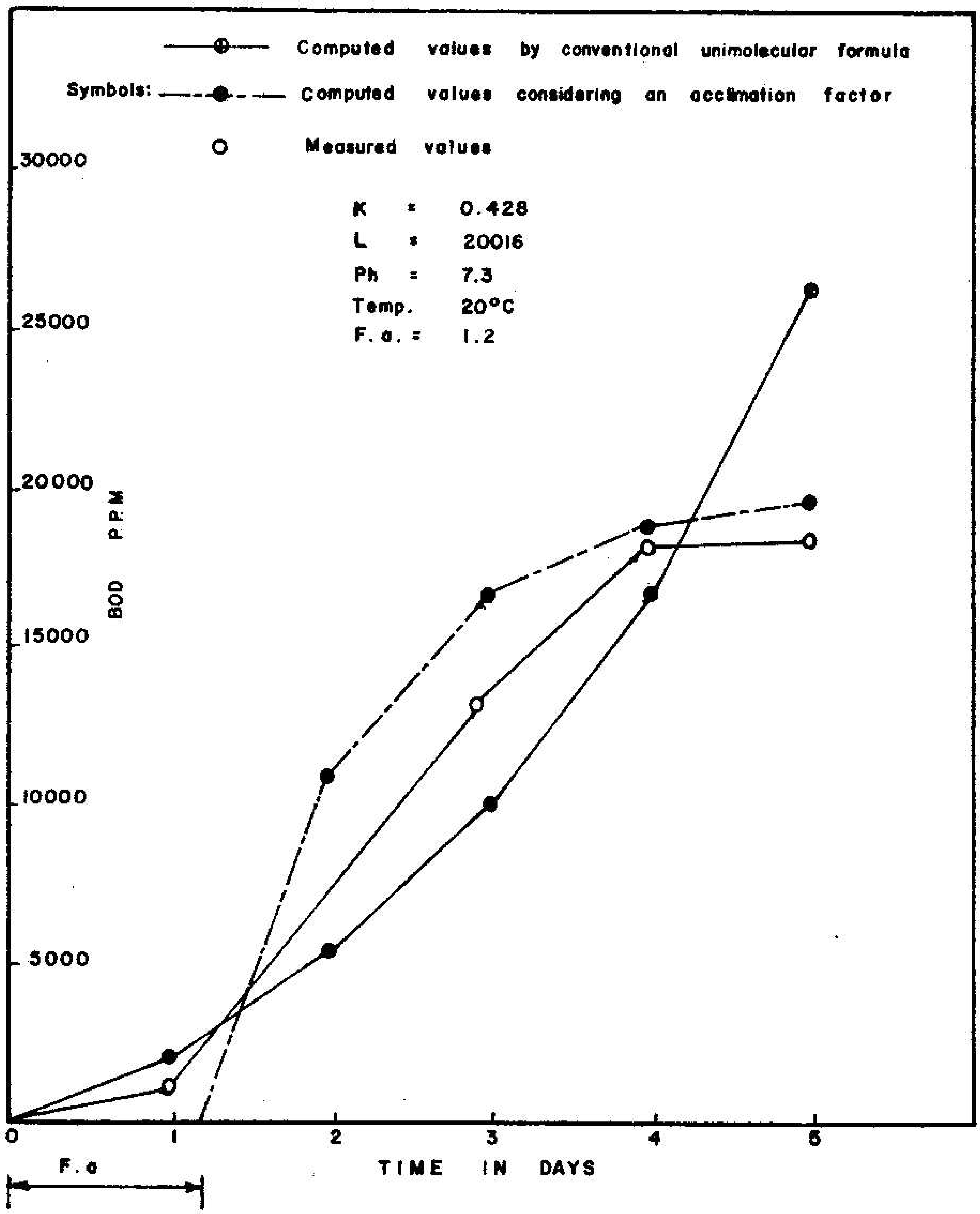

Fig 16— 2 B.O.D. Curves. Caribe Feed. Raw Waste, Undiluted.

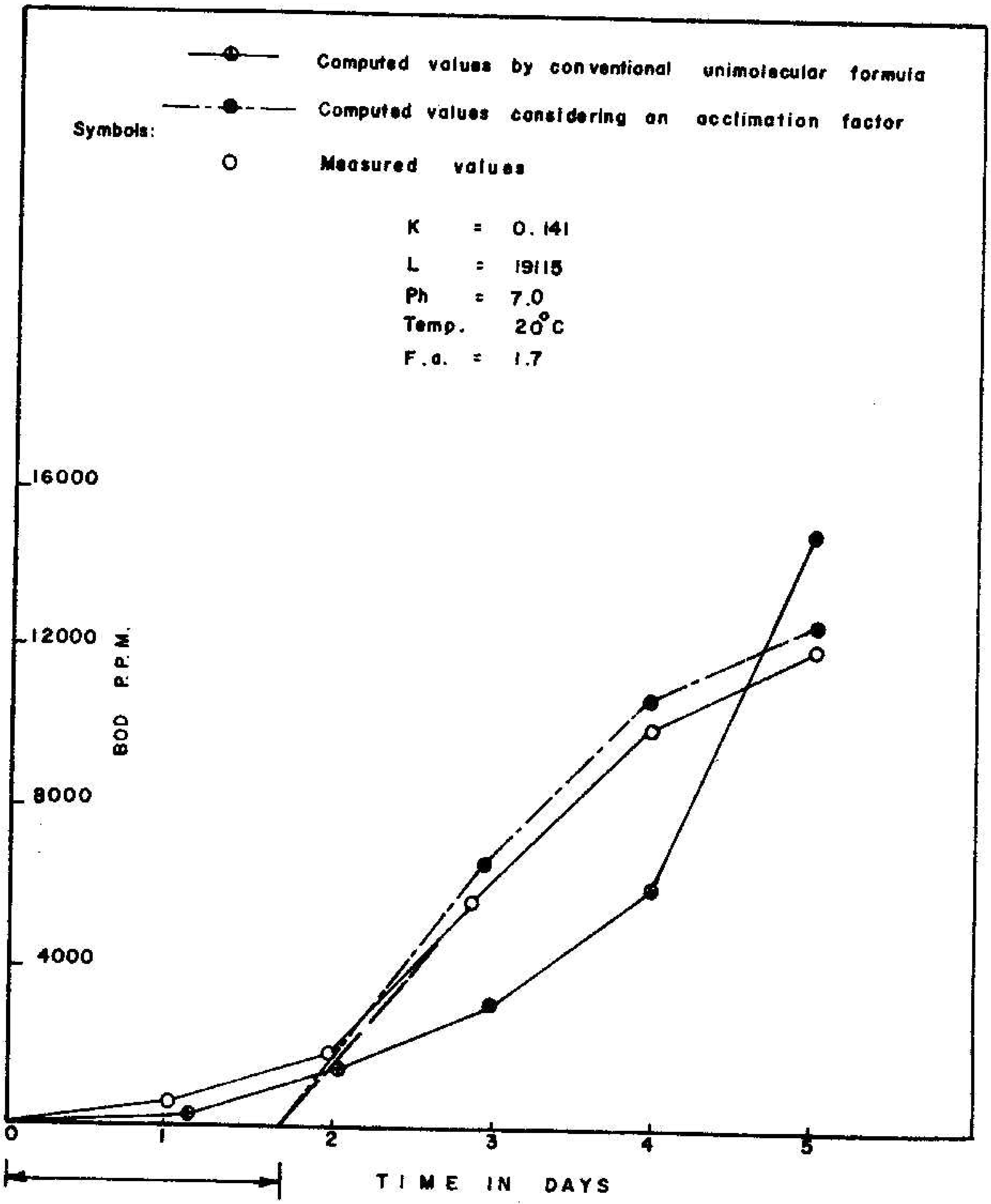

Fig 16—3 B.O.D. Curves. Carive Feed. Raw Waste Undulited.

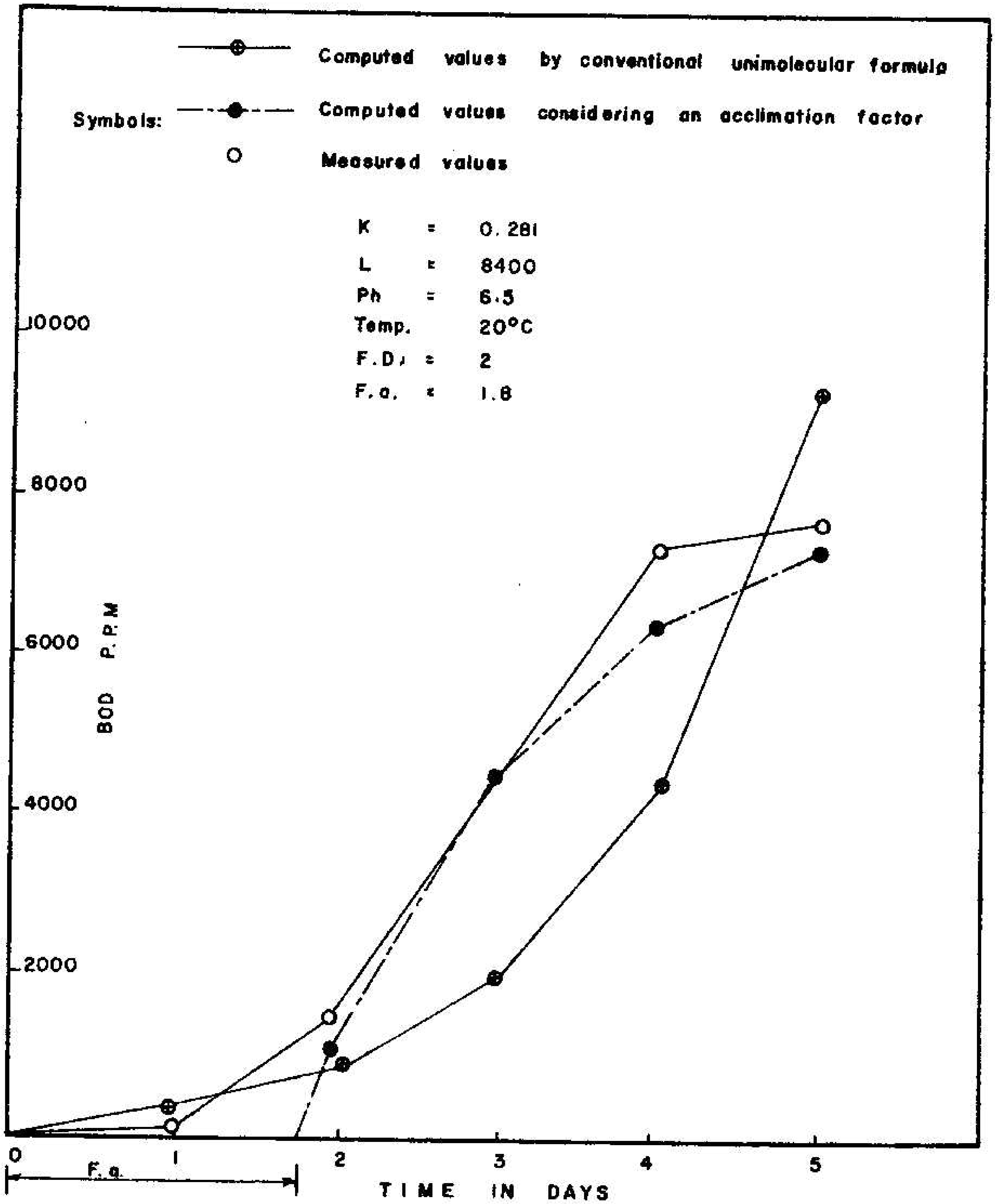

Fig 17-1 B.O.D. Curves. Caribe Feed. Raw Waste Diluted in Sweet Water by a Factor of 2

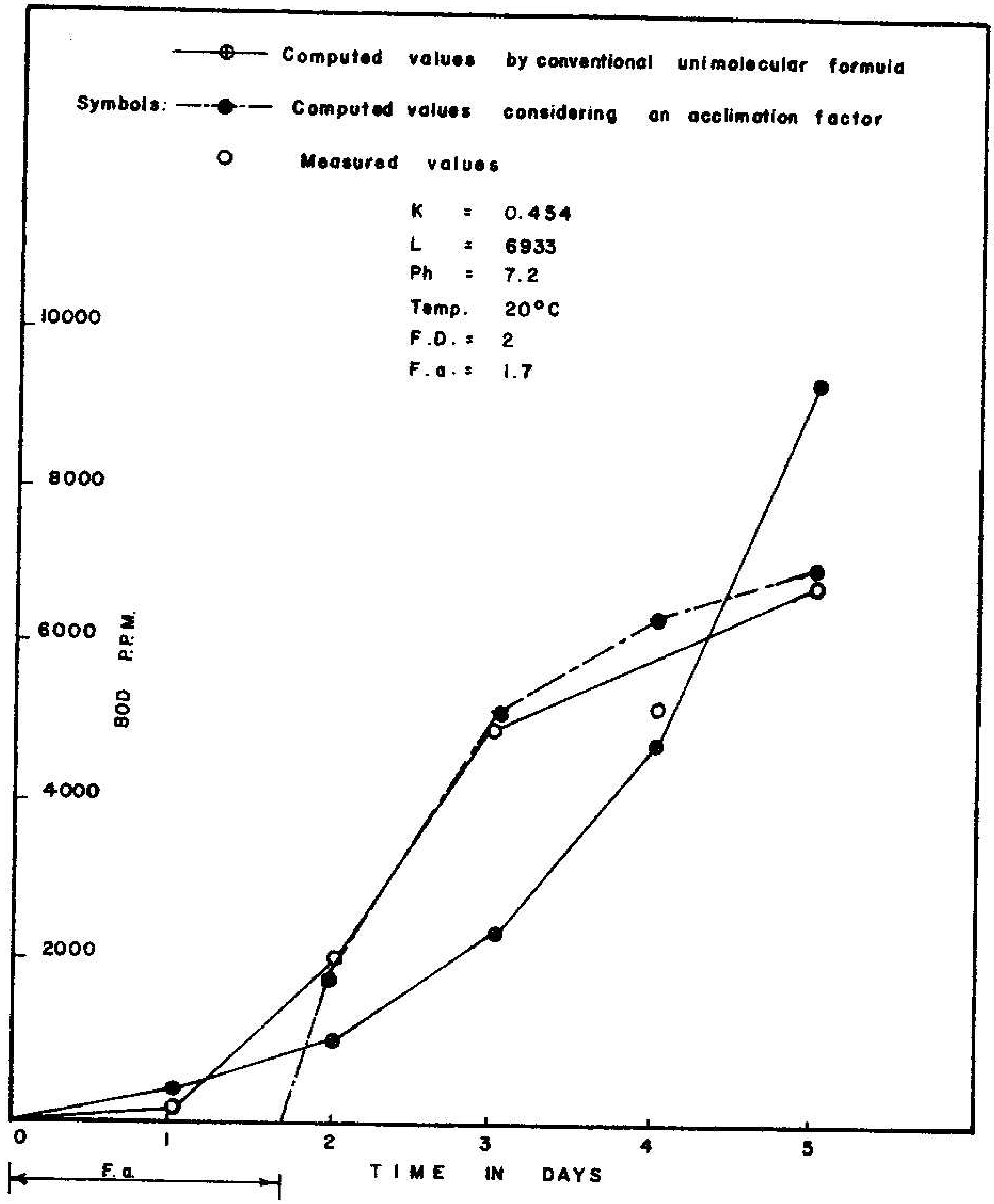

Fig 17- 2 B.O.D. Curves. Caribe Feed. Raw Waste Diluted in Sweet Water by a Factor of 2

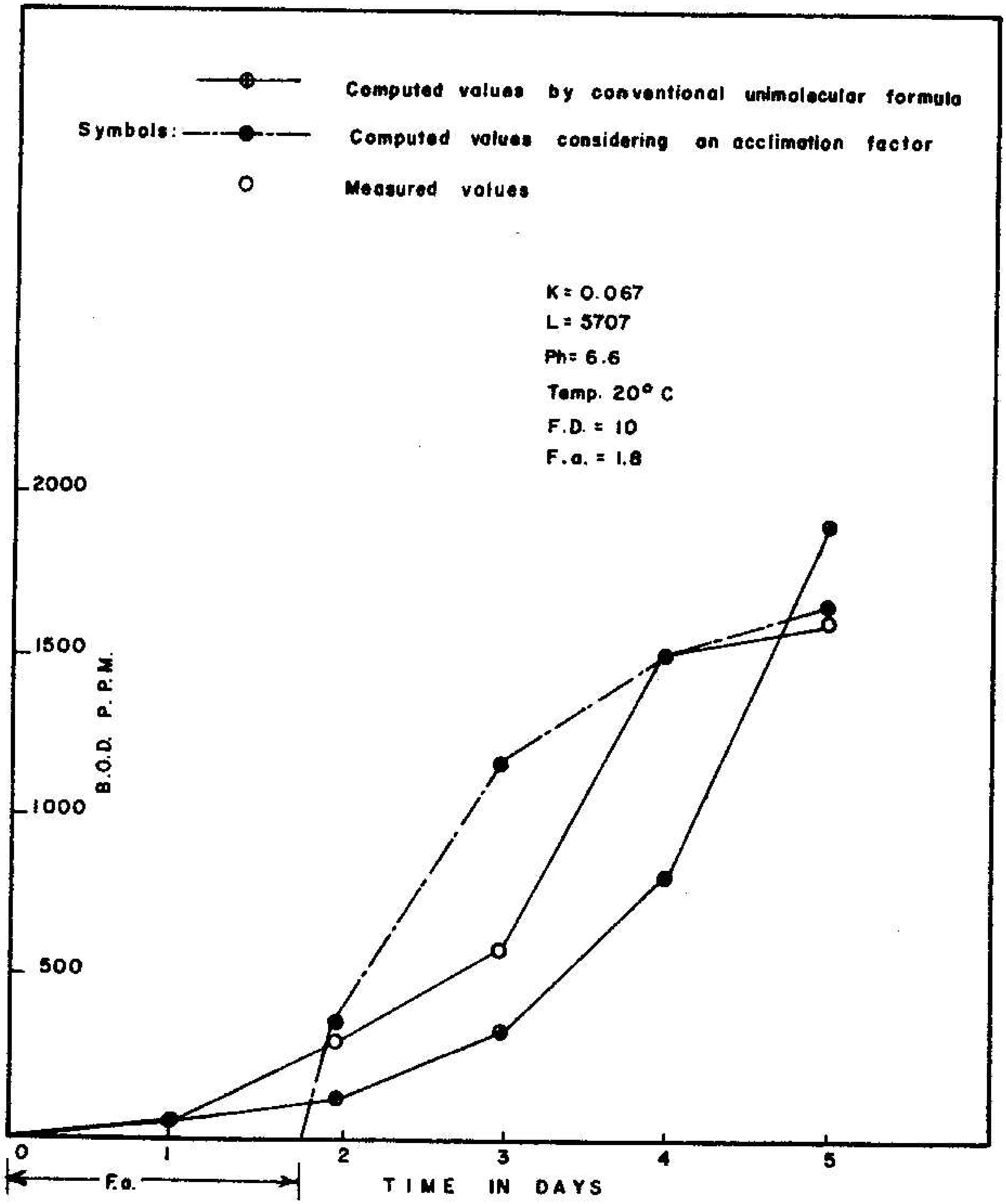

Fig 18—1 B.O.D. Curves. Caribe Feed Co. Wastewater diluted in Sweet Water by a Factor of 10.

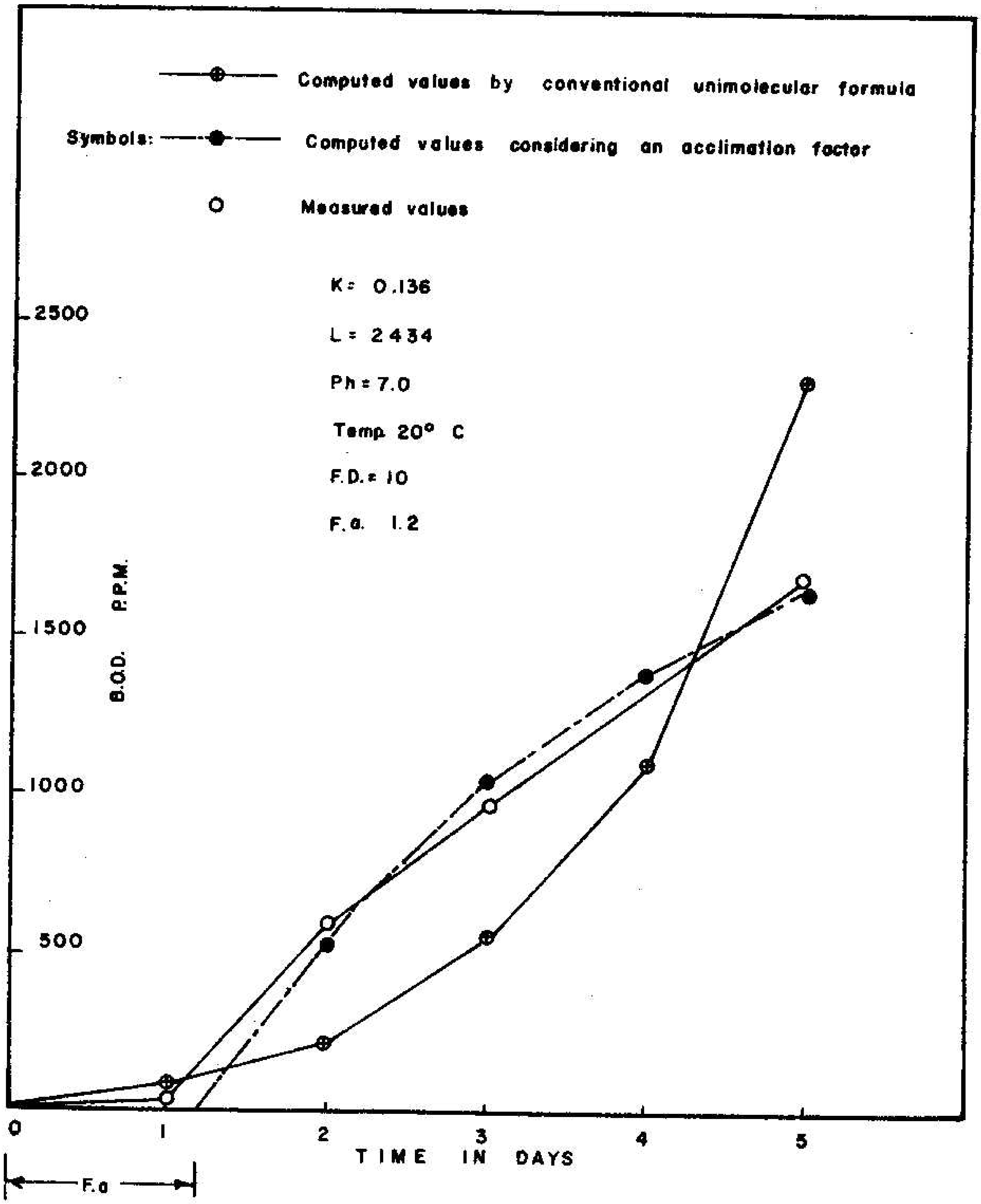

Fig 18-2 B.O.D. Curves. Caribe Feed Co. Wastewater diluted in Sweet Water by a Factor of 10

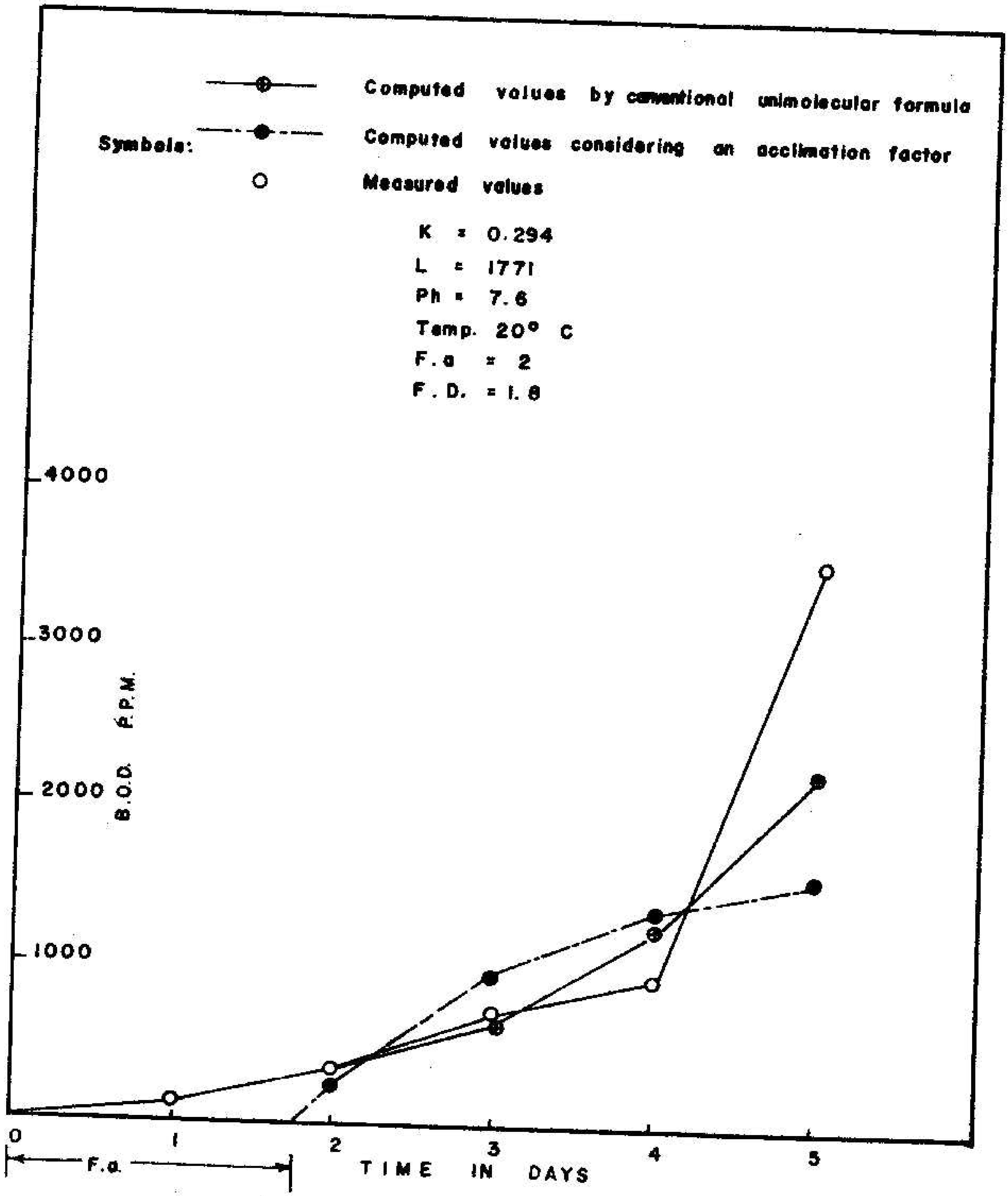

Fig 19-1 B.O.D. Curves. Caribe Feed Co. Wastewater diluted in Sea Water by a Factor of 2

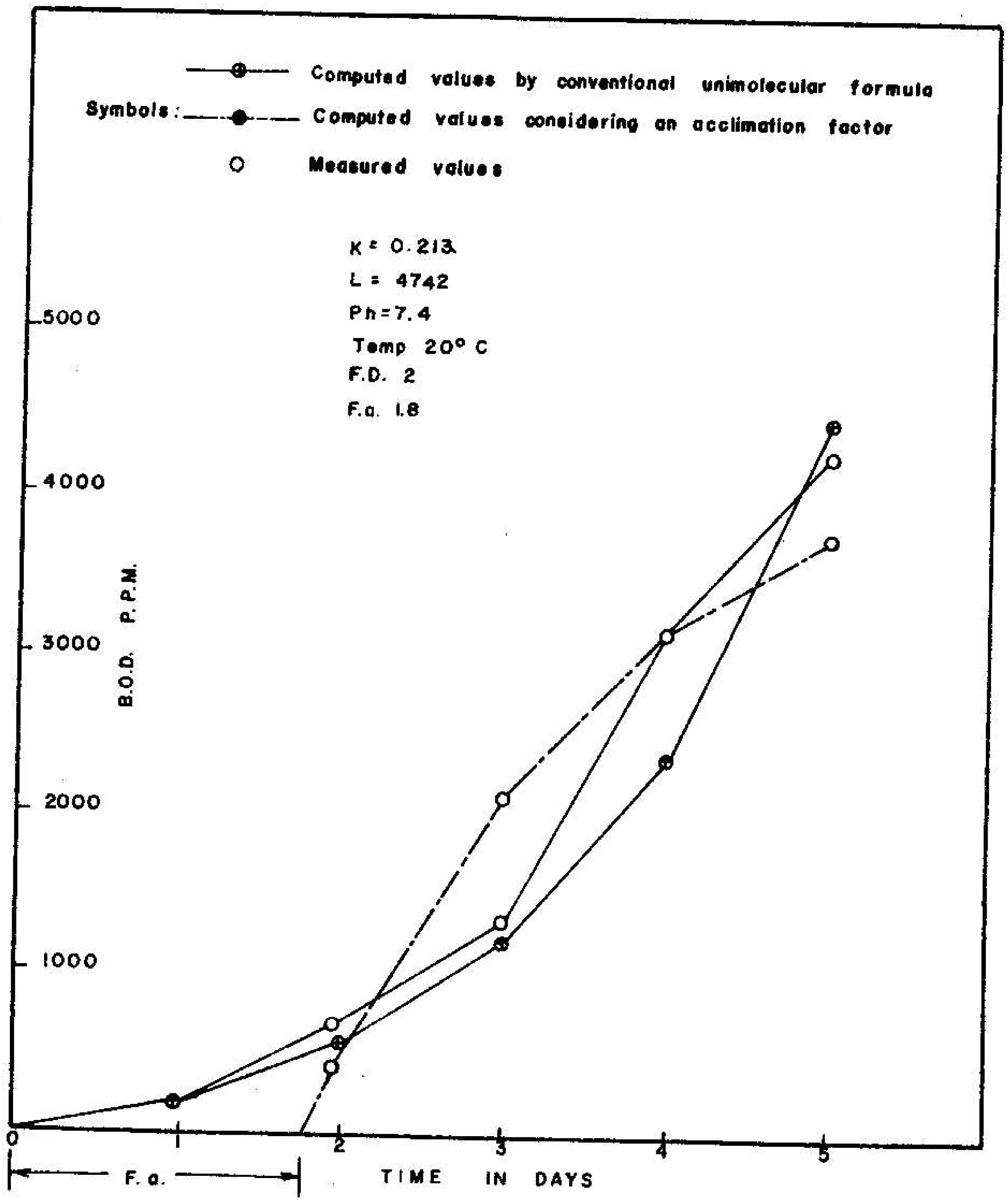

Fig 19-2 B.O.D. Curves. Caribe Feed Co. Wastewater diluted in Sea Water by a Factor of 2

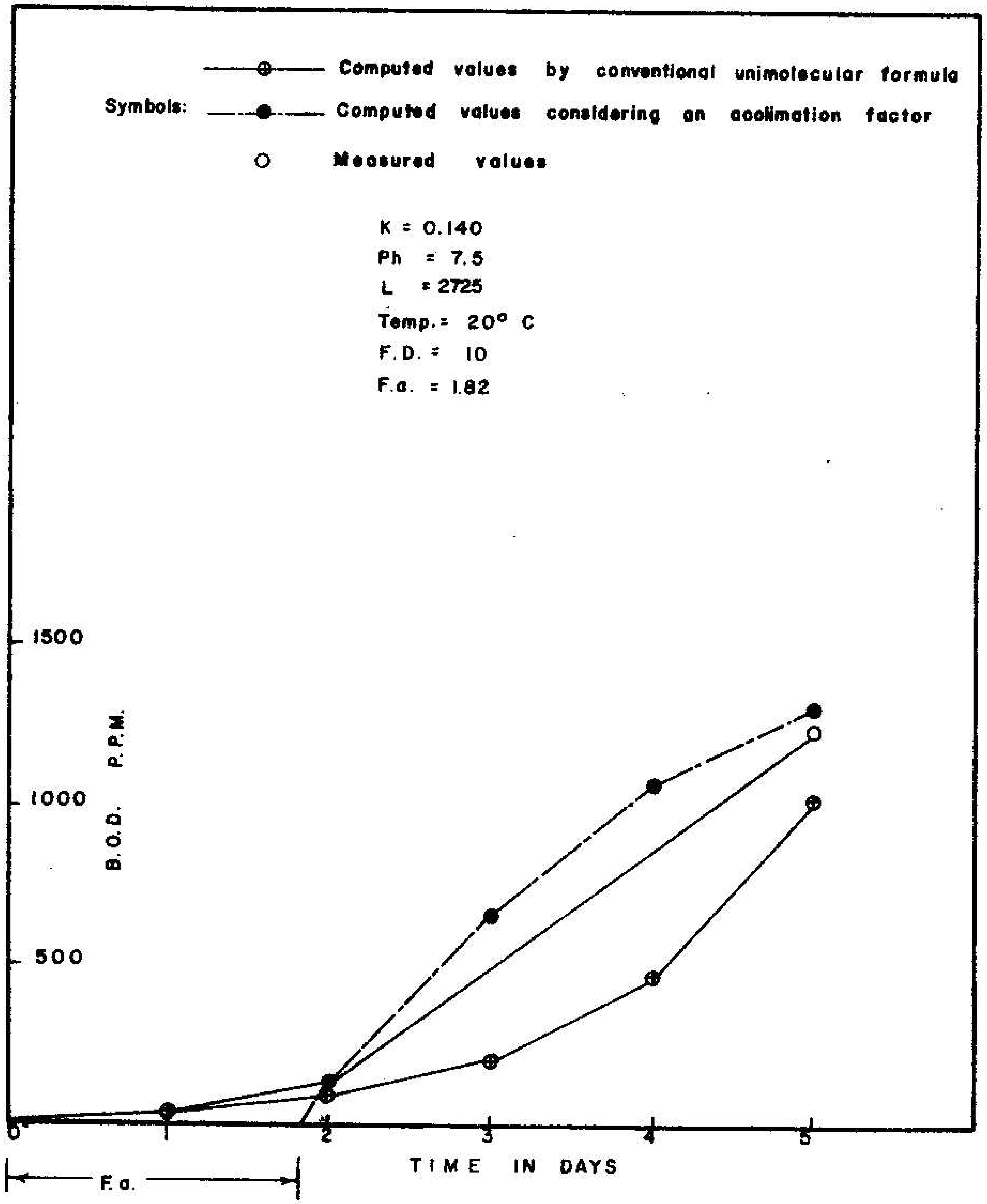

Fig 20-1 B.O.D. Curves. Caribe Feed Co. Wastewater diluted in Sea Water by a Factor of 10

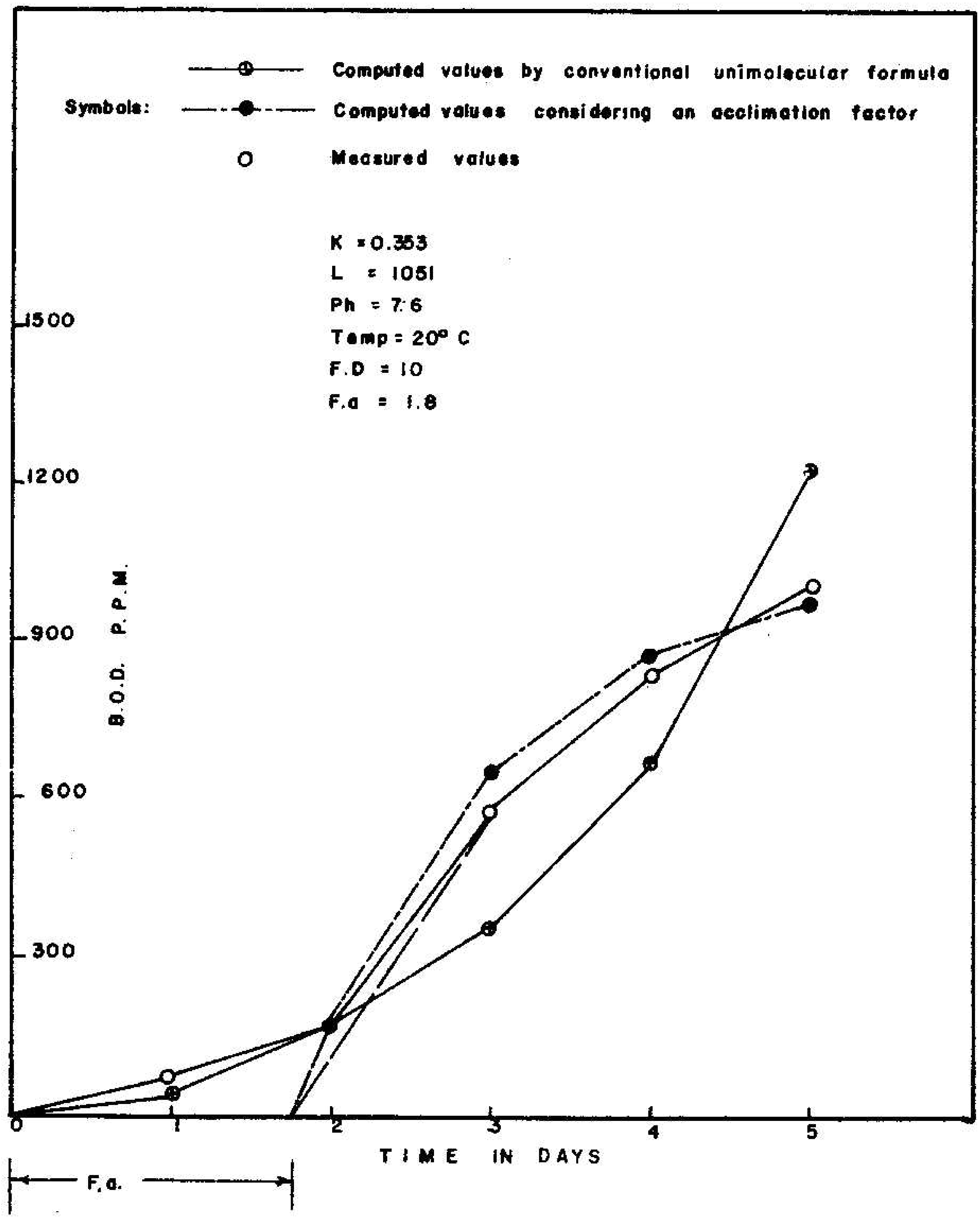

Fig 20-2 B.O.D. Curves. Caribe Feed Co. Wastewater diluted in Sea Water by a Factor of 10

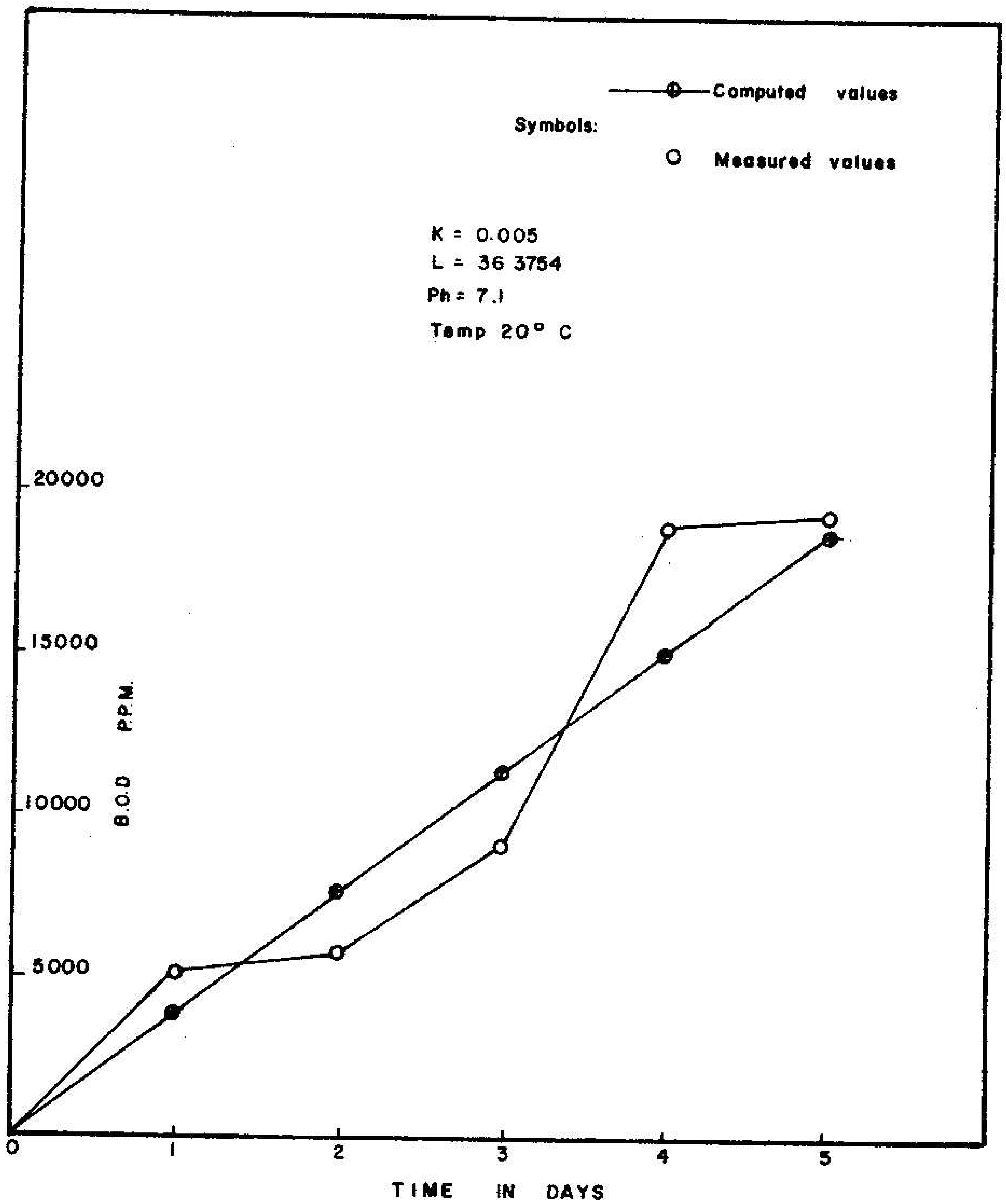

Fig 21-1 B.O.D. Curves. India Brewery. Undiluted raw wastewater.

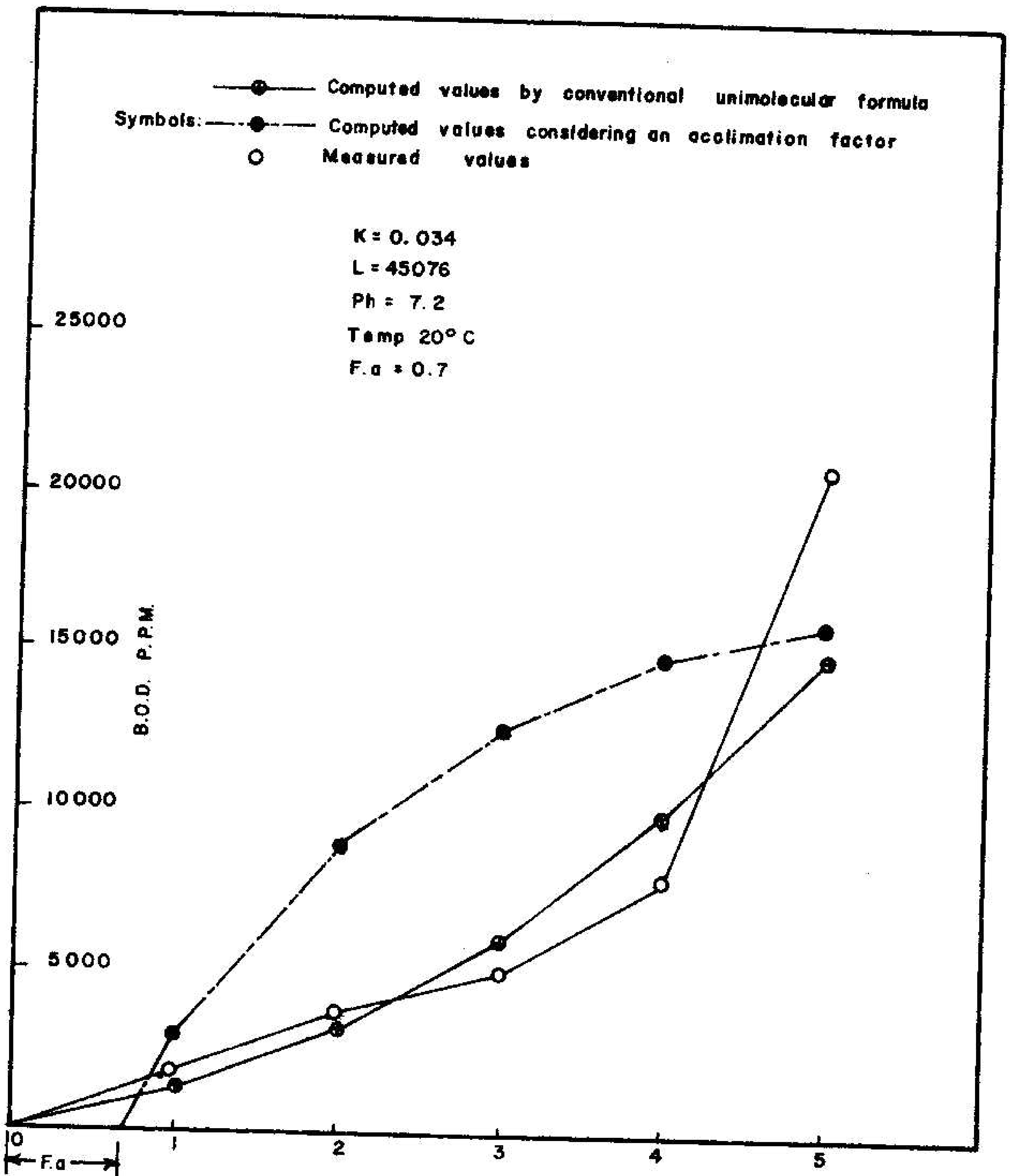

Fig 21-2 B.O.D Curves. India Brewery. Undiluted raw wastewater.

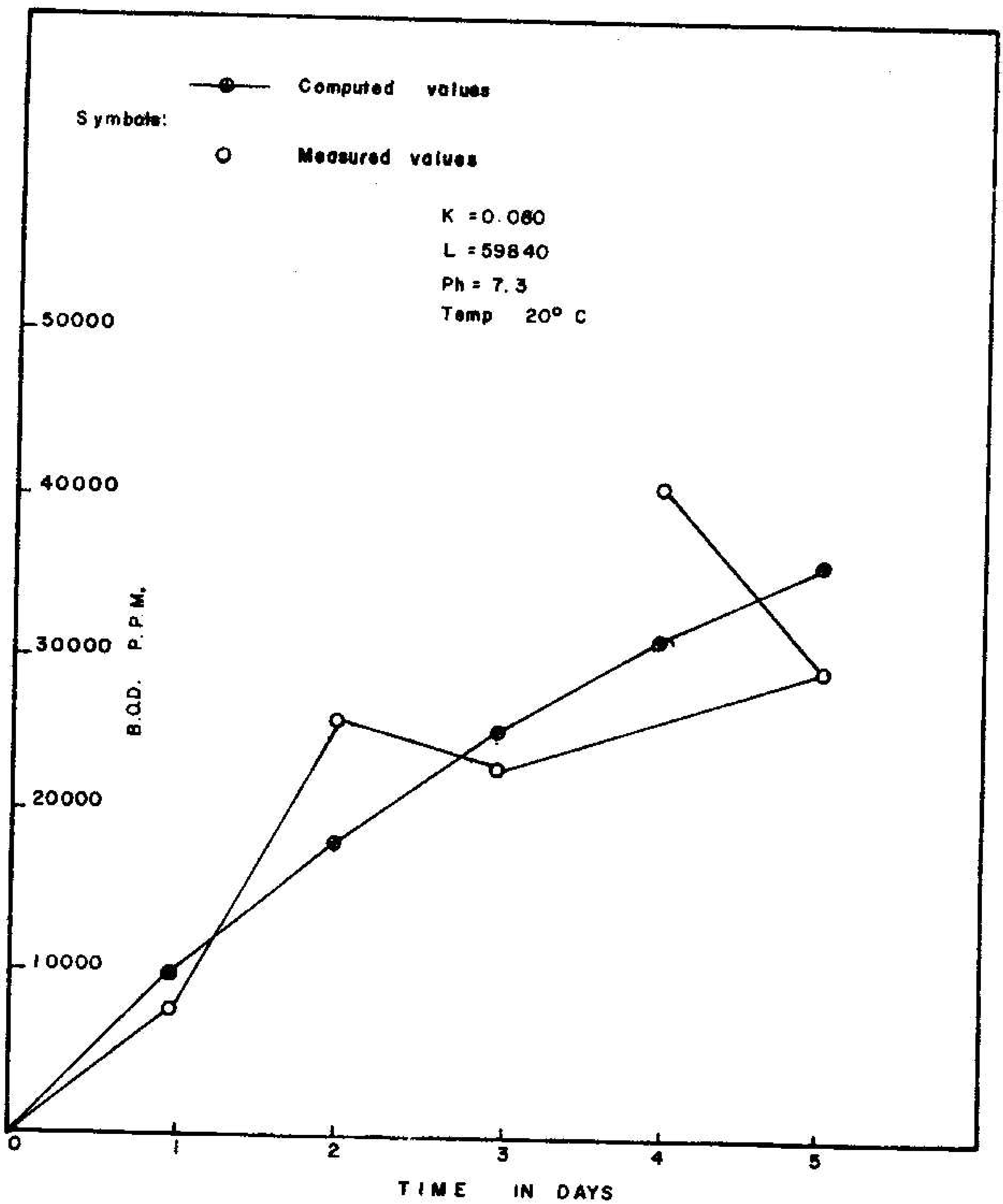

Fig 21-3 B.O.D. Curves. India Brewery. Undiluted raw wastewater.

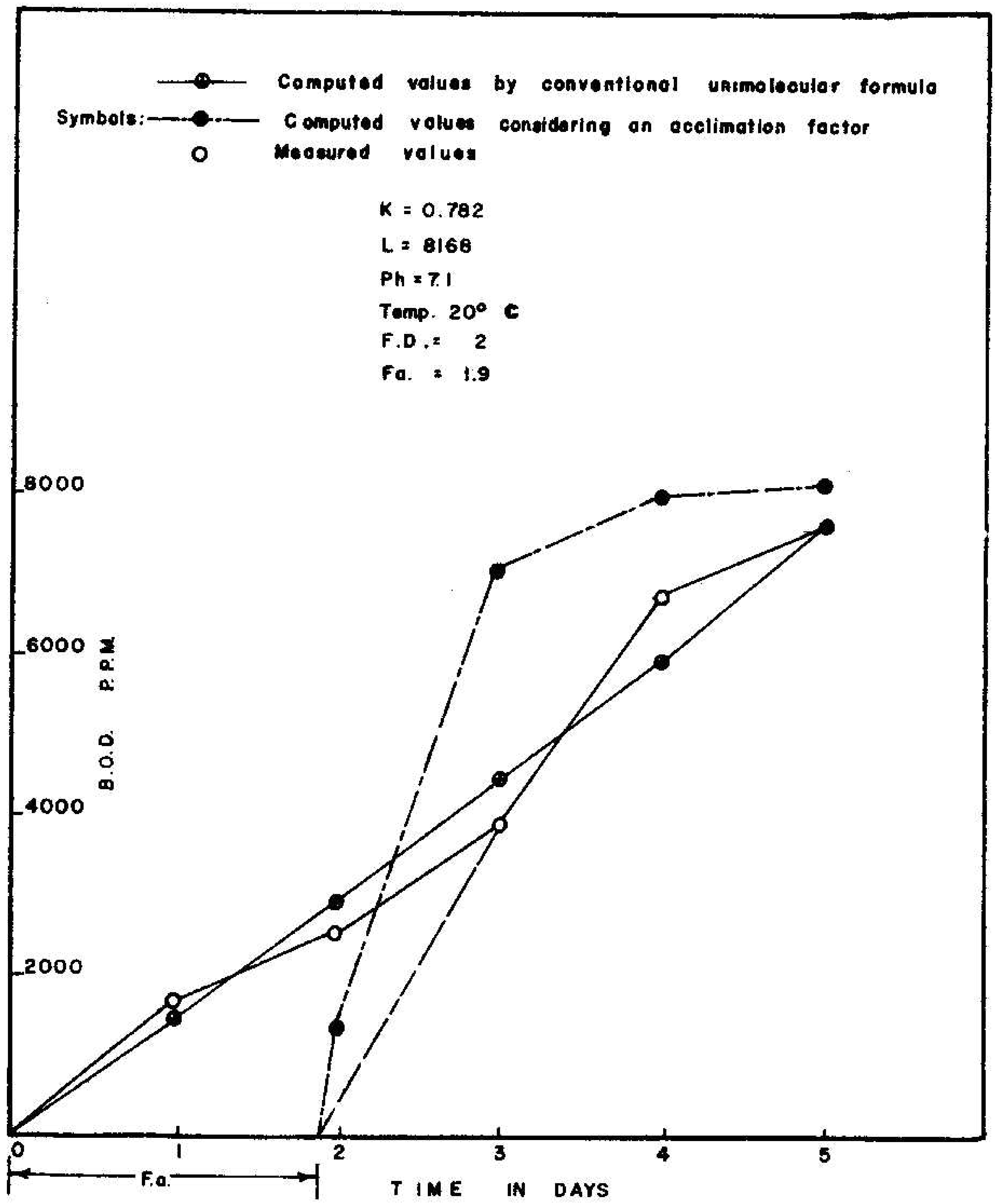

Fig 22-1 B.O.D. Curves. India Brewery. Wastewater diluted in Sweet Water by a Factor of 2

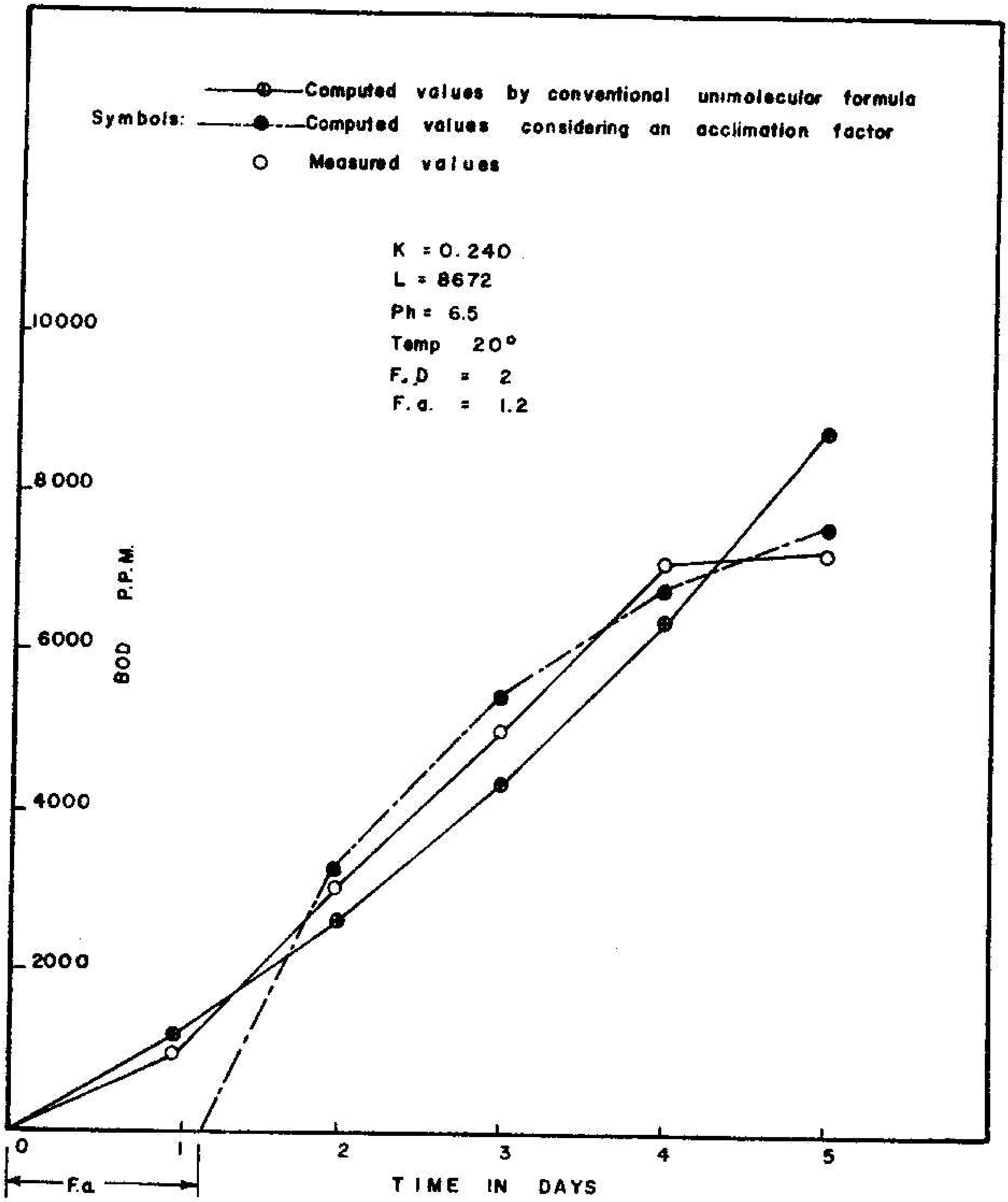

Fig 22-2 B.O.D. Curves. India Brewery. Wastewater diluted in Sweet Water by a Factor of 2

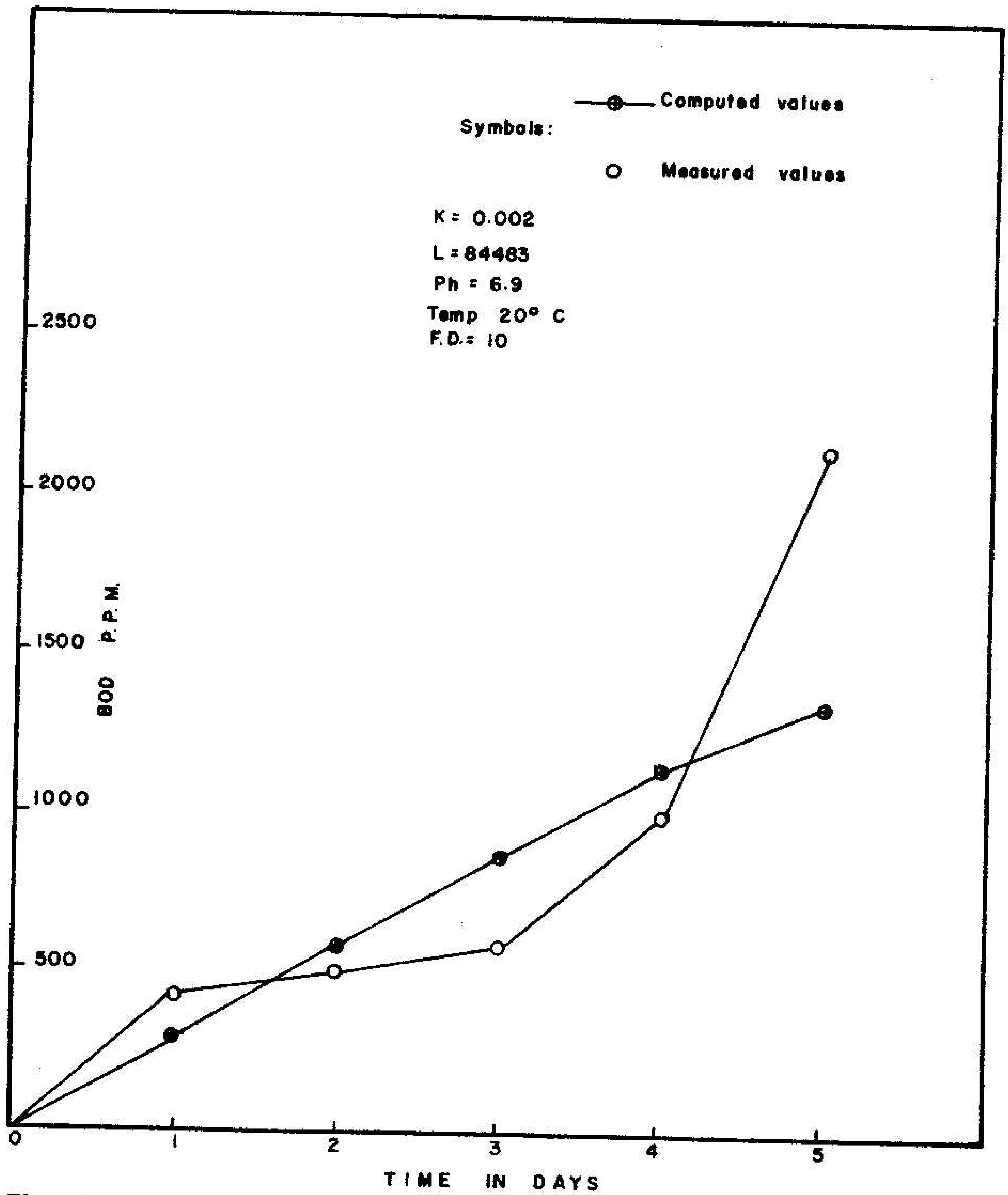

Fig 23-1 B.O.D. Curves. India Brewery. Wastewater diluted in Sweet Water by a Factor of 10.

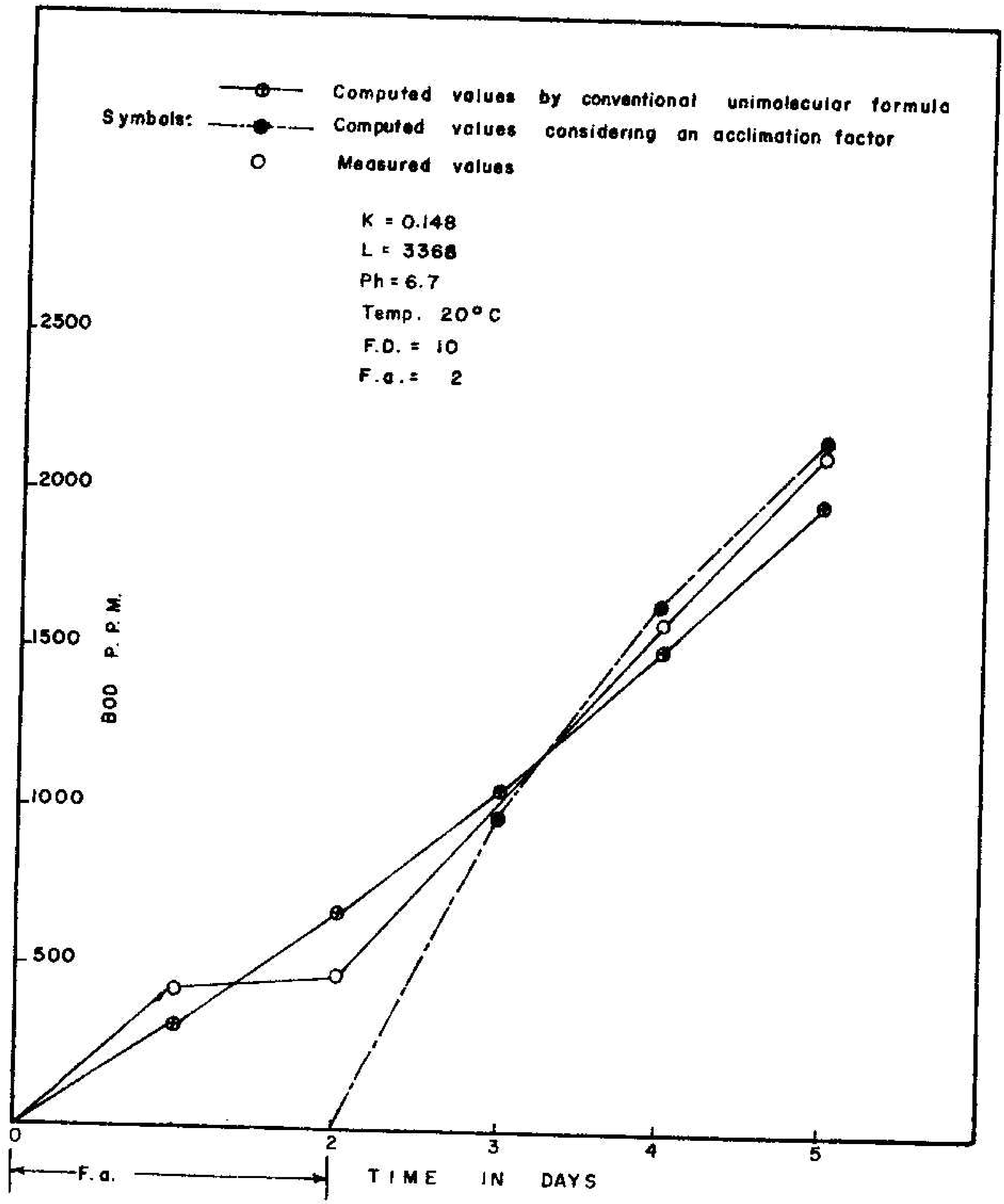

Fig 23-2 B.O.D Curves. India Brewery. Wastewater diluted in Sweet Water by a Factor of 10

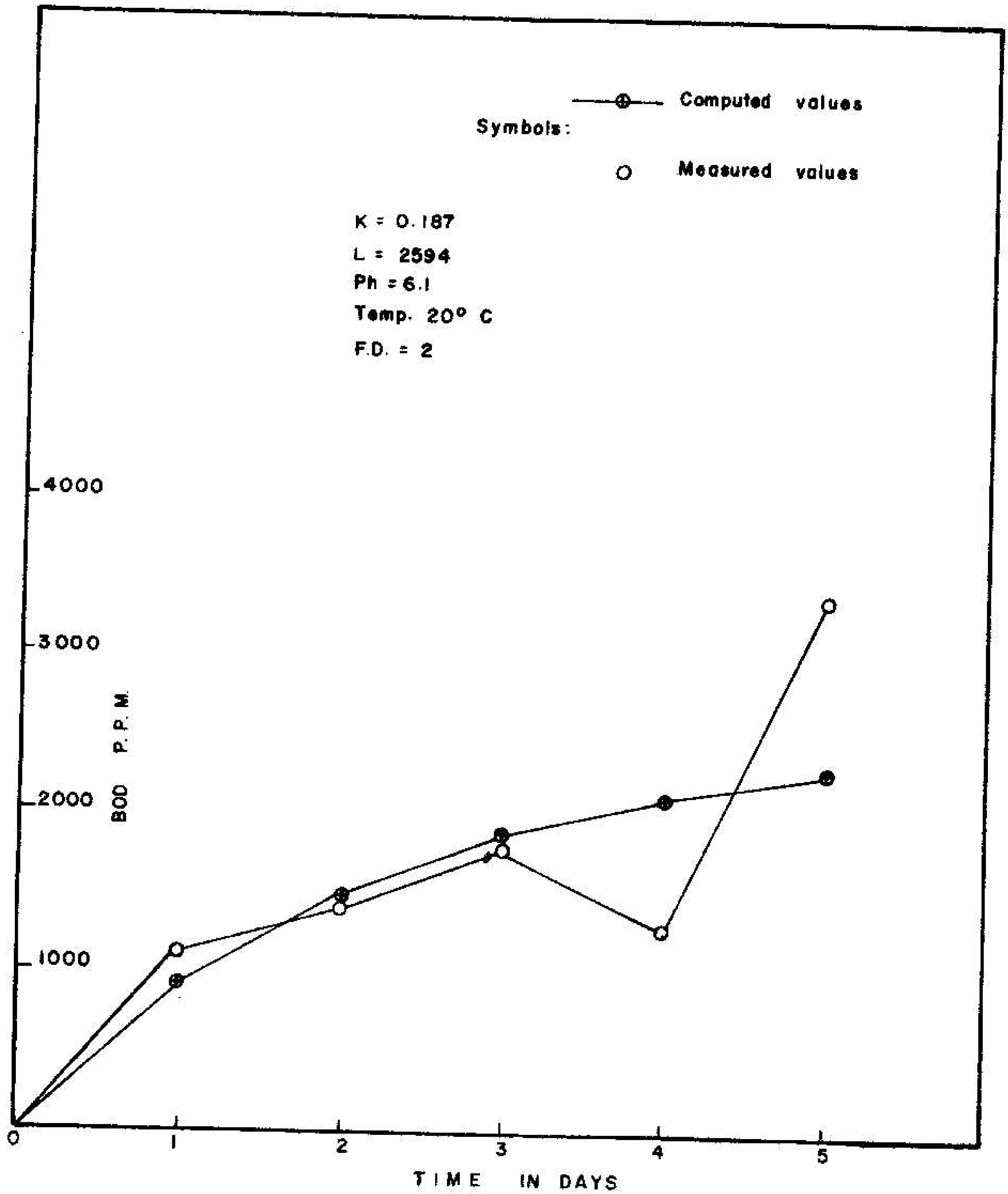

Fig 24-1 B.O.D. Curves. India Brewery. Wastewater diluted in Sea Water by a Factor of 2

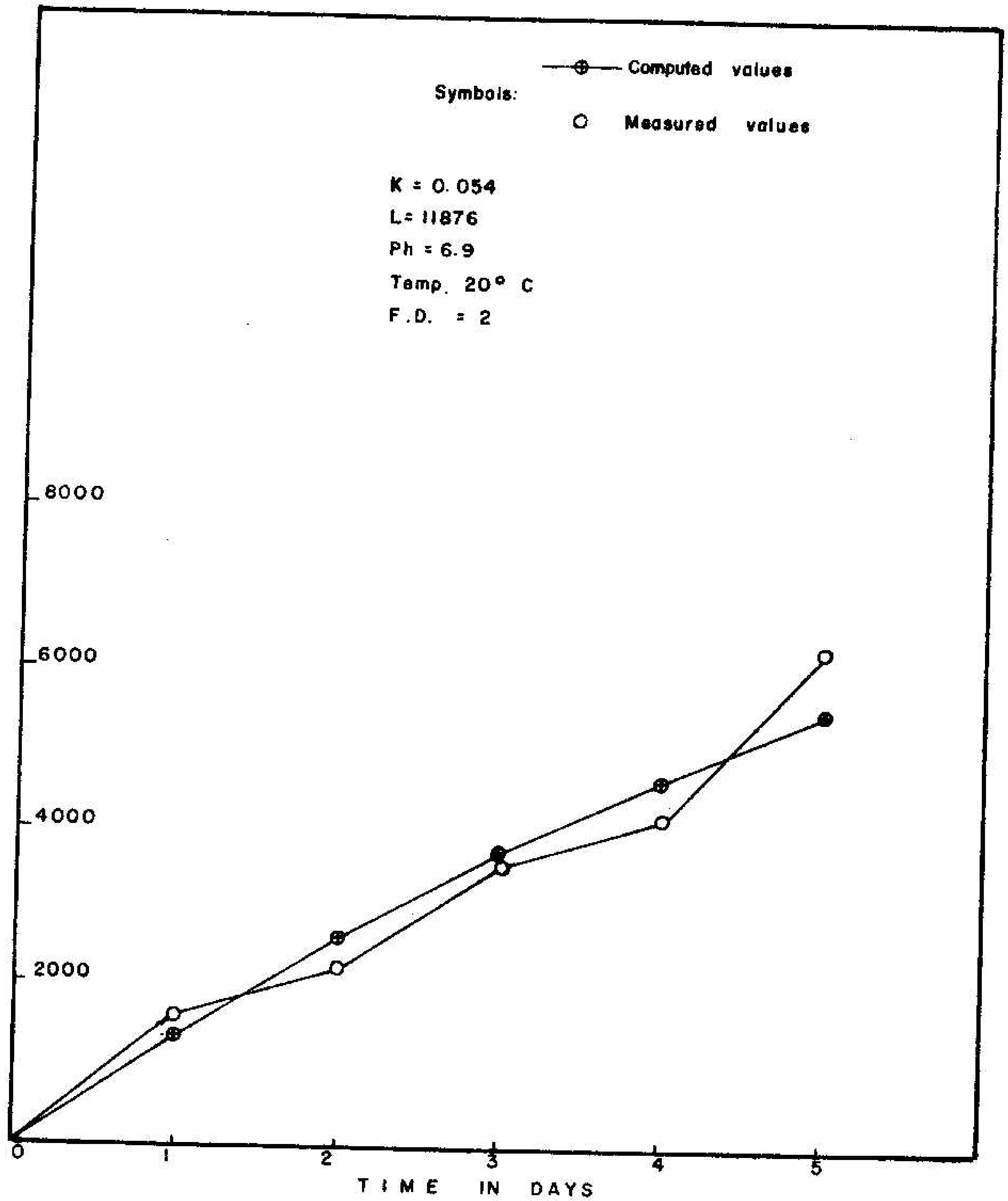

Fig 24-2 B.O.D. Curves. India Brewery. Wastewater diluted in Sea Water by a Factor of 2

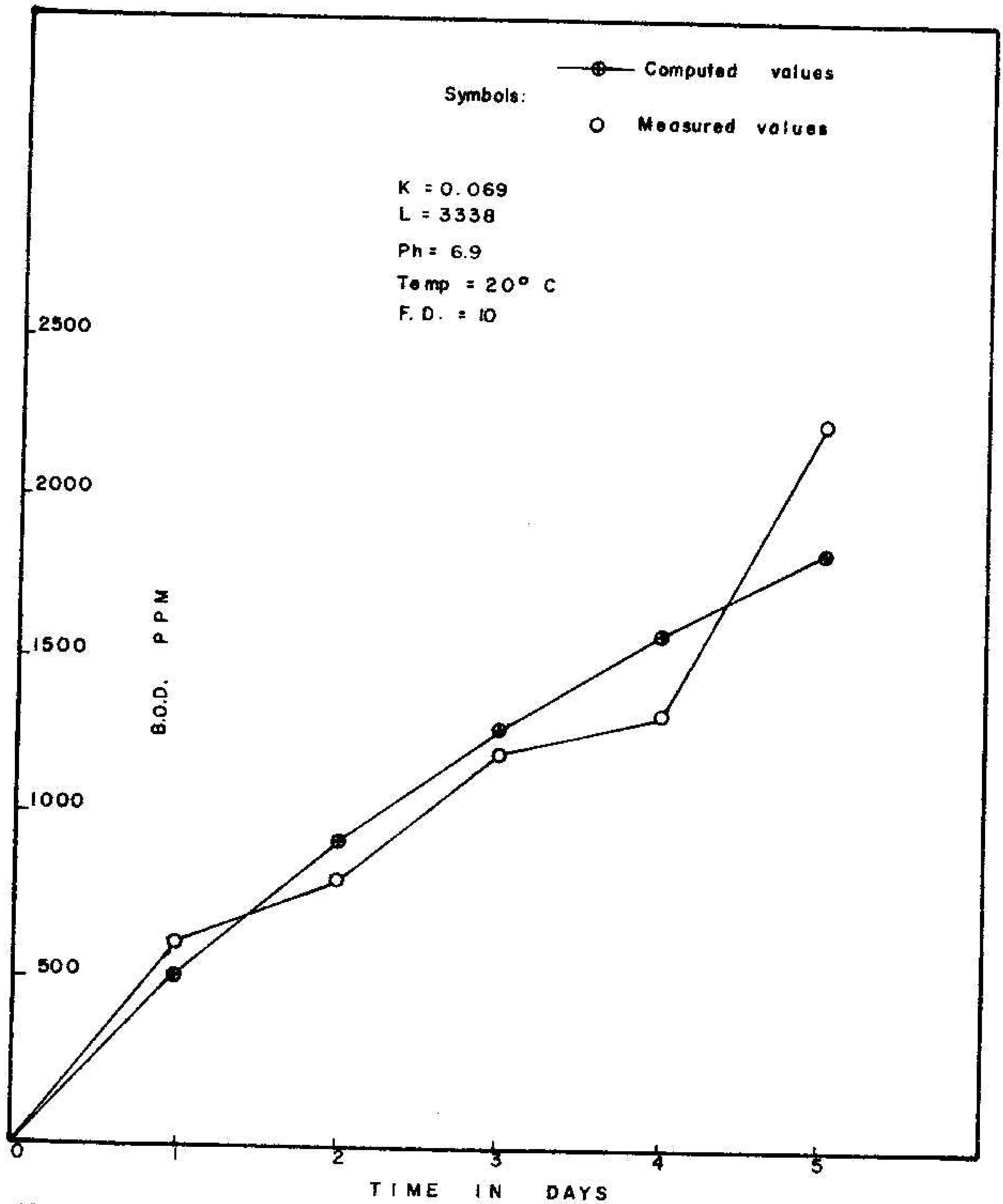

Fig 25-1 B.O.D. Curves. India Brewery. Wastewater diluted in Sea Water by a Factor of 10

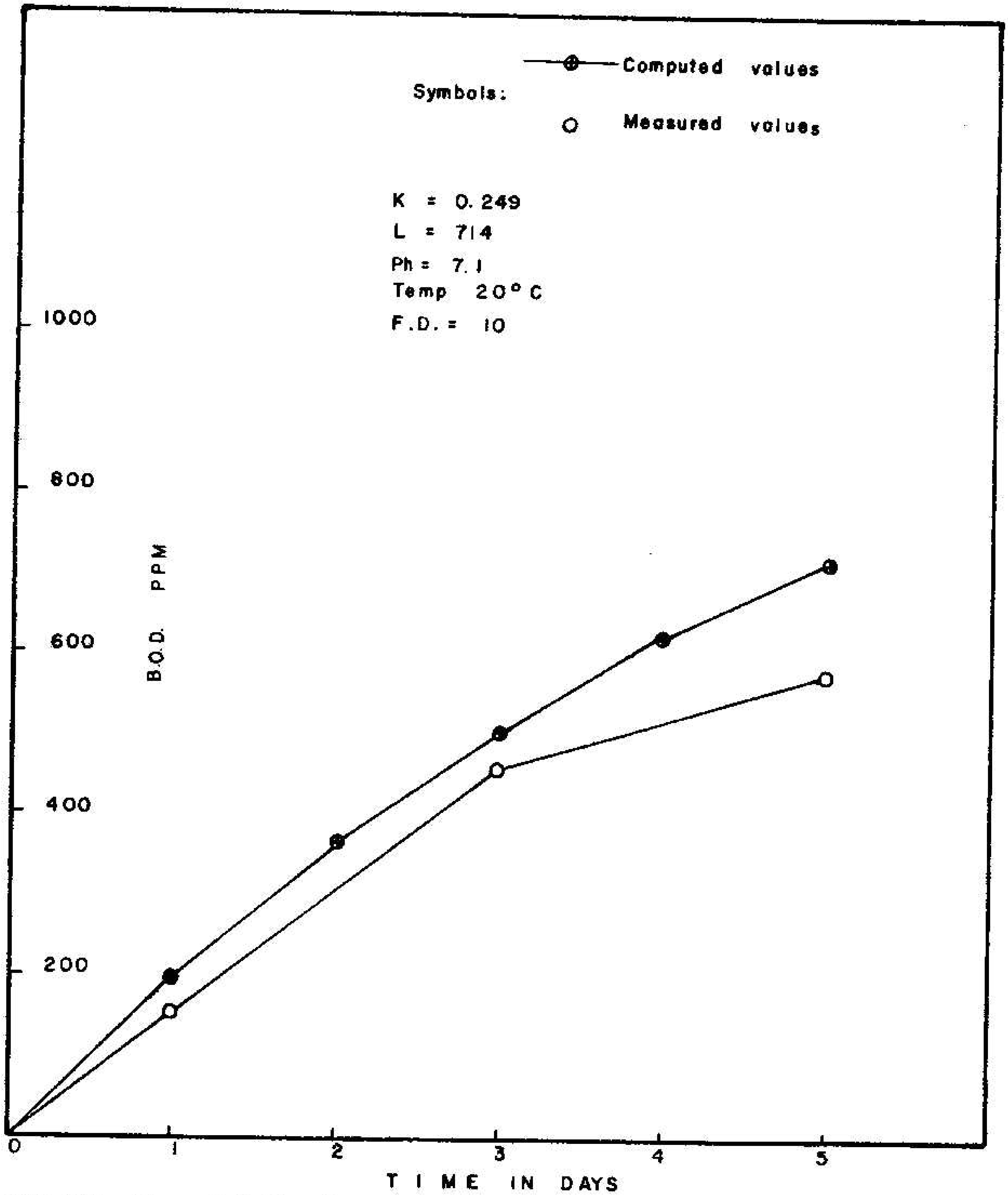

Fig 25-2 **B.O.D. Curves. India Brewery. Wastewater diluted in Sea Water by a Factor of 10**

mixed with natural waters than in their original concentrated state, regardless of the dilution factor; the degree of dilution does not seem to have any significant effect though. On the other hand, when the dilution water is sea water the value of "K" tends to be higher than when the waste is diluted in fresh water. Since all dilutions were made with waters at the same temperature (20°C), the observed effect can not be explained on the basis of temperature dependent factors.

This finding is a very significant one because it indicates that the effect of an organic pollutant on a natural body of water, from the standpoint of oxygen depletion, is greater than what can be predicted from standard mathematical models in which the "K" value of the undiluted waste is used in certain operations. In sea water, in which available dissolved oxygen is less because of the high chloride content, the situation is still worse, with higher "K" values, which indicate accelerated biodegradation with the accompanying higher oxygen uptake rates.

With regard to the sanitary sewage, both domestic wastewaters studied showed "K" values somewhat higher than the standard accepted value of 0.1, the median value being of the order of 0.14, with no significant difference between both communities studied.

Both Caribe Feed Mills and Integrated Industries, being animal feed industries, had very similar wastes, although the raw material used in each case have different origins, as previously stated. The median "K" value for both industries is about 0.29.

Highly variable and uncertain results were obtained from India Brewery liquid wastes and, therefore, no conclusion can be derived from these.

The introduction of acclimation factor "a" when analyzing the industrial wastewaters was, certaintly, another important accomplishment of this study. With the use of this factor, industrial wastewaters may be analyzed without the use of lengthy and costly pilot plant studies. For all industrial wastes studied the value of "a" varied between 1 and 3 days, so that a total study period of 8 to 10 days seems adequate for this type of wastes.

Values of "L" were highly variable for most wastes analyzed probably due to varying degrees of dilution of the organics in the source. This is to be expected and is not deemed important for the purpose of this study, as this did not have any noticeable effect on the "K" values. Ultimate BOD for the raw domestic sewage varied from 50 to 263 mg/l with a median value of around 140 mg/l.

In general, Thomas method proved adequate for the evaluation of "K" and "L" values for all types of wastes and could be successfully programmed for computer solution, the only limitation being the need for a preliminary trial-and-error estimate of the acclimation factor "a" introduced in this study to make the method applicable to certain industrial wastewaters.

Recommendations for Further Study

After the completion of this study, considering the problems that developed with it, we feel that it is necessary to make certain recommendations to those who may want to enter into this interesting, but partially explored, field.

1- In any future study of this nature, it is convenient to conduct the three phases simultaneously. That is, to run the tests on the same sample for the raw waste and for the natural fresh and salt water dilutions, rather than to do it on samples from the same source taken at different dates. This will avoid the problem of sample variations and will permit more accurate comparisons of the results obtained from each test.

2- Greater precision may be obtained in this type of study, with regard to the industrial wastewaters, if a way may be devised to eliminate the trial-and-error estimation of the acclimation factor "a" by means of a new formulation that may permit its direct evaluation or developing a new BOD equation to be applied to wastes which require acclimation of the bacterial seed.

data.

<u>References</u>

(1) Clark, J. W. and Warren Wiessman, Jr., 1965, <u>Water Supply and Pollution Control</u>. International Textbook Company, Scranton, Penn.

(2) E. Frankland; 1908, "First Report of the Rivers Pollution Commission of 1868", extracted; <u>Royal Commission Fifth Report</u>, Appendix VI. P. R.; England.

(3) W. Adeney, 1908; "Studies in the chemical analysis of salt and fresh waters. Applications of the aeration method of analysis to the study of river water". <u>Royal Commission Fifth Report</u>, Appendix VII; England.

(4) Harold E. Babbitt, 1959; <u>Sewerage and Sewerage Treatment</u>. John Wiley and Sons; New York, N. Y.

(5) Reed, L. J., and E. J.; 1931, "The Statistical Treatment of Velocity Data:. Jour. Phys. Chem., 35: 673: 950.

(6) Fair, G. M. 1936;"The Log-difference Method of Estimating the Constants of the First Stage Biochemical Oxygen Demand Curve". Sewage Works Jour., 8, (3): 430.

(7) Thomas, H. A., Jr. 1935. "The Slope-Method of Evaluating the Constants of the First Stage Bio-Chemical Oxygen Demand Curve". Sewage and Works Jour. 9 (3): 425.

(8) E. W. Moore, H. A. Thomas, and W. B. Snow. 1950, "Simplified Method of Analysis of BOD Data". Sewage and Industrial Wastes. 22 (10): 1343.

(9) Oxford, H. E. and W. T. Ingram. 1954; "The Logarithm Equation to Determine the Velocity of BOD Curve". Vol. 419; 424; and 566.

(10) Rhame, George A. 1949; "Determination of first stage oxygen demand". Water and Sewage Works. Vol. 317-319.

(11) Ruchhoft, C.C., O. R. Placak, J. R. Kachmar, and Colbert, 1948, "Variations in BOD velocity contants of sewage dilutions". Ind. Eng. Chem. 40: 1290.

(12) Mukherje, S. K., A. K. Chatterji, and I. P. Saraswat. 1968; "Effect of Ph on the rate of BOD of waste water". Journ. Water Pollution Control Federation. 1943-1939 (Nov. 1968).

(13) Sawyer Clair N.; Chemistry for Sanitary Egineers. page 270-288.

(14) Thomas H. A., Jr., 1950, "Graphical determination of BOD curve constants". Waer and Sewage Works.

(15) Hald, Anders, 1959; Statistical Theory, with Engineering Applications. John Wiley & Sons, Inc. New York

(16) 1965; Standard Methods for the Examination of Water Waste Water. Twelve Edition. American Public Health Association. New York City.

APPENDIX

Computer Program

```
C       DETERMINACION DE LA CCNSTANTE DE ESTABILIZACICN BIOQUIMICA
C       TIEMES%I< DONDE %I<#1,M   #TIEMPO DE INCUBACION
C       BODMED %I< DONDE %I<#1,M   #BOD MEDIDO EN P.P.M
C       CONSTANTE DE ESTABILIZACION  K#CONES     #E
C       OXIGENO TOTAL ULTIMO G   #L
C       CXY#COVARIACION
C       SX,SY#DESVIACIONES ESTANDAR
C       R#COEFICIENTE DE CORRELACION
C       B#PENDIENTE DE LA LINEA DE MEJOR ACEPTACION OBTENIDA POR MINIMOS
C      1CUADRADOS
C       A#INTERCEPTO DE LA LINEA CON EL EJE VERTICAL
C       X,Y#PROMEDIOS ARITMETICOS
C       WY#BOD CALCULADO POR LA FORMULA ESTANDAR
        INTEGER T
        DIMENSION TIEMES(10),BODMED(10),RA(10),STI(10),DX(10),DY(10)
       1,PRO(10),VAR(10),WY(10)
        READ (1,1) M
        DO 70 I=1,M
     70 READ (1,3) TIEMES(I)
        DO 80 I=1,M
     80 READ (1,2) BODMED(I)
      1 FORMAT(I2)
      2 FORMAT(F15.8)
      3 FORMAT(F10.5)
     10 FORMAT(1H0,50X,F20.13,///////)
        SUM=0.0
        DO 4 I=1,M
        ALTLB=(ALOG(TIEMES(I))-ALOG(BODMED(I)))/3.
        RA(I)=EXP(ALTLB)
      4 SUM=RA(I)+SUM
        WRITE (3,10)  SUM
        Y=SUM/M
        WRITE (3,10)Y
        SUMACA=0.0
        DO 5 I=1,M
        STI(I)=TIEMES(I)
      5 SUMACA=STI(I)+SUMACA
        X=SUMACA/M
        WRITE (3,10) X
        SUM=0.0
        SUMA=0.0
        SUMON=0.0
        DO 6 I=1,M
        DX(I)=STI(I)-X
        DY(I)=RA(I)-Y
        PRD(I)=DX(I)*DY(I)
        SUM=PRD(I)+SUM
        WRITE (3,10)  SUM
        SUMA=DX(I)**2+SUMA
        WRITE (3,10) SUMA
      6 SUMON=DY(I)**2+SUMON
        WRITE (3,10) SUMON
        CXY=SUM/M
        WRITE (3,10) CXY
        SX=SUMA/M
        WRITE (3,10) SX
```

```
      SY=SUMON/M
      WRITE (3,10) SY
      SX1=SQRT(SX)
      WRITE (3,10) SX1
      SY1=SQRT(SY)
      WRITE (3,10) SY1
      R=CXY/(SX1*SY1)
      WRITE (3,10) R
      B=R*SY1/SX1
      WRITE (3,10) B
      A=Y-B*X
      WRITE (3,10) A
      E=(2.61*B)/A
      G=1/(2.3*E*A**3)
      DO 8 I=1,M
      VARIA = ((E * TIEMES (I) ) * ALOG (10.))
      VAR(I)=EXP(VARIA)
    8 WY(I)=G*(1-(1/VAR(I)))
      WRITE (3,20)
   20 FORMAT(1H1,46X,22HDATOS DE ESTE PROBLEMA,////)
      WRITE (3,30)
   30 FORMAT(1H0,15X,20HTIEMPO DE INCUBACION,30X,20HBOD MEDIDO EN P.P.M.
     1//)
      DO 7 I=1,M
    7 WRITE (3,40) TIEMES(I),BODMED(I)
   40 FORMAT(1H0,28X,F3.0,42X,F15.8)
      WRITE (3,50) E
   50 FORMAT(1H1,11X,48HRAZON A LA CUAL SE CONSUME EL OXIGENO POR DIA E#
     1,5X,F15.8,///)
      WRITE (3,60) G
   60 FORMAT(1H0,36X,23HOXIGENO TOTAL ULTIMO G#,5X,F15.8,///)
      WRITE (3,90)
   90 FORMAT(1H0,5X,76HBOD POR DIA CALCULADO SEGUN LA FORMULA ESTANDAR E
     1N P.P.M. DURANTE 10 DIAS WY, ///)
      DO 9 I=1,M
    9 WRITE(3,100) WY(I)
  100 FORMAT(1H0,60X,F15.8,////)
      WRITE(3,15)
   15 FORMAT('0'36X,'VALORES DE RA PARA TRAZAR LA GRAFICA SEGUN THOMAS',
     1//////)
      DO 25 I = 1,M
   25 WRITE(3,35) RA(I)
   35 FORMAT('0'50X,F15.8,////)
      STOP
      END
```

G. Hadley, *Linear Programming*, Addison-Wesley Publishing Company, Reading, Mass.

R.J. Levin & C.A. Kirkpatrick, *Planning and Control with PERT-CPM* McGraw Hill, New York.

Neal E. McClymonds, *Water Resources of the Guánica Area*, U.S. Geological Survey, 1967.

________________ *Population of Cities*, Towns and Villages, U.S. Department of Commerce, Bureau of the Census.

L.R. Shaffer, J.B. Ritter & W.L. Meyer, *The Critical Path Method*, McGraw Hill, New York.

Stephen C. Smith & Emery N. Castle (eds), *Economics of Public Policy*, Iowa State University Press, Ames, Iowa.

________________ *Statistical Abstract*, U.S. Department of Commerce, Bureau of the Census.

________________ *Subsequent of the Guánica - Guayanilla Bay Area* U.S. Geological Survey, 1963.