EFFECT OF SEED ON BOD PARAMETERS

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

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CIVIL ENGINEERING
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By

JYOTI SWARUP

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "EFFECT OF SEED ON BOD PARAMETERS" in partial fulfilment of the requirement for the award of degree of MASTER OF ENGINEERING in CIVIL ENGINEERING with specialization in ENVIRONMENTAL ENGINEERING submitted in the Department of Civil Engineering, University of Roorkee, Roorkee is an authentic record of my own work carried out for a period of about four months, from October 1994 to January 1995 under the supervision of Dr. A.K. Shrivastava, Professor, Department of Civil Engineering, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated : 1 Feb 1995

(JYOTI SWARUP)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. A.K. SRIVASTAVA)

Professor,
Deptt. of Civil Engineering,
University of Roorkee,
ROORKEE - 247 667

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J. Swarup

JYOTI SWARUP

ABSTRACT

The BOD exertion phenomena in an aquatic ecosystem is a complex biochemical reaction between heterogeneous assemblage of biota and complex organic substrate. The effect of varying environmental conditions such as temperature, pH, presence of toxicants, etc. have been studied in great details over the years. The phases during the BOD exertion have also been studied in great detail. Various models representing BOD kinetics have been proposed. Accordingly BOD parameters have been evaluated in the laboratory for various field applications.

However, the effect of seed, which a waste would generally encounter during its biological treatment has not been studied so far. In the past, different parameters of BOD kinetics for an industrial waste have been estimated using a sewage seed. This has led to an erroneous estimate of BOD parameters much, different from that encountered in the field. This, in, turn has probably been a major reason for malfunctioning of various effluent treatment plants. The need was therefore felt to study the effect of seed on BOD parameters. Accordingly wastes and corresponding seeds from effluent treatment plants of four industries viz. Dairy, Distillery, Paper and Sugar were used for this study. Four models of BOD kinetics currently in use have been used to predict BOD parameters. Numerical methods have been used for computation

of these parameters based on minimization of cumulation absolute proportionate error.

The study revealed that there is a significant difference in BOD exertion with indigenous and sewage seeds.

CONTENTS

INTRODUCTION

Biochemical Oxygen Demand (BOD) is arguably the most important parameter associated with any waste. This parameter is the most basic parameter used in the design and operation of biological waste water treatment processes. It is also used to characterize the industrial and municipal waste waters and treatment plant effluents. Besides above, it is also used to calculate the efficiency of waste treatment process and to assess the quality of streams and lakes.

The BOD tests are generally conducted using a sewage seed even for industrial wastes. It has been the practice to seed the wastes with unacclimatized sewage microbes for the purpose of conducting BOD exertion studies. However, BOD in lab by unacclimatized coliforms may give less ultimate BOD values than the one which is likely to be given by acclimatized seed containing specific microorganisms, operating in industrial wastes. Waste specific microorganisms, evolved over a period of time in the particular environment of that waste, by the method of natural selection are likely to be more effective in decomposing that waste as compared to unacclimatized sewage microbes.

The method used for predicting BOD values of an industrial waste using unacclimatized sewage seed, needs to be modified.

Because, the types of the organic matter or their derivatives present in an industrial wastes may not be decomposable by the heterogeneous assemblage of microorganism in sewage used as seed. In BOD tests, in such cases, some of the organic compounds may remain unutilised by sewage microbes giving erroneous BOD exertion rates and ultimate BOD.

The study finally revealed that ultimate BOD obtained using acclimatized Indigenous seed was significantly more than that obtained using sewage seed. The ratio of ultimate BOD using indigenous seed to ultimate BOD using sewage seed varied from 1.1 to 1.8 depending upon type of waste.

LITERATURE REVIEW

2.1 INTRODUCTION

Biochemical oxygen demand (BOD) is the most widely used parameter for estimating organic pollution in aquatic systems. The BOD test measures the dissolved oxygen consumed by microorganism for biochemical oxidation of organic matter at an incubation period of five days and temperature of $20^{\circ}C$ (Standard Methods 1980)*.

Biochemical oxidation is a slow process and theoretically can take an infinite time for completion. In most cases the oxidation is 60-70% complete in five days and 95-99% complete within 20 days (Metcalf & Eddy 1979).

Although the 5-day BOD yields useful results for the control of sewage treatment plant operation, it is generally concluded that the ultimate BOD and the exertion rate must be known in order to measure efficiency of the biological treatment process or to predict subsequent oxygen depletion in a stream.

Biochemically Oxygen Demand (BOD) is widely recognised as a measure of the non-toxic pollution strength. It is a parameter of

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* The references have been organised alphabetically yearwise in Bibiliography.

great importance in the design and operation of biological waste water treatment processes. It is frequently used to characterize municipal and industrial waste waters and treatment plant effluents to calculate the efficiency and organic removal functions of waste treatment processes, and to assess the water quality of streams and lakes, BOD is likely to remain in the future as one of the most important water quality indicators

2.2 HISTORICAL RESUME

The use of BOD as a yardstick for assessment of pollutional potential of a waste water was first carried out by Frankland (1868)*. In his studies he concluded that the amount of oxygen consumed, upon storage in a sample of water of river. Thames containing organic matter and microbes was dependent upon the time of storage. He believed then, that, it was the result of chemical reaction only.

Dupre (1894)*, however opined that oxygen depletion, during storage, in polluted waters, was due to the presence of growing organisms, so called "microphytes" for their metabolic needs.

Streater and Phelps (1925)* gave the concept that "the rate of biochemical oxidation of organic matter is proportional to the remaining concentration of unoxidized substance, measured in terms

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* Not referred to in Original.

of oxidizability". This led to the First degree formulation of BOD kinetics.

In wastes rich in Nitrogen - such as treatment plant effluents, the carbonaceous stage BOD is followed by a second stage, called nitrogenous stage (figure 2.1), in which Nitrogenous compounds are further broken into simpler compounds by nitrifying bacteria. Buswell, VanMeter and Gereke (1950) concluded from their studies that nitrification does not occur until about eight days, by which about 80-85 percent of the ultimate carbonaceous BOD is already exerted.

According to Klein (1957), during the first or carbonaceous oxidation stage, about 70-80 percent of organic carbon is oxidised and during the second or nitrification stage, biochemical oxidation of ammonia nitrogen occurs and at the same time remaining 20-30 percent of organic carbon is utilised by the bacteria for their nutrition and growth. Existence of diphasic BOD exertion was first reported by Hoover et al (1959). In waste waters having low substrate concentration, there is a saturation in earlier part of the curve, as depicted in fig. 2.2. This saturation level is called "Plateau" and the portion up to the end of plateau is called the first phase of BOD exertion. The remaining part of the carbonaceous stage BOD, after plateau is called second phase. This is attributed to change in predominance of microbial life from bacteria to protozoans or the acclimation period of the viable bacteria to endogenous substrate after the removal of exogenous substrate.

However, none of the workers in the field defined clearly the geometry of the diphasic carbonaceous BOD exertion curve with enough precision to warrant the use of plateau for predicting the course of BOD exertion (Gaudy, 1972).

After the first degree formulation, Young and Clark (1965) proposed a second degree equation for BOD exertion kinetics. Hewitt et.al. (1979) tried to view BOD exertion kinetics in multiorder perspective. All the above approaches were fraught with serious lacunae.

Theyer and Krutchkoff (1967) advocated the possibility of deriving probability functions for BOD exertion. The real breakthrough in the field of BOD kinetics came with the realization that BOD exertion being a response of heterogeneous mass of living organism to their environment, can not be described by a deterministic equation. Shrivastava (1982) gave the expression for probability of BOD exertion. Unny and McBean (1986) gave a stochastic model of first order BOD kinetics. However, this model fails to depict the different phases in the BOD exertion.

2.3 BOD FORMULATIONS

2.3.1 Phelps Model

It is also known as "monomolecular formula" or "first degree" formula. This model is based on the studies of Streeter and Phelps (1925). According to this, the oxygen consumed between time t=0 and time t=t is given by $\frac{dy}{dt} = +k(L-y)$

$$y = L\ (1-\exp(-kt)) \qquad \ldots(2.1)$$

where y = BOD exerted (i.e. oxygen consumed) between time t=0 and time t=t

L = Ultimate carbonaceous BOD at $t \to \infty$

k = Rate constant

t = time starting from t=0

A modification was proposed by Thomaas (1940) to incorporate the lag time, t_L at low temperature, unacclimated seed conditions or retarded BOD exertion in toxic environment

$$y = L\ [1 - \exp(-k(t-t_L))] \qquad \ldots(2.2)$$

where at $t=t_L$, $y=0$, t_L being lag time. It can be seen that equation (2.2) yields negative values of y for $t < t_L$ which is unrealistic.

When the importance of nitrogenous BOD was emphasized, the first degree equation was adopted by many to describe the second stage in the form

$$\frac{dy}{dt} = k_2\ (w_n L - y)\ :\ t > t_C \qquad \ldots(2.3)$$

which yields

$$y = L\ [1+(w_n-1)\{1-\exp(-k_2(t-t_C))\}]\ :\ t>t_C \qquad \ldots(2.3a)$$

where y = total BOD exerted by the times t ($t>t_C$)

t_C = apparent time of reaching first stage BOD (=L)

W_nL = Ultimate BOD ($W_n \geq 1.0$) after the second stage

L = Ultimate carbonaceous stage BOD

K_2 = A positive rate constant in nitrogenous stage

First order kinetics as a deterministic model for the BOD progression curve is nowadays a widely recognised characterization. The model is extensively used by practising environmental engineers (Metcalf & Eddy 1979) because it most often gives satisfactory results and perhaps, because the mathematical formulation for first-order kinetics is very simple.

Despite above, many researchers, Young and Clark (1965), Keshwan et al (1965), Hewitt and Hunter (1966), Swamee and Grewal (1972) and many others have criticized the first degree equations for various reasons as summarised below :

(a) The theoretical premise for the application of first degree equation to BOD kinetics stems from the fact that many simple chemical reactions can be expressed by "monomolecular law" of chemical kinetics. The fact is that biochemical oxidation involves complex interaction between biological flora and heterogeneous organic compounds.

(b) The so called positive rate constant K does not remain constant over the entire period of time. And therefore this parameter is left with little physical significance.

(c) The first degree equation represents BOD exertion curve faithfully in endogenous phase only. The various phases of

BOD exertion and plateau are not represented by first degree equation.

(d) The first degree equation is a deterministic model of a process which shows random fluctuations due to variability in the chemical and biochemical composition of complex organic compounds and also due to the presence of heterogeneous cultures of bacteria.

(e) Uncertainty in the measurements arising from instrumentation noise, sampling, analytical and data transmission techniques and errors or additive factors are not accounted for in first degree equation.

2.3.2 Second Degree and Multiorder Approach

(a) Young and Clark (1965) proposed the following second degree equation for BOD exertion kinetics.

$$\frac{dy}{dt} = k\ (L-y)^2 \qquad \ldots(2.4)$$

with initial conditions, that y=0 at t=0, this yields

$$y = \frac{L^2kt}{1+Lkt} \qquad \ldots(2.5)$$

y, L, K and t having the same meaning as in Equation 2.1.

(b) Hewitt et.al. (1979) proposed the multiorder approach

$$\frac{dy}{dt} = k(L-y)^j \qquad \ldots(2.6)$$

here j is the degree of equation

which on integration with appropriate initial conditions yields

$$y = L\left[1 - \left\{1 + (j-1)kL^{(j-1)}.t\right\}^{\frac{1}{(j-1)}}\right] \; : \; j \neq 1 \qquad \ldots(2.7)$$

A non-dimensional plot of y/L versus ($kL^{j-1}.t$) can be plotted as shown in fig. 2.3.

(c) Woodward (1953) formulation

$$y = L_1 \frac{t / t_{*1}}{1 + t/t_{*1}} \qquad \ldots(2.8)$$

A multiorder approach is a mathematical formulation which does not find adequate support in its theoretical basis.

2.3.3 Logarithmic Formulation

Orford and Ingram (1953) gave the following equation for BOD exertion.

$$y = a\ \ln(t) + b \qquad \ldots(2.9)$$

Here a, b are constants and y is BOD exerted between time t=0 to t=t.

2.3.4 Probabilistic Approach

Thayer and Krutchkoff (1967) advocated the possibility of deriving probability functions for BOD exertion; as biological system deals with the responses of living organisms to their environment. Such responses do not show the same degree of uniformity and consistency as chemical processes do. In the BOD exertion process where most of the contributing factors are subject to random fluctuations, probabilistic approach can be well applied.

Based on probabilistic approach, Shrivastava (1982) gave the expressions for probability of BOD exertion Δy in time Δt, as

$$\Delta y = L.p.\Delta t \qquad \ldots (2.10)$$

where p = probability density function of BOD exertion.

L = ultimate carbonaceous BOD exertion

ΔY = small increment in BOD value in time Δt

$$y = L_1 \left\{ w \frac{(t/t_{*11})^{m_{11}}}{\left[1+(t/t_{*11})^{m_{11}/n_{11}}\right]^{n_{11}}} + (1-w) \frac{(t/t_{*1})^{m_1}}{\left[1+(t/t_{*1})^{m_1/n_1}\right]^{n_1}} \right\}$$

$$+ L_2 \left\{ \frac{(t/t_{*2})^{m_2}}{\left[1+(t/t_{*2})^{m_2/n_2}\right]^{n_2}} \right\} \qquad \ldots (2.11)$$

The BOD parameters L_1 and L_2 are ultimate BOD values after first stage and after second stage respectively. m_1, m_{11} and m_2 are the rate exponents of time, at which BOD exertion takes place. t_{*1}, t_{*11} and t_{*2} represent the apparent ultimate time at which the microbial population must have exerted L_1, L_{11} and L_2 respectively. n_{11}, n_1 and n_2 represent the transition lengths of the curve to reach plateau, first stage and second stage BOD. A smaller value of t_{*1}, t_{*11} and t_{*2} and n_1, n_{11} and n_2 represents rapid rate of growth of microbial population and associated rapid decay, whereas a large value of these parameters are indicative of slower growth and slower decay of the biota responsible for BOD exertion.

2.3.5 Stochastic Model of First-Order BOD Kinetics

Unny and McBean (1986) gave a mathematical theory of stochastic differential equations to obtain models for the expectation and variance of the first order BOD equation.

2.4 EFFECT OF ENVIRONMENTAL PARAMETERS ON BOD EXERTION

2.4.1 Effect of Temperature

Gotaas (1948), Seth (1964), Bewtra et.al (1965) and Zonani (1967, 1969) have studied the effect of temperature in detail on different types of waste waters namely domestic sewage, treatment plant effluents and river water samples.

(a) The ultimate BOD is slightly affected

Phelps (1925)

$$L(T) = L(20)\ (0.6 + 0.02\ T) \qquad \ldots(2.12a)$$

Gotaas (1948)

$$L(T) = L(20)\ (1-0.00066\ T) \qquad \ldots(2.12b)$$

Although the metabolic rate of bacteria is slower at lower temperature, it is expected that they will use up the food supply if sufficient time is given.

(b) Lag or Zeroth phase - At low temperatures up to $10^{\circ}C$, there is very little or no BOD exertion for a few days showing the existence of zeroth phase. This duration decreases with increase in temperature.

(c) Second stage BOD - Nitrification does not start at low temperature ($\leq 10^{o}C$). It is evident only at higher temperatures ($15^{o}C - 40^{o}C$).

(d) Rate of BOD exertion - In general rate of BOD exertion increases on increase in temperature from about $15^{o}C$ to $35^{o}C$ after which it starts declining.

2.4.2 Effects of pH

The organisms which accomplish the biochemical oxidation of organic matter are acclimated to a narrow pH range. The normal range for these organisms is pH values 6.5 to 8.3. Outside this range, the rate of oxidation decreases (Chatterji, 1965). Ultimate demand falls down in the pH range of 7.2 to 8.0 (Chatterji, 1965).

2.4.3 Effect of Toxicants

Various chemical compounds, toxic to the microorganisms, affect the BOD exertion. At high concentration, the substance will kill the microbes and at sublethal concentration, their activities will be retarded. In general, Ghose (1980) reported that the bacterial kill is proportional to the concentration of heavy metal ion.

(a) Cyanide : Ludzack et. al (1951)* studied the effect of cyanide on BOD exertion. Reduction in BOD values with increasing concentration of cyanide in sub-lethal region was observed.

(b) Mercury : Ghose and Zelgeer (1978)* reported that a dose of 5.0 mg/l or higher, definitely inhibits the aerobic biological process.

(c) Cadmium : Kansal et.al. (1982)* observed that though the cadmium inhibits the BOD exertion, the inhibition is not same for all type of wastes.

The effect of toxicant concentration on ultimate BOD has been expressed in the following equations : (Shrivastava, 1982)

$$L(C) = L(O) \left\{ 1 - \frac{\ln\,(1+ C_T/C_{TT})}{\ln\,(1+ C_{TL}/C_{TT})} \right\} \qquad \ldots(2.13)$$

where L(C) = Ultimate carbonaceous BOD at concentration C_T of toxicant

L(O) = Ultimate carbonaceous BOD at zero concentration of toxicant.

C_{TL} and C_{TT} = lethal and threshold concentration of toxicants.

2.4.4 Effect of Seed Concentration

The microbial culture introduced or developed to oxidize the organic wastes in aquatic medium are called seeds. Eldridge (1933)* has reported that seed may affect 5 day BOD value, but ultimate BOD value (L) is not affected significantly. Ekenfeldeer

(1970) and Chaturvedi (1978) also observed similarly that seed concentration has very little effect on ultimate BOD value, but could affect BOD values in initial periods. At very low seed concentration (0.1 percent), there is the existence of zeroth phase.

2.4.5 Effect of Substrate Concentration

The dilution technique for BOD determination was initiated by Adney (1908)*. In this technique for substrates having BOD values higher than 10 mg/l the sample is diluted to a concentration with BOD within 10 mg/l in order to avoid exhaustion of DO in the closed ecosystem (BOD bottles). From such diluted samples no informations about the rate constants of the original sample can be drawn. However, the ultimate BOD inferred from such an experiment can be scaled up to obtain the ultimate BOD of the original sample.

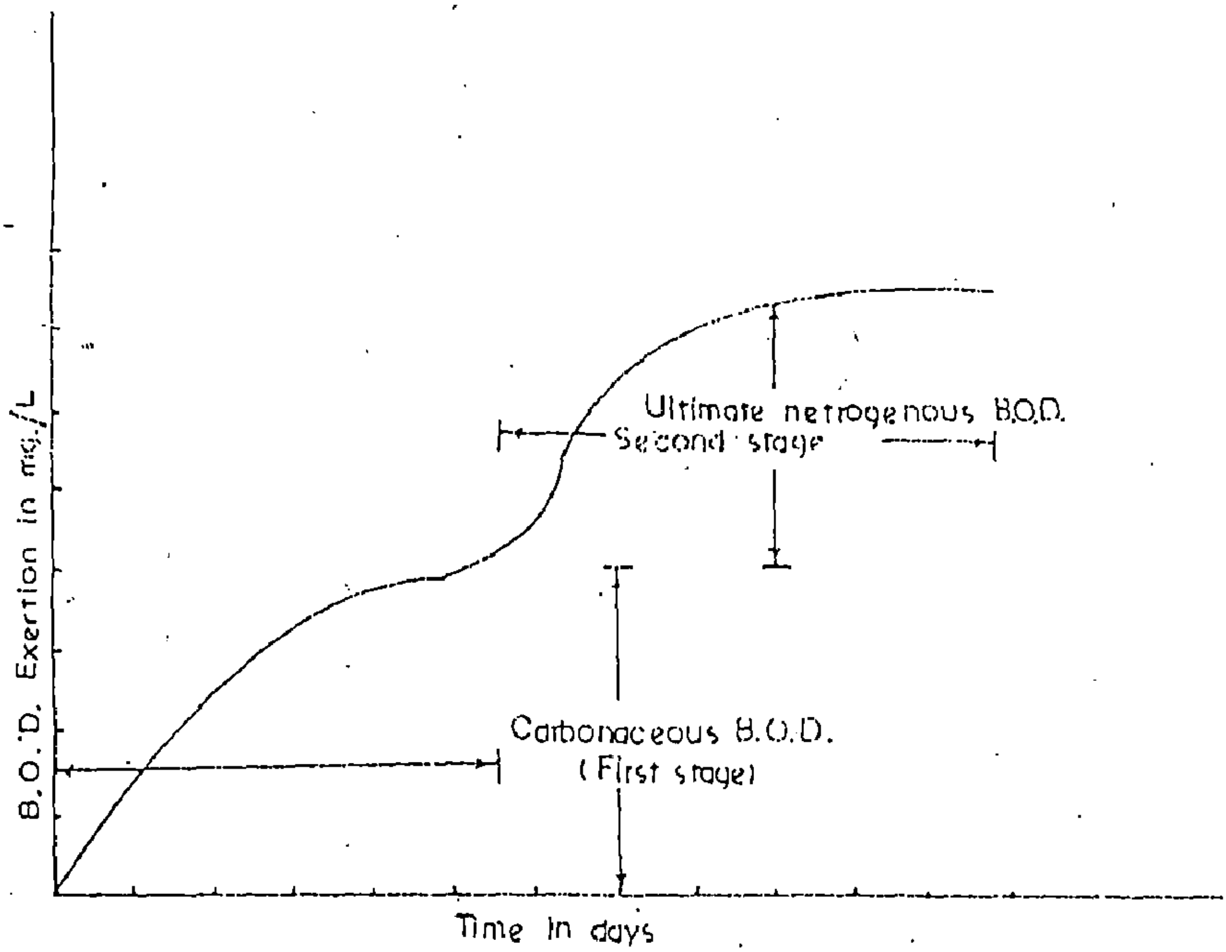

Fig. 2.1, Two stage B.O.D. exertion

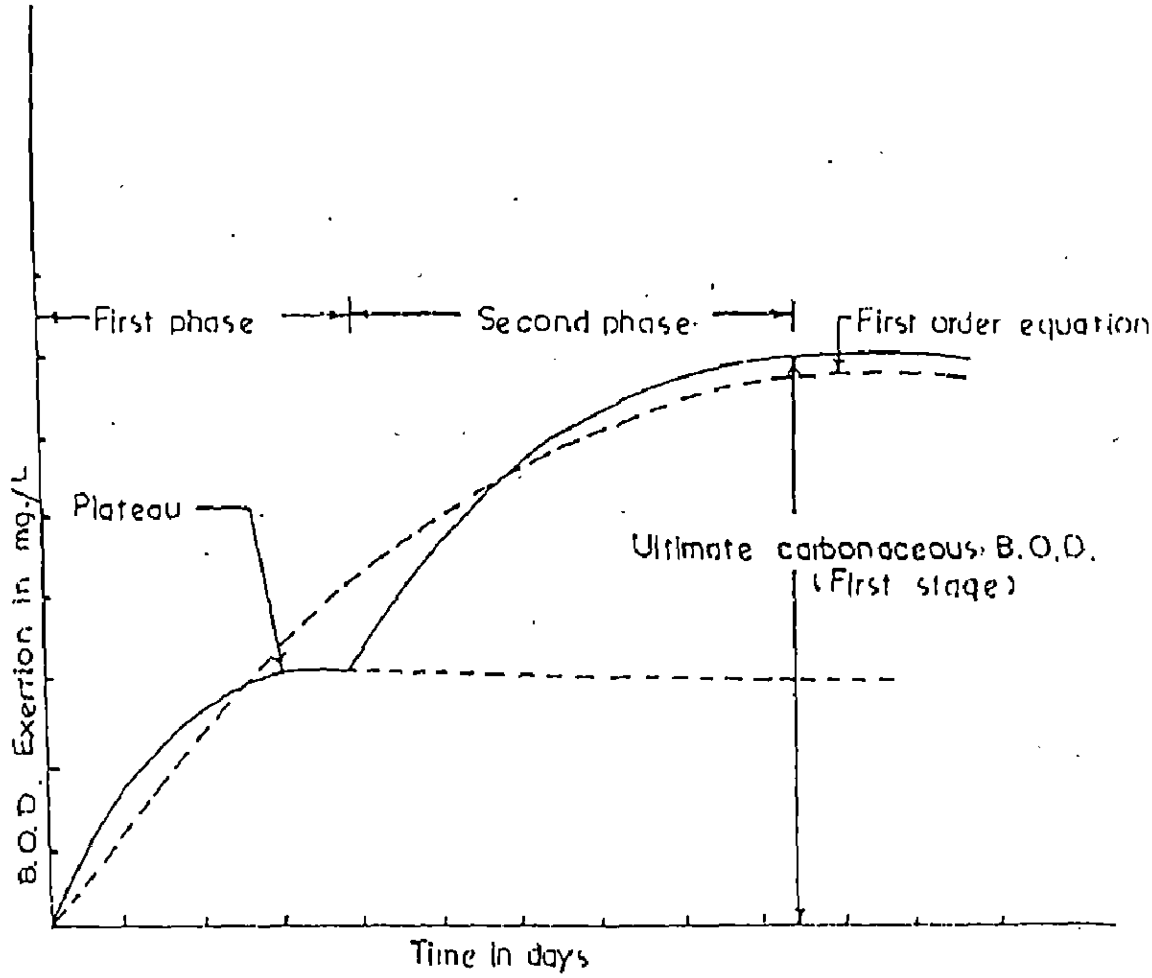

Fig 2.2, Diphasic B.O.D. exertion

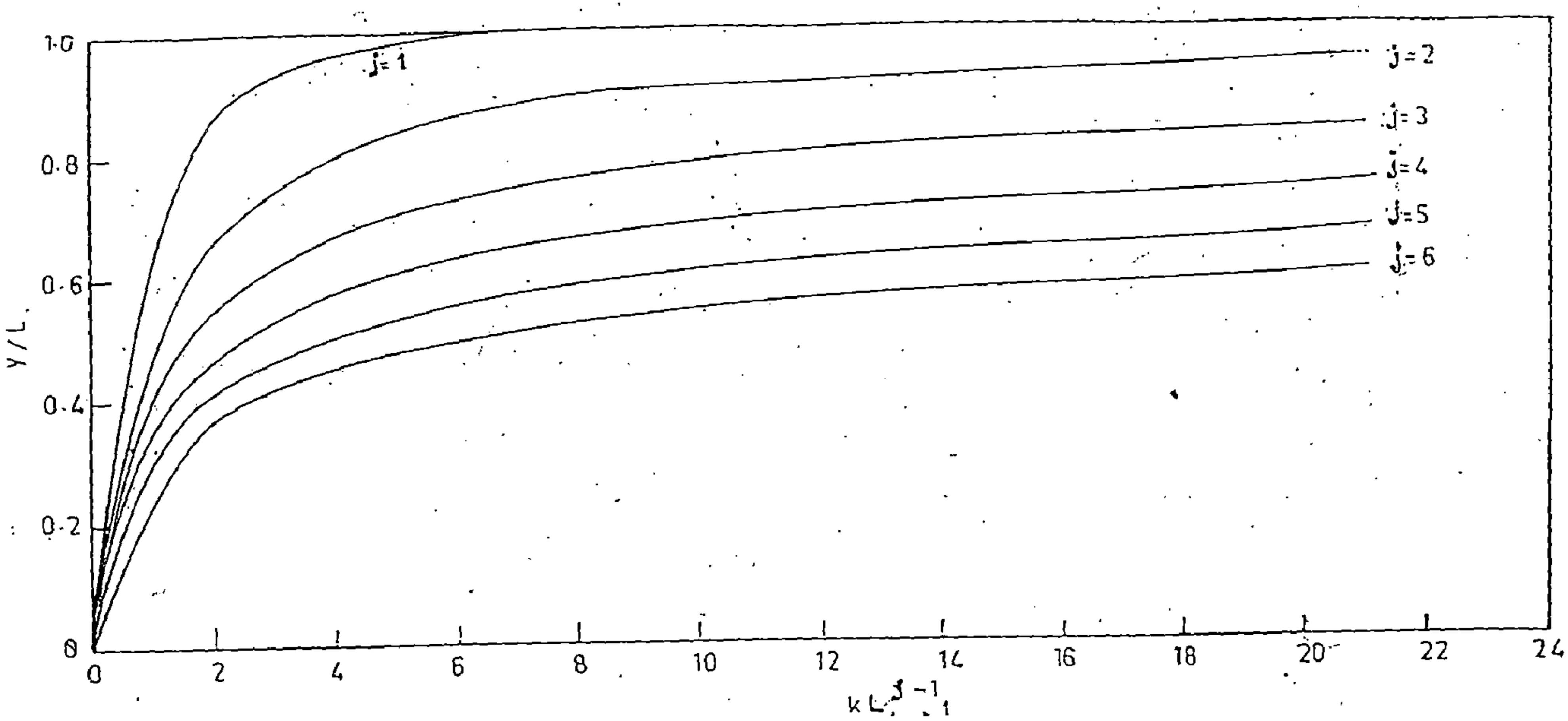

Fig.2.3 Non Dimensional Plots of Higher Degree Equations

CHAPTER - 3

EXPERIMENTAL AND ANALYTICAL PROCEDURE

Eight sets of experiments were conducted in the laboratory for BOD exertion of specific industry wastes, so as to collect data for studying the effect of Indigenous seed vs sewage seed on ultimate BOD. Data was also used to predict the various parameters associated with various prevalent equations representing BOD exertion. The effect of seed on these parameters of different BOD equations were compared and the fitness of these equations to obtained data was also studied.

3.1 EXPERIMENTAL PROCEDURE

Since the study was to establish the effect of seed on BOD exertion of different industrial waste, four industries were chosen for the purpose of this study. The industries chosen were paper, sugar, distillery and dairy industries located in western U.P. The acclimatised seed containing the microfauna already growing in the environment of the particular waste was collected from the respective treatment plants of the industry. In all cases except Dairy, the seed was obtained from the recirculated portion of activated sludge. In case of dairy, since there was no ASP, the seed was collected from the settled sludge at the bottom of the effluent manhole.

The characteristics of the waste so obtained are given in Table 3.1. The characteristion of the waste was done as per Standard Methods (1980).

Table 3.1 Initial Characteristics of Wastes Used in Experiments

Parameters \ Wastes	Paper	Sugar	Dairy	Distillery
pH	9.42	5.2	7.2	8.2
COD	14000 mg/l	2400 mg/l	360 mg/l	18400* mg/l
Total Solids	26238 mg/l	3400 mg/l	810 mg/l	63000 mg/l
Dissolved Solids	51190 mg/l	2760 mg/l	160 mg/l	14728 mg/l
Suspended Solids	21119 mg/l	640 mg/l	650 mg/l	48272 mg/l

* After Anaerobic digestion (Bio Methanation)

Since BOD of the wastes obtained were generally very high, these wastes were required to be diluted.

3.1.1 Dilution Water

Dilution water was prepared separately for each waste and for each seed e.g. for Distillery waste, dilution water was prepared separately for

(a) Distillery waste with sewage seed and blank.

(b) Distillery waste with Indigenous Seed and blank.

Following four standard reagents 1 ml/l each, were added to prepare the dilution water

(i) Phosphate buffer

(ii) Magnesium Sulphate

(iii) Calcium Chloride

(iv) Ferric Chloride

The above ingredients were dissolved in the distilled water and after seeding it with appropriate seed, it was aerated for half an hour. 2 ml/l of seed was used throughout.

3.2 BOD DETERMINATION

Four sets of bottles were prepared; one set corresponding to one waste. Each set contained separate bottles with indigenous and sewage seeds and blanks.

Metcalf and Eddy (1979) has recommended the range of dilution of waste to be effected corresponding to the COD of waste. Accordingly dilution as in Table 3.2 were used.

Table 3.2 Dilution of the Waste Used for BOD Determination

Waste	% Dilution	COD Value mg/l	Range recommended mg/l
Paper	0.02	14000	10000 - 35000
Distillery	0.02	18400	10000 - 35000
Sugar	0.10	2400	2000 - 7000
Dairy	1.00	360	200 - 700

D.O. was determined using WINKLER'S method. 'y' the BOD exerted after incubation was calculated using the relationship.

$$y = \left[(DO_b - DO_i) \times \frac{100}{d}\right] - (DO_b - DO_s)$$

in which DO_b = DO of blank after incubation

DO_i = DO of mixture after incubation

DO_s = Initial DO of undiluted sample

d = Dilution of waste in percent

3.2 ANALYTICAL PROCEDURE

Four prevalent equations were used for analysing the BOD data obtained. These are

(a) First degree (eqn. 2.1) $y = L_1(1 - \exp(-kt))$

(b) Second degree (eqn. 2.4) $y = L_1^2 \dfrac{kt}{1 + L_1kt}$

(c) Woodword second degree (eqn. 2.8)

$$y = L_1 \frac{t/t_{*1}}{1 + t/t_{*1}}$$

(d) Shrivastava (1982) (eqn. 2.11)

$$y = L_1 \frac{(t/t_{*1})^{m_1}}{\left[1 + (t/t_{*1})^{m_1/n_1}\right]^{n_1}}$$

Separate programs were written for fitting the experimental data in each of the above equations and to evaluate corresponding parameters.

The fitting of the curve was carried out by minimising the error estimate CAPE (Cumulative Absolute Proportional Error) (Srivastava, 1982).

$$\text{CAPE} = \sum \left| \frac{Y_{cal} - Y_{obsv}}{Y_{cal}} \right|$$

CHAPTER - 4

PRESENTATION AND ANALYSIS OF DATA

The data obtained from experimental investigations pertain to the phenomenon of BOD exertion in case of industrial wastes, namely Dairy, Paper, Sugar and Distillery by the sewage and indigenous seed. The data has been recorded in tables 4.1 to 4.4 (Appendix) and shown plotted in figures 4.1 to 4.4 and the discussion of results are given here under.

4.1 EFFECT OF TYPE OF SEED

(a) General - From the perusal of the figures 4.1 to 4.4, it is seen that in each case of BOD exertion, the BOD exerted by an indigenous seed is generally more than that exerted by sewage seed on all days of experiment.

Also from the figures 4.1 to 4.4 it is apparent that plateau is distinct in case of sewage seed wherein the carbonaceous and nitrogenous BOD satisfaction takes place at different times. Possibly in case of indigenous seed the organisms work together from the very beginning and no plateau is observed.

(b) BOD_5 and BOD_{20} - The 5-day 20^oC BOD value (BOD_5) and 20-day 20^oC BOD (BOD_{20}) values as obtained by the sewage and indigenous seed are tabulated in Table 4.5.

It is observed that both BOD_5 and BOD_{20} with the indigenous seeds are higher as compared to that obtained in case of the sewage seeds and the ratio of BOD_5 exerted by indigenous seed to BOD_5 exerted by sewage seed (hereafter referred as R_5) varies from 1.38 to 2.45 and the same ratio for BOD_{20} (R_{20}) varies from 1.12 to 1.85. It is also observed that R_5 is always higher then R_{20} except in case of Paper, in which case R_5 and R_{20} are approximately same. This indicates that in the initial stages of log phase of growth, the indigenous microorganism exert BOD faster as compared to sewage seeds which are probably in the lag phase. By 20^{th} day as most of the organic compounds are degraded in case of each waste, R_{20} values becomes less than respective R_5 value and the difference remains that of organic compounds degradable by indigenous seed and non-degradable by coliforms.

4.2 BOD PARAMETERS

BOD parameters have been used by various researchers as means of design of effluent treatment plants, understanding of BOD exertion phenomenon, evaluation of performance of effluent treatment plants etc.

An attempt, hence, was made to compare BOD parameters of different existing BOD equation with the sewage and indigenous seeds.

A large number of equations have been suggested for BOD kinetics (as detailed in chapter 2). For comparative study following equations and their respective parameters were considered.

Equation	Parameters
a. First Order (degree)	L, K
b. Woodward	L, t_{*1}
c. Second Order (degree)	L, K
d. Shrivastava	L, t_{*1}, m_1, n_1

(a) First Order Equation - Figures 4.5 to 4.12 show the observed BOD values and those estimated by First Order. From the curves it is clear that the first order equation fits quite well in the data all through the experimental time period. The average variation of the data estimated by First Order Equation from the observed data is about 5.3%.

Parameters values obtained by the first order equation are tabulated in table 4.6a (Appendix). Corresponding parameter ratios for indigenous versus sewage seeds are tabulated in table 4.6b.

It can be seen that the ratio of BOD exerted by indigenous seed to that by sewage seed is always greater then unity. It varies between 1.12 for sugar waste to 1.94 for

Distillery waste. BOD rate exponent ratio (Indigenous/Sewage) is also always greater than unity. It varies between 1.17 to 1.7.

Thus both ultimate BOD values (L) and the (K) rate constants in case of indigenous seeds are higher than those obtained in case of sewage seeds.

(b) Shrivastava equation - Figures 4.13 to 4.20 shows the observed BOD values and those estimated by Shrivastava (1982) equation. The BOD exertion equation proposed by Shrivastava fits in the observed data all through the experimental period. The average variation of the data, estimated by Shrivastava equation, from the observed data is about 2.9%.

The BOD parameter values of this equation are tabulated in table 4.7a (Appendix), and the ratios for indigenous and sewage seeds are tabulated in table 4.7b. It can be seen that the ratio of ultimate BODs by indigenous and sewage seed is always greater than unity. The ratio varies from a minimum of 1.09 to a maximum of 1.79. Apparent ultimate time (t_*) for BOD exertion with indigenous seed is always less than the time for BOD exertion with sewage seeds except in case of Dairy where the both are almost equal.

BOD rate exponent (m) in case of indigenous seed is generally more than that for sewage seed. Also the transition exponent (n) for indigenous seed is much smaller than that for sewage seed.

(c) Woodward Equation - Figures 4.21 to 4.28 show the observed BOD values and those estimated by Woodward equation. The average variation of the data estimated by Woodward equation, from the observed data is about 5.8%. This error is slightly more than that obtained for First order equation but is almost twice of the error obtained by Shrivastava's equation. The general fit of this equation to observed data is good except for the observation that this equation shows a marked divergence from the observed data, on around 20th day of observation. And therefore, this equation predicts an ultimate BOD which is much higher than that predicted by any other model.

Parameter values obtained by the Woodward equation are tabulated in table 4.8a (Appendix). Corresponding parameter ratios for indigenous to sewage seeds are also tabulated in table 4.8b (Appendix). The trend in this case is more distinct. Ultimate BOD values obtained by indigenous seed are always greater than that obtained by sewage seed. Also the apparent ultimate time for indigenous seed is always less than that obtained by sewage seed.

(d) Second Order Equation - Figures 4.29 to 4.36 show the observed BOD values and those estimated by second order equation. The average variation of the data estimated by second order equation, from the observed data is about 19.20%. It can be seen that though the equation matches the observed data during the first five days of experimental observation, thereafter, there is a marked increase in the difference between observed and estimated data. This indicates that second order equation is not a good representation of BOD kinetics, specially for periods more than 5 days.

The parameter values obtained by the second order equation are tabulated in table 4.9a (Appendix). Corresponding parameter ratios for indigenous to sewage seeds are tabulated in table 4.9b (Appendix). The BOD ultimate value as exerted by indigenous seed is always more than that obtained by sewage seed. Here the ratio of BOD exerted by indigenous seed to that exerted by sewage seed varies from 1.67 to 2.24. And the parameter K in the equation is always more for sewage seed than that for indigenous seeds.

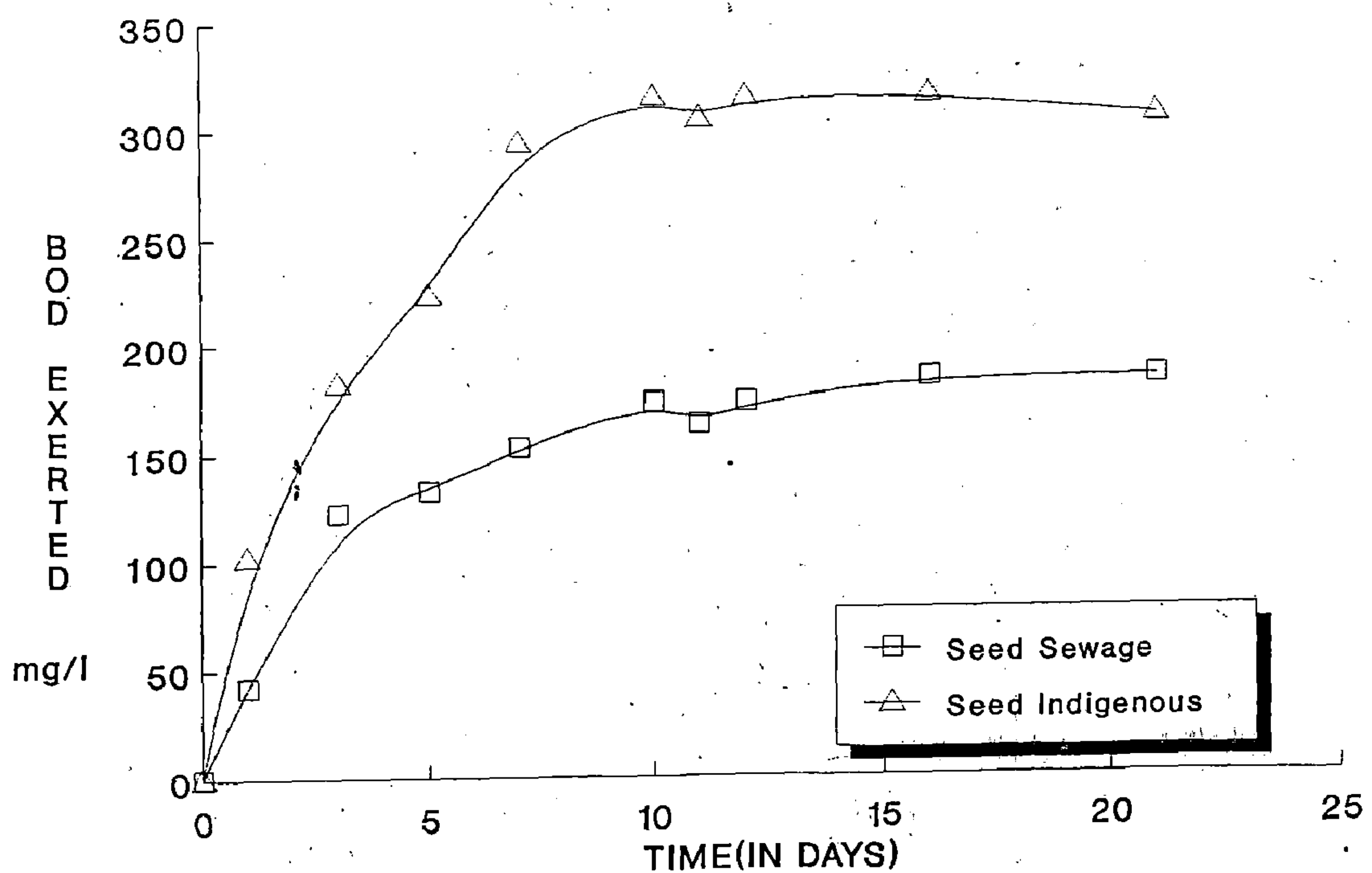

Fig4.1 BOD Exertion of Dairy Waste with Sewage & Indigenous Seed

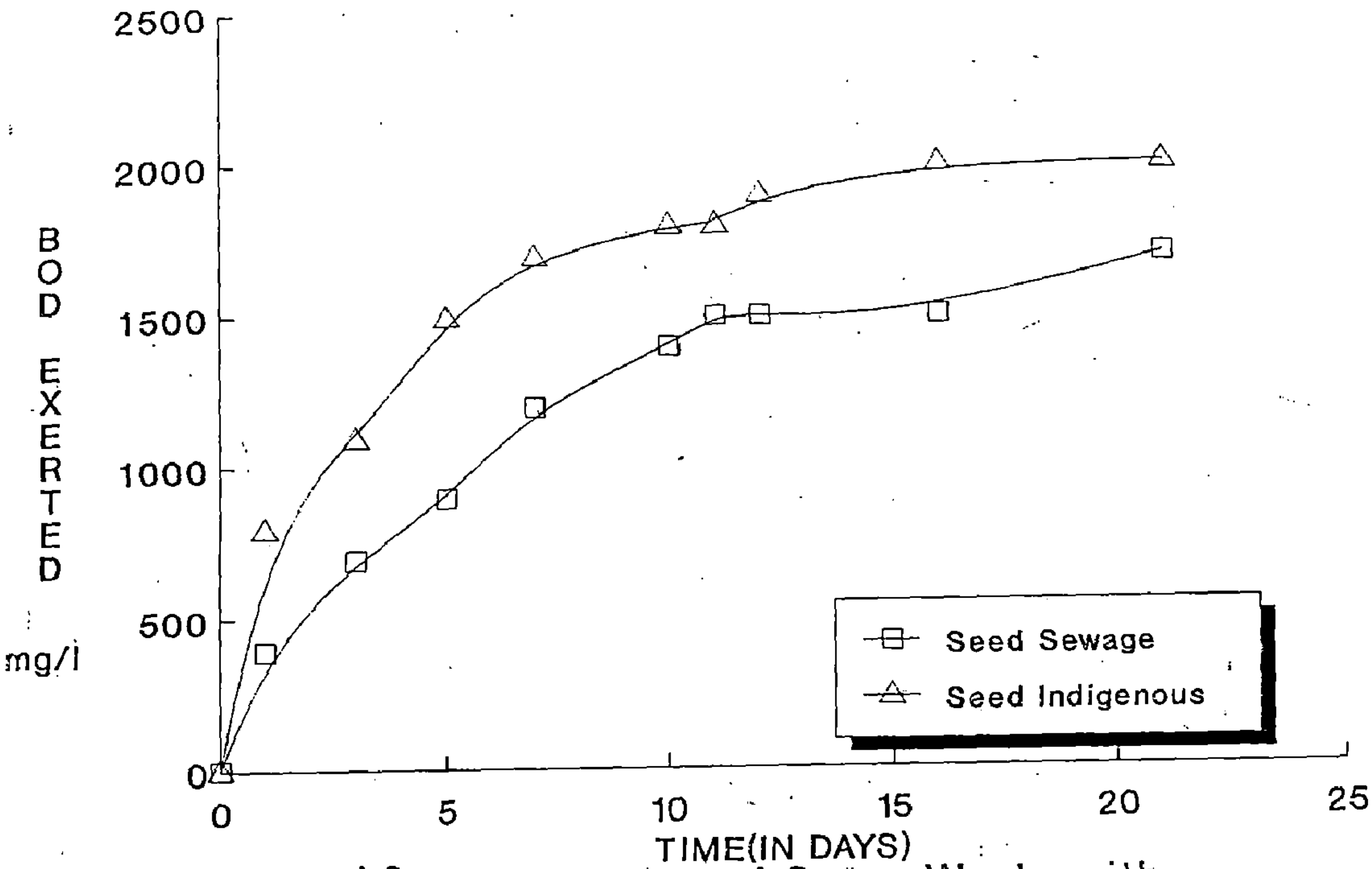

Fig_4.2_BOD Exertion of Sugar Waste with Sewage & Indigenous Seed

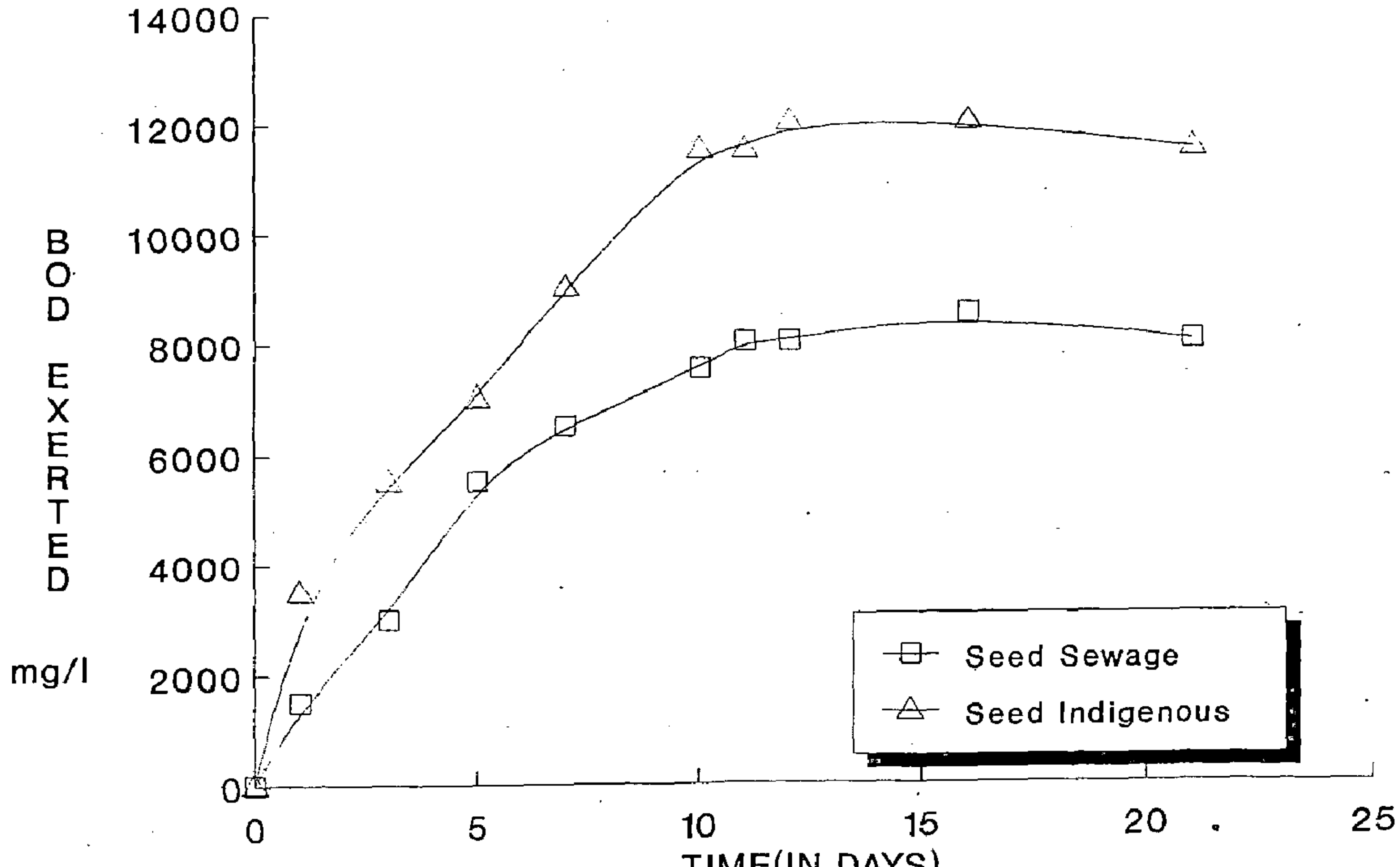

Fig 4.3 BOD Exertion of Paper Waste with Sewage & Indigenous Seed

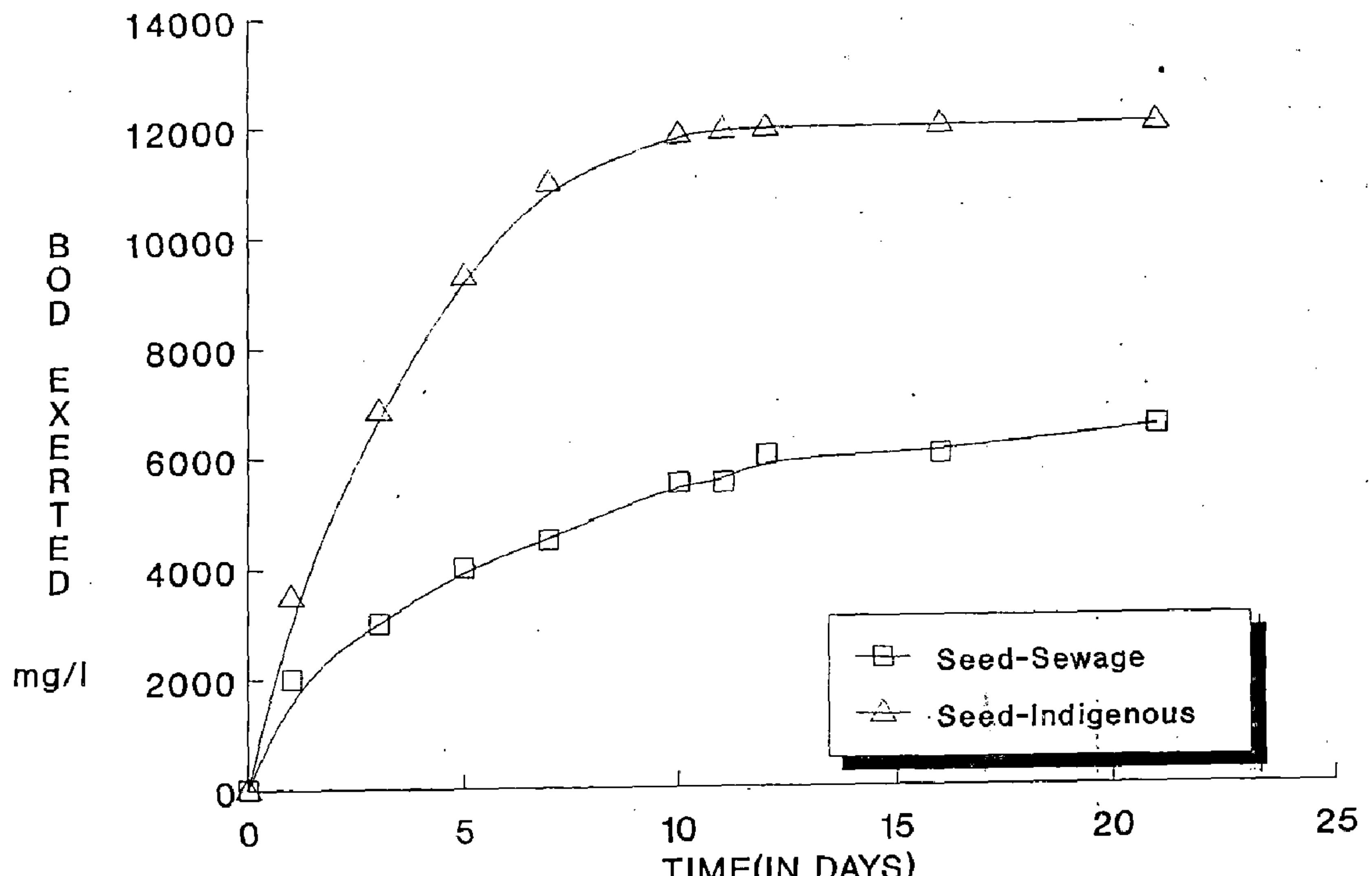

Fig_4.4_BOD Exertion of Distillery Waste with Sewage & Indigenous Seed

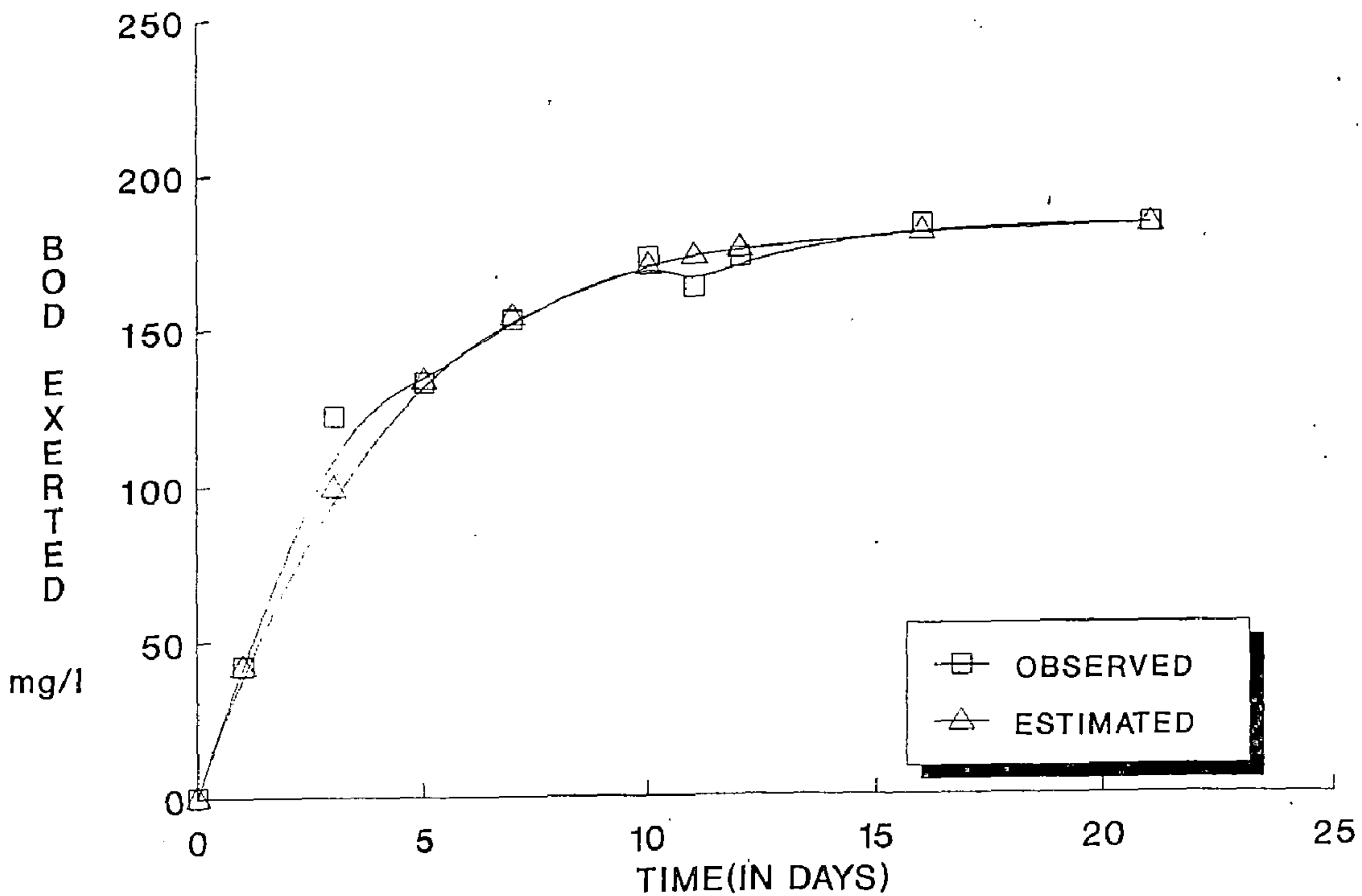

Fig. 4.5 BOD Exertion of Dairy Waste with Sewage Seed

equation 2.1

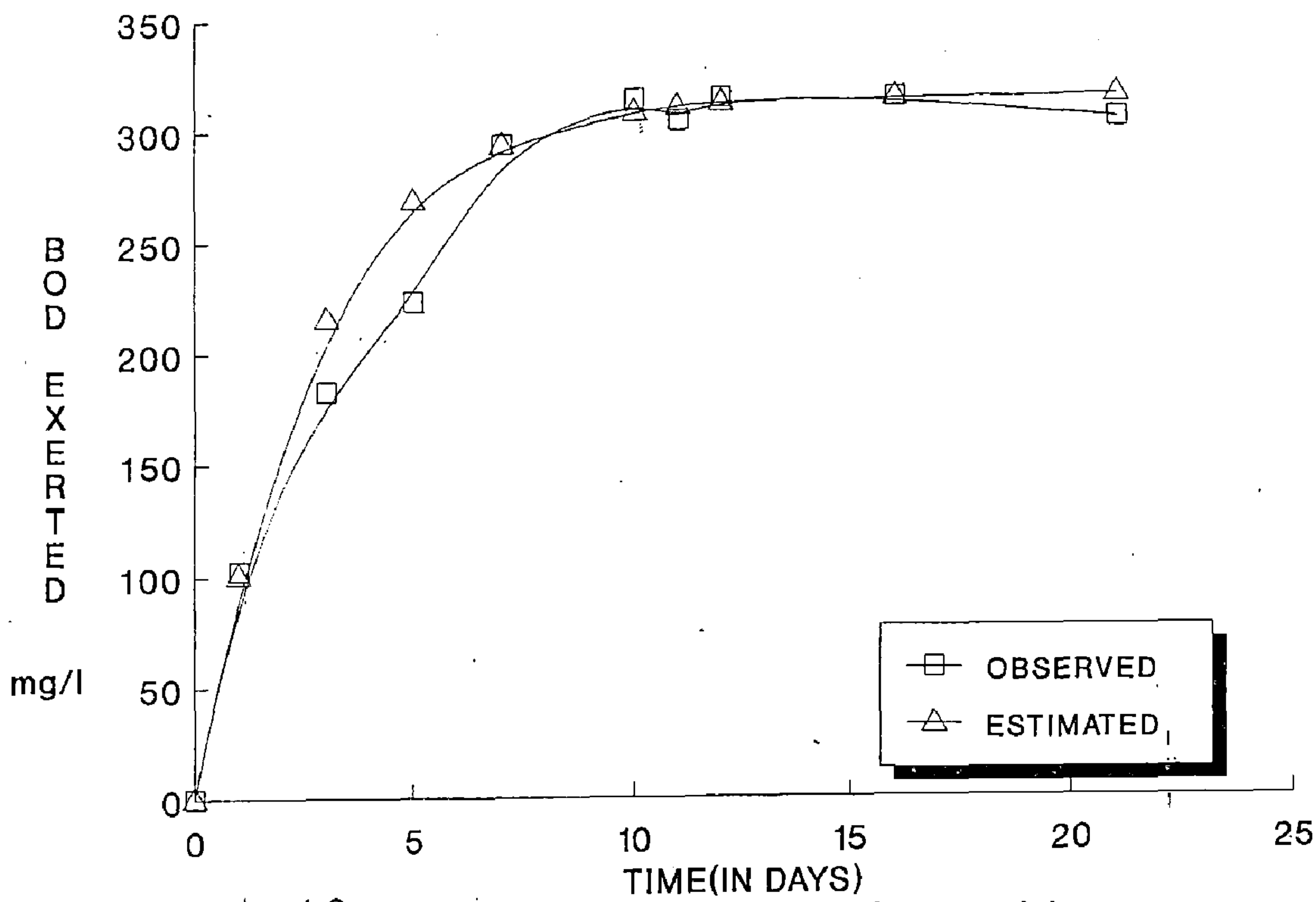

Fig. 4.6 BOD Exertion of Dairy Waste with Indigenous Seed

equation 2.1

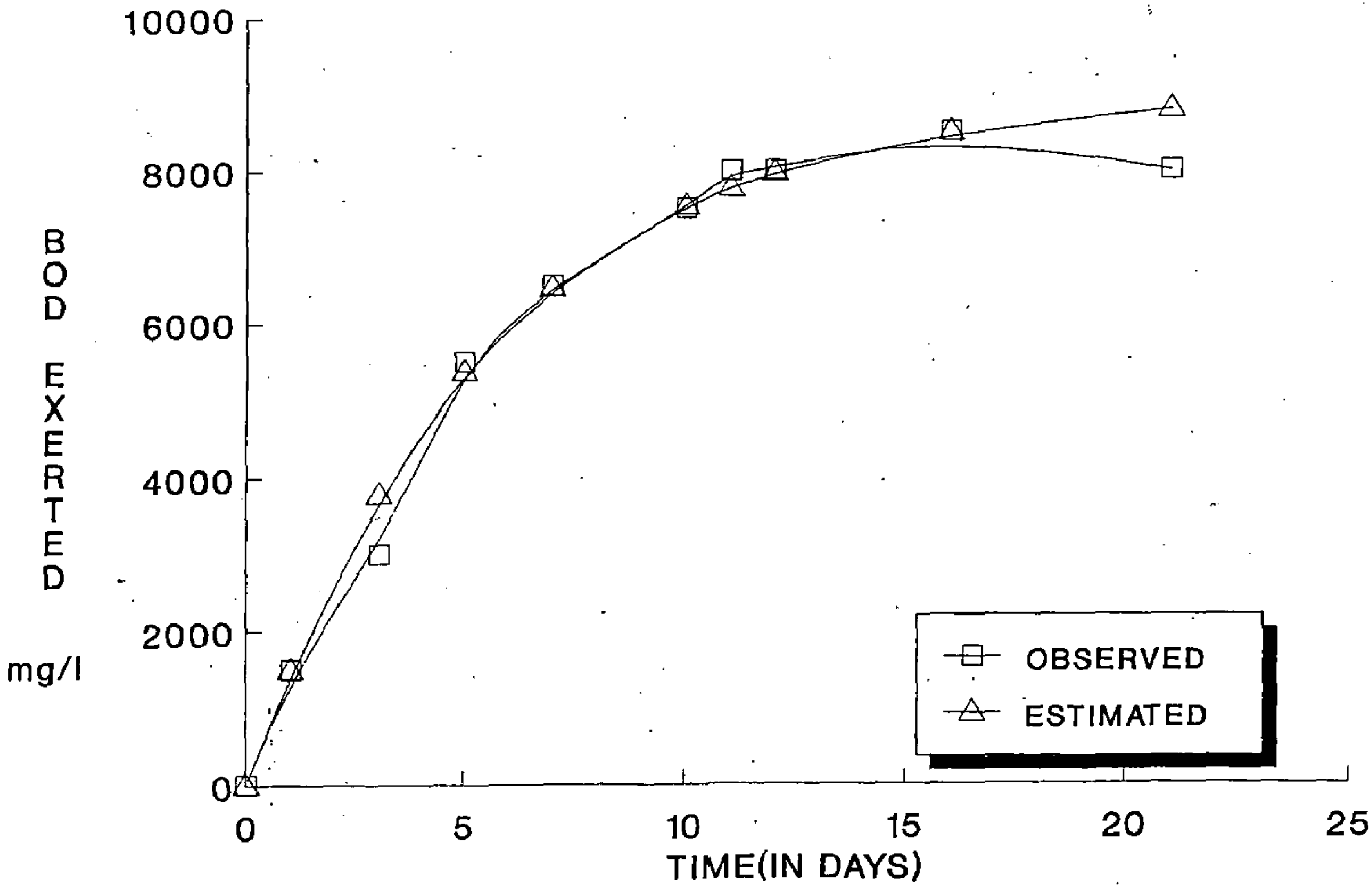

Fig 4.7 BOD Exertion of Paper Waste with Sewage Seed

equation 2.1

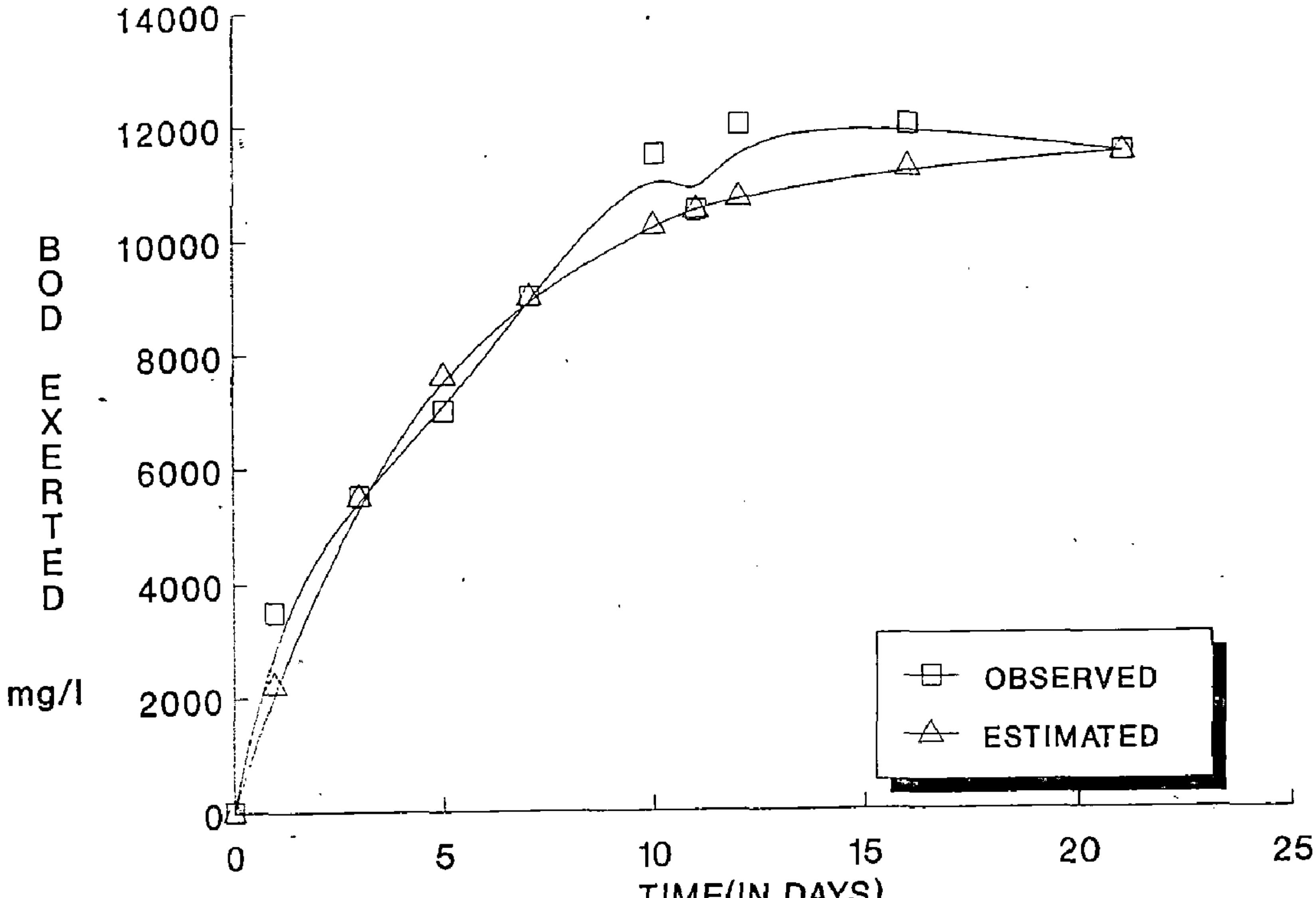

Fig 4.8 BOD Exertion of Paper Waste with Indigenous Seed

equation 2.1

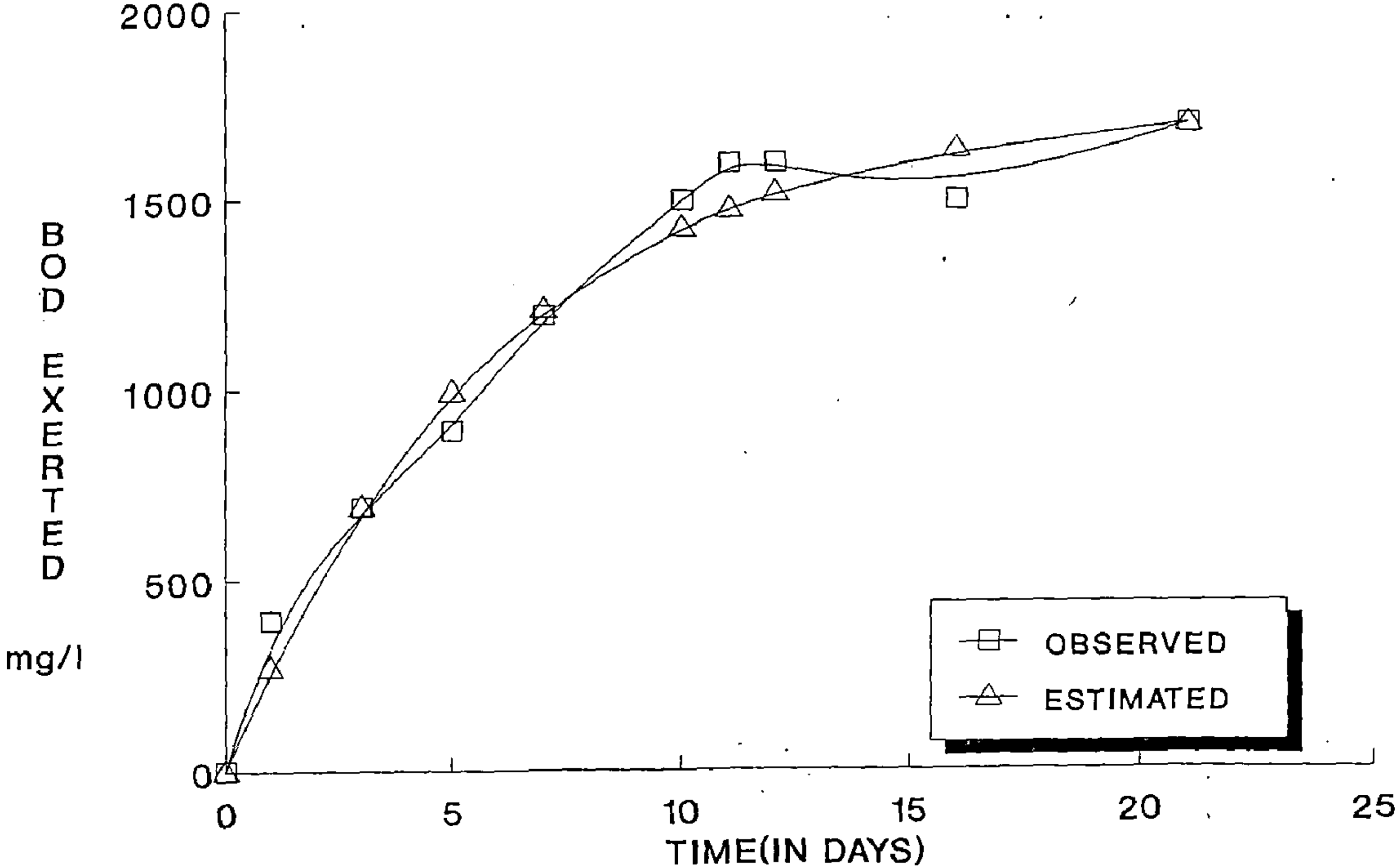

Fig. 4.9 BOD Exertion of Sugar Waste with Sewage Seed

equation 2.1

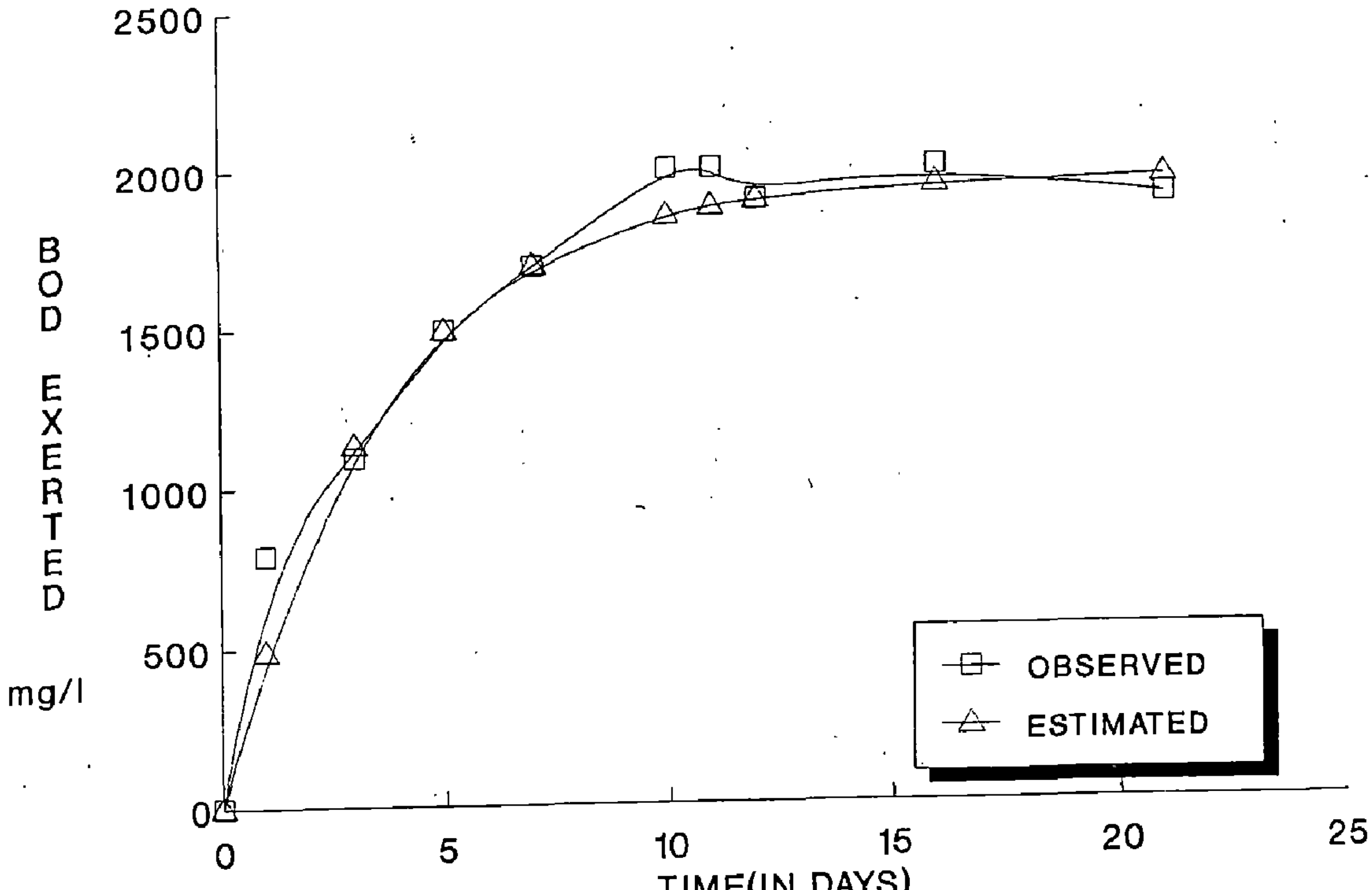

Fig 4.10 BOD Exertion of Sugar Waste with Indigenous Seed equation 2.1

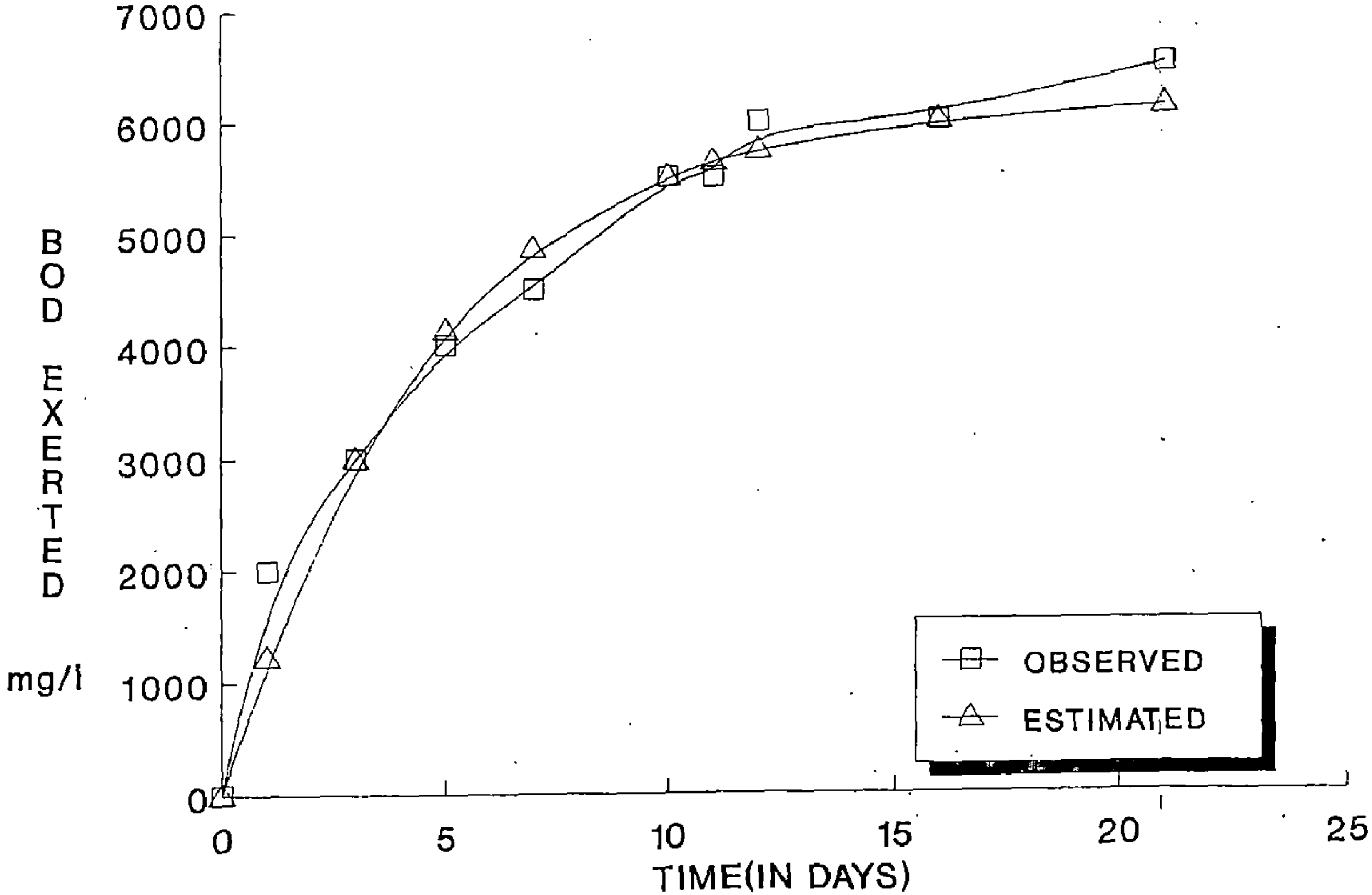

Fig 4.11 BOD Exertion of Distillery Waste with Sewage Seed

equation 2.1

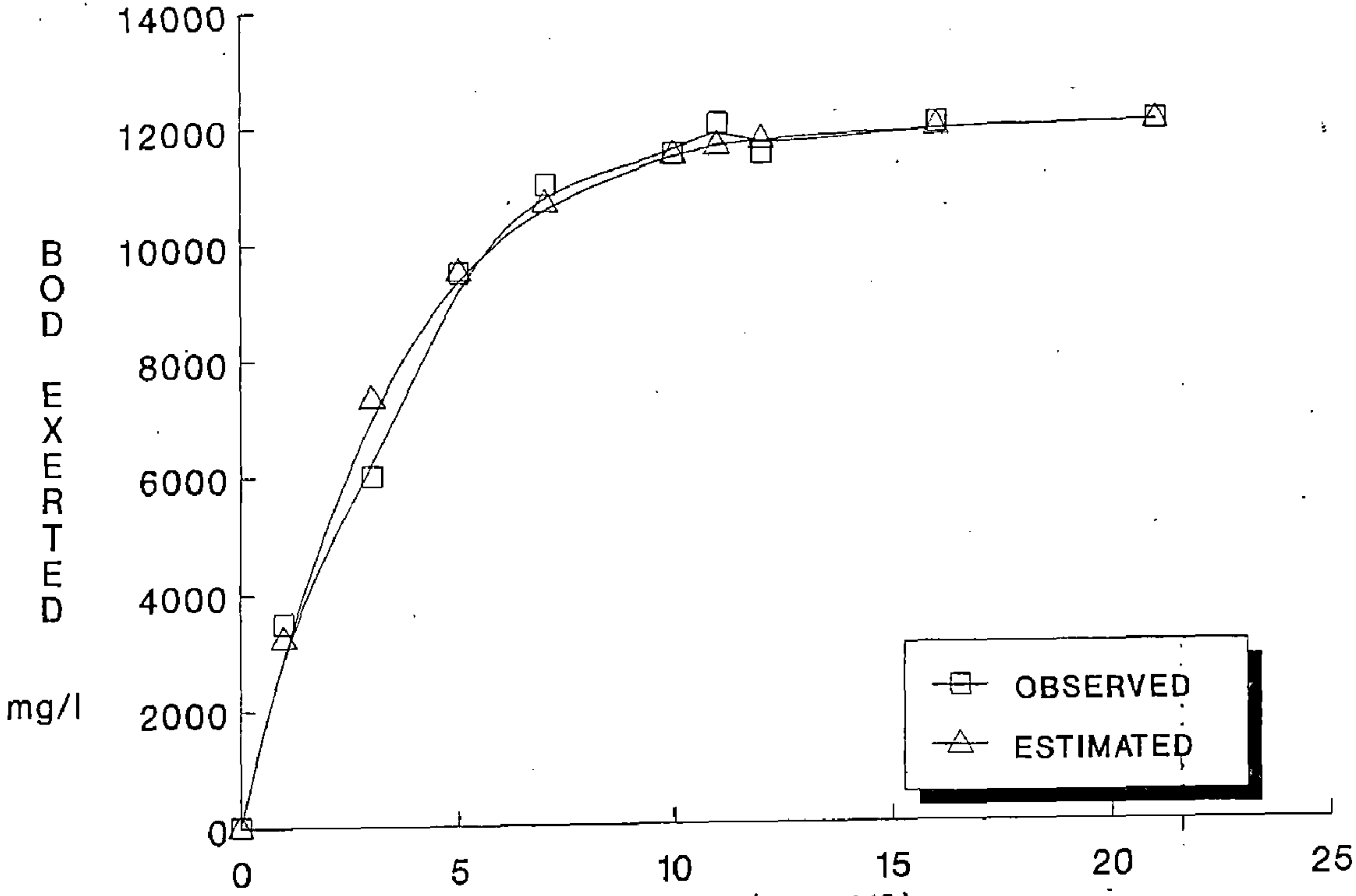

Fig 4.12 BOD Exertion of Distillery Waste with equation 2.1 Indigenous Seed

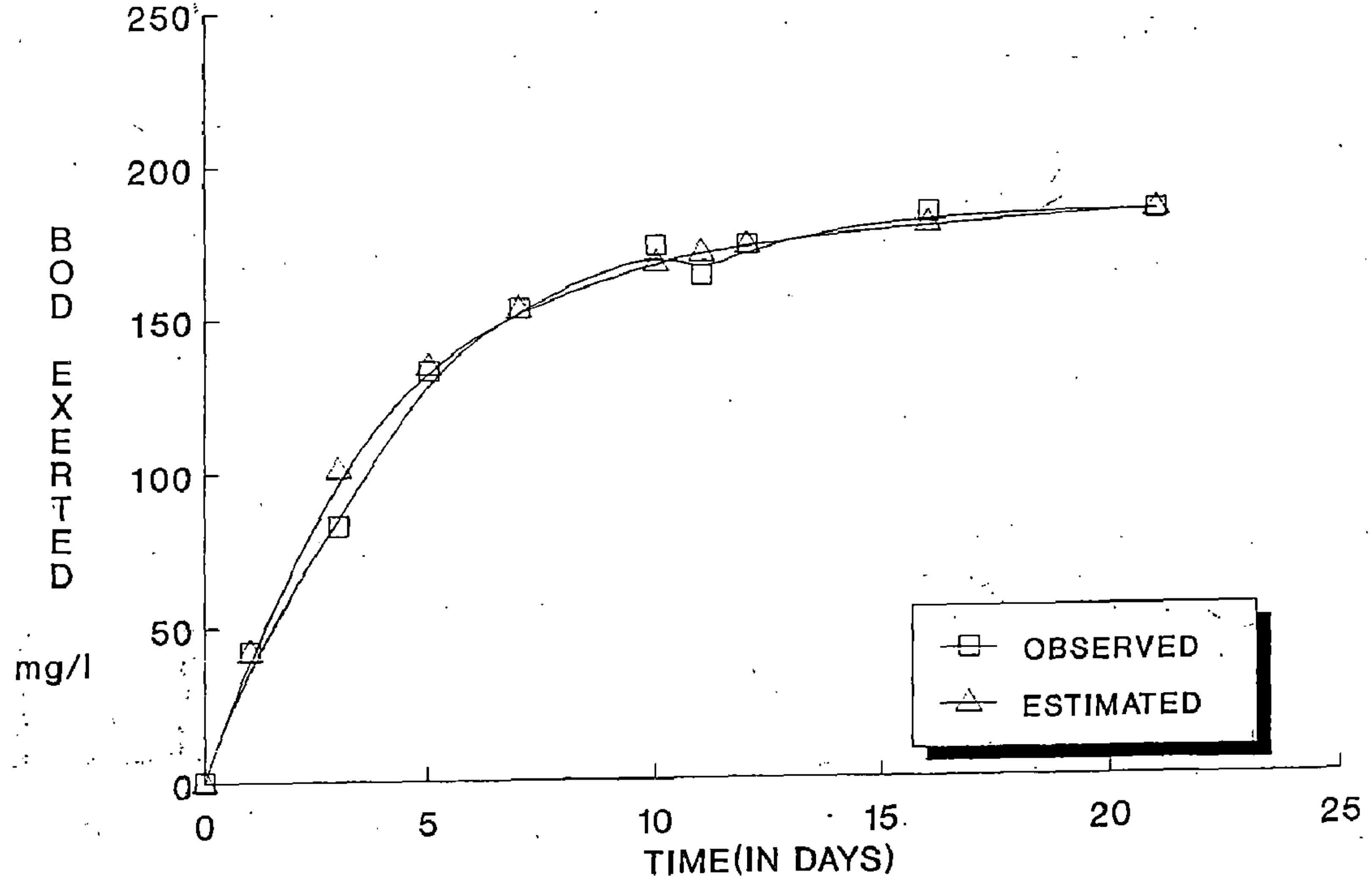

Fig.4.13 BOD Exertion of Dairy Waste with Sewage Seed

equation 2.11

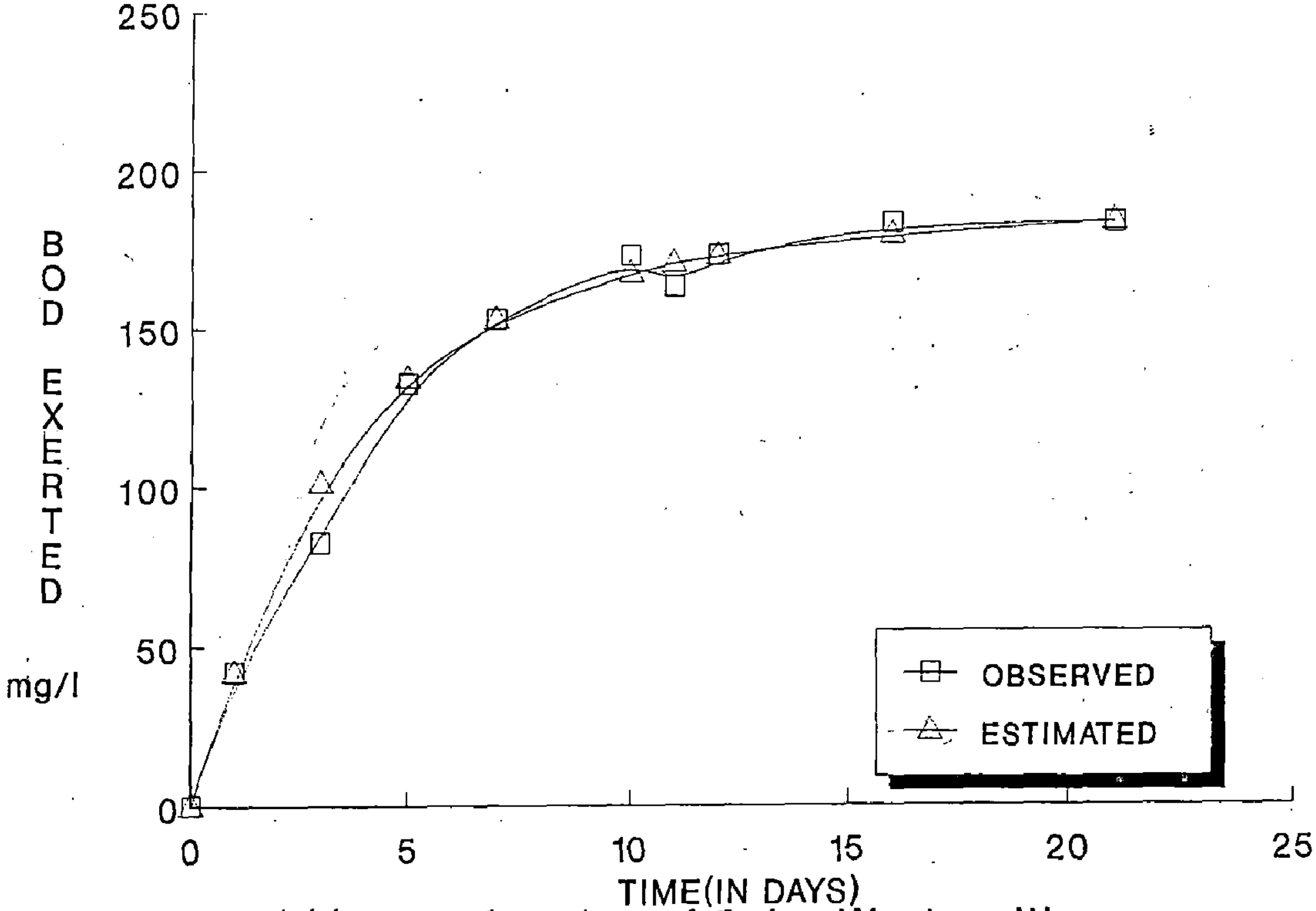

Fig.4.14 BOD Exertion of Dairy Waste with Indigenous Seed

equation 2.11

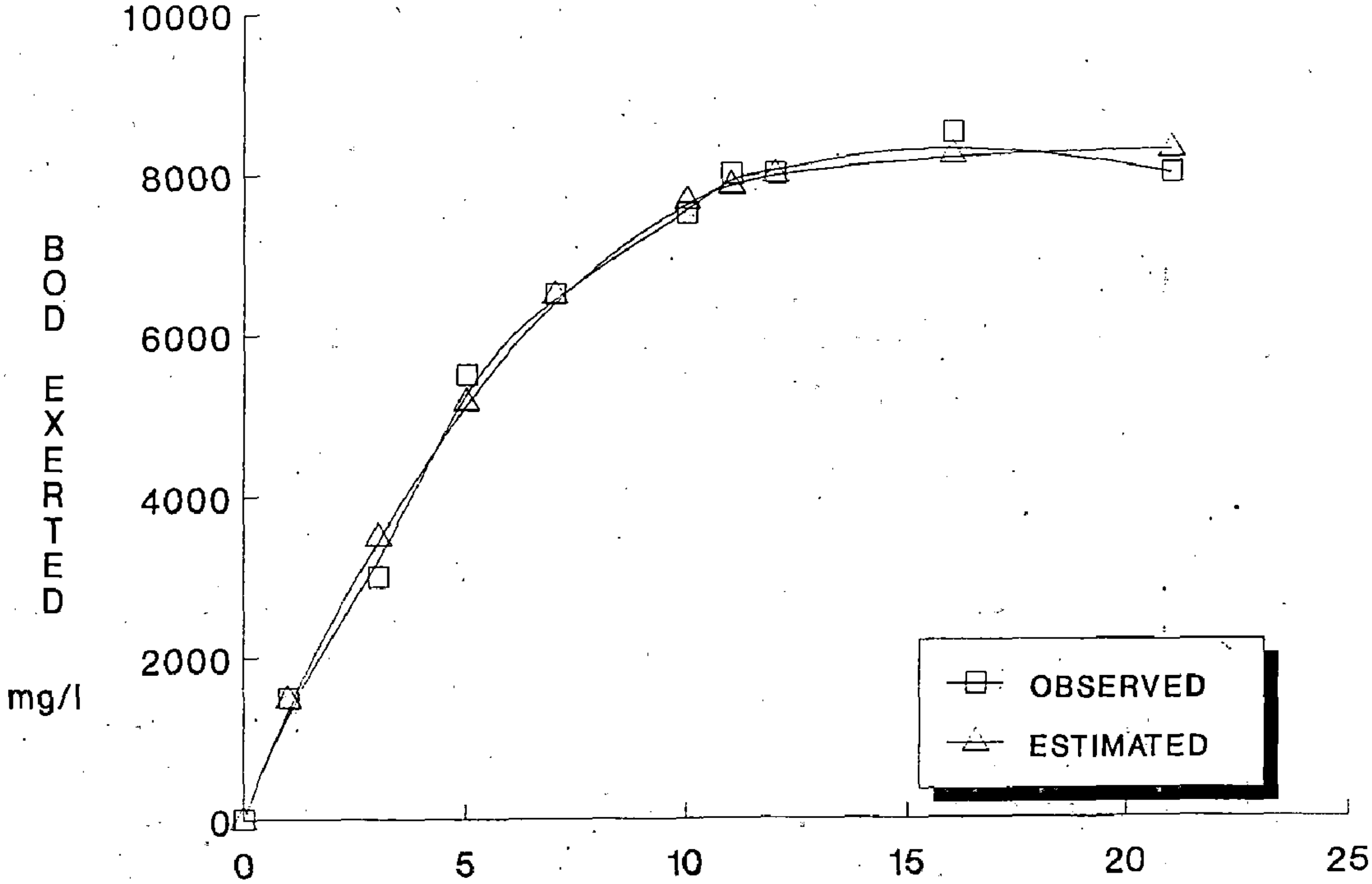

Fig 4.15 BOD Exertion of Paper Waste with Sewage Seed

equation 2.11

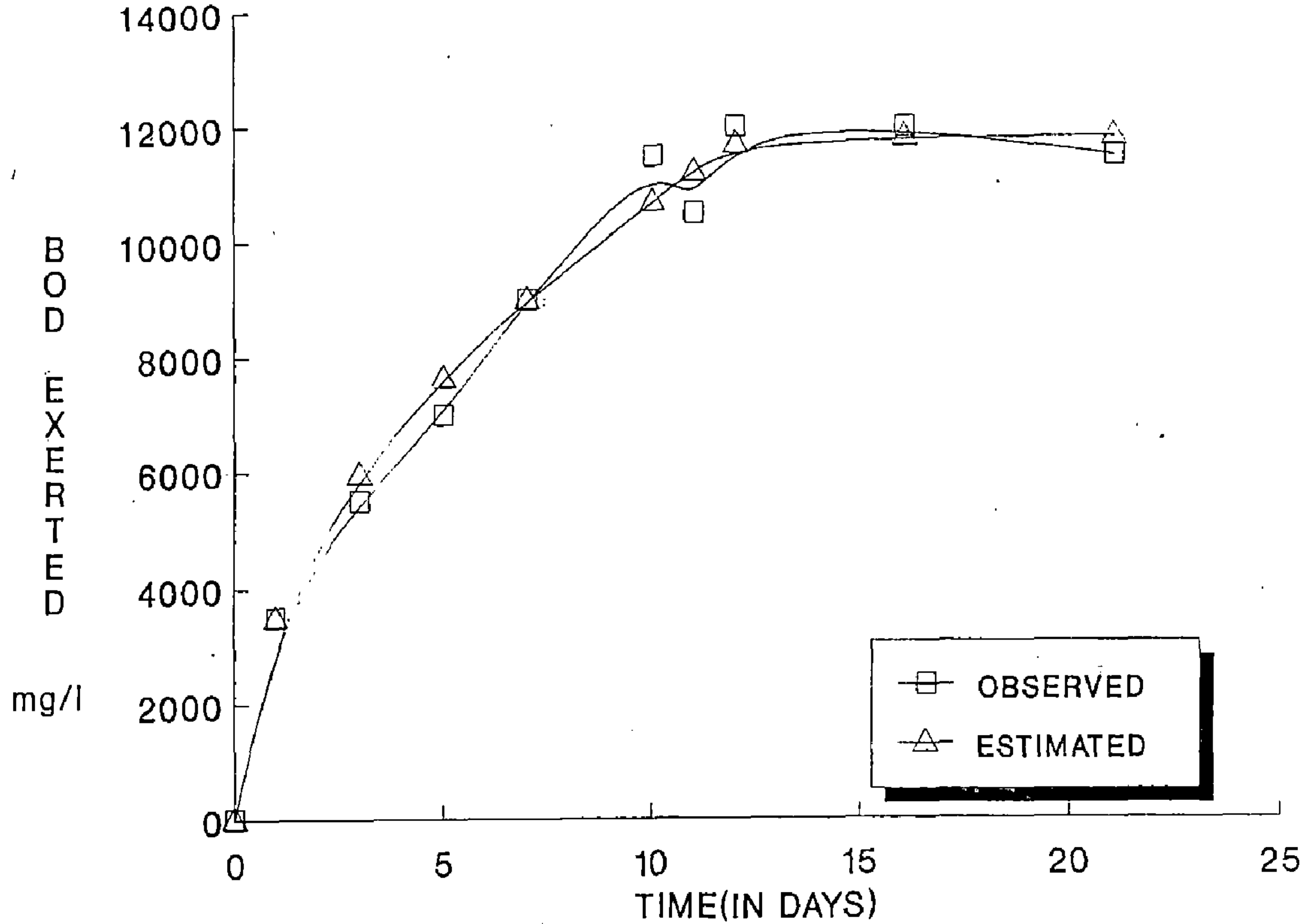

Fig 4.16 BOD Exertion of Paper Waste with Indigenous Seed

equation 2.11

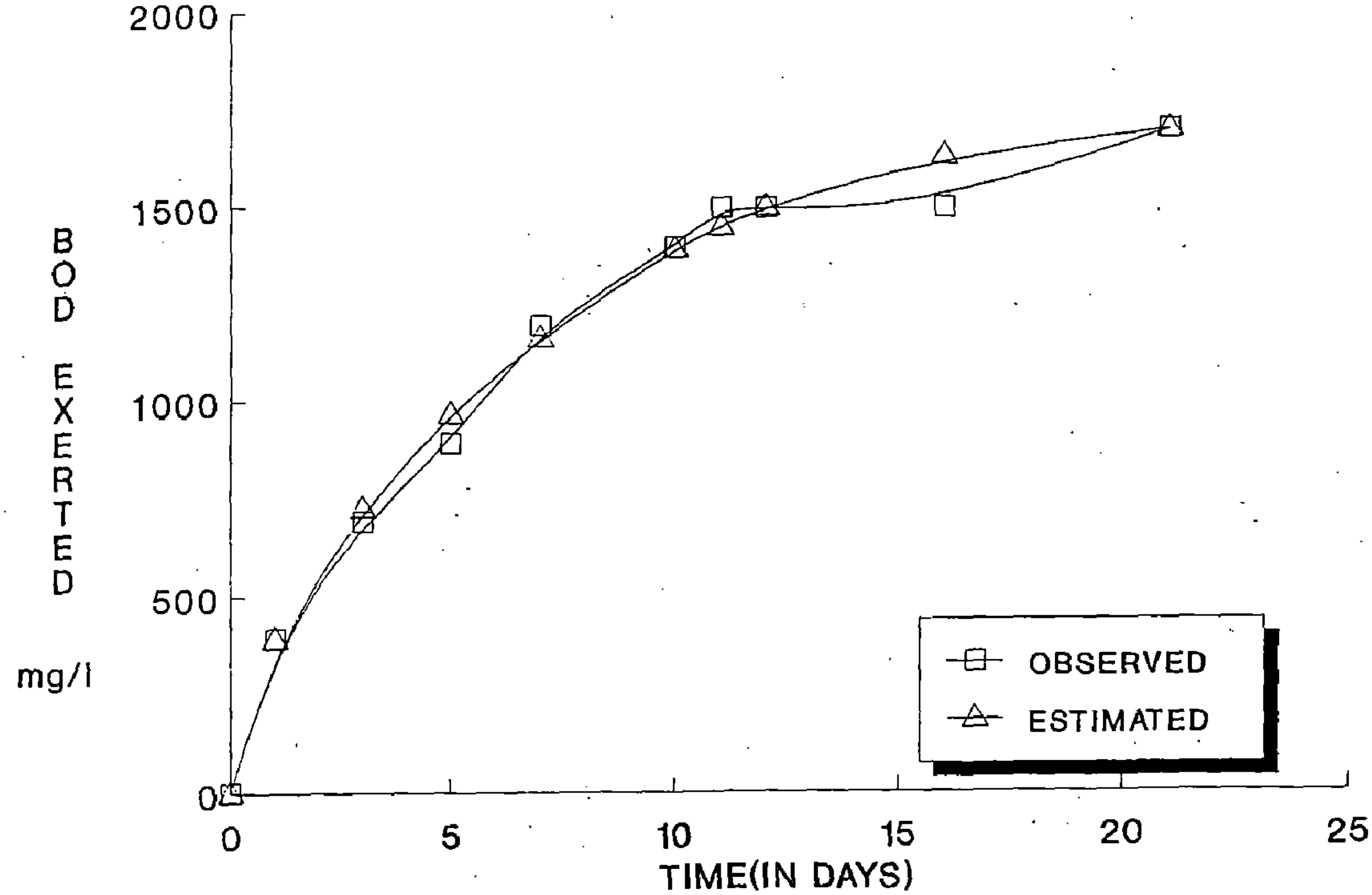

Fig 4.17 BOD Exertion of Sugar Waste with Sewage Seed equation 2.11

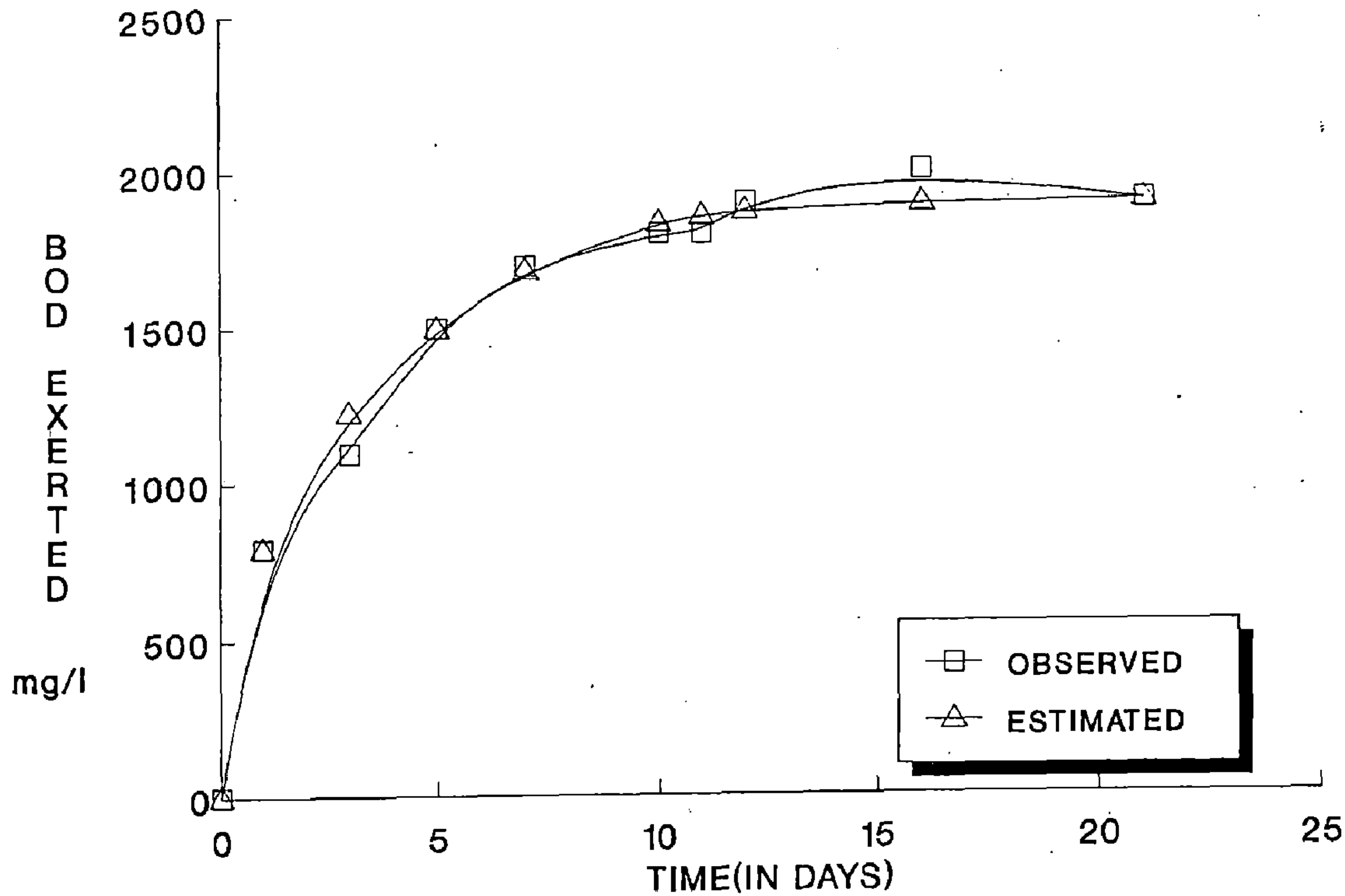

Fig 4.18 BOD Exertion of Sugar Waste with Indigenous Seed equation 2.11

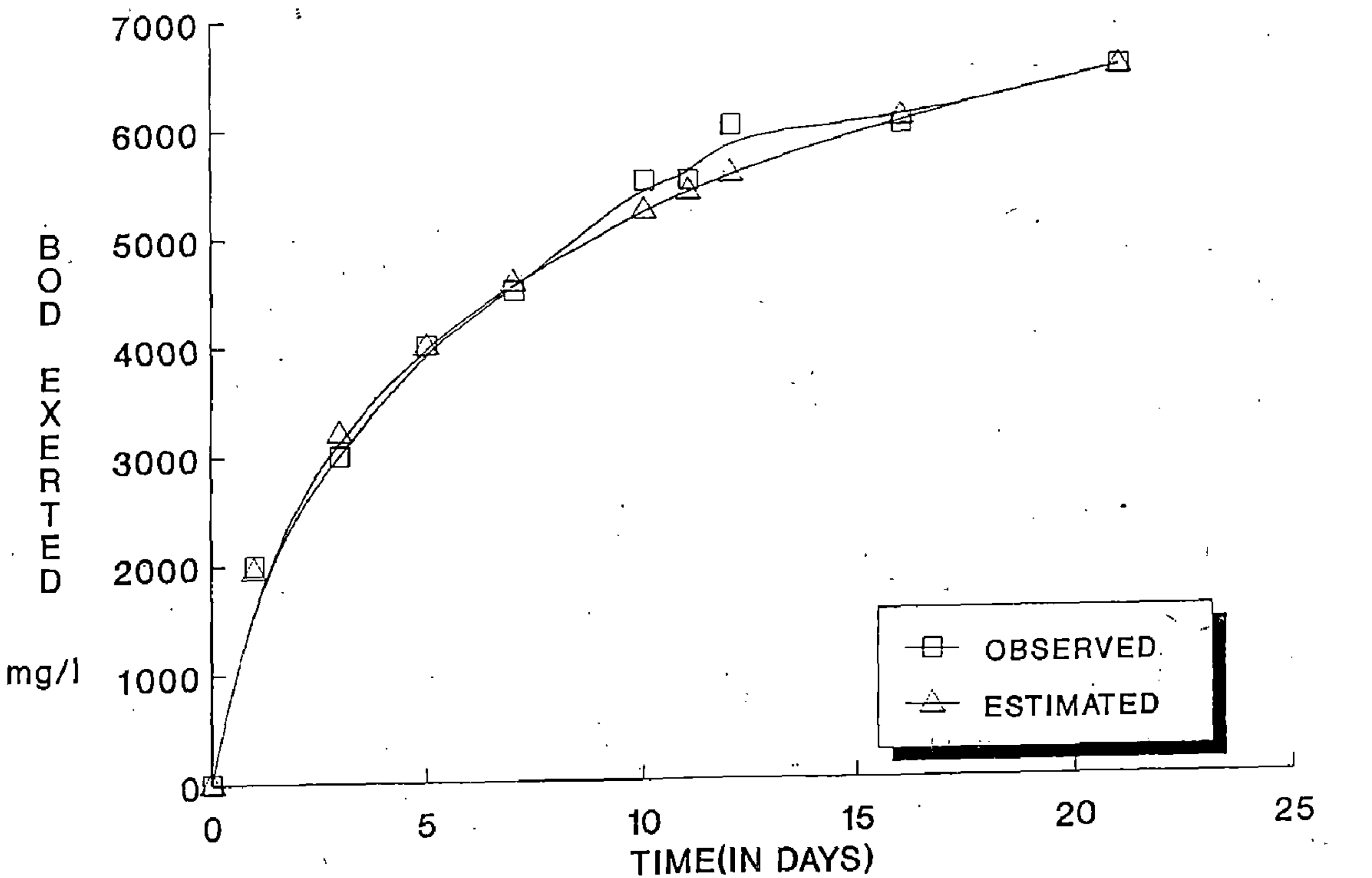

Fig 4.19 BOD Exertion of Distillery Waste with Sewage Seed

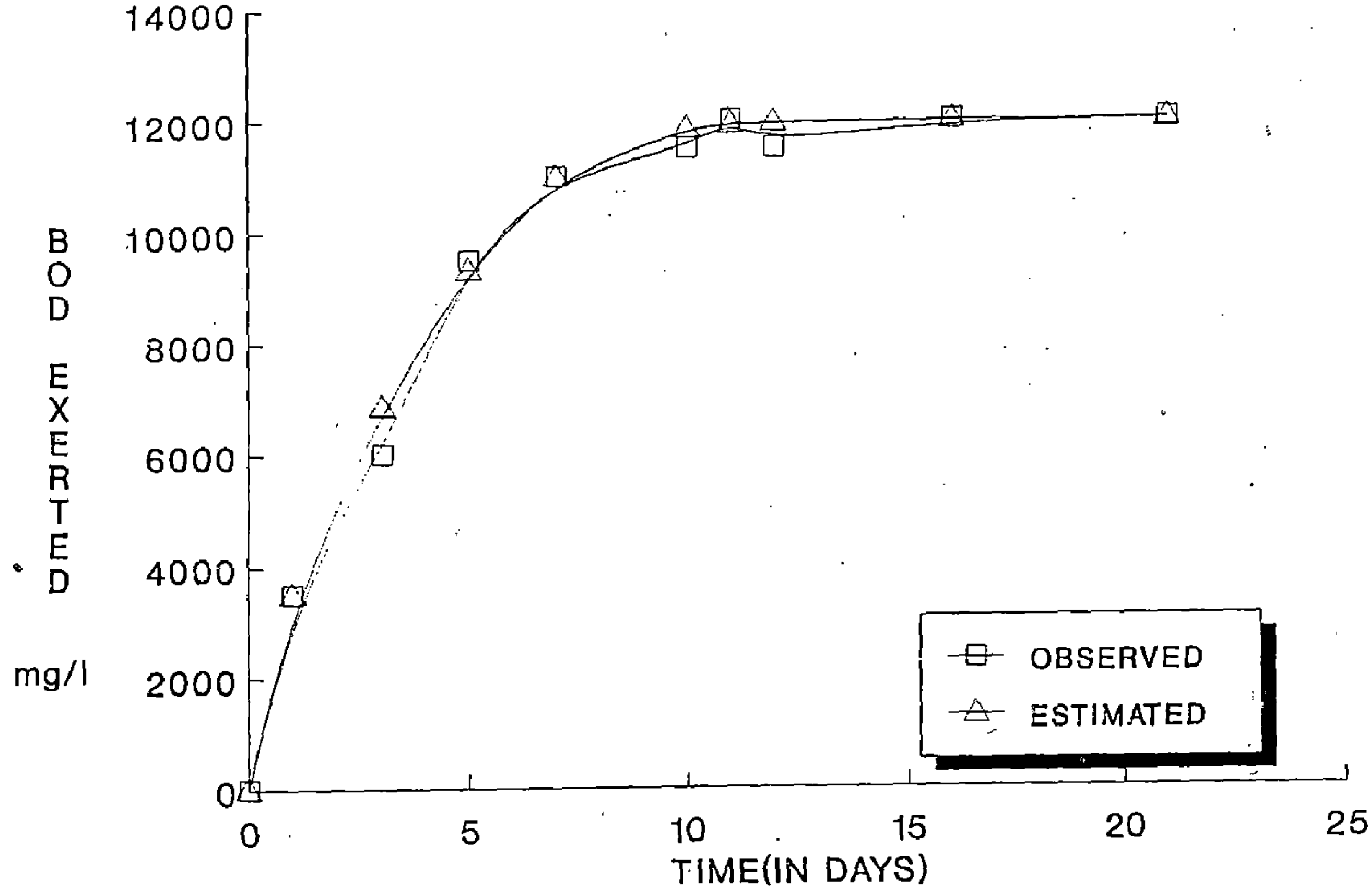

Fig 4.20 BOD Exertion of Distillery Waste with Indigenous Seed equation 2.11

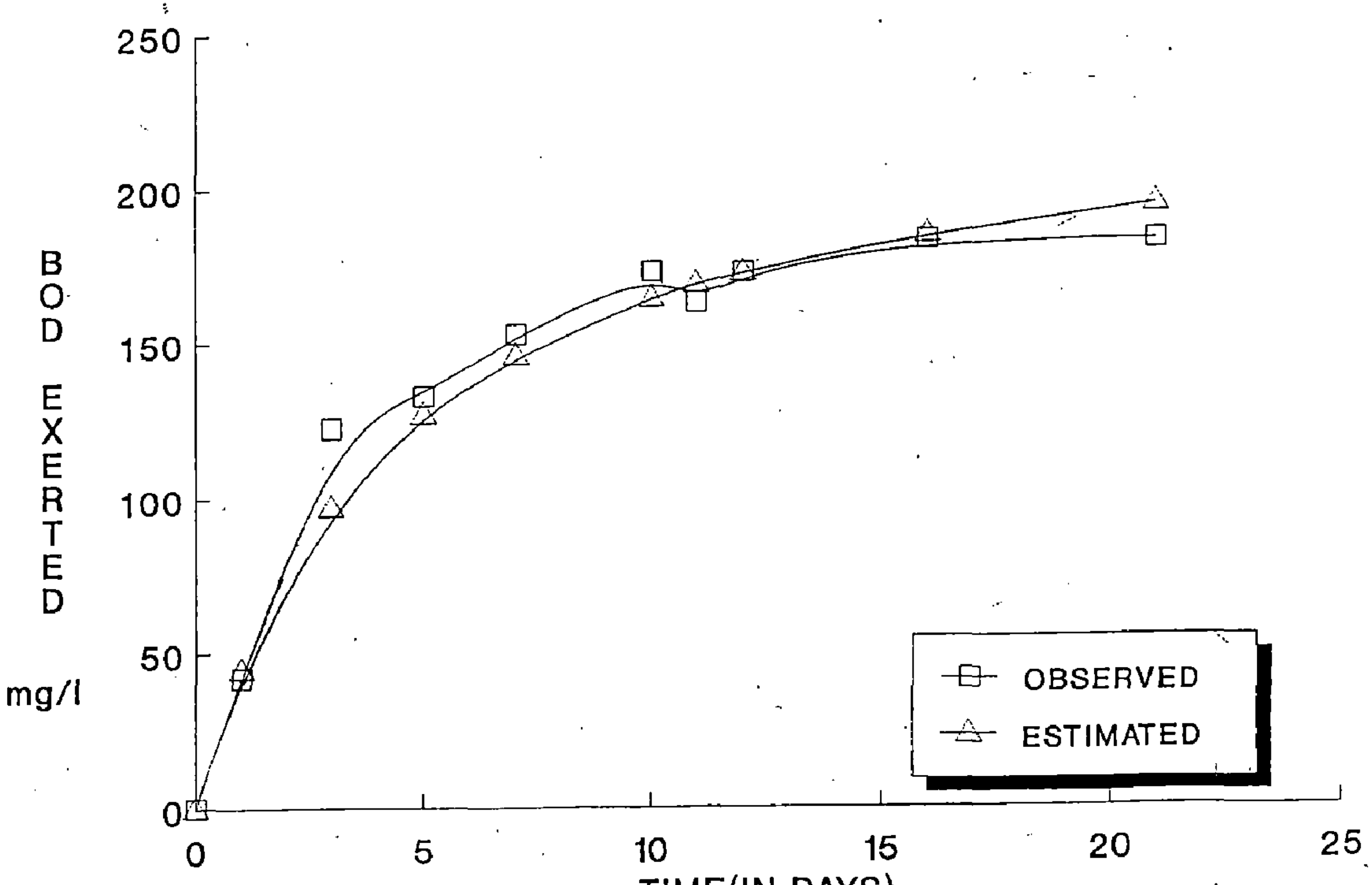

Fig.4.21 BOD Exertion of Dairy Waste with Sewage Seed

equation 2.8

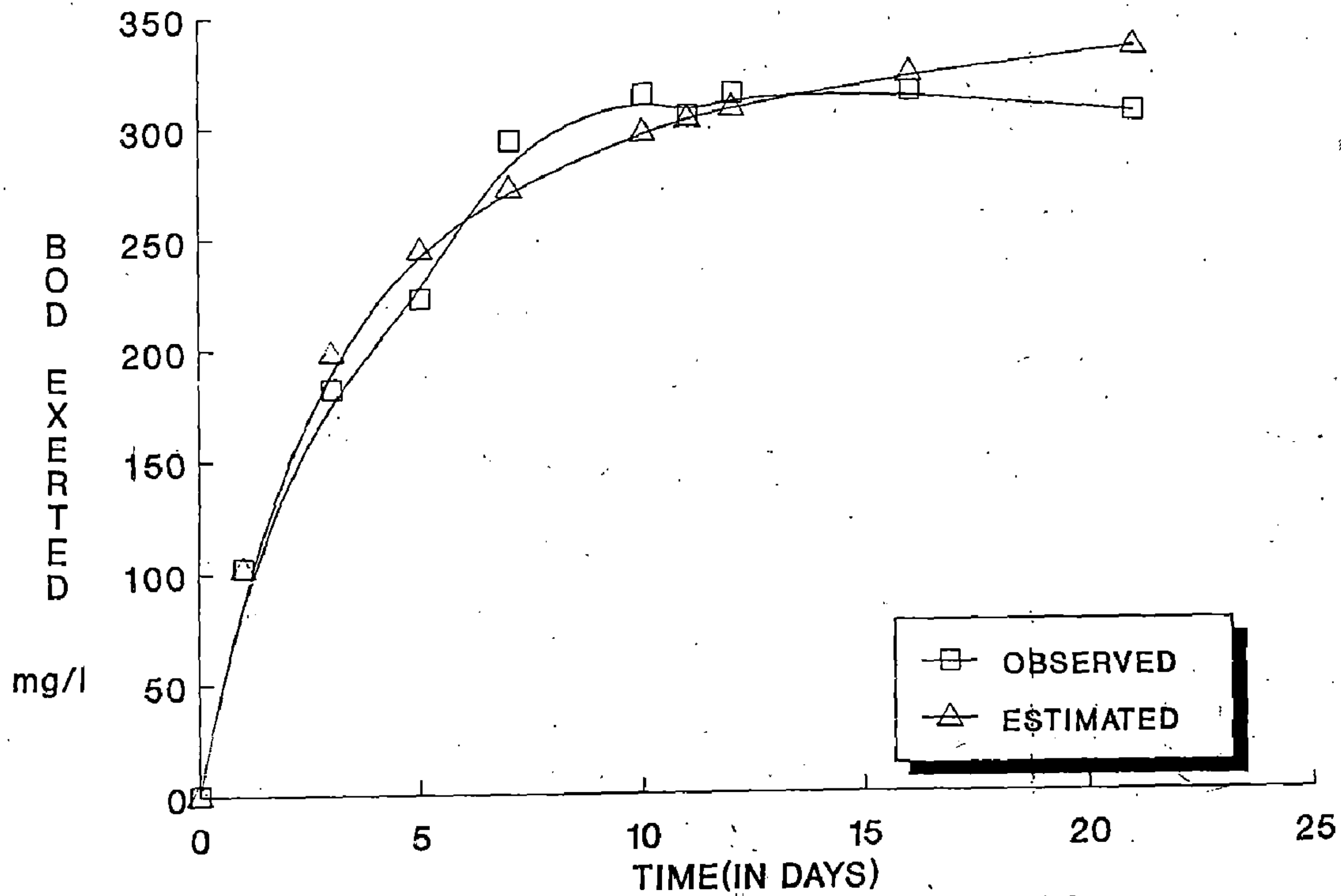

Fig. 4.22 BOD Exertion of Dairy Waste with Indigenous Seed

equation 2.8

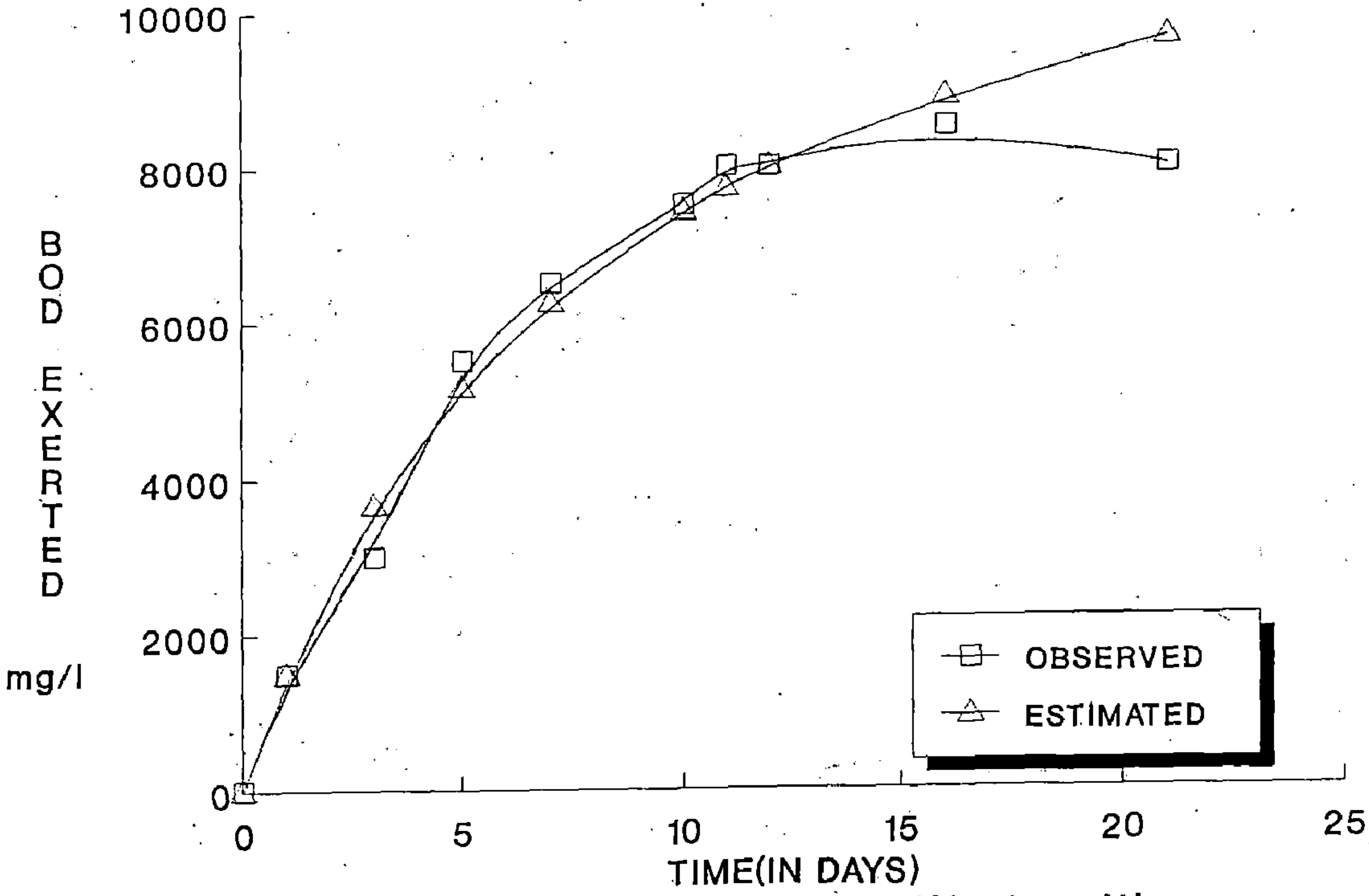

Fig 4.23 BOD Exertion of Paper Waste with Sewage Seed

equation 2.8

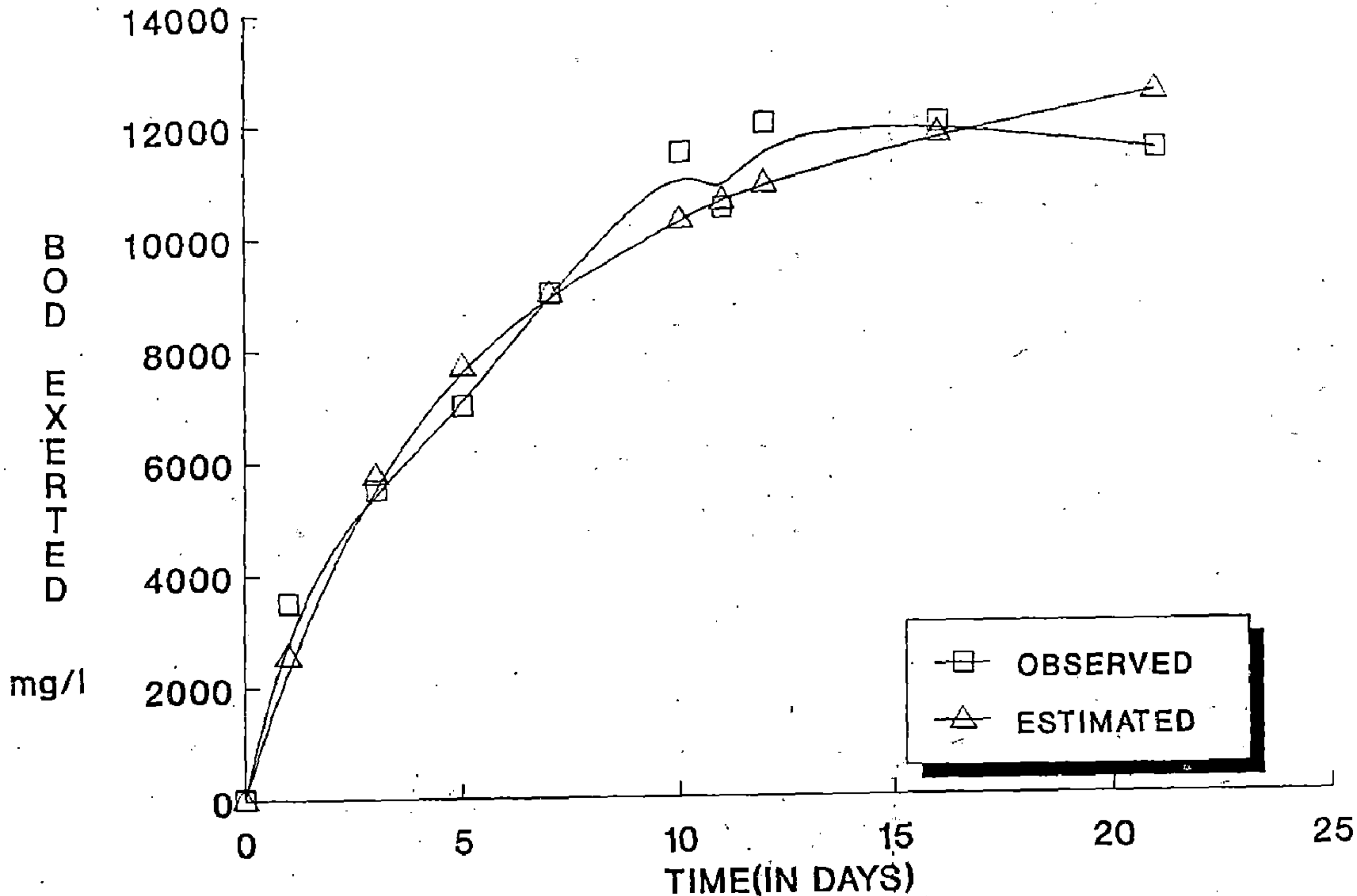

Fig 4.24 BOD Exertion of Paper Waste with Indigenous Seed

equation 2.1

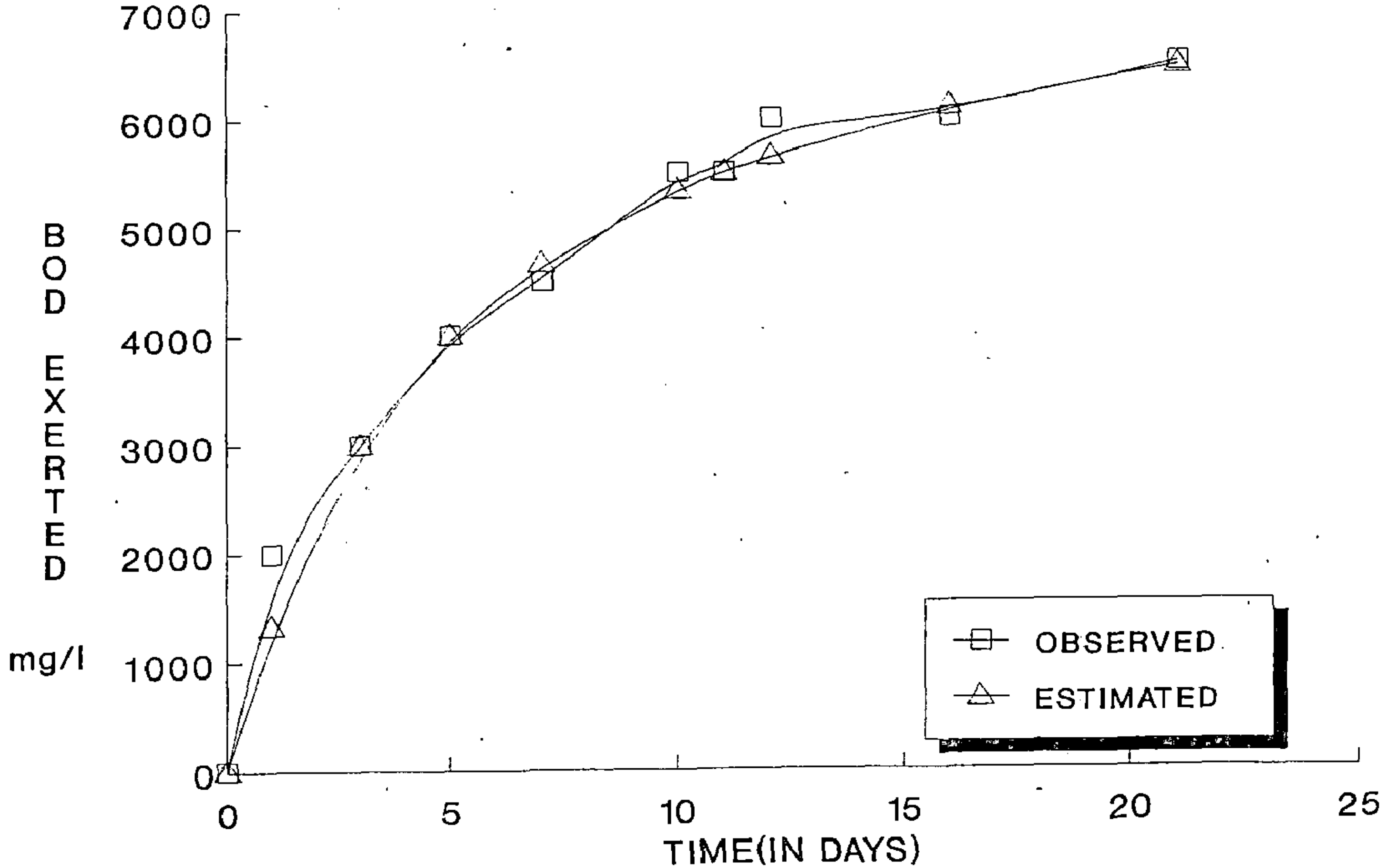

Fig 4.25 BOD Exertion of Distillery Waste with Sewage Seed

equation 2.8

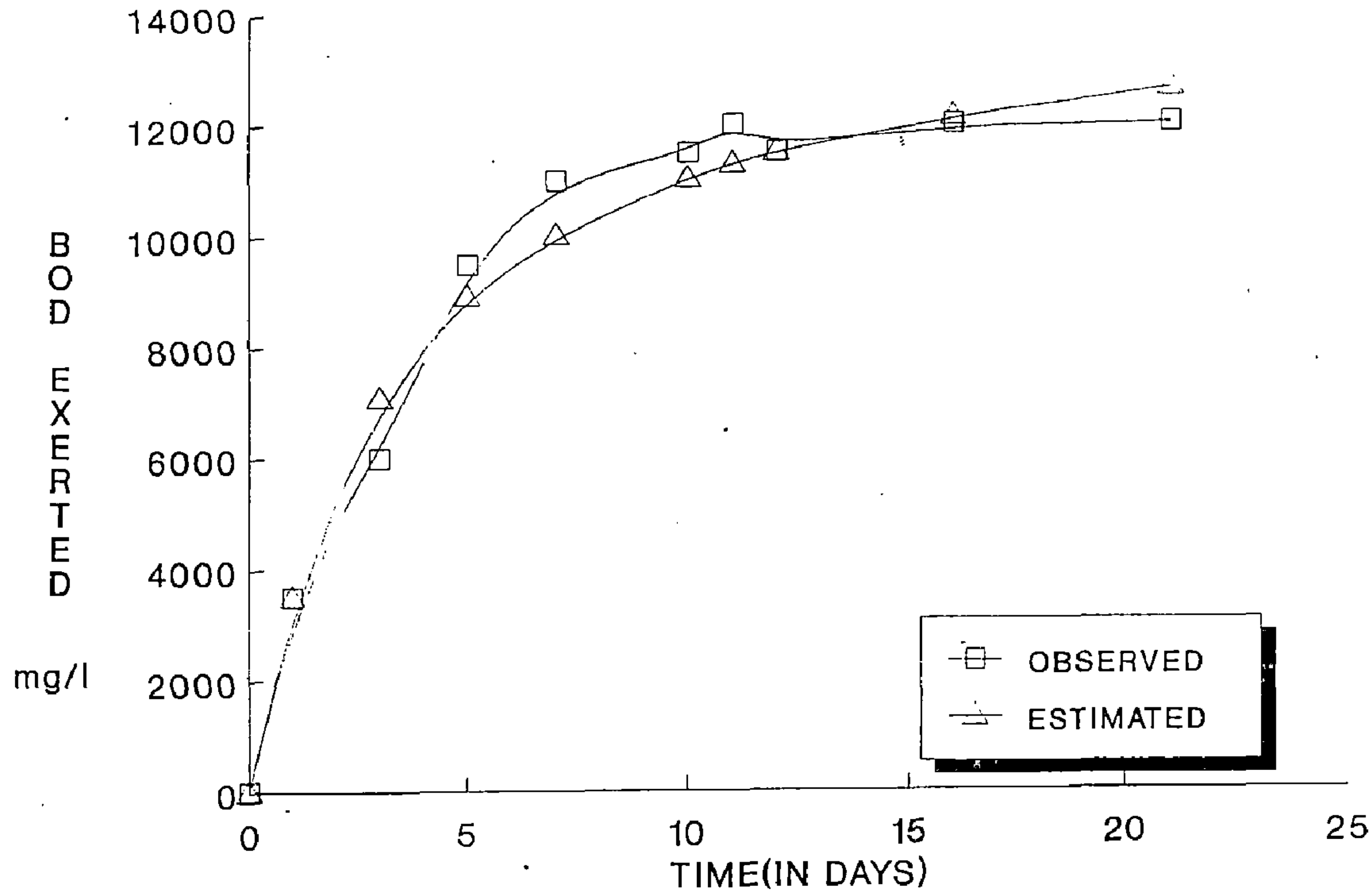

Fig 4.26 BOD Exertion of Distillery Waste with Indigenous Seed equation 2.8

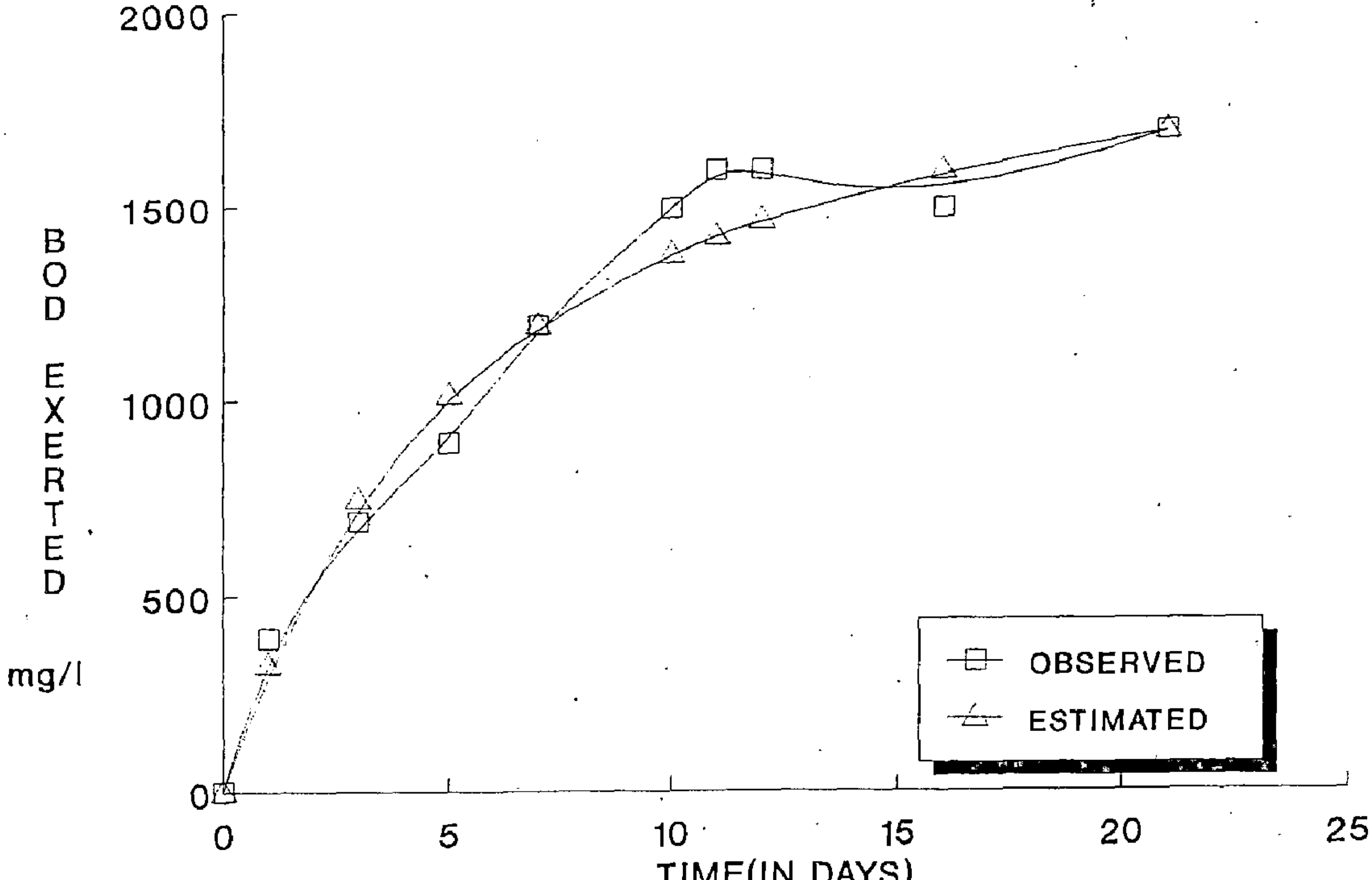

Fig 4.27 BOD Exertion of Sugar Waste with Sewage Seed

equation 2.8

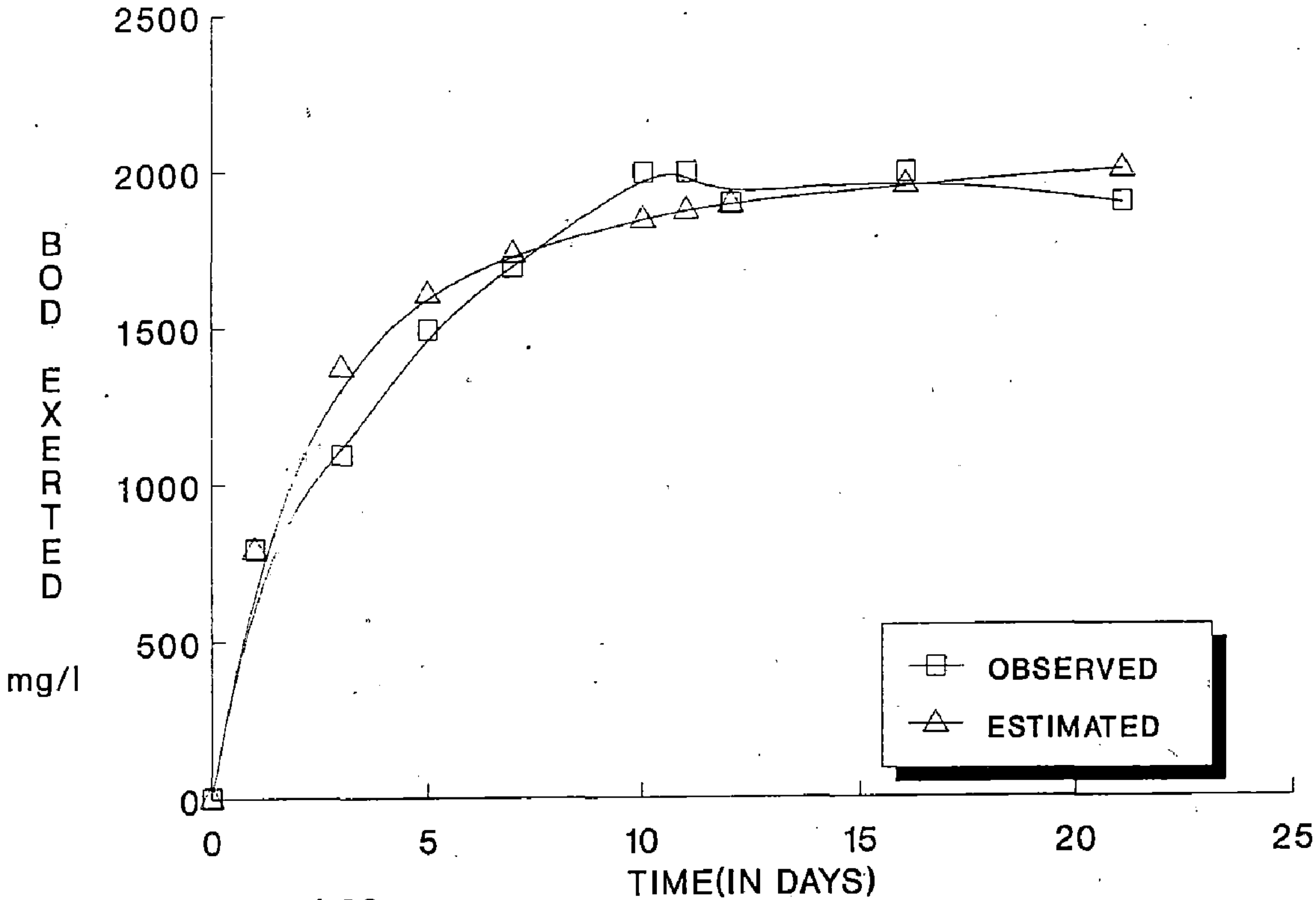

Fig 4.28 BOD Exertion of Sugar Waste with Indigenous Seed

equation 2.8

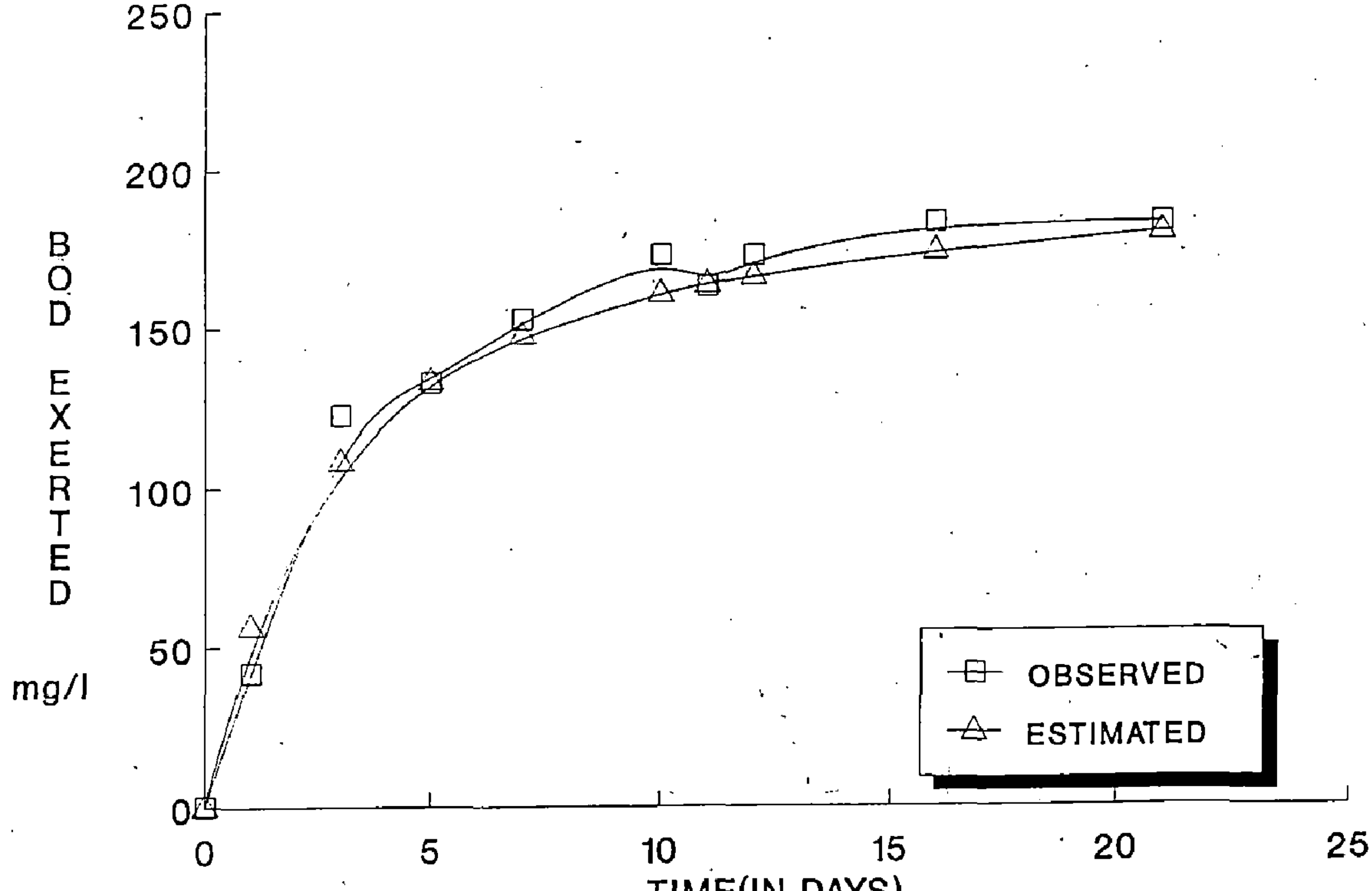

Fig. 4.29 BOD Exertion of Dairy Waste with Sewage Seed

equation 2.4

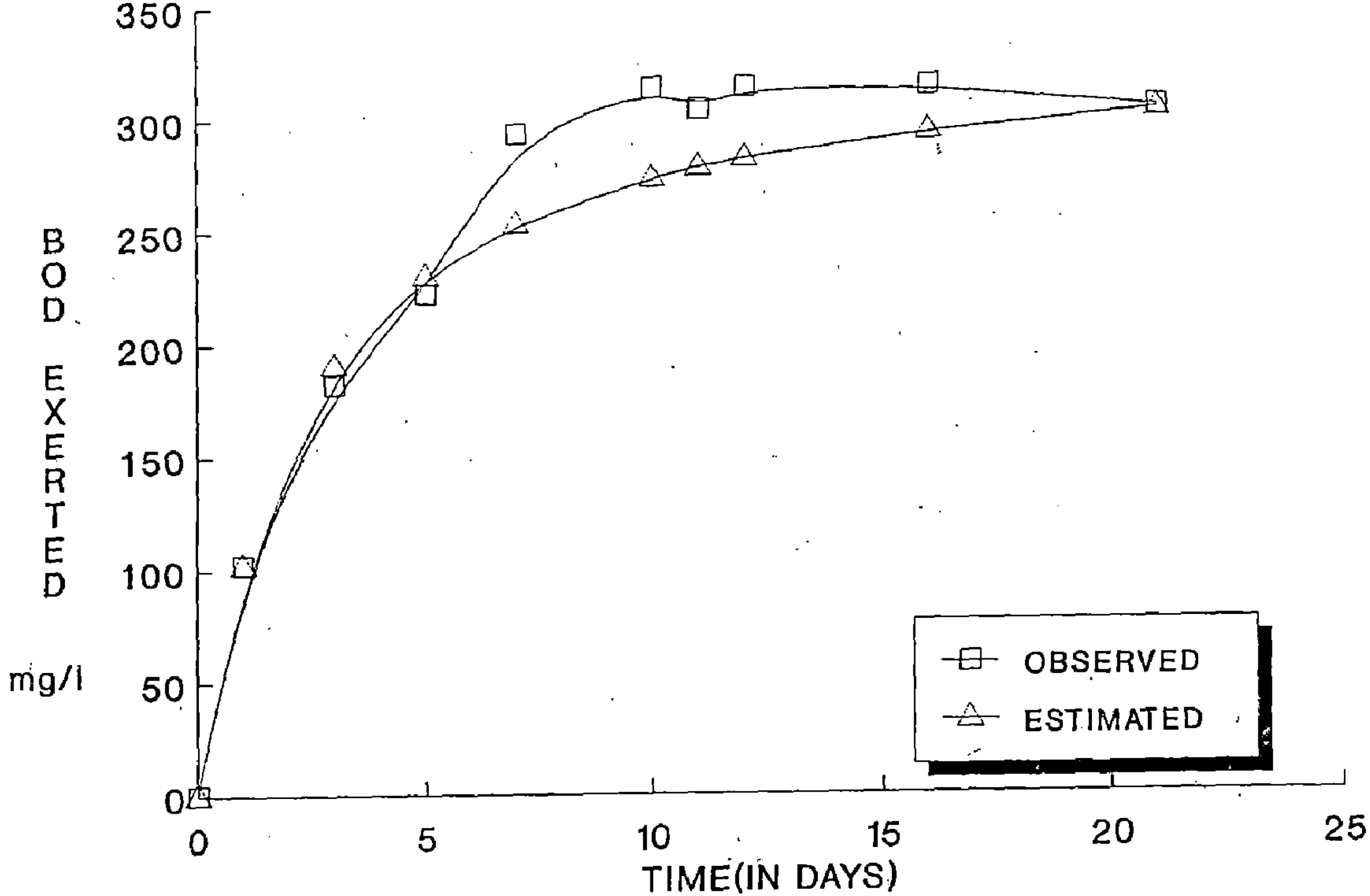

Fig. 4.30 BOD Exertion of Dairy Waste with Indigenous Seed

equation 2.4

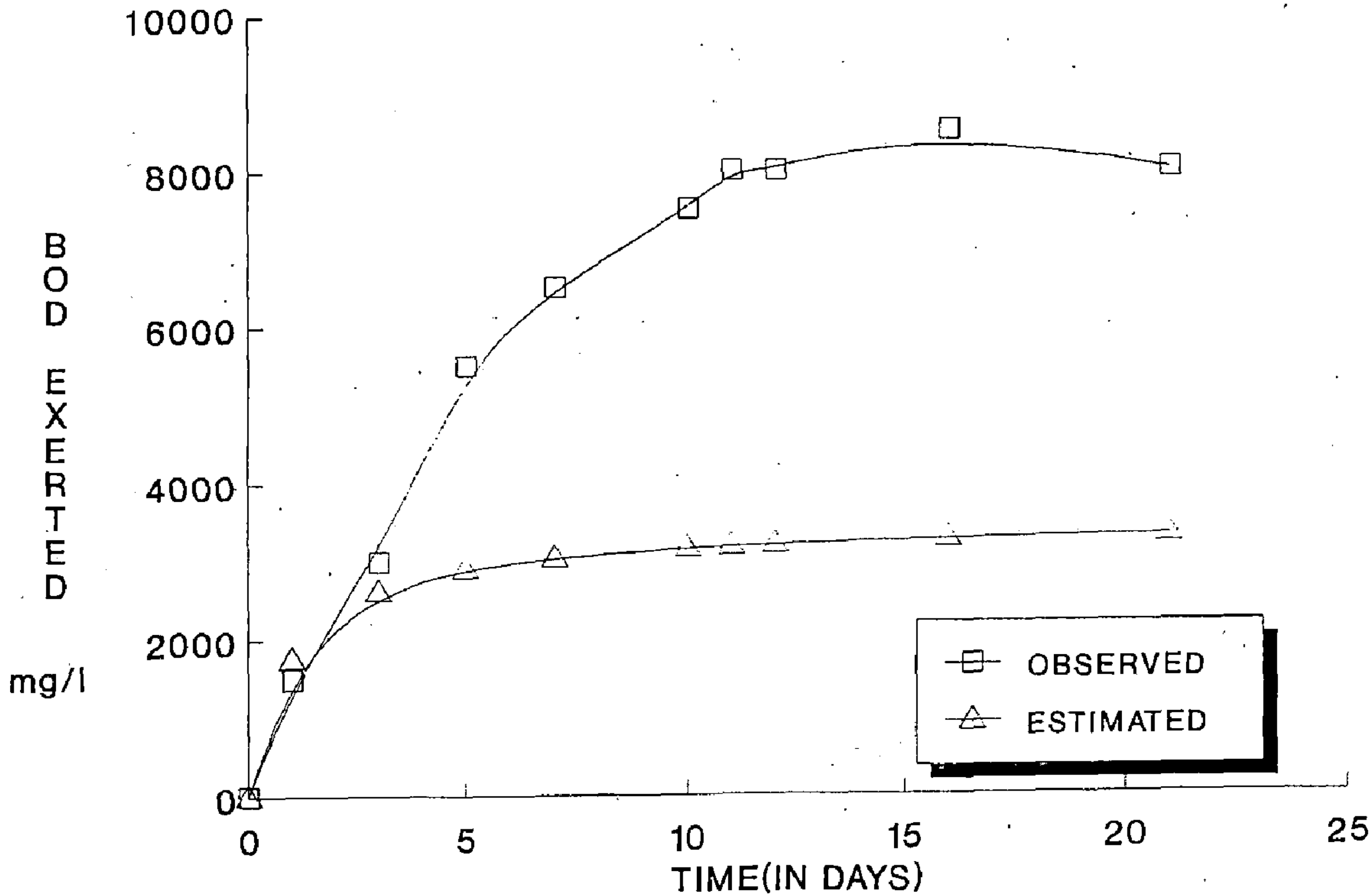

Fig 4.31 BOD Exertion of Paper Waste with Sewage Seed

equation 2.4

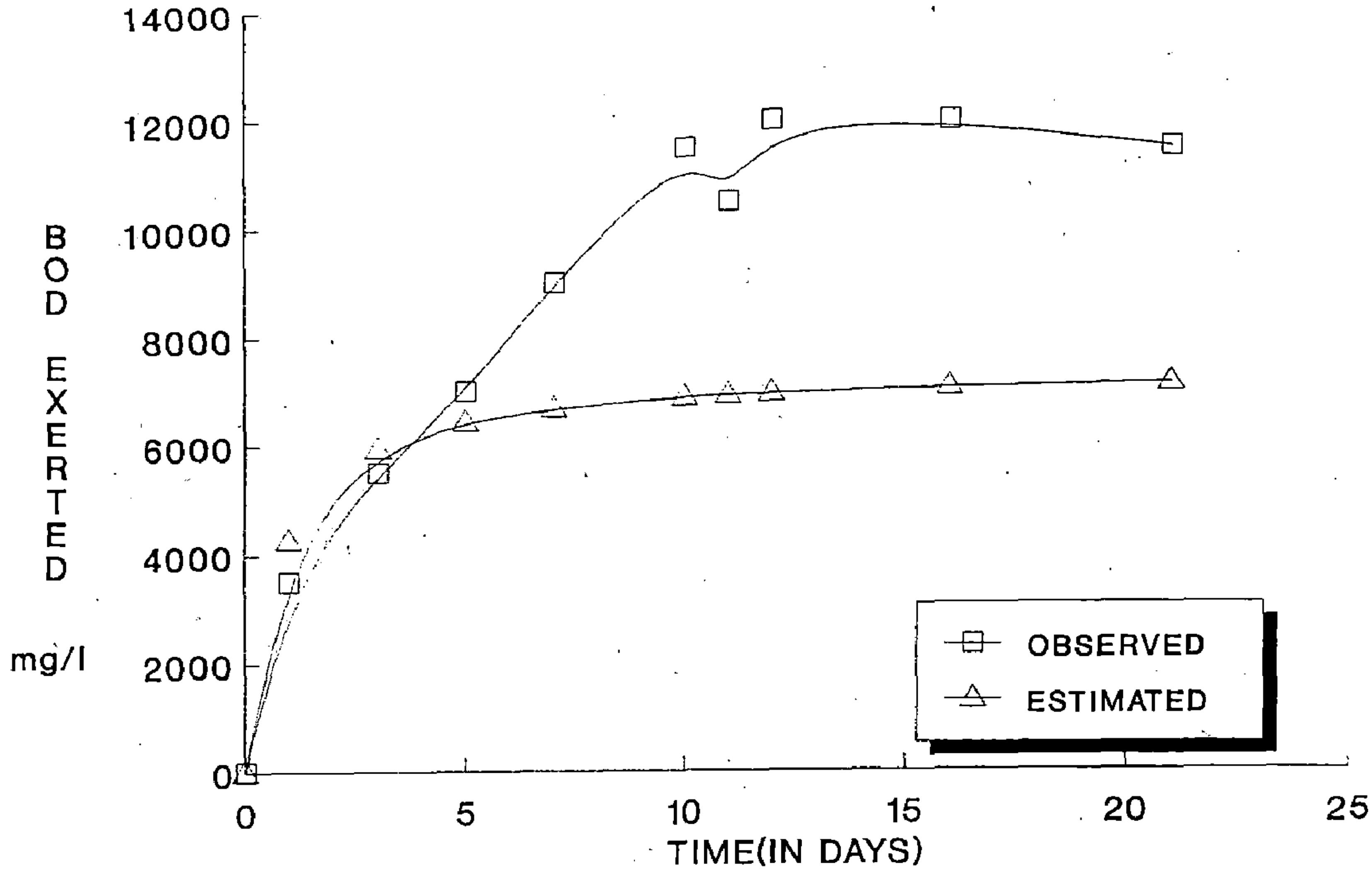

Fig 4.32 BOD Exertion of Paper Waste with Indigenous Seed

equation 2.4

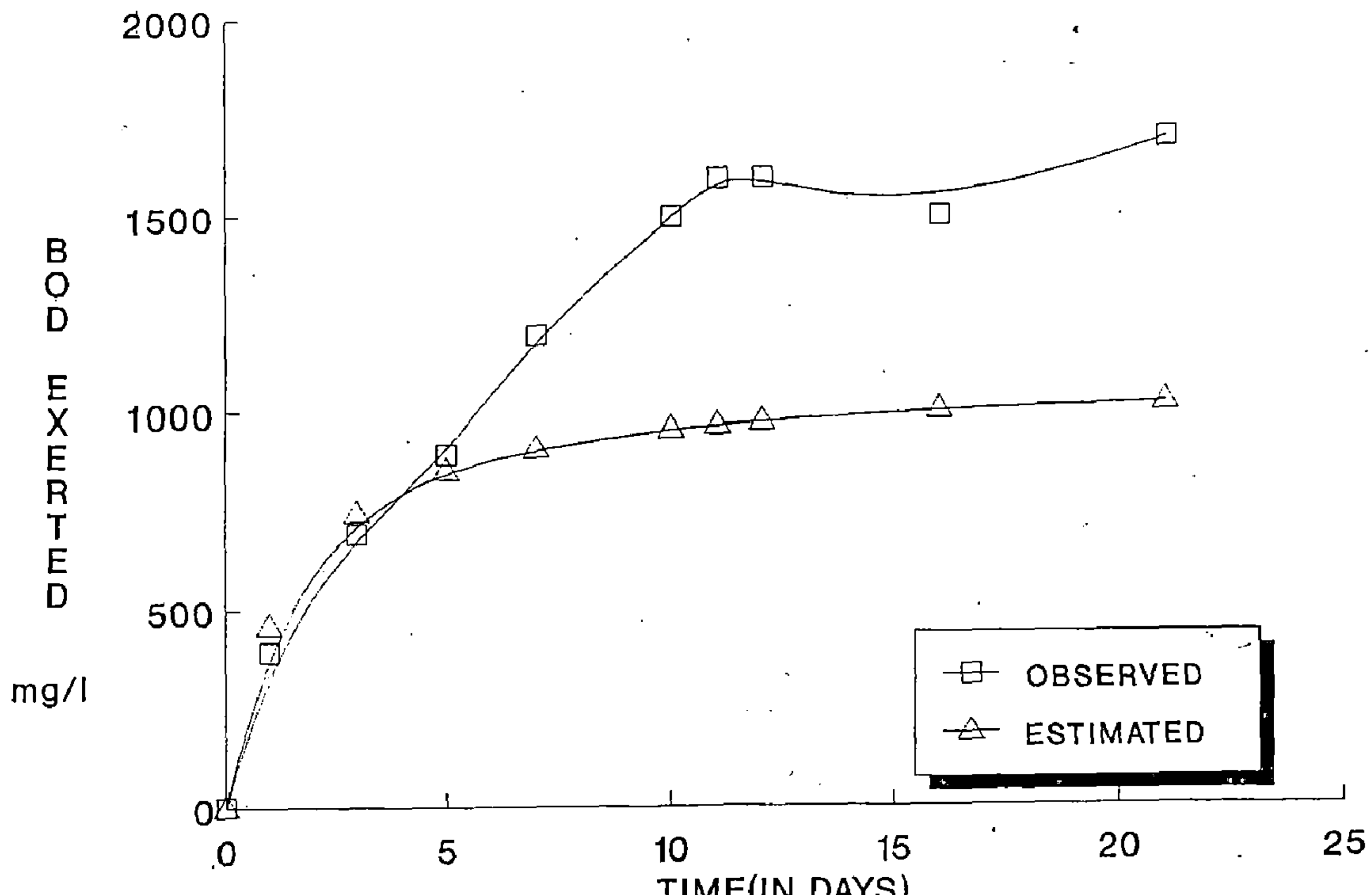

Fig 4.33 BOD Exertion of Sugar Waste with Sewage Seed

equation 2.4

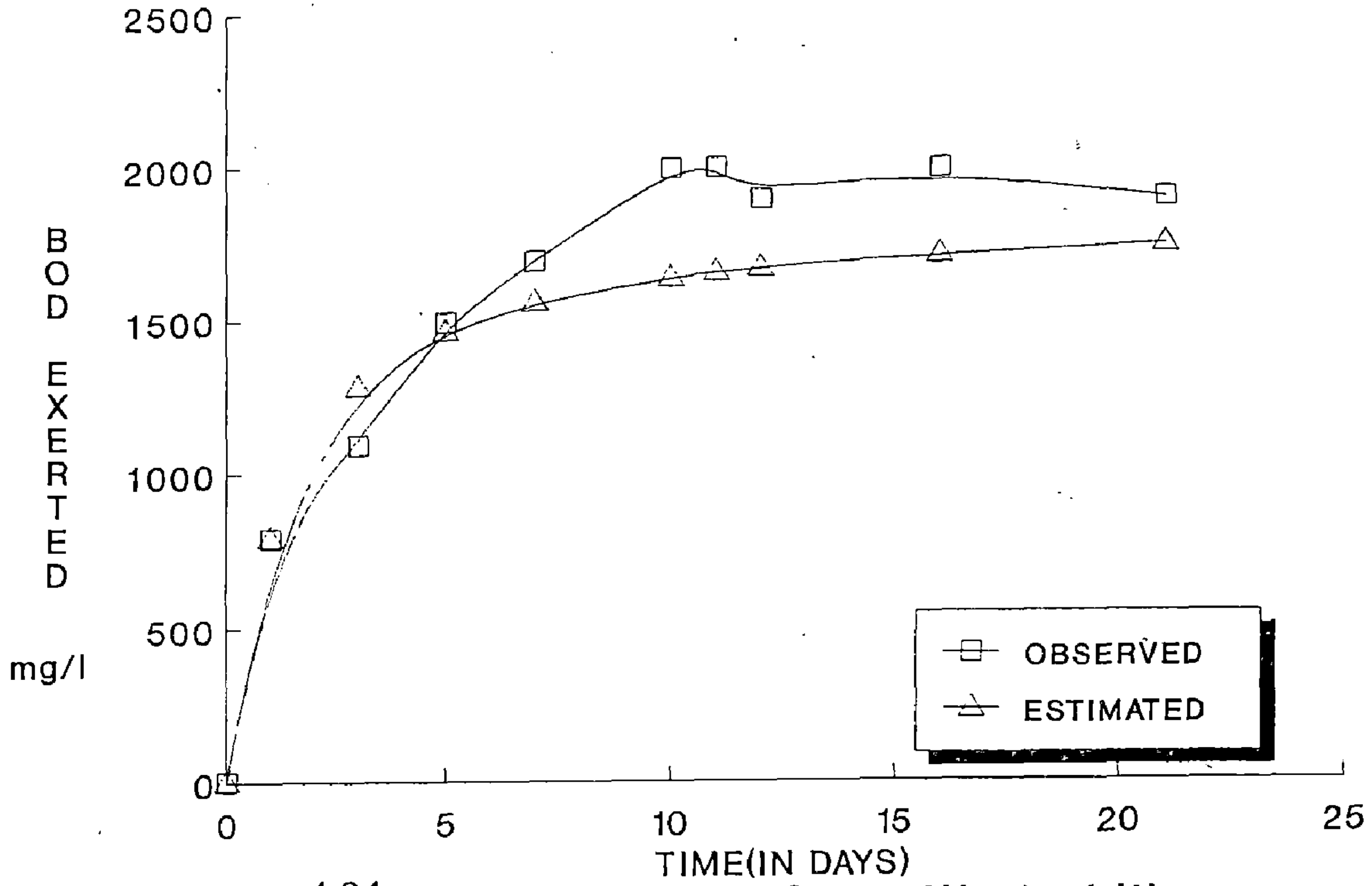

Fig 4.34 BOD Exertion of Sugar Waste with Indigenous Seed equation 2.4

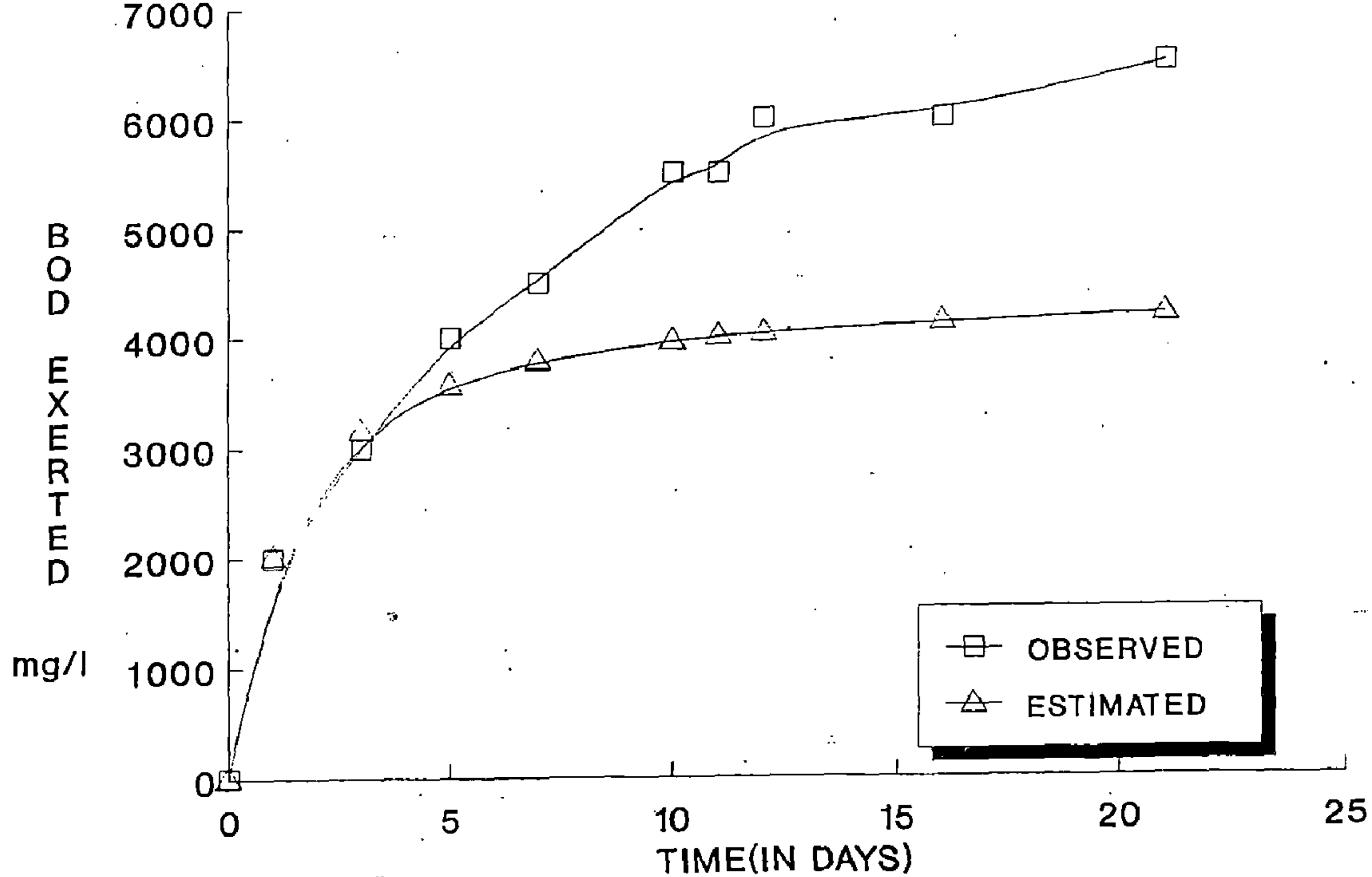

Fig 4.35 BOD Exertion of Distillery Waste with Sewage Seed

equation 2.4

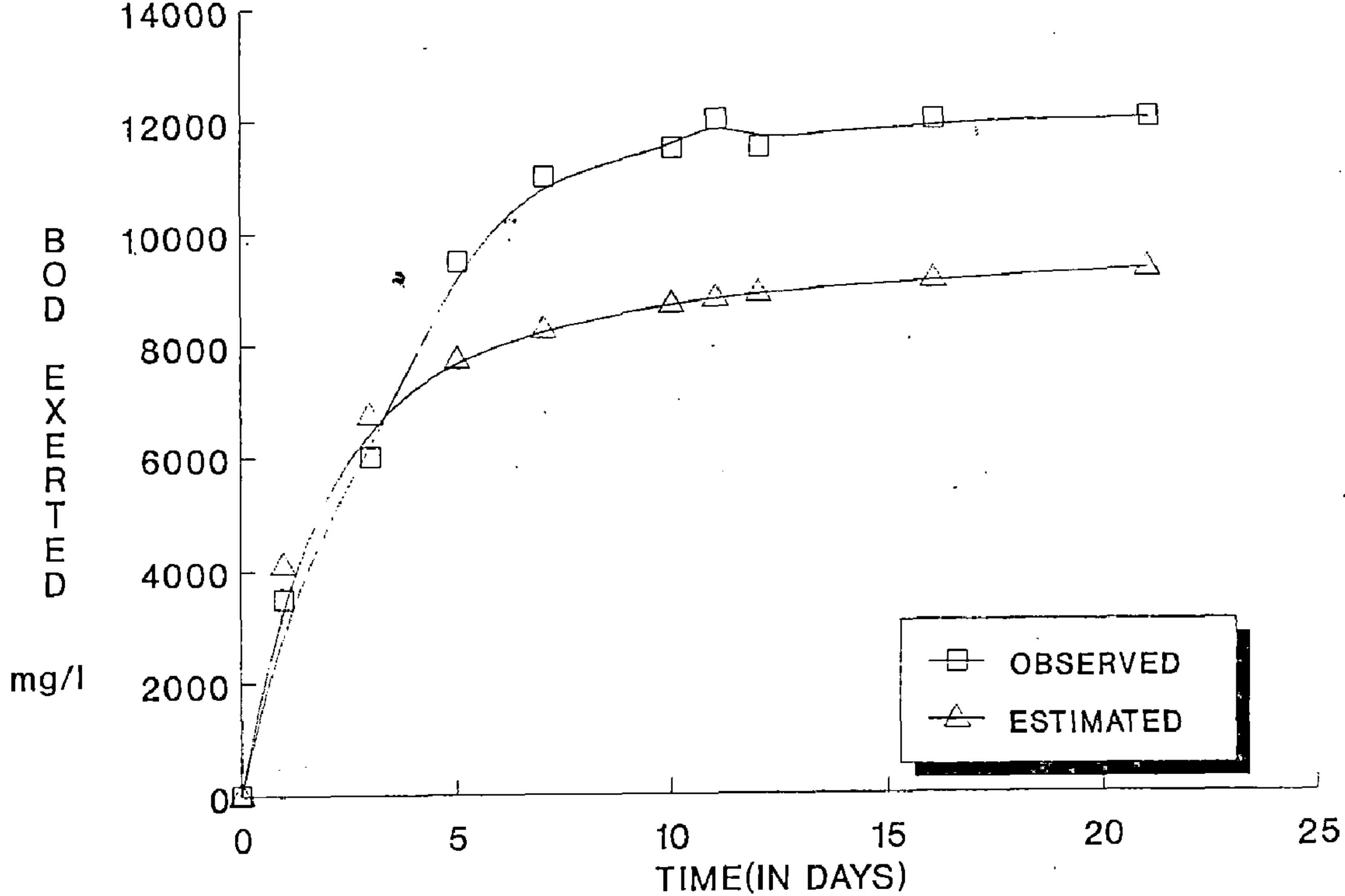

Fig 4.36 BOD Exertion of Distillery Waste with Indigenous Seed

equation 2.4

CHAPTER - 5

CONCLUSIONS

From the lab studies concluded on BOD exertion of industrial wastes (namely, paper, dairy, distillery and sugar) with the indigenous and sewage seeds following conclusions are drawn.

1. The plateau is distinctly present in the BOD curves with sewage seeds, whereas with indigenous seeds there is apparently no plateau observed.
2. The BOD_5 and BOD_{20} are observed to be higher in case of indigenous seed than those obtained with sewage seeds. The ratio for BOD_5 (indigenous/sewage) varies between 1.38 to 2.44 and that for BOD_{20} (indigenous/sewage) varies between 1.12 to 1.85.
3. The first order equation fits the data well in both cases and the analysis of data reveals that both L and K parameters have larger values in case of indigenous seeds than those obtained with sewage seeds. The respective ratios vary from 1.2 to 1.94 for L and 1.17 to 1.47 for K.
4. The equations suggested by Shrivastava best fits the data in all the cases. The analysis of data reveals that the values of parameters L and m are more in case of indigenous seed while the values of parameters t_{1*} and n are more in case of sewage seeds. The L ratio varies from 1.09 to 1.79.

5. The equation suggested by Woodward fits the data almost at the same level of error as First order equation. However, it gives a much higher value for ultimate BOD. The divergence from the data becomes accentuated around 20 days. The ratio of L for indigenous to sewage seed varies from 1.01 to 1.81.

6. The second order equation gave the worst fit among the four models considered with the average percentage error going as high as 19%. The divergence from the data starts from around 5 days. The ratio of L for indigenous to sewage seed varies from 1.67 to 2.24. The ratio of K for indigenous to sewage seed varies from 0.38 to 0.67.

From the above study it is clear that both the rate constants and ultimate BOD values are higher for the indigenous seeds than those for sewage seeds.

RECOMMENDATIONS

1. Further work for more types of industrial wastes should be conducted to establish the conclusions of the present study.

2. It is recommended that for design of the ETP, the indigenous seed should be used to get the design parameter for better performance of ETPs.

3. For effluent standards, BOD_5 determination should be done by indigenous seeds.

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APPENDIX

S.NO.	DAY	WASTE DAIRY----------BOD_OBSERVED SEWAGE SEED	INDIGENOUS SEED
1	0.00	0.00	0.00
2	1.00	392.00	791.50
3	3.00	692.10	1091.70
4	5.00	892.20	1491.90
5	7.00	1192.20	1692.20
6	10.00	1392.80	1793.00
7	11.00	1492.80	1793.10
8	12.00	1492.90	1893.10
9	16.00	1492.90	1993.70
10	21.00	1692.90	1894.00

TABLE No. 4.1 OBSERVED BOD DATA FOR DAIRY WASTES

S.NO.	DAY	WASTE DISTILLERY------BOD_OBSERVED SEWAGE SEED	INDIGENOUS SEED
1	0.00	0.00	0.00
2	1.00	1992.00	3491.20
3	3.00	2992.10	5991.40
4	5.00	3992.20	9491.60
5	7.00	4492.30	10991.80
6	10.00	5492.20	11492.00
7	11.00	5492.30	11992.00
8	12.00	5992.30	11492.10
9	16.00	5992.40	11992.30
10	21.00	6492.40	11992.40

TABLE No. 4.2 OBSERVED BOD DATA FOR DISTILLERY WASTES

S. NO.	DAY	WASTE PAPER----------BOD_OBSERVED SEWAGE SEED	INDIGENOUS SEED
1	0.00	0.00	0.00
2	1.00	1492.00	3492.10
3	3.00	2992.10	5492.20
4	5.00	5492.20	6992.60
5	7.00	6492.20	8992.80
6	10.00	7492.80	11492.90
7	11.00	7992.80	10493.00
8	12.00	7992.90	11992.90
9	16.00	8493.00	11993.30
10	21.00	7992.90	11493.80

TABLE No. 4.3 OBSERVED BOD DATA FOR PAPER WASTES

S. NO.	DAY	WASTE SUGAR----------BOD_OBSERVED SEWAGE SEED	INDIGENOUS SEED
1	0.00	0.00	0.00
2	1.00	392.00	791.50
3	3.00	692.10	1091.70
4	5.00	892.20	1491.90
5	7.00	1192.20	1692.20
6	10.00	1392.80	1793.00
7	11.00	1492.80	1793.10
8	12.00	1492.90	1893.10
9	16.00	1492.90	1993.70
10	21.00	1692.90	1894.00

TABLE No. 4.4 OBSERVED BOD DATA FOR SUGAR WASTES

S. NO.	WASTE SAMPLE	BOD EXERTED AT 5 DAYS	BOD EXERTED AT 20 DAYS	BOD RATIO (INDIGENOUS/ SEWAGE SEED) 5 DAYS	BOD RATIO (INDIGENOUS/ SEWAGE SEED) 20 DAYS
1	Dairy Sewage	892.20	1692.90	1.67	1.12
2	Dairy Indigenous	1491.90	1894.00		
3	Distilery Sewage	4492.30	6492.40		
				2.44	1.84
4	Distilery Indigenous	10991.80	11992.40		
5	Paper Sewage	6492.20	7992.90		
				1.38	1.43
6	Paper Indigenous	8992.80	11493.80		
7	Sugar Sewage	892.20	1692.90		
				1.67	1.11
8	Sugar Indigenous	1491.90	1894.00		

TABLE.NO. 4.5 EFFECTS OF SEED ON BOD EXERTED WITH RESPECT TO TIME

FIRST ORDER

S. NO.	WASTE SAMPLE		BOD ULTIMATE (L)	BOD RATE EXPONENT (k)
1	Dairy	Sewage	183.79	0.25
2	Dairy	Indigenous	315.08	0.38
3	Distilery	Sewage	6172.02	0.22
4	Distilery	Indigenous	12008.63	0.31
5	Paper	Sewage	8984.64	0.18
6	Paper	Indigenous	11626.09	0.21
7	Sugar	Sewage	1743.48	0.16
8	Sugar	Indigenous	1954.96	0.28

TABLE NO. 4.6a VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.1

FIRST ORDER

S. NO.	WASTE SAMPLE	RATIOS(INDIGENOUS/SEWAGE)	
		BOD ULTIMATE	BOD RATE EXPONENT
1	Dairy	1.71	1.47
2	Distilery	1.94	1.42
3	Paper	1.29	1.17
4	Sugar	1.12	1.70

TABLE NO. 4.6b RATIO OF VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.1

SHRIVASTAVA

S NO	WASTE SAMPLE	BOD ULTIMATE (L)	APPARENT ULTIMATE TIME t_{*1}	BOD RATE EXPONENT m	TRANSITION EXPONENT n
1	Sugar Sewage	1735.42	14.11	0.56	0.13
2	Sugar Indigenous	1896.09	9.07	0.39	0.07
3	Dairy Sewage	184.06	8.05	0.70	0.18
4	Dairy Indigenous	329.48	8.21	0.55	0.21
5	Distilery Sewage	8045.268	21.16	0.46	0.30
6	Distilery Indigenous	11993.75	7.46	0.61	0.09
7	Paper Sewage	8314.60	12.27	0.77	0.16
8	Paper Indigenous	11813.93	9.13	0.48	0.00

TABLE NO. 4.7a VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.11

SHRIVASTAVA

		RATIOS (INDIGENOUS/SEWAGE)			
S. NO.	WASTE SAMPLE	BOD ULTIMATE	APPARENT ULTIMATE TIME	BOD RATE EXPONENT	TRANSITION EXPONENT
1	Sugar	1.09	0.64	0.70	0.56
2	Dairy	1.78	1.01	0.78	1.11
3	Distilery	1.49	0.35	1.32	0.30
4	Paper	1.42	0.74	0.62	0.01

TABLE NO. 4.7b RATIO OF VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.11

WOODWARD

S. NO.	WASTE SAMPLE		BOD ULTIMATE (L)	APPARENT ULTIMATE TIME (t_{1*})
1	Dairy	Sewage	233.75	4.23
2	Dairy	Indi	376.93	2.69
3	Distilery	Sewage	8005.22	5.02
4	Distilery	Indigenous	14516.45	3.15
5	Paper	Sewage	13235.57	7.87
6	Paper	Indigenous	15560.72	5.11
7	Sugar	Sewage	2142.88	5.58
8	Sugar	Indigenous	2167.40	1.73

TABLE NO. 4.8a VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.8

WOODWARD

S. NO.	WASTE SAMPLE	RATIOS(INDIGENOUS/SEWAGE) BOD ULTIMATE	APPARENT ULTIMATE TIME
1	Dairy	1.612519	0.637638
2	Distilery	1.813371	0.628324
3	Paper	1.175674	0.649532
4	Sugar	1.011441	0.311496

TABLE NO. 4.8b RATIOS OF VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.8

SECOND ORDER

S. NO.	WASTE SAMPLE		BOD ULTIMATE (L)	BOD RATE EXPONENT. (k)
1	Dairy	Sewage	201.93	1.92E-3
2	Dairy	Indigenous	336.55	1.30E-3
3	Distilery	Sewage	4438.20	1.85E-4
4	Distilery	Indigenous	9945.12	0.70E-4
5	Paper	Sewage	3446:80	0.30E-3
6	Paper	Indigenous	7369.22	1.85E-4
7	Sugar	Sewage	1082.53	0.68E-3
8	Sugar	Indigenous	1853.91	0.40E-3

TABLE NO. 4.9a VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.4

SECOND ORDER

S. NO.	WASTE SAMPLE	RATIOS (INDIGENOUS/SEWAGE)	
		BOD ULTIMATE (L)	BOD RATE EXPONENT (k)
1	Dairy	1.66	0.67
2	Distilery	2.24	0.37
3	Paper	2.13	0.61
4	Sugar	1.71	0.59

TABLE NO. 4.9b RATIOS OF VARIOUS BOD PARAMETERS OF WASTE AS PER EQUATION NO. 2.4