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Development of Dynamic Simulation and Modeling for Bio P Removal

Ahmed El-Zayat
Environmental Engineering Group, Cairo, Egypt

Abstract

Pilot-testing and traditional methods for kinetic parameter determination are complex and time consuming, which can make the evaluation of biological phosphorus removal "BPR" processes too costly for smaller treatment facilities. A simple COD fractionation method is developed to determine the fraction of readily biodegradable soluble COD, which is vital for biological phosphorus removal process design. These detailed fractionation results of raw wastewater COD and phosphorus can be used in biological nutrient removal (BNR) process design models. These models can be used to determine the process volume and to evaluate the effect of COD loading, biomass concentration, and sludge age on the nutrient removal efficiency. The use of these models along with the wastewater characterization technique specific for BPR and kinetic parameter determination will allow small wastewater treatment plants or industries to evaluate the feasibility of biological phosphorus removal of their wastewater with minimum cost. To encourage the use of biological removal techniques, the alternative of an enhanced biological phosphorus removal (EBPR) process must be used. The alternative limit requires the removal of 90% of the phosphorus that would have been removed to achieve a 1 mg-P/L effluent limit.

The overall total phosphorus removal obtained in a conventional biological wastewater treatment is generally less than 20% and is even less in wastewater treatment plants where anaerobic digester supernatant is recycled to the head of the plant. Since it is not possible to achieve the 1 mg-P/L effluent limit with conventional biological wastewater treatment processes, additional or alternative treatment methods must be employed. Biological phosphorus removal (BPR) techniques offer a number of advantages over chemical addition, including enhanced treatment, reduced energy consumption, and reduced sludge production. A rapid, low-cost method for determining the feasibility of biological phosphorus removal should allow these techniques to be more widely used. A simple test is proposed to determine the amount of phosphorus that can be removed from a particular wastewater using a BPR process. The test involves measuring phosphorus release during a 2-hour anaerobic stage in a batch reactor containing phosphorus-accumulating organisms (PAOs) and estimating the effluent phosphorus concentration using a biochemical relationship. The batch reactor experiment (BPR Test) developed in this thesis was used to evaluate BPR feasibility of actual existing wastewater

treatment plant of interest to meet with the total effluent phosphorus concentration of 1 mg/L. Comparing the test result with the effluent phosphorus concentration from the grab samples of the actual plant and validated the (BPR Test) by the predicted empirical biochemical relationship and mathematical modeling (BNR-Model), were found comparable and accepted.

Methodology and Experimental Work

The paper is consisted of four main stages as following:

(A) Seasonal Intrinsic Wastewater Characterization.
(B) Batch Reactor Experiment (BPR Test).
(C) Results Analysis / Evaluation.
(D) Mathematical Modeling.

(A) Seasonal Intrinsic Wastewater Characterization

It is required for the evaluation of biological phosphorus removal. Laboratory Tests are conducted based on the yearly seasonal change actual intrinsic wastewater characteristics including the influent / effluent wastewater sampling analysis, influent COD and Phosphorus fractions determination tests from an actual existing treatment plant under operation during two years (2006 & 2007).

The soluble readily biodegradable fraction (S_{bsi}) plays an important role in biological phosphorus removal because phosphorus-accumulating microorganisms (PAOs) sequester volatile fatty acids (VFAs) in the (S_{bsi}) fraction, using the energy obtained from cleavage of a phosphate bond of the polyphosphates stored within the biomass. Biodegradable COD (S_{bi}) may be determined using the Total Biological Oxygen Demand (T_bOD) concept. The T_bOD concept assumes that particulate organic materials are hydrolyzed when the biological oxidation process is completed (normally after 24 hours).

The laboratory tests are presented in two seasonal groups (A &B) of two years (2006, 2007) as illustrated in the figures (1, 2).

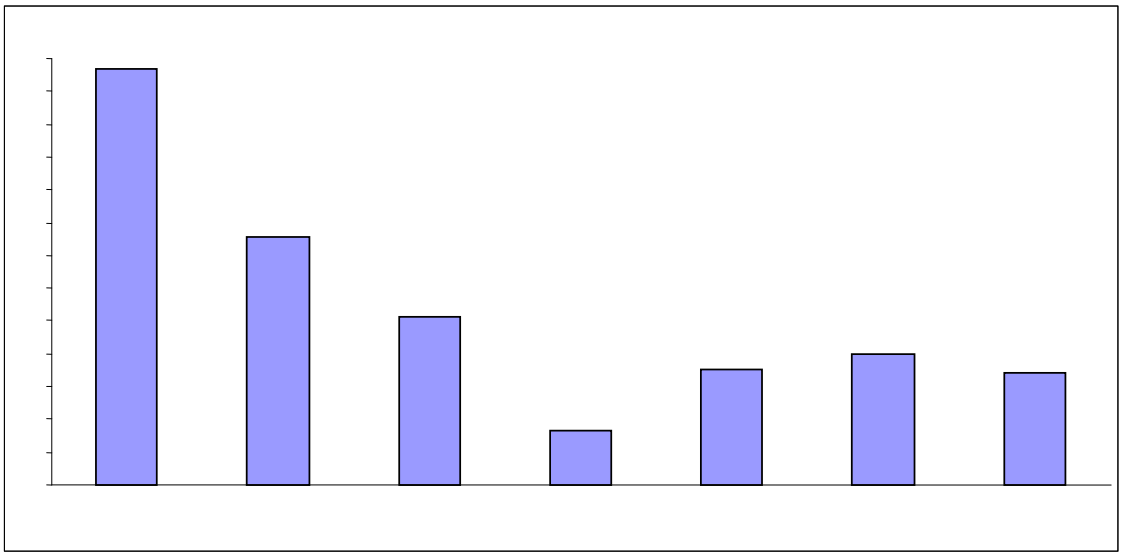

Fig. (1) : Average COD Fractions from the Seasonal Wastewater Sampling Group (A)

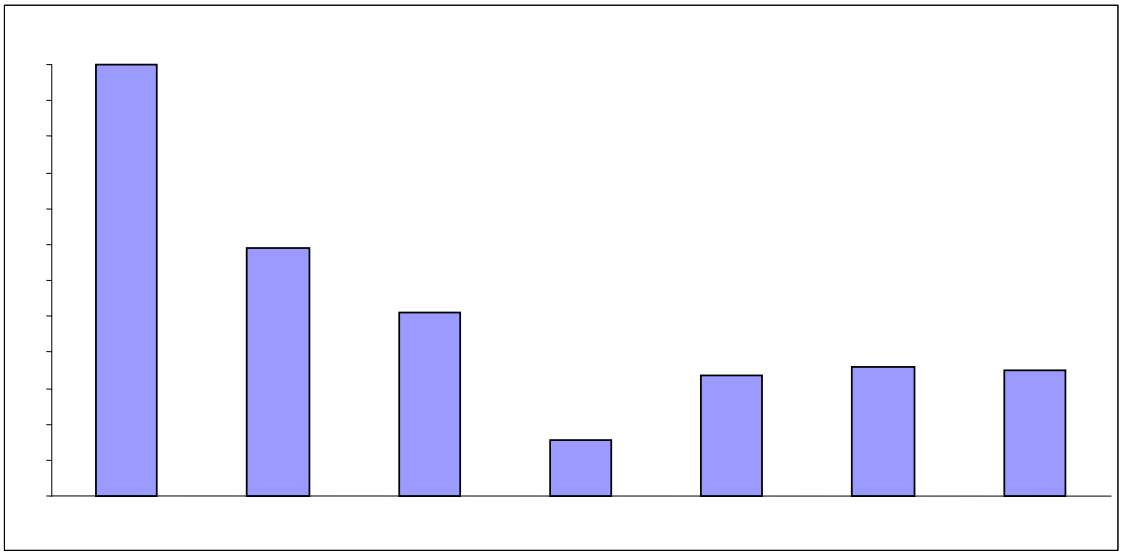

Fig. (2) : Average COD Fractions from the Seasonal Wastewater Sampling Group (B)

(B) Batch Reactor Experiment (BPR Test):

BPR Test is achieved by growing microorganisms that are capable of storing phosphorus intracellularly as polyphosphate. The growth of phosphorus-accumulating organisms (PAOs) is favored by subjecting the activated sludge to a cycle of anaerobic and aerobic conditions. Phosphorus is then removed by wasting excess sludge. The treatment efficiency of a BPR process depends not only on the size of anaerobic and aerobic basins but also on intrinsic wastewater characteristics. Not all wastewater may be suitable for BPR. If the characteristics of the wastewater are not well defined, the BPR process may be improperly designed. Thus, it would be useful to develop a method to assess the feasibility of BPR for a wastewater of interest. In a biological phosphorus removal process, phosphorus will be released by (PAOs) under anaerobic conditions and taken up under aerobic conditions.

The measurement of phosphorus release / uptake rates is meaningful only when (PAOs) have been selected. An enhanced culture that removes phosphorus can be obtained from an actual existing plant under operation. The purpose of the (BPR Test) is to develop a simple procedure for determining whether BPR can be adapted for a wastewater of interest. By controlling parameters such as sludge composition and operational conditions, only the actual of the biodegradable COD substrate will determine the phosphorus release rate. The phosphorus release rate pattern will indicate the lack of short-chain fatty acids (SCFAs) for PAOs in the wastewater. The batch reactor experiment (BPR Test) developed is conducted at the location where a PAO-containing sludge is available (from an actual plant) to simulate similar operational conditions of the actual wastewater treatment plant of interest, including sludge age, food to microorganism ratio (F/M), mixed liquor suspended solid (MLSS) concentration, etc. The operational conditions and procedure developed for the BPR Test was conducted using the Dynamic Simulation Technique, whereas the enhanced culture must depend on influent wastewater characteristics and PAO-containing activated sludge of an actual existing plant under operation and analyze the total phosphate (TP) vs. COD

every 30 minutes for a period of time corresponding to both of the anaerobic and aerobic retention time. The purpose of the dynamic simulation is to evaluate BPR feasibility of the wastewater of interest to meet with the total effluent phosphorus concentration of 1 mg/ L in compliance with the Environmental Protection Standard.

The rates of phosphorus release and uptake are simply expressed by the increase or decrease in phosphorus concentration per unit biomass per unit time (mg-P/gVSS/min). This BPR Test is conducted under room temperature condition (25 ^{o}C). We are highly recommend that the batch experiment BPR test should be conducted with composite samples taken during various seasons to represent the intrinsic wastewater characteristics and that consideration be given to recycle streams. The BPR Test frequency is done over a period of two years (2006, 2007) based on the seasonal change of the actual intrinsic wastewater characteristics from an actual plant and the results obtained are presented in two seasonal groups (A &B) as illustrated in figures (3, 4) and the batch reactor is illustrated in figures (5, 6).

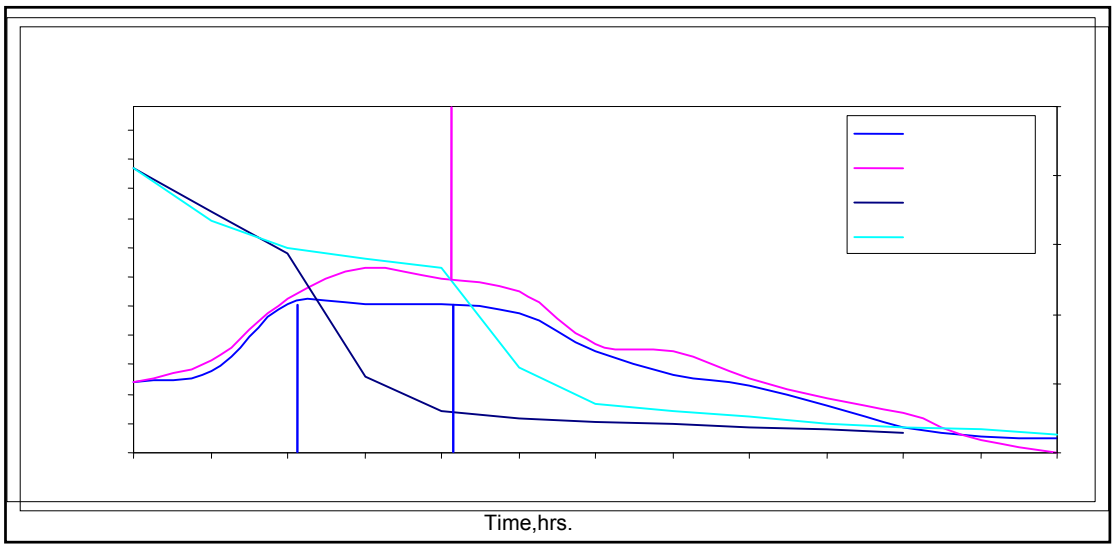

Fig.(3): Group (A) Change of (TP) vs. COD (S_{bsi})

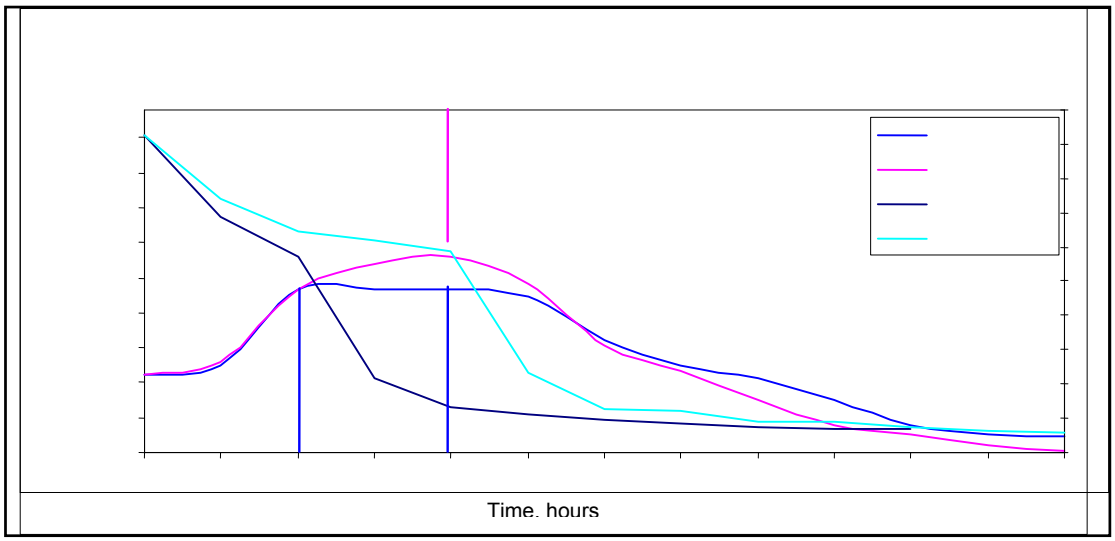

Fig. (4): Group (B) Change of (TP) vs. COD (S_{bsi})

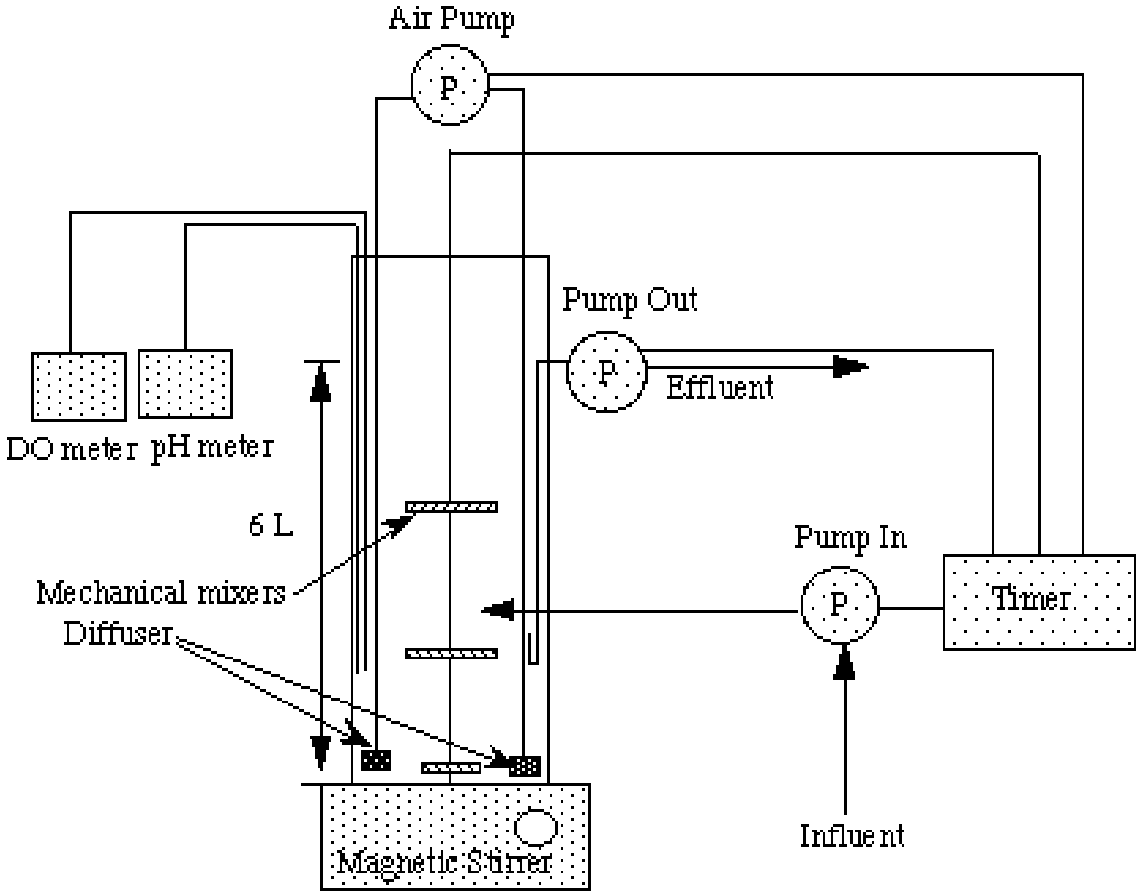

Fig. (5): Typical Batch Reactor Experimental Model (BPR Test)

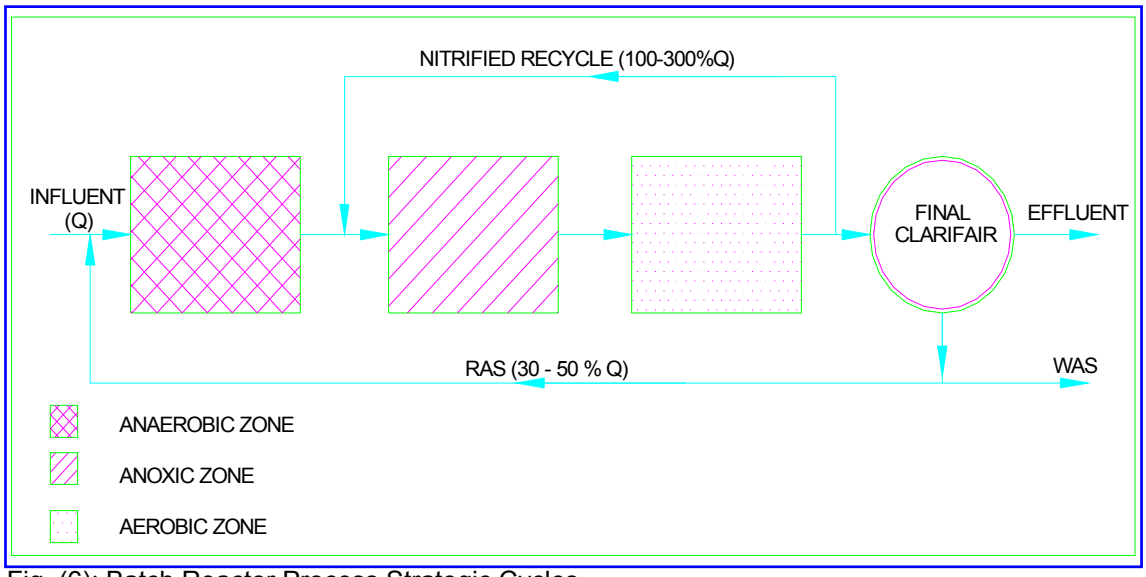

Fig. (6): Batch Reactor Process Strategic Cycles

(C) Results Analysis / Evaluation:

As shown in the BPR Test results, the profile / pattern of phosphorus release and uptake were a close linear relationship between phosphorus release and uptake, the specific phosphorus release average rate ranged from 0.051 to- 0.059 mg-P/gVSS/min, and the specific phosphorus uptake average

rate ranged from 0.044 to- 0.049 mg-P/g VSS/min. The total phosphorus released was obtained from the difference between the initial phosphorus concentration and the phosphorus concentration at the end of anaerobic stage (maximum release value). The phosphorus release average rates (0.053 and 0.054) are comparable with reported values ranging from 0.042 to-0.056 mg-P/gVSS/min (Kang et al. 1991). BPR Test Ratio of phosphorus Uptake to Phosphorus Release (□) average value (1.18) and is comparable with reported values, these rates 1.15 to 1.20 (Wentzel et al., 1985). It is believed that the ratio of phosphorus uptake to release ranges (from 1.15 to 1.20).

The effluent phosphorus concentration obtained from the BPR Test is reached its optimum value (1.12 & 1.13 mg/L) after anaerobic detention time (2 hrs.) followed by aerobic detention time for no longer than (4 hours). The results obtained from the two seasonal groups (A & B) of two years (2006, 2007) are illustrated in figures (7, 8).

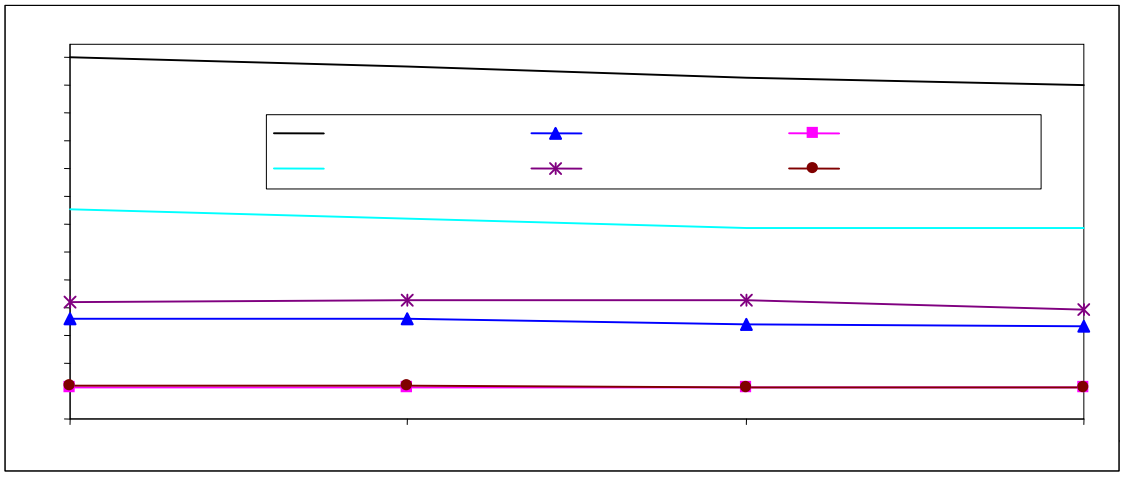

Fig. (7): Seasonal Group (A) Influent and (Actual / Tested) Effluent Phosphorus

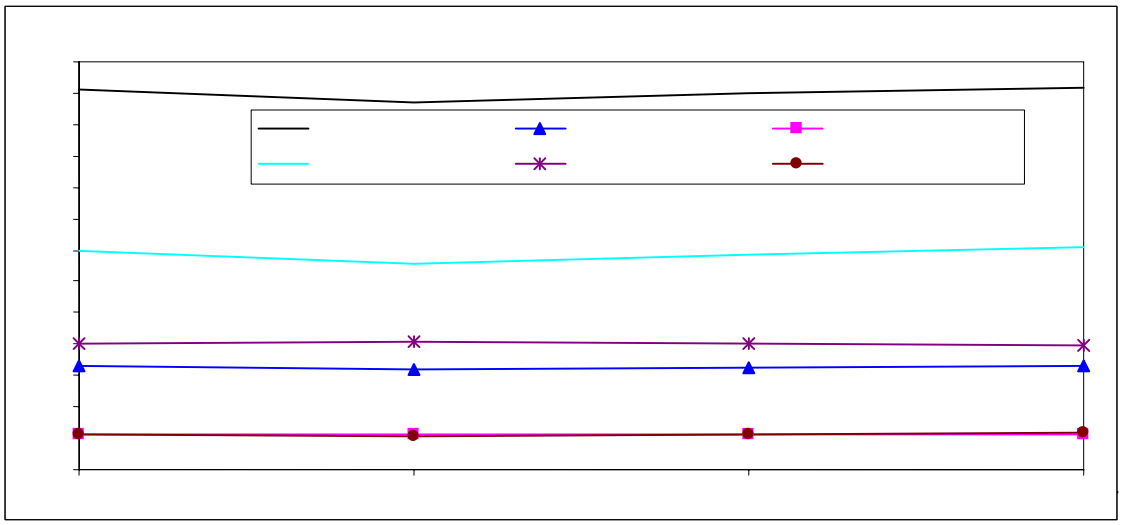

Fig. (8): Seasonal Group (B) Influent and (Actual / Tested) Effluent Phosphorus

(D) Mathematical Modeling:

Since in the anaerobic zone of the BPR process, only the readily biodegradable soluble COD (S_{bsi}) component is susceptible for fermentation to form VFAs within the short detention time (1 to- 2 hours) and that the enrichment of activated sludge with the phosphate accumulating bacteria (PAOs), Acinetobacter, would ensure efficient biological phosphorus removal. The growth of Acinetobacter could be ensured by supplying readily biodegradable short carbon chain substrates such as ethanol, acetate, and succinate to an anaerobic zone in the process.

These seasonal experiments indicated that (S_{bsi}) is mostly utilized in the anaerobic reactor. This concept was postulated that (S_{bsi}) was taken up into the cell under anaerobic conditions and stored as poly-ß-hydroxybutyrate, and found that phosphorus release increased as the influent readily biodegradable soluble COD (S_{bsi}) increased. In the batch experiment, a basic assumption is that the characteristics of PAO-containing sludge will not affect the outcome.

This implied that the effect of sludge characteristics on the (BPR Test) will be insignificant if the total phosphorus release were measured at 2 hours. The total phosphorus release is anticipated to be the same when the test is conducted longer than 2 hours. We concluded that that the concentration of readily biodegradable soluble COD (S_{bsi}) surrounding the microorganisms in the anaerobic zone is very important wastewater characteristic in the BPR process.

Using a linear approximation for the results obtained from the seasonal groups (A & B) (2006 & 2007) as shown in tables (1 & 2) and figures (9, 8, 10, 11) we can predict Effluent Sewage Soluble Phosphorus (P_{eff}) empirically using the following parameters as illustrated in figure (12):

1. $P_{release}$ (Max. Phosphorus Release, mg/L),
2. P_{inf} (Influent Soluble Phosphorus, mg/L),
3. θ_c (Sludge Age, days),
4. t (Anaerobic Detention Time, hours), and
5. COD (S_{bsi}) (Readily Soluble Biodegradable COD, mg/L).

In order to validate the (P_{eff}) Predicated Empirical Values, a Mathematical (BNR-Model) is applied for the comparison with the other values obtained from the (BPR Test), and the Actual Plant. No significant difference were found, so the accuracy of (P_{eff}) Predicted Empirical Values are comparable and accepted based on the actual influent intrinsic wastewater characteristics (S_{bsi}) and is applicable for evaluation the feasibility of any case of similar biological phosphorus removal process type (BPR) to predict the effluent phosphorus concentration (P_{eff}) value in compliance with standard environmental protection regulations around (1 mg/L) for final effluent discharge to water bodies.

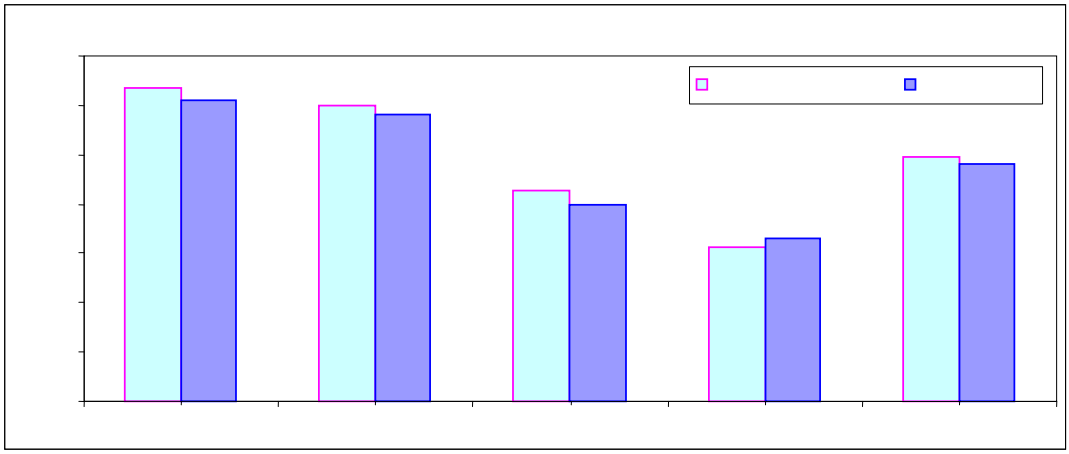

Fig. (9): Seasonal Group (A) Effluent Phosphorus (Actual vs. Predicted)

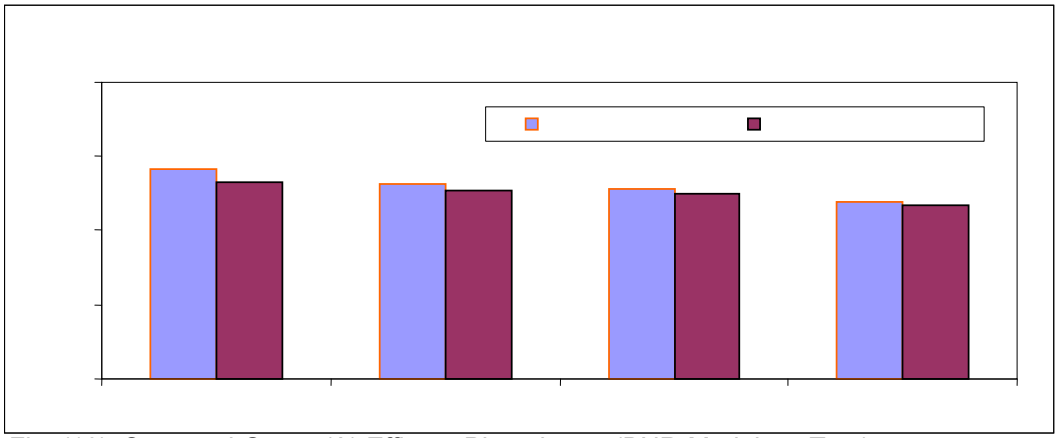

Fig. (10): Seasonal Group (A) Effluent Phosphorus (BNR-Model vs. Test)

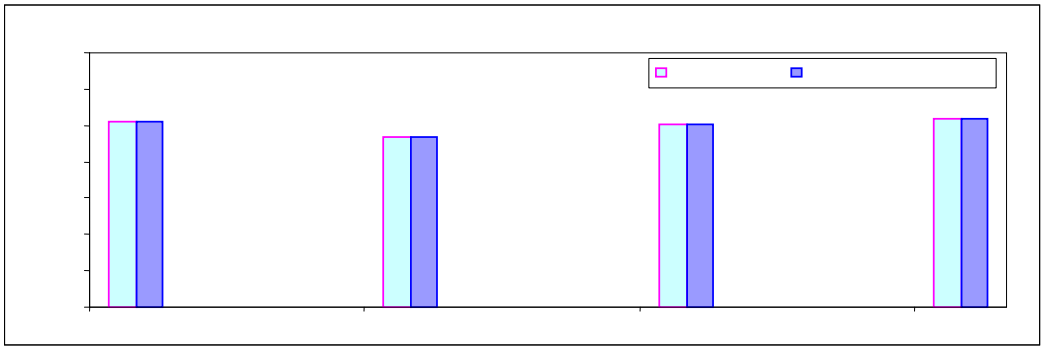

Fig. (11): Seasonal Group (B) Effluent Phosphorus

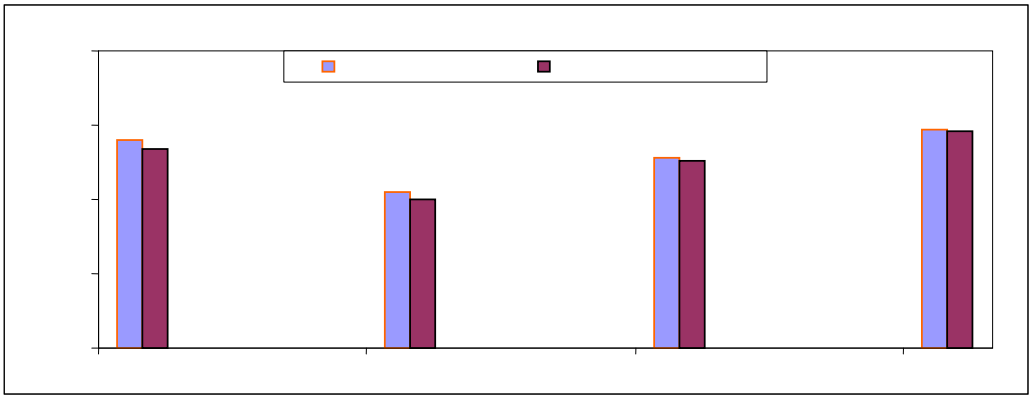

Fig. (12): Seasonal Group (B) Effluent Phosphorus (BNR-Model vs. Test)

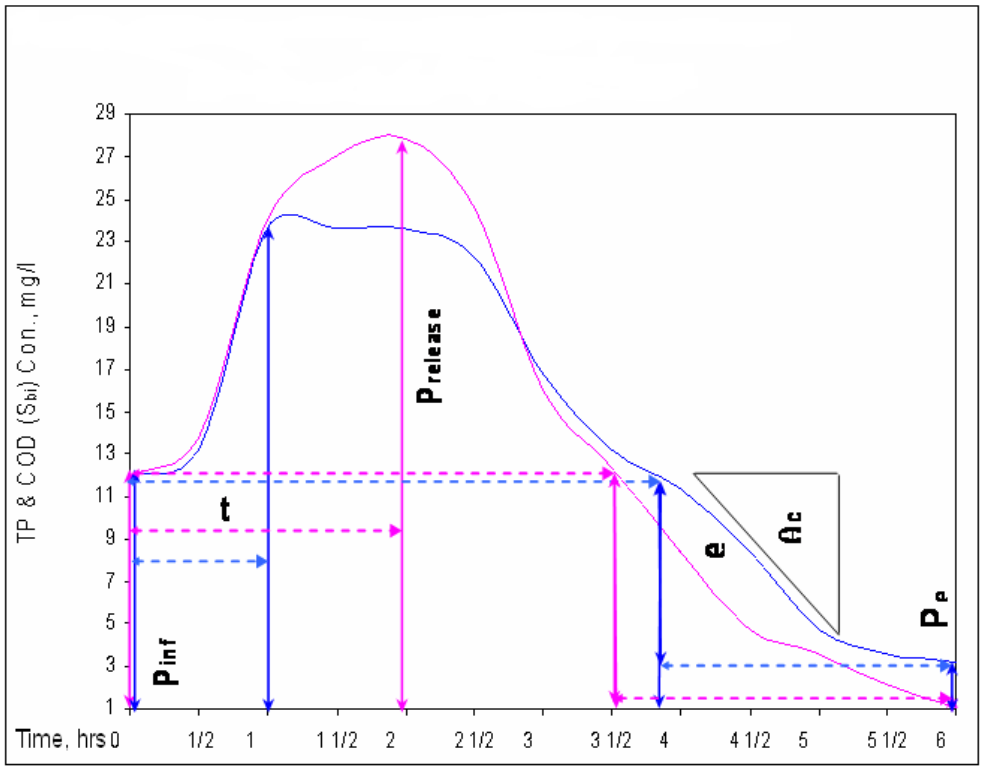

Fig. (13): Predicted Effluent Sewage Soluble Phosphorus (P_{eff}) [Empirical]

Table (1): Seasonal Group (A) Effluent Phosphorus (Actual Plant vs. Predicated Empirical)

Parameter	Aug-07	Sep-07	Oct-07	Nov-07	Average
P_{inf} (mg/L)	13.00	12.70	12.30	12.00	12.50
$P_{release}$ (mg/L)	30.55	28.96	28.04	27.42	28.74
Sludge Age (days)	15.00	15.00	15.00	15.00	15.00
COD (S_{bsi}) (mg/L)	205	177	166	160	177
t (Anaerobic Period, hrs)	2	2	2	2	2
$P_{eff\ (Predicted)}$ (mg/L)	1.133	1.127	1.125	1.117	1.125
$P_{eff\ (Test)}$ (mg/L)	1.140	1.130	1.120	1.110	1.125

Table (2): Seasonal Group (B) Effluent Phosphorus (Actual Plant vs. Predicated Empirical)

Parameter	Jun-07	Mar-07	Dec-06	Sep-06	Average
P_{inf} (mg/L)	12.20	12.00	11.70	12.10	12.00
$P_{release}$ (mg/L)	28.95	27.40	26.59	28.31	27.81
Sludge Age (days)	15.00	15.00	15.00	15.00	15.00
COD (S_{bsi}) (mg/L)	185	158	151	175	167
t (Anaerobic Period, hrs)	2	2	2	2	2
$P_{eff\ (Predicted)}$ (mg/L)	1.146	1.126	1.100	1.134	1.126
$P_{eff\ (Test)}$ (mg/L)	1.140	1.120	1.100	1.130	1.123

Conclusions & Recommendations

1- These kinetic parameters and the detailed fractionation of raw wastewater COD, and phosphorus can be used in biological nutrient removal process design mathematical modeling (BNR-Model) to obtain optimum design.

2- The proposed batch experiment representing (BPR Test) is a simple and economic procedure for evaluation the feasibility of BPR. The (BPR Test) is validated by comparing the ratio of release / uptake behavioral pattern profile with the actual existing full-scale plant under operation.

3- The (BPR Test) is indicating that the readily biodegradable soluble COD (S_{bsi}) is mostly utilized in the anaerobic reactor. This concept is postulated that (S_{bsi}) was taken up into the cell under anaerobic conditions and stored as poly-ß-hydroxybutyrate, and found that phosphorus release increased as the influent readily biodegradable soluble COD (S_{bsi}) increased.

4- Using a linear approximation to estimate (P_{eff}) empirical parameters, ($P_{release}$, P_{inf}, $\square_c$, S_{bsi}, and t), we concluded that the concentration of readily biodegradable soluble COD (S_{bsi}) surrounding the microorganisms in the anaerobic zone is a very important wastewater characteristic in the process of biological phosphorus removal.

5- Based on the yearly seasonal groups (A & B) done for both (BPR Test) and the (Actual Plant) with the applied intrinsic wastewater characteristics, the amount of phosphorus release measured, the excess uptake phosphorus, and the removed phosphorus can be calculated, and consequently, the effluent phosphorus concentration will be predicted.

6- BNR-Model can be used to determine the process volume and to evaluate the effect of chemical oxygen demand (COD) loading, biomass concentration, and sludge age on the nutrient removal efficiency. Multiple process design configurations can be evaluated, and the sensitivity of designs to variations in wastewater characteristics can be economically evaluated. The wastewater characterization methods presented in this thesis will provide the inputs to the mathematical design models.

7- The operational conditions and procedure developed for the (BPR Test) is conducted using the Dynamic Simulation Technique, whereas the enhanced culture must depend on influent wastewater characteristics and PAOs-containing activated sludge of an actual existing plant under operation and analyze the total phosphate (TP) and COD for a period of time corresponding to both of the anaerobic and aerobic retention time.

8- The (BPR Test) is developed using the Dynamic Simulation Technique which conducted the Biochemical Empirical Mathematical Modeling for prediction of the (P_{eff}), and it is found applicable and feasible for the evaluation of the biological phosphorus removal process of the wastewater

treatment plants of interest to reach an optimum effluent phosphorus concentration value around (1 mg/ L), incompliance with the requirements of the Environmental Protection Standards for the performance standards applied to wastewaters at the outfall discharge to coastal waters bodies.