ENHANCEMENT OF DYE PROCESSING FACTORY ACTIVATED SLUDGE BY ADDITION OF POWDERED ACTIVATED CARBON

LEE HENG KENG

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by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Engineering.

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ABSTRACT

Textile wastewater is generally highly alkaline, high in BOD_5, COD and color. Conventional biological treatment methods can reduce the biodegradable organics efficiently but poorly for refractory organics and particularly for color. Tertiary treatment would normally be required. However the addition of powdered activated carbon in the aeration basin of the activated sludge system proved effective in the removal of refractory organics and color.

A study on the powdered activated carbon-activated sludge system revealed that a high loading rate of 0.92 kg COD/m^3-d can be applied to the powdered activated carbon unit without affecting its stability. COD and color removal was better than that of the control unit. COD removal was 95% and color reduction was 76% at a carbon dosage of 3 g/L as compared to the control unit achieving 84% COD removal and 16% color reduction. The average influent COD was 919 mg/L and color was 44.6 percent transmittance at 330 nm. BOD_5 however showed slight improvement at 99.4% and 98.6% for the carbon unit and control unit respectively implying that adsorption was the main mechanism in increased COD and color reduction. Average influent BOD_5 was 539 mg/L. Variation of sludge age had little effect on COD removal but color reduction was highest at a sludge age of 10 days.

At the face value cost could be a deterrant in the utilization of PAC. However taking into account the other benefits such as increased loading rate, better sludge settleability and reduced aeration foaming, it could be a viable alternative.

The color of the wastewater after gamma radiation treatment changed from brown to amber. COD values remain almost the same as before irradiation. The effluent COD removal of the unit fed with irradiated wastewater deteriorated but BOD_5 removal was unaffected.

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AS	activated sludge
BOD	biochemical oxygen demand
BOD_5	5 days biochemical oxygen demand
cm^2	square centmeter
cm^3	cubic centimeter
COD	chemical oxygen demand
d	day
Expt	experiment
g	gram
h	hour
HRT	hydraulic retention time
kg	kilogram
L	liter
m	milli
M	mega
m^3	cubic meter
MLSS	mixed liquor suspended solids
nm	nanometer
PAC	powdered activated carbon
rad	a measure of radiation adsorbed
rpm	revolutions per minute
SRT	sludge retention time
%T	percent transmittance
TKN	Total Kjeldahl Nitrogen
T-P	Total Phosphorus
VSS	volatile suspended solid

I INTRODUCTION

With increasing rate of industrialization, the pollution load into the rivers and canals has also increased accordingly. Discharged standards would have to be tightened so that the beneficial uses of the river systems will not be seriously threatened. When discharge standards are made more stringent, industries would have to look into ways of upgrading existing treatment facilities. This could be done by incorporating tertiary treatment methods or providing additional treatment plants to cater for the increased load. For many factories, such improvements may not be feasible due to lack of funds or inadequate available space.

Powdered activated carbon has proven to be effective in the enhancement of effluent quality in overloaded sewage treatment plant (ADAMS, 1974). Powdered activated carbon was added directly to the aeration basin of the activated sludge system. The use of powdered activated carbon to upgrade the treatment efficiency of industrial wastewater was also experimented with various degree of success (ROLLINS et al, 1982 ; SPECCHIA and GIANETTO, 1984).

1.1 Statement of Problem

The textile industry uses a great quantity of water and hence generate considerable amount of wastewater. Treatment of this wastewater can be expensive and efforts to develop low cost treatment methods have little success (NEMEROW, 1978). Textile wastes are a mixture of both organic impurities extracted from fibers and chemical substances present in dyes. The wastes are generally colored, highly alkaline, high in BOD and suspended solids (NEMEROW, 1978; SHAUL et al, 1982). In Thailand, the wastewater treatment method typically employed in the synthetic fiber production mills is the activated sludge system (VIROJANAVAT and INTARACHOTE, 1986).

Therefore wastewater from the textile mill is a potential candidate for treatment enhancement using the powdered activated carbon-activated sludge process (PAC-ASP). The need would be more urgent when the mill's production is increased and available space is limited or when the environmental enforcement agency introduces more stringent discharge standards.

1.2 Objectives of the Study

The objectives of the study are:

(i) To determine the optimum operating conditions of the PAC-AS process, more specifically the loading rate, PAC dosage and sludge retention time (SRT);

(ii) To propose modification to upgrade the factory's existing activated sludge system.

(iii) To study the feasibility of gamma irradiation in the treatment of textile mill wastewater, particularly for the removal of color;

1.3 Scope of the Study

Laboratory scale experiments using both batch and completely mixed, continuous-flow modes at various operating conditions will be conducted.

Carbon adsorption isotherms will be developed to determine the range of PAC dosages to be used for the batch tests.

The batch tests will be carried out to determine the optimum PAC dosage. A control experiment will be performed, with no PAC addition, for comparison.

The completely, mixed continuous-flow tests will be conducted to evaluate the optimum SRT at the optimum PAC dosage as determined in the batch experiments.

With the optimum PAC dosage and SRT, gamma irradiated wastewater will be subjected to the AS process on a continuous-flow mode.

II LITERATURE REVIEW

2.1 Textile Wastewater Characteristics

Textile wastewater originates from the various operations that are being carried out in the mill. The quantity and quality also varies with the process and material used. The processes that produce wastewater include slashing, desizing, kiering, bleaching, mercerizing and dyeing. The materials used can be divided into three groups: cotton, wool and synthetic fiber (NEMEROW, 1978).

YANG and PESCOD, (1975) conducted a study to determine the treatability of wastewater from a factory in Thailand manufacturing nylon filament and fabric which also has dyeing and finishing facilities. They found significant variations in the characteristics of wastewater from the polymerization plant and dyeing sections. Polymerization wastewater was alkaline with a pH range of 7.3 to 10.1. Maximum BOD_5 and COD values recorded were 7500 mg/L and 22400 mg/L respectively, with an average ratio of BOD_5/COD of 0.5 indicating that the waste can be biologically treated. Dyeing wastewater was also alkaline and highly colored but with a low BOD_5/COD ratio. N and P levels were found to be adequate for biological treatment.

CHEN, (1974) analyzed wastewater from a synthetic textile factory in Bangkok and found that the characteristics of the mixed wastes (wastewater from sizing, desizing, dyeing and finishing processes) was alkaline, highly colored and low in COD and BOD_5 values. The COD and BOD_5 values were 226 mg/L and 36 mg/L respectively. It was suggested that the low COD values was because of dilution by extremely high volume of rinse water used during washing of the dyed fabrics while the low BOD_5 values was due to the toxic effect of some of the dyes. N and P levels were on the low side of 8.24 mg/L and 2.21 mg/L respectively. The results obtained by CHEN, (1974) was confirmed by MEMON, (1975) in a subsequent study.

The use of dyes and finishing chemicals in the textile industries results in an alkaline wastewater with significant BOD_5, high COD and high color level (PITKAT and BERNDT, 1980). SHAUL et al, (1982) reported that the wastewater was often deficient in nutrients (Nitrogen and Phosporus) and for microbial growth, urea and phosporus salts need to be added.

2.2 Activated Sludge Process

2.2.1 Process description

This process is widely used for the stabilization of organic matters. The essential features of the activated sludge process are an aeration stage, sedimentation stage and a sludge recycle system. Wastewater is brought into contact with a mixed flocculent suspension called mixed liquor suspended solids (MLSS) and is aerated to supply the required oxygen for metabolic degradation of the organic matter by bacteria. Suspended and colloidal materials are removed from the wastewater by adsorption and agglomeration on to the microbial flocs. In the stabilization process, part of the organic matter is oxidized to carbon dioxide and water and part is assimilated to new microbial cells. When the desired degree of treatment has been achieved, the mixture of new cells and old cells are separated from the treated wastewater by sedimentation. A portion of the settled sludge is recycled to maintain the desired concentration of organisms in the aeration basin, and a portion is wasted.

The performance of an AS process depends on the characteristics of the influent, operating parameters such as organic loading rate and sludge age and environmental conditions like pH, temperature and availability of oxygen.

2.2.2 Operating parameters

The SRT is one of the most important operational parameters in the AS process (WINKLER, 1981) and the major control variable for biological wastewater treatment systems (SHERRAD, 1977). It is defined as the total amount of sludge solids in the system divided by the rate of loss of sludge solids from the system. The SRT or mean cell residence time is given by:

$$\Theta_c = VX/(Q_w X_w + Q_e X_e) \qquad (2.1)$$

where,

Θ_c = mean cell residence time, day

V = aeration tank volume, m^3

X = concentration of VSS in the aeration tank, g/m^3

Q_w = waste sludge flowrate, m^3/d

X_w = concentration of VSS in the waste sludge, g/m^3

Q_e = treated effluent flowrate, m^3/d

X_e = concentration of VSS in the treated effluent, g/m^3

High quality effluent and good excellent settling sludge were found in laboratory studies and treatment plants in the United States operating with mean cell residence times of about 6 to 15 days (METCALF and EDDY, 1979).

The loading criteria commonly used is the 'sludge loading factor' or food-to-microorganism ratio (F/M), where the organic loading is related to the amount of sludge in the aeration tank.

The F/M ratio is defined as

$$F/M = S_o/\Theta X \qquad (2.2)$$

where,

F/M = food-to-microorganism ratio, d^{-1}

S_o = influent substrate concentration, g/m^3

Θ = hydraulic retention time, d

The F/M ratio in a conventional AS plant is in the region of 0.5 d^{-1} and in the range of 0.2 to 0.6 d^{-1} (WINKLER, 1981).

2.2.3 **Kinetic models**

The AS process is a microbial growth system and the wastewater treatment is dependent on bacterial growth. SHERRAD, (1977) reviewed the kinetics and stoichiometry of completely mixed AS process and summarized as follows. The specific growth rate is a function of substrate concentration and follows the Michaelis-Menten enzyme kinetic relationship and was proposed by Monod in 1942 as

$$\mu = \mu_m S/(K_s + S) \tag{2.3}$$

where,
μ = specific growth rate, d^{-1}
μ_m = maximum specific growth rate, d^{-1}
S = substrate concentration, mg/L
K_s = substrate concentration at one-half the maximum growth rate, mg/L

Taking into account the effects of microbial cell decay which is assumed to follow the first-order kinetics, the net rate of microbial growth is expressed as

$$R_g = -YR_{su} - bX \tag{2.4}$$

where,
R_g = net rate of bacterial growth, mg/L-day
Y = maximum growth yield coefficient
R_{su} = substrate utilization rate, mg/L-day
b = endogenous decay coefficient, d^{-1}

From material balance on the microorganisms and at steady state

$$VR_g = Q_e X_e + Q_w X_w \tag{2.5}$$

The net specific growth rate is given

$$\mu' = (Q_e X_e + Q_w X_w)/VX \tag{2.6}$$

The reciprocal of equation 2.6 defines the concept of mean cell residence time, Θ_c.

Similarly a material balance for substrate utilization and assuming substrate is metabolized only in the aeration tank,

$$Y/(1 + b\Theta_c) = \Theta X/[\Theta_c (S_o - S)] \tag{2.7}$$

By defining the term specific utilization rate as,

$$U = -R_{su}/X \tag{2.8}$$

Substituting equation 2.4 into equation 2.8

$$1/\Theta_c = YU - b \tag{2.9}$$

From equation 2.7 and equation 2.9

$$U = (S_o - S)/\Theta X \tag{2.10}$$

Mathematically, the observed yield coefficient may be stated as

$$Yobs = -R_g / R_{su} \tag{2.11}$$

Substituting equations 2.4 and 2.9 in equation 2.11

$$Yobs = Y/(1 + b\Theta_c) \tag{2.12}$$

2.2.4 Treatment of textile wastewater using the activated sludge process

The AS process has been used to treat combined wastewater from textile mills and sewage. LAURIA and WILLIS, (1964) observed 90% BOD removal in a pilot plant study with 4:1 mixture of textile and sewage waste. LITTLE, (1969) using waste from bleaching and dyeing of cotton and synthetic materials achieved 60 - 80% COD reduction. SOUTHER and ALSPAUGH, (1957) in a pilot plant study observed that a mixture of dye waste and domestic sewage was able to remove and an average of 79% BOD and 64% color. However dye waste in excess of 30% of the mixture resulted in treatment failure.

PORTER, (1972) reported that in the early 1950's color removal by activated sludge process were able to achieve 84 - 93% but with new improved and non-destructible dyes, color reduction was in the range of 50 - 85%. In most cases pretreatment such as polymer coagulation, ion-exchange and carbon adsorption is required. PETRU, (1968) studied the treatment of cotton mill and diary waste with sewage utilizing a two stage activated sludge process, with a primary load of 8 kg BOD/m^3-d and secondary load of 0.8 kg BOD/m^3-d was able to reduced BOD by 70% in the primary and 94% in the secondary stage. However good BOD removals was not accompanied by high COD removal. JONES et al, (1962) obtained 85 - 90% BOD reduction in the treatment of cotton manufacturing and finishing wastes in combination with domestic wastewater, using the contact-stabilization process.

MEMON, (1975) in his study concluded that dyeing waste was not biologically treatable due to its toxic nature but the combined desizing and finishing waste could be biologically treated and achieved an efficiency of 58% COD removal. In a batch activated sludge study, YANG and PESCOD, (1975) obtained 51.7% COD reduction for dyeing waste and 76.3% reduction for polymerization waste after 23 hour retention time. Color in the dyeing waste was not biologically broken down even after one month of aeration. However when the dyeing wastewater was pretreated with alum, 73.2% COD removal was achieved.

2.3 Powdered Activated Carbon - Activated Sludge Process

2.3.1 Process description

Powdered activated carbon-activated sludge process (PAC-AS) involves the direct addition of PAC to a biological reactor to form a matrix of microorganisms and carbon particles (FLYNN _et al_, 1976). ADAMS, (1974) postulated that there are four mechanisms that allowed for the enhancement of the activated sludge system. Firstly, pollutants are adsorbed and concentrated in the high pores of the carbon ensuring complete reaction. Secondly carbon holds the less readily degraded molecules longer in the sludge to allow for biological degradation. Thirdly, the ability to utilized microorganisms in a way that results in renewed adsorptive capacity of the carbon (biological regeneration) and finally, carbon acts as a weighting agent giving better sludge settleabilty.

There seems to be some difference in opinions among researchers regarding to the mechanisms of organic removals by PAC. SCARAMELLI and DiGIANO, (1973) found that upon PAC addition no increase in MLSS or oxygen uptake rate of the sludge was observed, thus concluding that the reduction of total organic carbon (TOC) was due to physical adsorption onto the carbon. YONG, (1975) in a study with wastewater from a beverage factory in Bangkok agreed with the findings of Scaramelli and DiGiano. On the other hand, KALINSKE, (1972) in batch tests observed that glucose removal rates were higher than that possible by carbon adsorption, suggesting that PAC enhanced biological uptake rates. LEE _et al_, (1989) in their study also concluded that PAC addition showed higher biological activities , based on the oxygen uptake rate, yield coefficient and first order substrate removal rate constant. SCHULTZ and KEINATH, (1984) in a research to determine among other things, whether PAC addition enhanced biodegradation and the extent of bioregeneration of adsorbed substrate, utilizing phenol as the sole carbon source and carbon-14 radiotracers. It was found that no significant difference in the rate of carbon dioxide-14 evolution from the PAC-AS and biomass culture, hence concluding that PAC addition did not enhanced the rate of phenol degradation. It was also found that bioregeneration did occur when all the initially adsorbed phenol was eventually removed from the carbon surface.

2.3.2 Process kinetics in PAC-AS process

FLYNN, (1974) derived the kinetics for a PAC-AS process based on models of LAWRENCE and McCARTY, (1970), with modifications for carbon addition. For the PAC-AS process, equations 2.1 through 2.10 were assumed to apply to the biological portion of the process for all the BOD removed.

The addition of PAC introduces a conservative substance to the activated sludge system, then at steady state,

$$QC_o - (Q_e C_e + Q_w C_w) = 0 \tag{2.13}$$

where,
Q = influent flowrate, m^3/d
C_o = influent carbon concentration, g/m^3
C_e = effluent carbon concentration, g/m^3
C_w = wastage carbon concentration, g/m^3

Rewriting equation 2.13

$$QC_o/VC = (Q_e C_e + Q_w C_w)/VC \tag{2.14}$$

where,
C = mixed liquor carbon concentration, g/m^3

then,

$$C_o/\Theta C = 1/\Theta_c$$

$$C = C_o(\Theta_c/\Theta) \tag{2.15}$$

Therefore for a PAC-AS process, the total mixed liquor suspended solids is given by

$$X = C_o(\Theta_c/\Theta) + Y(S_o - S)\Theta_c/\{(1 + b\Theta_c)\Theta\} \tag{2.16}$$

Since the plot of 1/S Vs 1/U is sensitive to error in substrate analysis, FLYNN, (1974) used second order kinetics to derive the equation for effluent substrate concentration as

$$S = 1/Yk(1/\Theta_c + b) \tag{2.17}$$

where k is the second order rate constant

From experimental data FLYNN, (1974) was able to predict effluent BOD which matched pilot plant effluent BOD.

LEE _et al_, (1989), using equation 2.15 found good agreement between the calculated PAC concentration and the measured concentration in a continuous flow reactor.

DeWALLE and CHIAN, (1977) used the empiral Freundlich equation to predict the reduction in organic matter concentration in a PAC-AS process.

$$x/M_p = aC_t^{\,b} \tag{2.18}$$

where,
x = adsorbate removed by carbon, g/m^3
M_p = adsorbent added, g/m^3
a, b = constants
C_t = adsorbate remaining in solution, g/m^3

The data obtained was found to fit the equation satisfactorily.

2.3.3 PAC-AS process for the treatment of wastewater

Many researchers have suggested that PAC addition to activated sludge improves efficiency of pollutant removal and process stability. The PAC-AS process is particularly suited for wastewater which are toxic, poorly biodegradable and can be adsorbed (FERGUSON et al, 1976).

KALINSKE, (1972) in batch scale experiments with glucose as the carbon source observed substantial increase in the reduction rate of BOD when activared carbon was present. In the continuous flow tests, it was found that COD reduction of 95% was attained with 1000 mg/L carbon dose while the reactor without carbon dose only achieved 58% COD reduction. Increasing the carbon dose to 2000 mg/L, the COD reduction was 93%.

SCARAMELLI and DiGIANO, (1973), using primary effluent from a municipal wastewater treatment plant to feed the laboratory scale continuous flow reactors at a rate of 1 L/h observed that a PAC dosage of 50 mg/L showed no effect. After a period of 48 hour and a carbon dosage of 100 mg/L, the TOC level was reduced to 7 mg/L while the control unit effluent concentration remained at 30 mg/L. With a carbon dosage of 200 mg/L the effluent TOC was 7 mg/L and 13 mg/L for the control unit. They further observed that, with the termination of carbon dosage of 100 mg/L and 200 mg/L, the test unit maintained an effluent TOC of 10 mg/L and 8 mg/L respectively even after five days of stoppage.

Dye and pigment processing wastewater was treated using PAC addition at three different dosages, to both a plug-flow and completely mixed pilot activated sludge systems. SHAUL et al, (1982) found that removal of COD increased with PAC concentration in the aeration tank. Also color removal was poor at low PAC dose and at a dose greater than 1000 mg/L, complete color removal was attained and COD reduction by 96%. It was also observed that only slight differences in organics and color removal at PAC doses between 1000 mg/L and 1800 mg/L.

Bench scale studies were carried out by GRULICH et al, (1972) with wastewater containing very difficult-to-treat constituents like dyes, large dye fragments, fiber intermediates, halogenated hydrocarbon, phenols and aromatics. At a PAC dosage of 200 mg/L the PAC-AS process was able to attain BOD level of less than 10 mg/L, 70% of the time but only 30% of the time by the conventional activated sludge system. Color removal was found to be dependent on carbon dosage, higher dosage gave better color removal efficiency.

An activated sludge treatment plant for treating wastewater from a cotton and synthetic cloth dye works was added with PAC to a concentration of 800 mg/L. The removal efficiency of COD and BOD increased from 55.8% to 75.6% and from 78% to 98.5% respectively (SPECCHIA and GIANETTO, 1984).

DeWALLE et al, (1977) conducted a study to determine the effectiveness of low carbon concentrations in removing organics when added to activated sludge units. Final carbon dosage of 50 mg/L and 300 mg/L in the mixed liquor was used and the units were operated at sludge ages of 5 days and 10 days. They found that even low equilibrium concentration of carbon was effective in reducing organic concentration. COD reduction was 15 and 25% for carbon dosages of 50 mg/L and 300 mg/L respectively. They further concluded that PAC addition was equally effective at 5 days as compared to 10 days SRT. In a separate study DeWALLE and CHIAN, (1977) maintained that COD removal is generally independent of the sludge age.

However FERGUSON et al, (1976), suggested that a long SRT is desirable for the contact-stabilization process.

SUNDSTROM et al, (1979) investigated the response of biological reactors with PAC under transient conditions, using a laboratory reactor without recycle. The results indicate that the continuous addition of carbon had relatively little effect on a step change in glucose due to the low adsorptive capacity of carbon for glucose. However addition of PAC greatly moderated the transient resulting from a phenol impulse input. It was suggested that PAC can be used to control reactors that are subjected to severe upsets of adsorbable toxic materials.

To study the effectiveness of PAC for the treatment of wastewater containing Cr(VI), LEE et al, (1989) used laboratory scale completely mixed continuous flow activated sludge reactors with internal sludge recycle; one with PAC addition and the other without. Cr(VI) was provided in the form of $K_2Cr_2O_7$ in the synthetic feed. The results of the study showed that the PAC unit required only 1 day to recover from an increased in Cr(VI) concentration while the unit without PAC needed 7 days. Also Cr(VI) removal was higher in the PAC unit (41%) as compared to 9% in the other unit.

SRITHARAN, (1987) found that addition of 300 mg/L PAC to the activated sludge system reduced the inhibitory effect of mercury, but PAC concentration of 1000 mg/L neither enhanced organic removal or improved sludge settleabilty.

Spent carbon/biomass slurry wasted from the aerator of a PAC-AS plant can be regenerated by wet air oxidation. ROLLINS et al, (1982) used a one-gallon batch autoclave regeneration unit and found that the reused carbon produced consistently good quality effluent in the PAC-AS process at all operating conditions.

2.4 Gamma irradiation in wastewater treatment

Other than the classical physico-chemical and biological removal of color from textile dye effluents, gamma radiation has been shown to be effective in the destruction of color in various organic compounds, especially dyes which are resistant to oxidation by aeration. An additional advantage is that gamma radiation induces oxidation of the organic compounds in the presence of an oxygen source (CASE et al, 1973).

CASE et al, (1973) in a study to investigate the radiation induced oxidation of various dye compounds for the destruction of color, used authentic effluents from a silk screen print textile mill and a separate batch from a weaving dyeing and finishing plant. Both effluents were filtered before introducing to a charcoal-loaded Cobalt-60 Gamma Irradiator. Charcoal was used to separate the organic fraction from the water fraction, thus eliminating the necessity for irradiating large quantities of water. After the effluent was processed through the irradiator at a dose rate of 5×10^5 rad/h and under 35 kg/cm^2 oxygen, 82% color removal and 91% filtered COD reduction was achieved. When solid materials were removed, color removal was almost 100%.

Azo dyestuff mother liquor which is low in biodegradability, chemically complex and has high color intensity was subjected to Cobalt-60 gamma radiation to a dose of 2.56×10^6 rads, MYTELKA and MANGANELLI, (1967) observed that COD was reduced by 61% and practically none of the dye (and color) remained. It was also found that as the radiation dose increased, the organic compounds remaining in the waste became more amenable to biological oxidation.

III EXPERIMENTAL SET-UP

Carbon adsorption experiments were conducted to determine the appropiate PAC dosage. With this, batch tests were carried out to obtain the HRT followed by continuous-flow operations.

Gamma radiation was also used to treat the textile wastewater prior to feeding to the activated sludge system.

3.1 Description of experimental set-up

3.1.1 Carbon Adsorption

The adsorption kinetics and equilibrium isotherm tests of organic (COD) and color were determined for PAC. The optimum contact time and optimum dose was obtained at a fixed pH and room temperature. The operating parameters for the carbon adsorption tests are as folows:

Optimum contact time

Volume of wastewater	200 mL
PAC dose	2000 mg/L
pH	7.6
Temperature	room temperature
Mixing speed	200 rpm
Contact times	5, 10, 20, 30, 40 and 60 minutes
Parameters analysed	COD and color

Optimum PAC dose

Volume of wastewater	200 mL
pH	7.6
Temperature	room temperature
Mixing speed	200 rpm
Contact time	30 minutes
PAC doses (Expt.1)	0, 0.5, 1, 2, 5, 10, 12.5 and 15 g/L
(Expt.2)	0, 2.5, 5, 10, 20, 30 and 40 g/L
Parameters analysed	COD and color

3.1.2 Batch tests

Four parallel reactors each 8 L capacity of the type as proposed by SYMONS et al (1960) and shown in Fig P1 were used. The reactors were supplied with diffusers which were connected to the laboratory air supply unit.

Equal volume of acclimatized activated sludge was placed in the reactors and mixed with wastewater to make the initial MLSS concentration about 2000 mg/L. The operating conditions were as follows:

Operating conditions

PAC dosage	0, 0.5, 1, and 2 g/L
Aeration time	0, 0.5, 1, 2, 4, 6, 8 and 23 h
Parameters analysed	COD, color and MLSS

COD and color were analysed after vacuum filtering through glass fiber filters.

Fig P1 Batch test reactors

3.1.3 **Continuous-flow tests**

Two reactors as shown in Fig P2 were used, one with PAC and the other without PAC to act as a control. The reactor was separated into two compartments by an adjustable baffle. The aeration basin was 6 L and the internal clarifier was 3 L. Aeration was provided by compressed air through two parallel diffusers at the bottom of the aeration compartment.

Equal volume of mixed liquour of concentration about 2000 mg/L were placed in both the reactors. PAC was added in one reactor.

After two days of operation, severe sludge bulking occured in both the reactors and microscopic examinations of the sludge confirmed the growth of filamentous microorganisms. The organic loading was reduced to half but with very little improvement. Furthermore the positioning of the diffusers posed some problems. Low air flow resulted in poor circulation while high air flow caused disturbance in the settling chamber. It was then decided to change the experimental unit to one with an external clarifier.

Fig P3 shows the experimental set-up. The aeration basin has a capacity of 6 L and the settling chamber was 2.5 L. The operating conditions for the continuous mode were as follows:

Operating conditions

Loading rate	0.59 - 1.02 kg COD/m^3-d
PAC dose	1 and 3 g/L
HRT	24 and 40 h
SRT	7, 10 and 15 days
Parameters analysed	COD, color, MLSS, BOD_5 and SVI

Sludge wasting was carried out by withdrawing a predetermined amount of mixed liquour from the aeration basin. Daily PAC addition was done to compensate for the loss during sludge wasting.

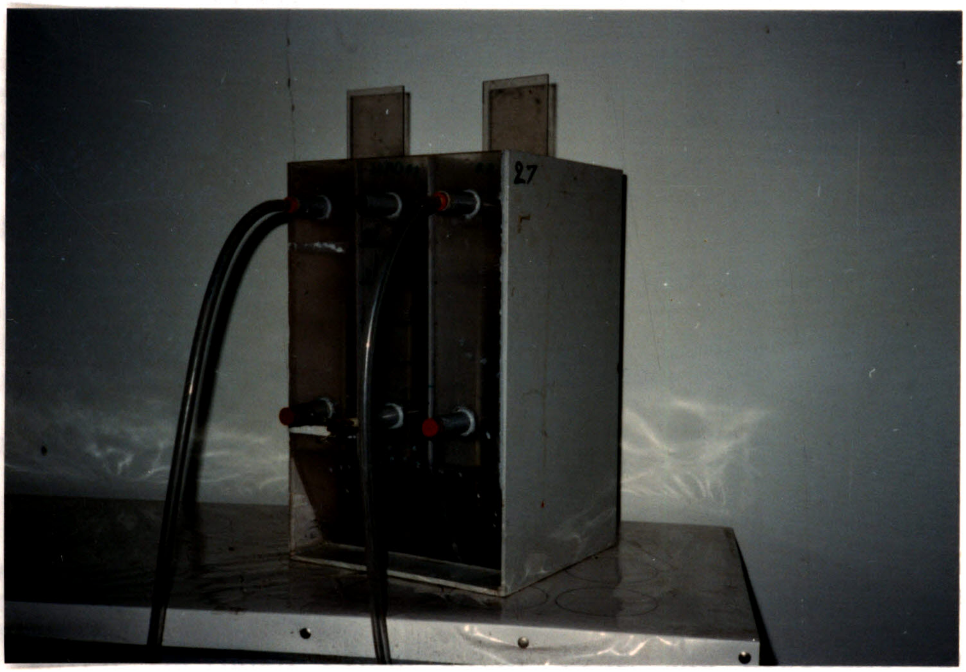

Fig P2 Continuous-flow reactor with internal clarifier

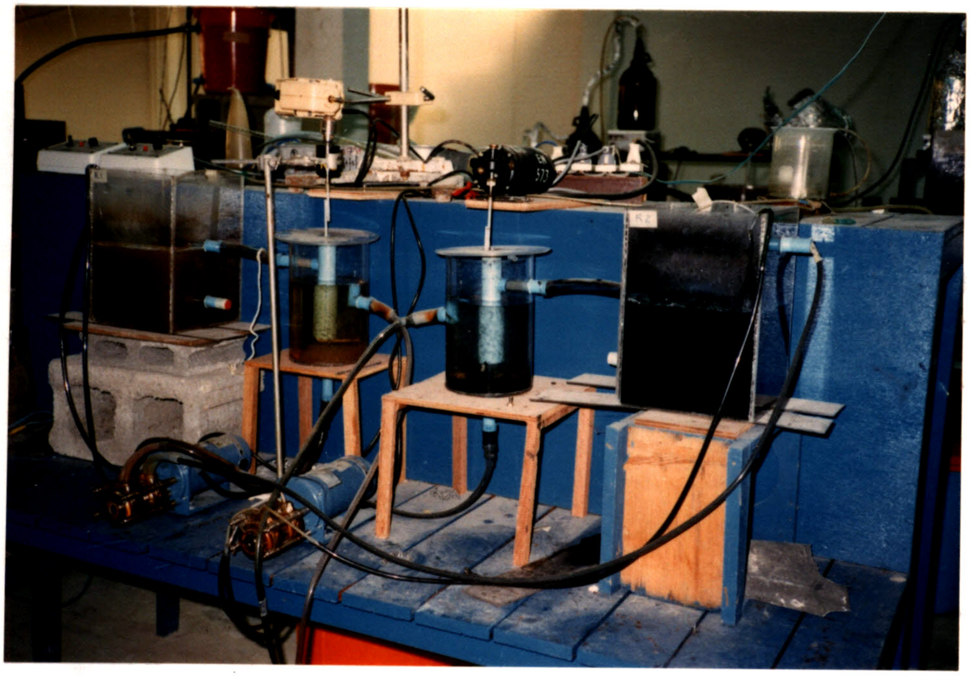

Fig P3 Continuous-flow reactors with external clarifier

3.1.4 Gamma irradiated activated sludge tests

The experimental set-up was similar to that of the continuous tests except gamma irradiated textile wastewater was fed into the reactor without PAC. The operating conditions were as fllows:

Operating conditions

Loading rate	0.57 kg COD/m^3-d
HRT	40 h
SRT	15 days
Parameters analysed	COD and BOD_5

3.2 Materials

3.2.1 Wastewater

Textile wastewater from a textile factory in Patum Thani Province, Thailand was used throughout the course of the study. The wastewater was from the printing and dyeing section of the factory which included rinse water from the desizing operation. Wastewater was collected from the outlet of the equalization pond and stored at 5°C before being used. Seed activated sludge was taken from the return line of the factory's wastewater treatment plant.

Nutrients in the form of $(NH_4)_2SO_4$ and KH_2PO_4 were added to maintain the nutrient balance according to the BOD:N:P ratio of 100:5:1 (ECKENFELDER and O'CONNER, 1961)

The pH of the wastewater was neutralized by adding H_2SO_4.

3.2.2 Powdered Activated Carbon

Darco activated carbon was used throughout the study. The characteristics of the PAC are as shown in Table 3.1.

Table 3.1 Characteristics of PAC (Darco) used

Properties	Values
Bulk density (g/cm^3)	0.32
Ash (wt %)	1.8
pH	7.9-8.6
Screen analysis	
Passes 100 mesh (wt%)	99.7
Passes 200 mesh (wt%)	97.9

3.3 Measurements

3.3.1 Parameters monitored

The main parameters measured were COD, color and MLSS. High MLSS in the PAC unit made representative sampling difficult. The biomass fraction was assumed as the difference between MLSS and the equilibrium PAC concentration. BOD_5 was also determined for a fixed period of time to ascertain the degree of organic reduction even though when COD has stabilized. Dissolved oxygen and pH of the reactors were also measured to ensure that the values were within the required range.

3.3.2 Method of analysis

All measurements were conducted according to the procedure laid down in Standard Methods, 16th edition (APHA,1985) except color.

Color of raw wastewater and effluent from the reactors were measured in percent transmittance at the minimum transmittance wavelength using the "SHIMADZU UV-240" spectrophotometer. The minimum transmittance wavelength was checked for every batch of fresh wastewater collected. Fig 3.1 shows a typical curve of minimum transmittance. The optimum wavelength was found to be in the range of 320 - 340 nm. This was probably due to the different types of dyes used by the factory (see Appendix B).

The color reduction curve used by NEMEROW and DOBY (1958) was adapted and used in this study. This was also used by CHEN (1974) and MEMON (1975). An example of the color reduction curve is shown in Fig. 3.2.

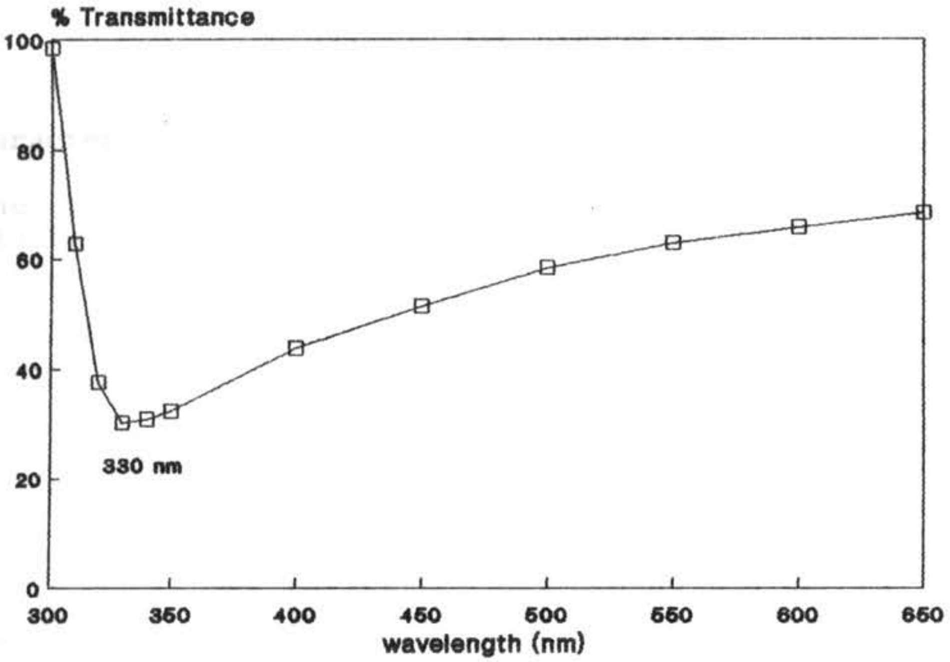

Fig. 3.1 Minimum transmittance curve

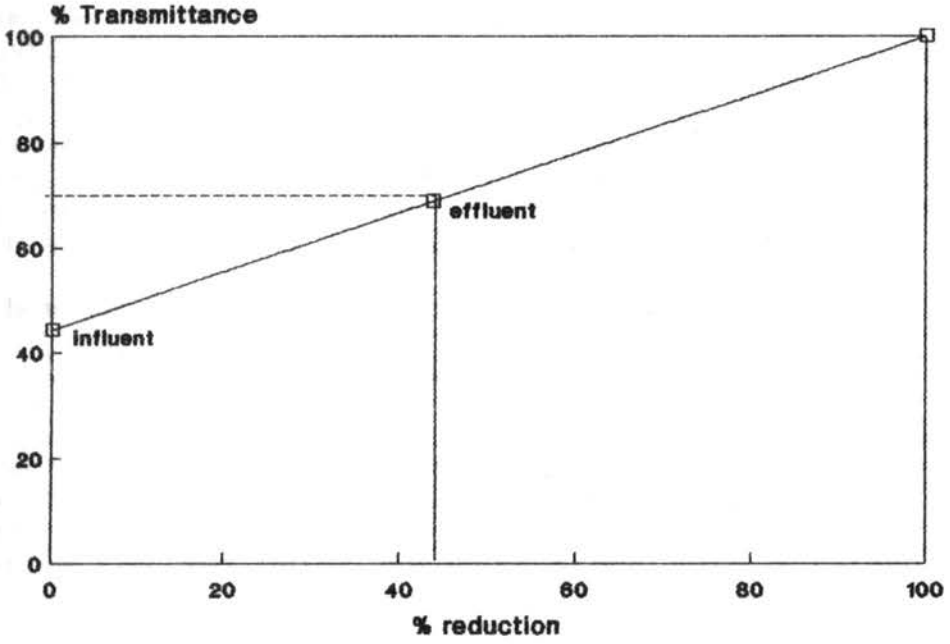

Fig 3.2 Color reduction curve

IV RESULTS AND DISCUSSION

4.1 Characteristics of textile wastewater

The chacteristics of the textile wastewater analysed are shown in Table 4.1.

Table 4.1 Characteristics of textile wastewater

Parameter	Concentration
pH	9.4 - 10
BOD_5 (mg/L)	540 - 645
COD (mg/L)	711 - 1096
SS (mg/L)	26.8 - 30.5
TKN (mg/L)	2.02 - 2.66
T-P (mg/L)	1.25 - 1.61
Temperature (° C)	32 - 34

The color of the wastewater ranged from yellow to brown. A list of the dyes used is presented in Appendix B.

The wastewater was highly alkaline which is the case for most textile wastewater. For efficient biological treatment the pH needed to be adjusted to near neutral. BOD_5/COD ratio was in the range of 0.6-0.8 which is comparable to the findings of YANG and PESCOD (1975). Hence the wastewater can be biologically treated. However nutrients concentrations (nitrogen and phosphorus) were rather low which required the addition of nitrogen and phosphorus compound for microbial growth.

4.2 Carbon adsorption

4.2.1 Optimum contact time

Color and COD removal at a fixed carbon dosage as a function of contact time were determined. Wastewater at a pH of 7.6 was added with 2000 mg/L wastewater of PAC and agitated at 200 rpm for various times. As can be seen from Figs 4.1 and 4.2, the equilibrium COD and color concentrations were attained after 30 minutes of mixing. Color removal was 75.3% and COD removal 22.1%.

4.2.2 Optimum PAC dosage

With the optimum contact time set at 30 minutes, 200 mL of wastewater was added with different doses of PAC, ranging from 500 mg/L to 15000 mg/L. Again the mixing speed was at 200 rpm. From Figs 4.3a and 4.3b, it was observed that high color removal can be achieved with higher dose of PAC. COD removal was only 36.2% even at a high PAC dosage of 15000 mg/L.

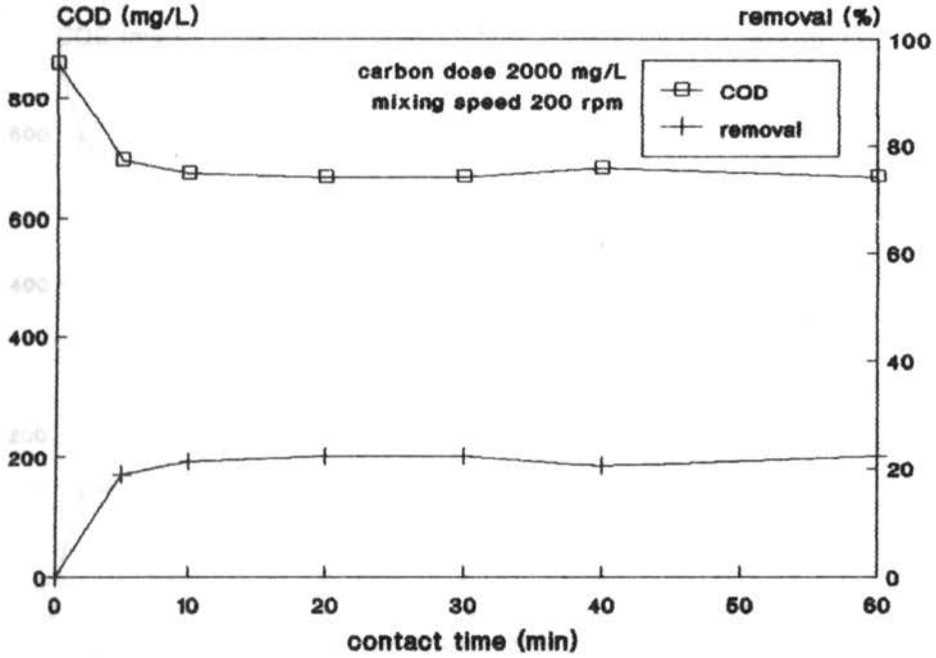

Fig. 4.1 Carbon adsorption: COD variation with time

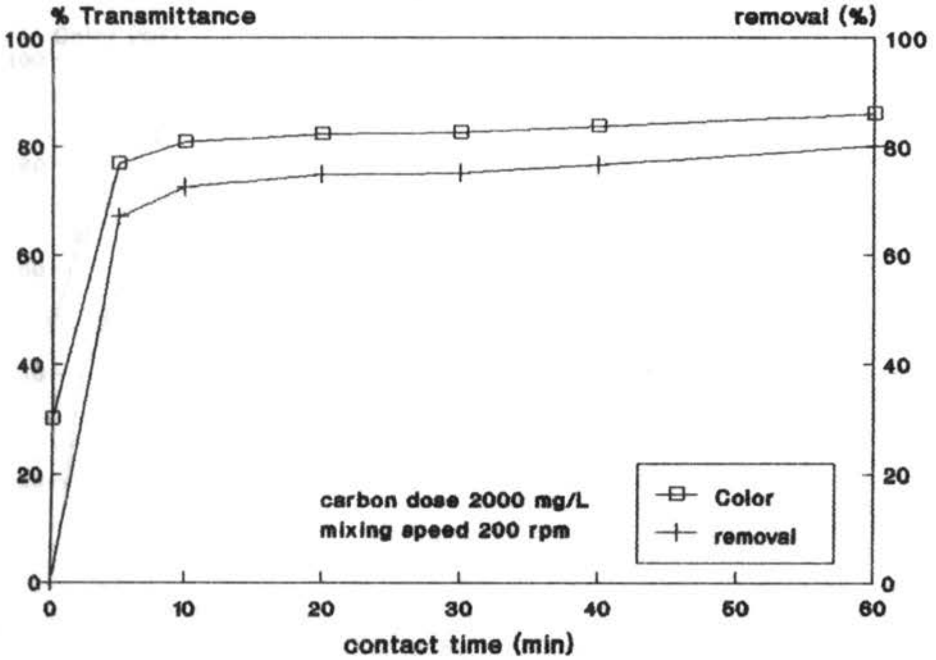

Fig. 4.2 Carbon adsorption: Color variation with time

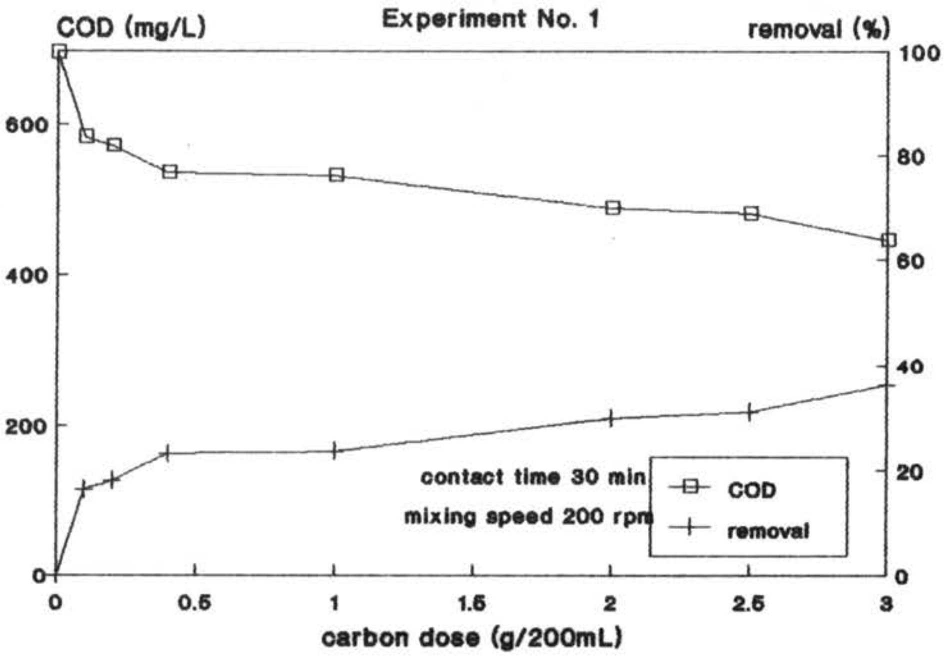

Fig 4.3a Carbon adsorption: COD variation with dose

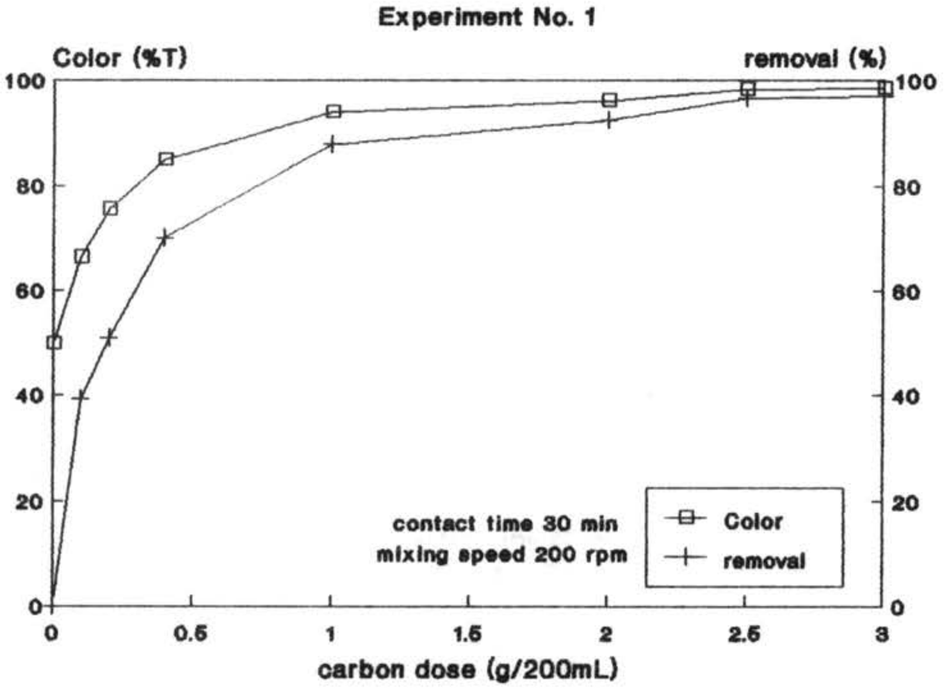

Fig 4.3b Carbon adsorption: Color variation with dose

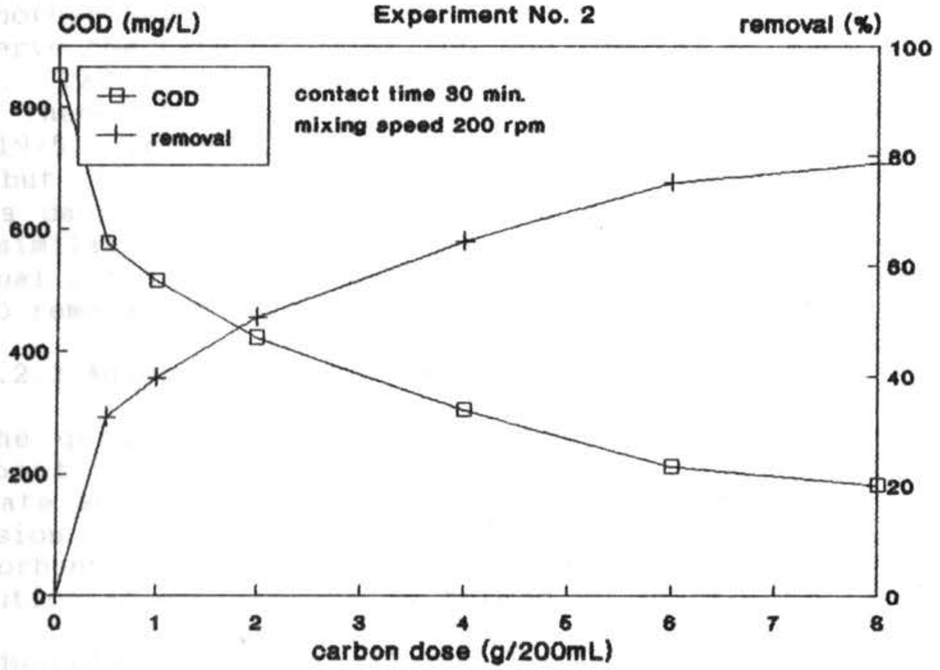

Fig. 4.4a Carbon adsorption: COD variation with dose

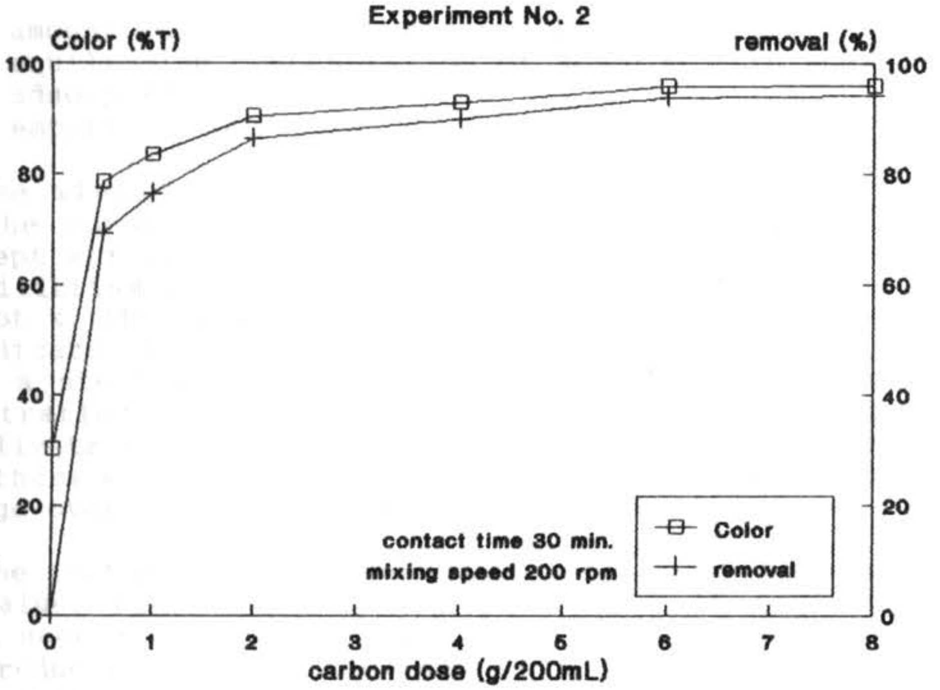

Fig. 4.4b Carbon adsorption: Color variation with dose

Another set of experiment (Experiment No. 2) was performed to observe the rate of color and COD removal at much higher doses of PAC. PAC in concentrations of 2500 mg/L to 40000 mg/L were used. These concentrations were also used by CHANG (1988) and YONG (1975) in their studies. Color reductions did not improve much but COD removal increased to 78.8% at a PAC dosage of 40 g/L, as can be seen from Figs 4.4a and 4.4b. This result was quite similar to that obtained by CHANG (1988) using PAC to treat municipal solid waste leachate. He obtained color removal of 94% and COD removal of 75.1% at a PAC dosage of 20 g/L.

4.2.3 **Adsorption isotherms**

The quantity of adsorbate that can be taken up by an adsorbent is a function of both the concentration of the adsorbate and the temperature (METCALF and EDDY, 1979). The expression of the distribution of adsorbed solute per unit weight of adsorbent as a function of concentration of solute remaining in solution at equilibrium is termed an adsorption isotherm.

Adsorption isotherms for color and COD of the wastewater generally correspond to the Freundlich equation as shown in Figs 4.5 and 4.6. Freundlich equation is stated as

$$x/M = kC^{1/n} \tag{4.1}$$

where,

x/M = amount adsorbed per unit weight of adsorbent

C = equilibrium concentration of adsorbate in solution after adsorption

k, n = empirical constants

The adsorption capacity of the carbon used can be estimated from the constants k and n. Linearizing equation 4.1, the intercept k represents the adsorption density when the carbon is in equilibrium with the influent concentration. The higher the value of k, the higher will be the adsorption density. The slope 1/n indicates the adsorption capacity of the carbon. An isotherm having a steep slope indicates that adsorption is good at high concentrations but much less at low concentrations. This is generally true in column treatment. However for batch treatment, an isotherm with a slight slope would be better as the adsorption is large over the entire range of concentrations.

The isotherm for the adsorption of color gave a lower slope (1/n value) than that for the adsorption of organics (COD), as can be seen from Figs 4.5 and 4.6. This indicates that higher color reduction can be attained at a lower concentration of PAC while removal of organics is higher at higher concentrations of PAC.

4.3 **Batch tests**

The batch test was conducted to determine the appropiate hydraulic retention time and the optimum PAC dosage to be used in the continuous-flow mode.

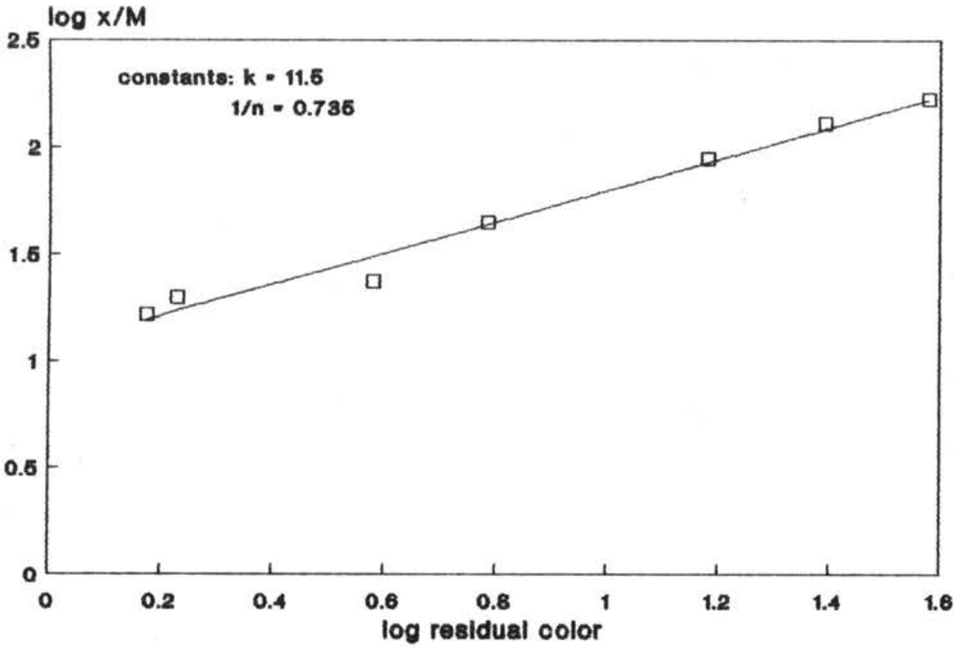

Fig 4.5 Freundlich plot of adsorption isotherm (color)

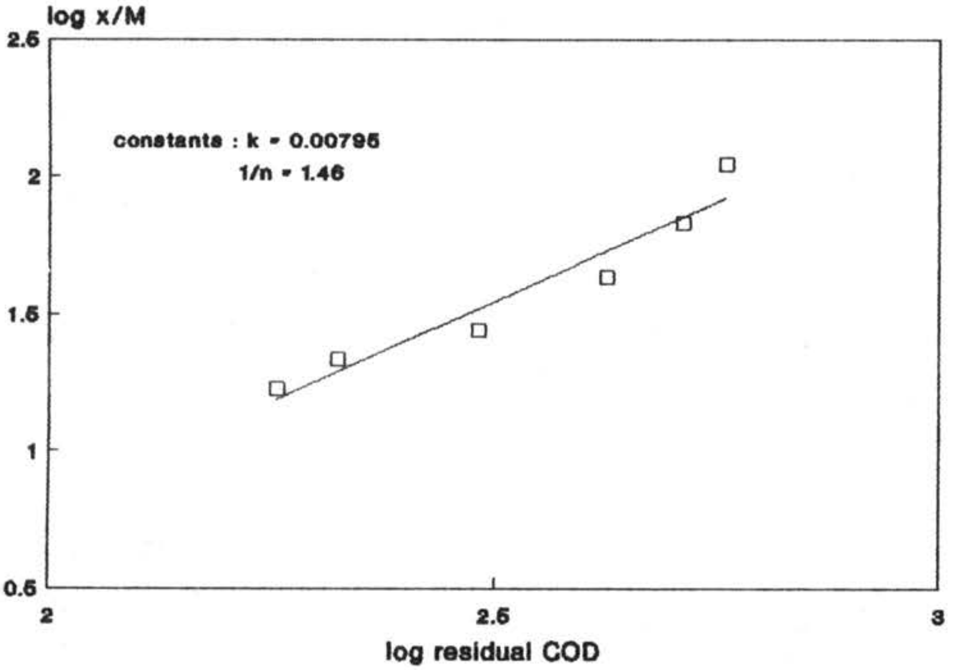

Fig 4.6 Freundlich plot of adsorption isotherm (COD)

4.3.1 PAC dosage

From the carbon adsorption tests it was observed that color reduction greater than 70% can be achieved with a PAC dosage of 2000 mg/L. It was decided to choose three doses of PAC in the batch tests, viz 500 mg/L, 1000 mg/L and 2000 mg/L.

4.3.2 COD removal

COD degradation for the four units is shown in Fig 4.7. As can be seen from the curves, COD removal was greatest for the unit with PAC concentration of 2000 mg/L and the least for the unit without PAC (control unit). COD removal was 70.3%, 88.0%, 92.0% and 94.3% for the reactors with no PAC, 500 mg/L, 1000 mg/L and 2000 mg/L PAC respectively after an aeration time of 6 hours. There was a slight increase in removal efficiency after 23 hours of aeration.

4.3.3 Color reduction

As in the case of COD removal, color reduction also followed a similar trend. It was highest for the reactor with the highest dose of PAC, while the control unit had a low percentage of color reduction. Figure 4.8 shows the color removal efficiency for the batch tests. Similarly color reduction reached almost a constant value after 6 hours of aeration. Color reduction was 16.3%, 33.4%, 57.1% and 81.6% for the control unit and units with 500 mg/L, 1000 mg/L and 2000 mg/L PAC respectively.

4.3.4 MLSS variation

Figure 4.9 show the MLSS variation for the four reactors. MLSS concentrations reached the maximum value after 6 hours of aeration.

MLSS was found to be less in the units with PAC than the control unit. This was also indicated by DEWALLE and CHAIN (1977). It was postulated that the decrease could be the result of enhanced bacterial respiration, while some of the adsorbed organics may not be available for the formation of biomass.

4.3.5 Batch-Adsorption isotherm

Again using the Freundlich equation, the values of x/M were plotted against residual COD concentrations. The x/M values were calculated from the decrease in organic matter in the PAC unit as compared to the control unit after aeration time of 23 h.

As can be observed from Fig 4.10, most of the points fall on the straight line giving a k value of 13.0 and 1/n value of 0.575. $(x/M)_o$, the amount of organic adsorbed per unit weight of carbon was found to be 0.22 mg COD/mg of activated carbon. This value is comparable to those found by other researchers as summarized by DEWALLE and CHIAN (1977) in Table 4.2.

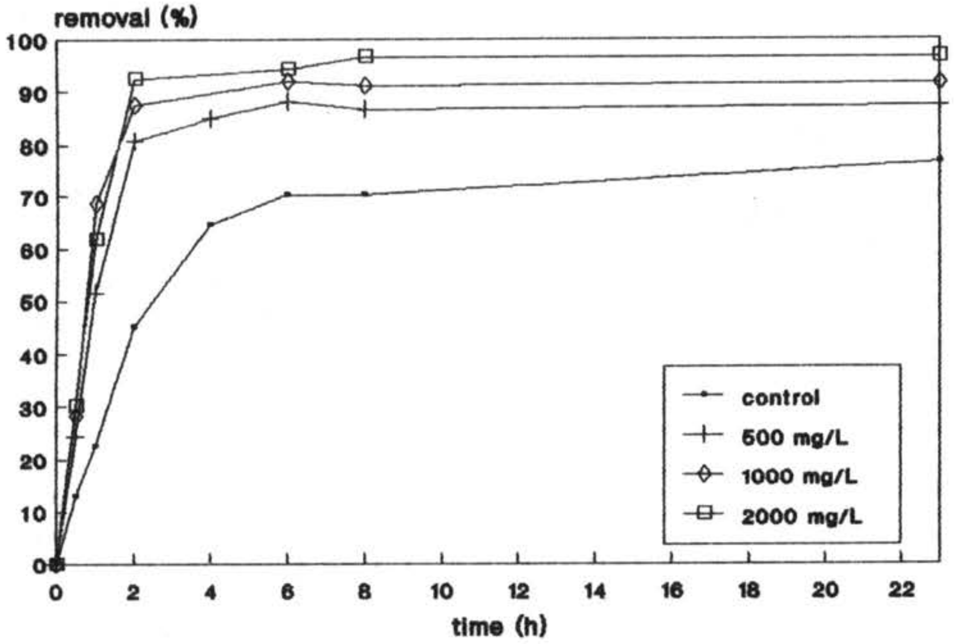

Fig 4.7 Batch test: COD removal efficiency

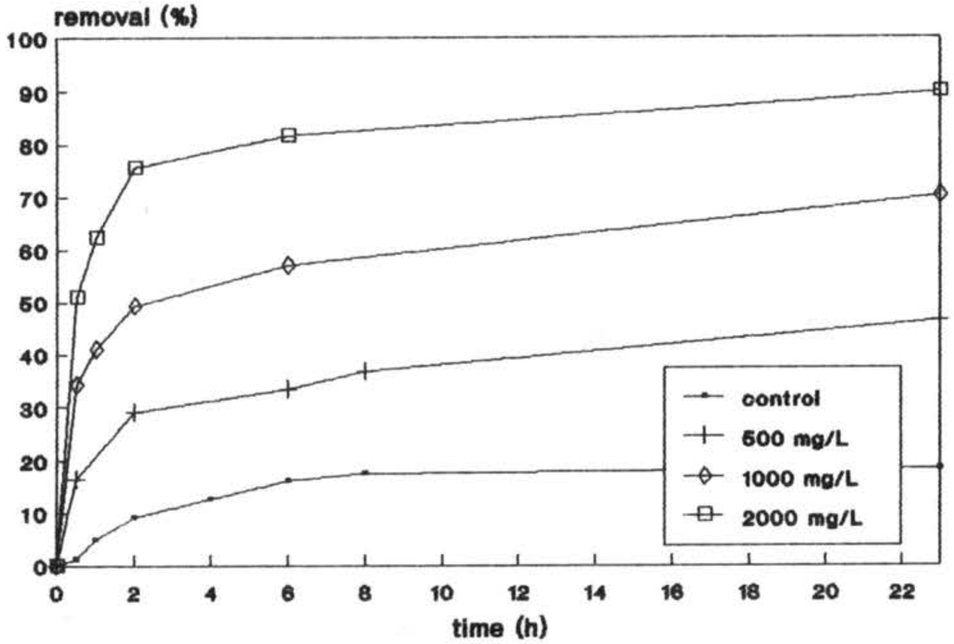

Fig. 4.8 Batch test: Color removal efficiency

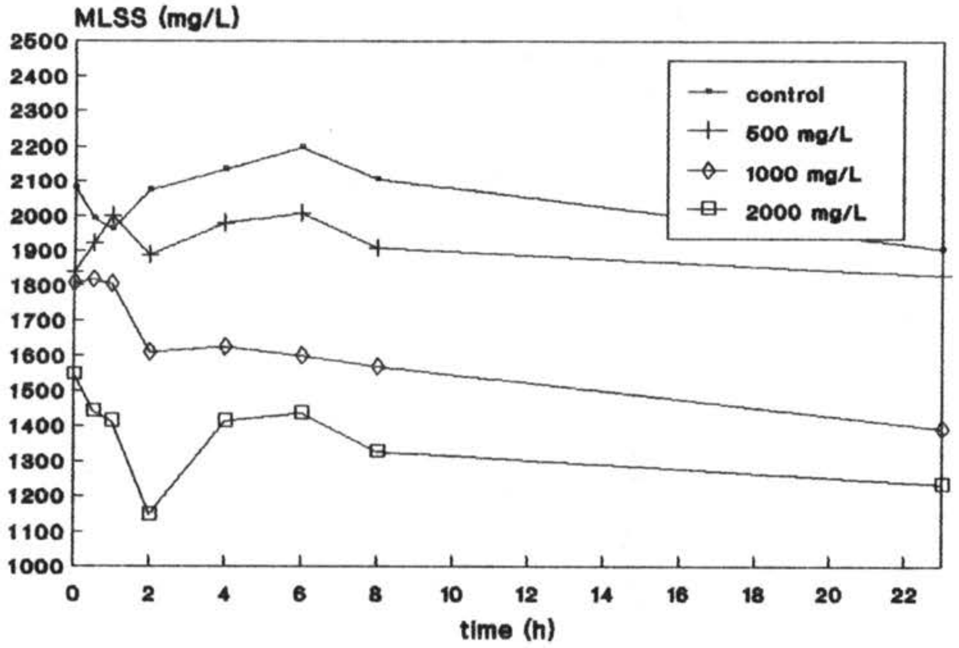

Fig. 4.9 Batch test: MLSS variation with time

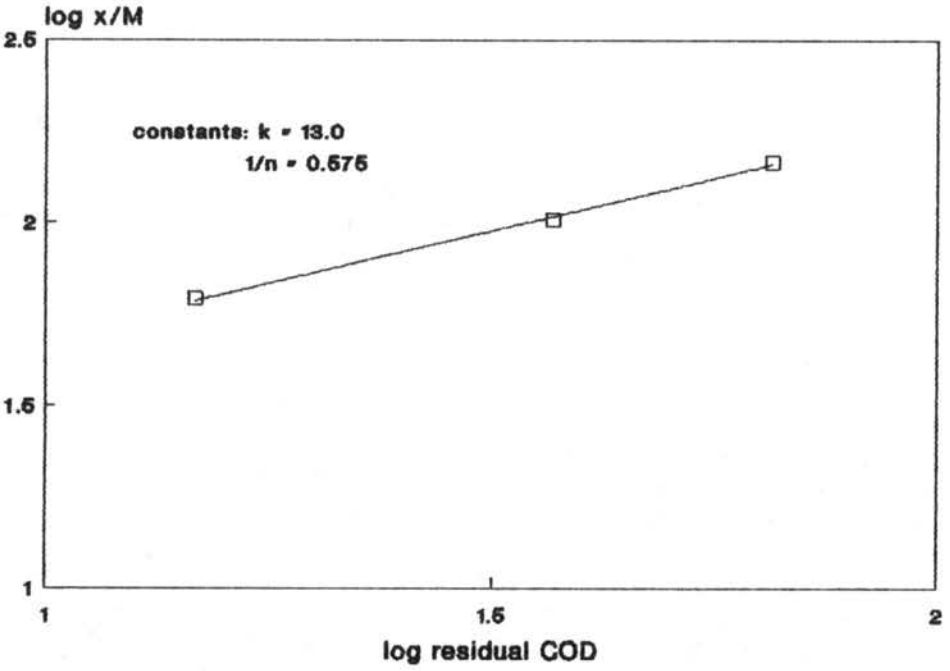

Fig 4.10 Batch test: Freundlich plot of adsorption isotherm

Table 4.2 Observed adsorptive capacities of PAC studies (source: DEWALLE and CHIAN, 1977).

						Initial organic matter	
Author	Waste stream	Pre-treatment	Carbon used	Type of test	Sorptive capacity $(x/m)_u$	Conc COD (mg l^{-1})	Exponential term n
Beebe (1973)	Sewage	0.45 μm filtered	Darco	Lab isotherm	0.22	87	0.5
Burns & Shell (1973)	Sewage	0.45 μm filtered	Nuchar A	Lab isotherm	0.5	50	2.5
Burn & Shell (1974)	Sewage	Coagulated	Nuchar A	Single stage pilot plant carbon contactor	0.15	40	
				Two stage pilot plant carbon contactor	0.3	55	1.2
Wallace & Burns (1974)	Sewage	Coagulated	Nuchar A		0.31	22	0.76
					0.36	37	0.43
Stuckenberg (1975)	Sewage	Filtered	Nuchar A	Lab isotherm	0.25	40	1.9
Davies & Kaplan (1966)	Secondary	0.45 μm Filtered	Nuchar A	Lab isotherm	0.15	40	1.0
Johnson (1969)	Secondary effluent	Glass fiber filtered	Hydro darco	Lab isotherm	0.45	100	1.7
Garland & Beebe (1970)	Secondary effluent	0.45 μm Filtered	Darco	Lab isotherm	0.15	28	1.6
This study	Sewage	0.45 μm Filtered	Hydro darco-C	lab AS unit			
				$0 = 3d$	0.13	41	3.1
				$0 = 5d$	0.21	38	5.3
				$0 = 10d$	0.55	36	6.0
				$0 = 15d$	1.20	35	6.0
Flynn (1975)	Industrial waste	Filtered	Nuchar	Lab AS unit			
				$0 = 8{\cdot}7d$	0.62	148	0.9
Fergerson *et al* (1975)	Sewage	Glass fiber filtered	Hydro darco-C	Lab AS unit			
				$0 = 6.7d$	0.26	37	2.1

4.4 Continuous-flow tests

Results from the batch experiments indicated that COD and color removal and MLSS attained almost the maximum values after an aeration time of 6 hours. It was decided to set the hydraulic retention time (HRT) at 6 hours.

With a HRT of 6 hours and an initial COD of 960 mg/L the reactors were fed at a loading rate of 3.84 kg COD/m^3-d. After two days of operation, severe bulking occured. Microscopic examination reveals the existance of filamentous microorganism. Bulking could be due to a number of reasons, inter-alia oxygen tension, overloading, nutrient imbalance and feed pattern (CHAMBERS and TOMLINSON, 1982). Since the DO was maintained at a concentration greater than 2 mg/L, the loading was reduced to half by adjusting the flowrate but the situation remains the same. Adding of hydrogen peroxide at a dosage as recommended by MUNGKARNDEE (1983) also resulted in very little improvement. This could be due to the direct addition of hydrogen peroxide in the clarifier rather than the return sludge line as was done in the earlier study. It was then decided to change the experimental set-up with one having an external clarifier and the HRT was set at 1 day giving an initial loading rate of 1.02 kg COD/m^3-d. However due to the fluctuating organic strength of the wastewater, the loading rate ranges from 0.59 - 1.02 kg COD/m^3-d.

COD removal between PAC dosages of 1000 mg/L and 2000 mg/L did not differ much (92.0% and 94.3% respectively) but color removal showed a significant difference, with a value of 57.1% for 1000 mg/L PAC as oppose to 81.6% for a PAC concentration of 2000 mg/L. Taking into account the economics of the treatment system, 1000 mg/L PAC (based on aeration tank volume) was initially used for the continuous-flow experiments and fed batch-wise.

4.4.1 **Organics removal**

Generally the PAC unit performed better than the control unit in terms of COD removal as shown in Figs 4.11 and 4.12. The unit with PAC achieved an average COD removal efficiency of 89.8% while that without PAC averaged about 83.5%. The slightly higher removal rate could be due to adsorption of refractory organics that could not be biodegraded in the normal activated sludge treatment process. This is especially so since the sizing polymer used was polyvinyl alcohol (PVA) which is not biodegradable.

BOD_5 determinations showed that the degradable organics removed in both the control and PAC units did not differ much. The BOD_5 removal efficiency was about 98.6% and 99.4% in the control and PAC units respectively. This implied that adsorption was the main mechanism for the increased COD removal with some degree of enhanced bio-oxidation in the PAC unit. Table 4.3 gives the results of the BOD_5 analyses.

Table 4.3 Continuous test: BOD_5 determinations.

Date	BOD_5 (mg/L)			removal efficiency (%)	
	influent	effluent			
		control	PAC	control	PAC
17-01-90[a]	525	7	4	98.7	99.2
18-01-90[a]	520	8	3	98.5	99.4
20-01-90[a]	490	7	3	98.6	99.4
19-02-90[b]	566	4	2	99.3	99.6
01-03-90[c]	544	2	2	99.6	99.6

a SRT 7 days
b SRT 15 days
c 3 g/L PAC

4.4.2 **Color reduction**

Conventional biological treatment has very poor ability to remove soluble non-biodegradable color from wastewater. In the PAC unit color reduction as expected out-performed the control unit. After adding PAC the effluent was turbid for about four days as a result of the carry-over of carbon particles but became

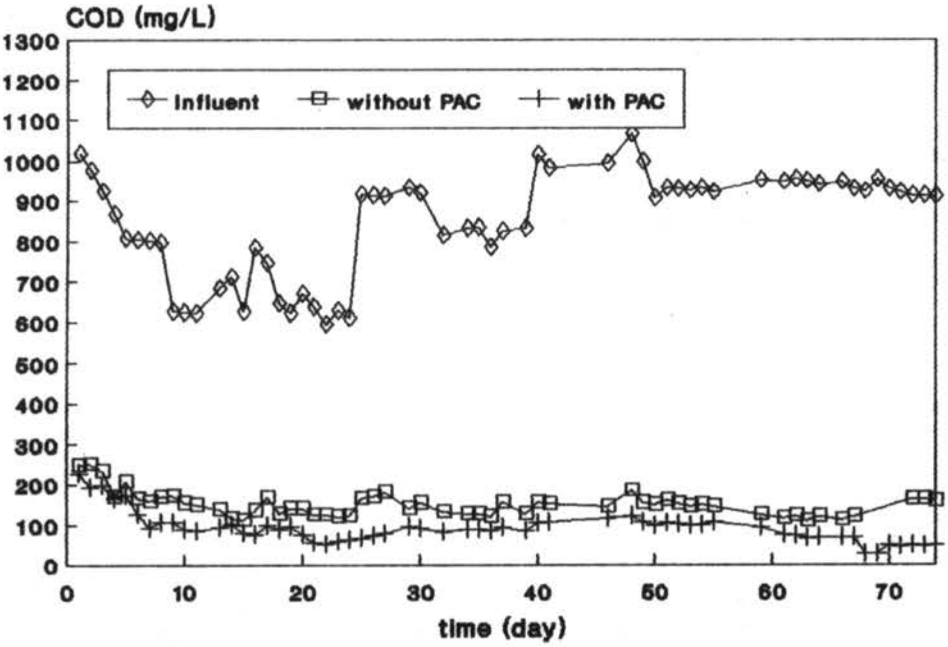

Fig 4.11 Continuous test: COD variation with time

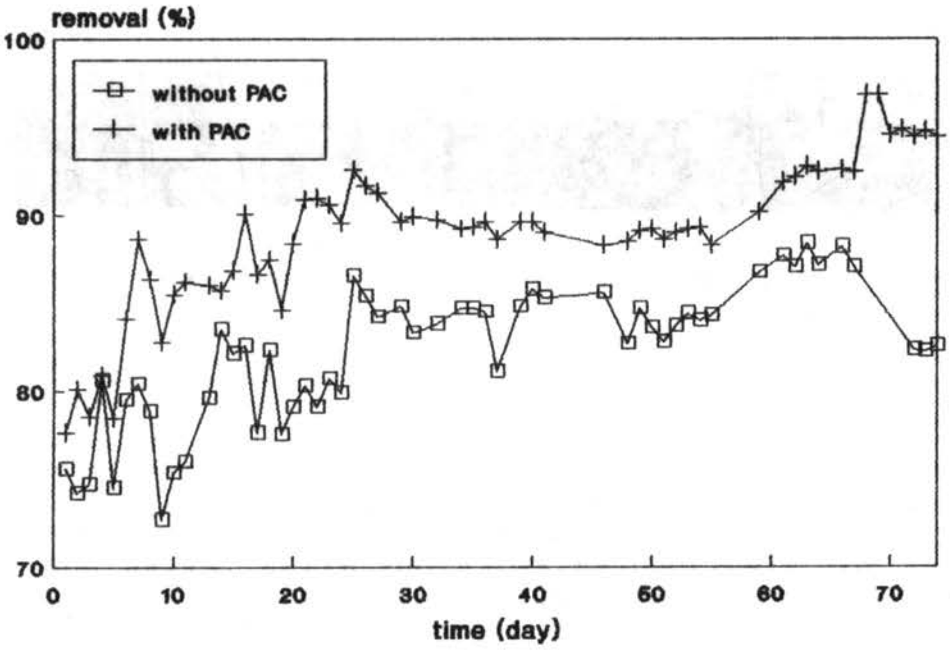

Fig 4.12 Continuous test: COD removal efficiency

clear thereafter as can be seen from Fig P4. Color reduction during the test period averaged about 35.1% in the unit with PAC addition as compared to the control unit which achieved an average reduction of 16.8%.

However it was observed that color reduction in the PAC unit deteriorated with time as depicted in Figs 4.13 and 4.14. It was also noted that large flocs were formed which apparently caused the carbon particles to settle-out and not completely effective in adsorbing the dyes.

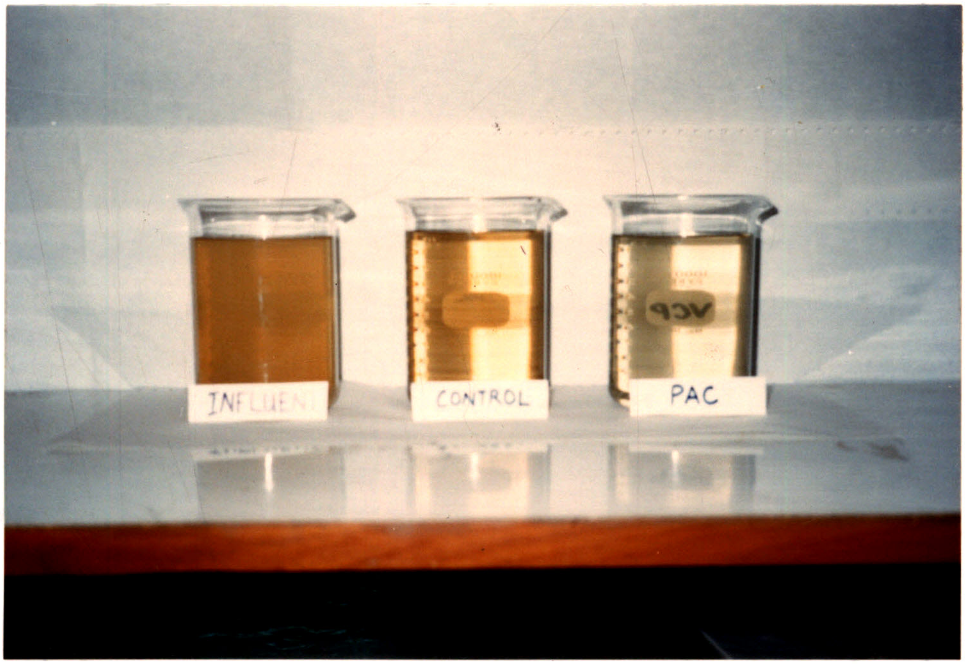

Fig P4 Wastewater samples of influent and effluent.

4.4.3 Effect of SRT

The average COD removal, calculated from the daily steady-state removal percentage was found to be generally independent of sludge age (Fig 4.15). The removal efficiency for sludge age of 7, 10 and 15 days was 89.2%, 91.1% and 89.0% respectively for the PAC unit and 84.4%, 82.2% and 83.9% respectively for the control unit. This was also reported by SRITHARAN (1987) in his study using synthetic feed and different doses of PAC. Fig 4.17 shows the steady-state COD removal efficiency at different SRT. BOD_5 removal in the PAC unit showed little improvement but increased slightly in the control unit at the SRT of 15 days (Table 4.3) since BOD concentrations decrease with increasing sludge age.

Color reduction also showed very little variation in the control unit at different sludge age. But in the PAC unit the variation was quite significant (Fig 4.16). Color reduction at

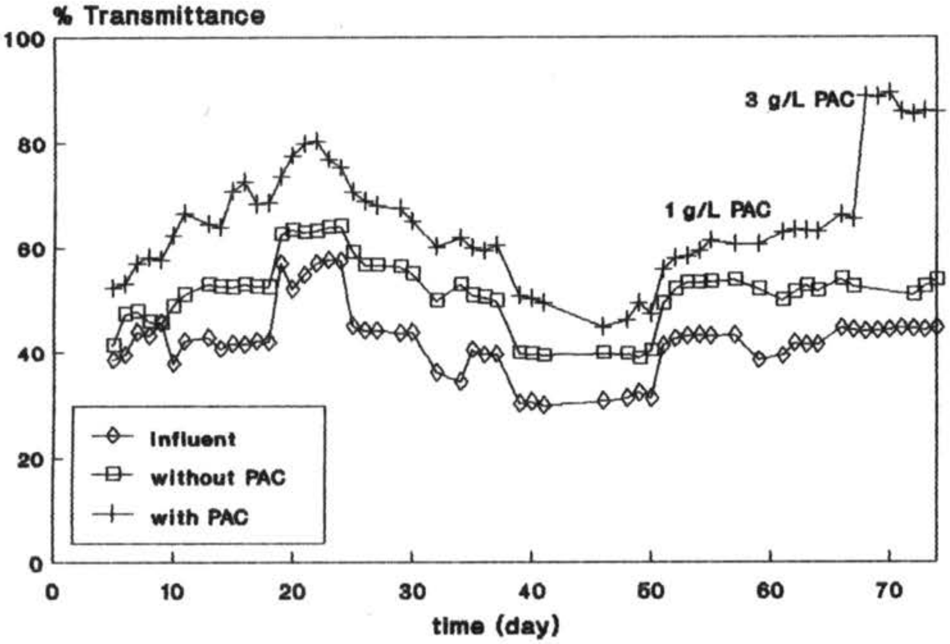

Fig 4.13 Continuous test: Color variation with time

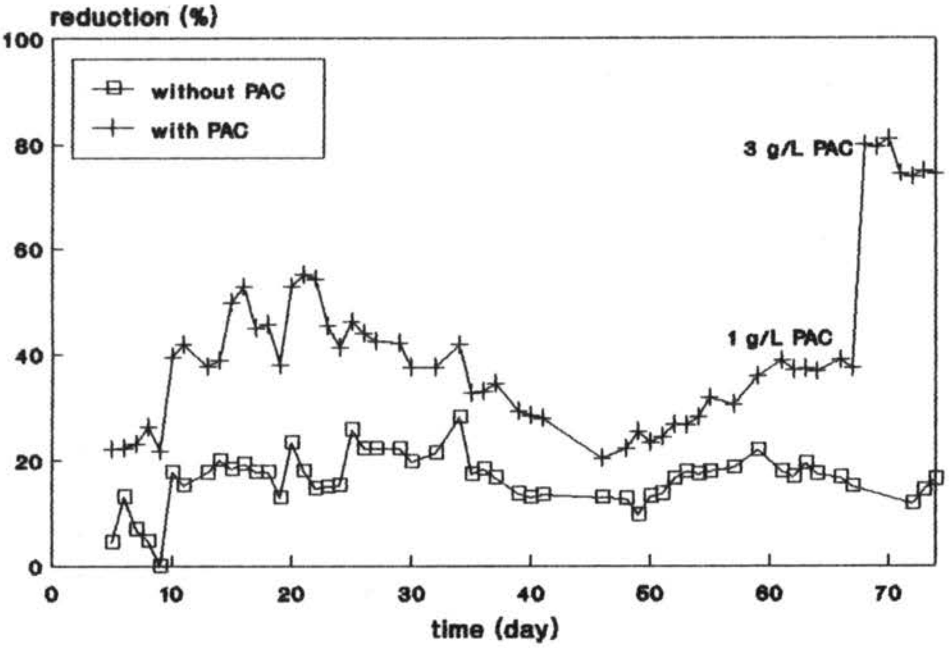

Fig 4.14 Continuous test: Color reduction efficiency

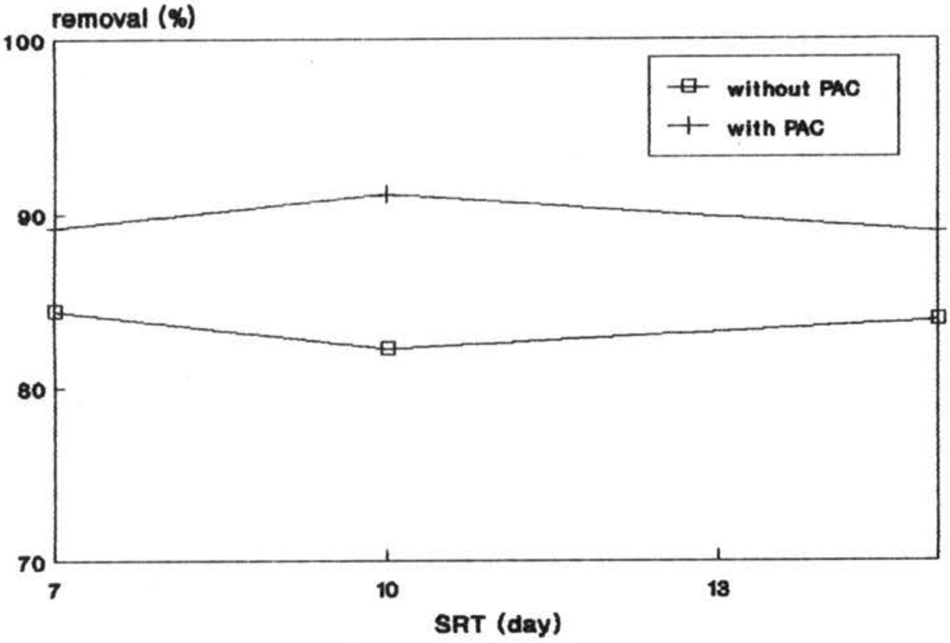

Fig 4.15 COD removal with sludge age

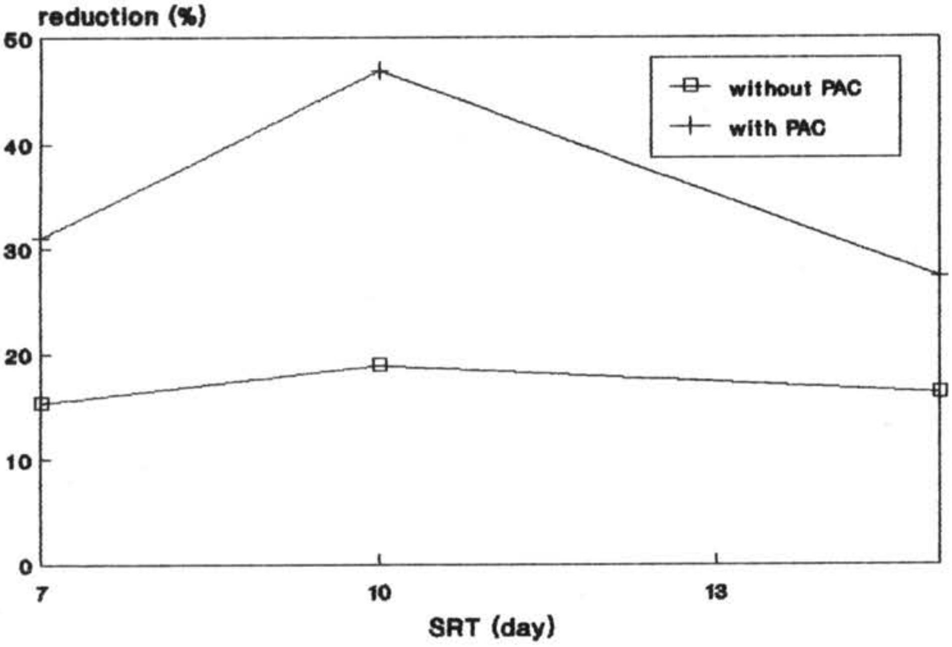

Fig 4.16 Color reduction with sludge age

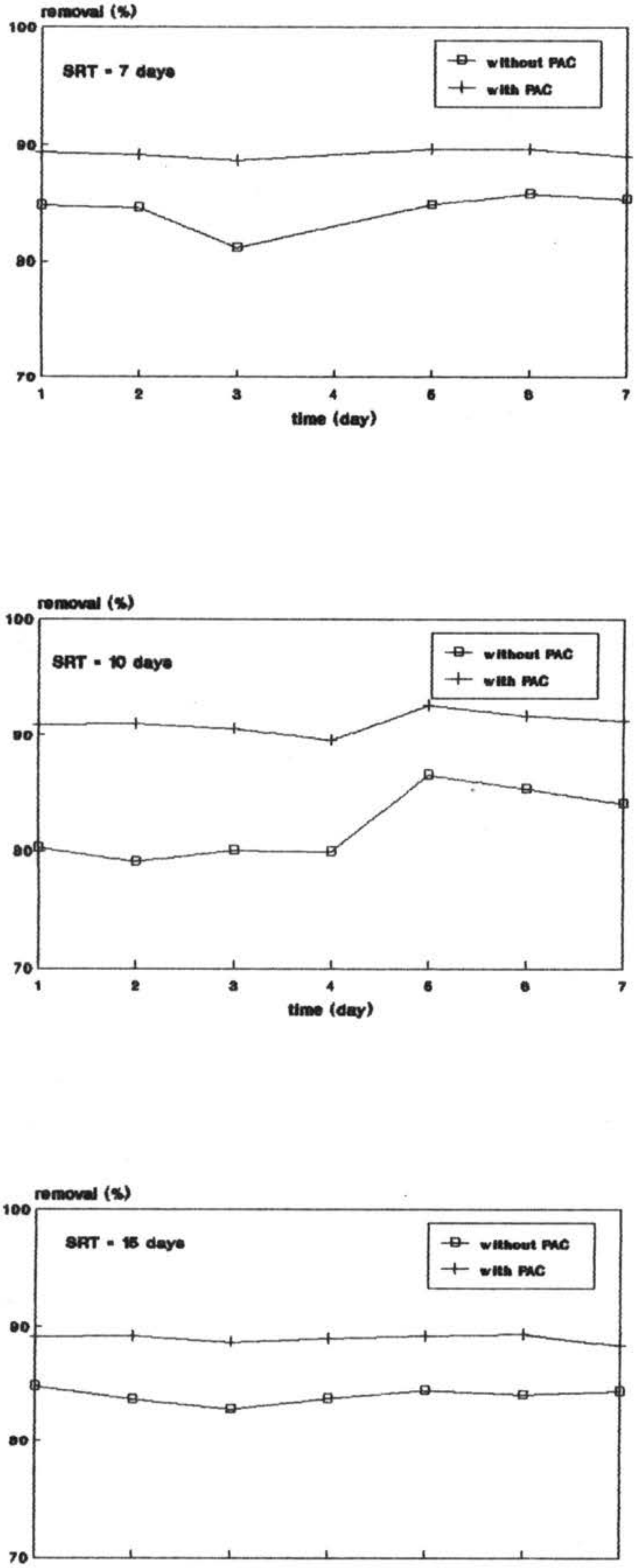

Fig 4.17 COD removal at different sludge age

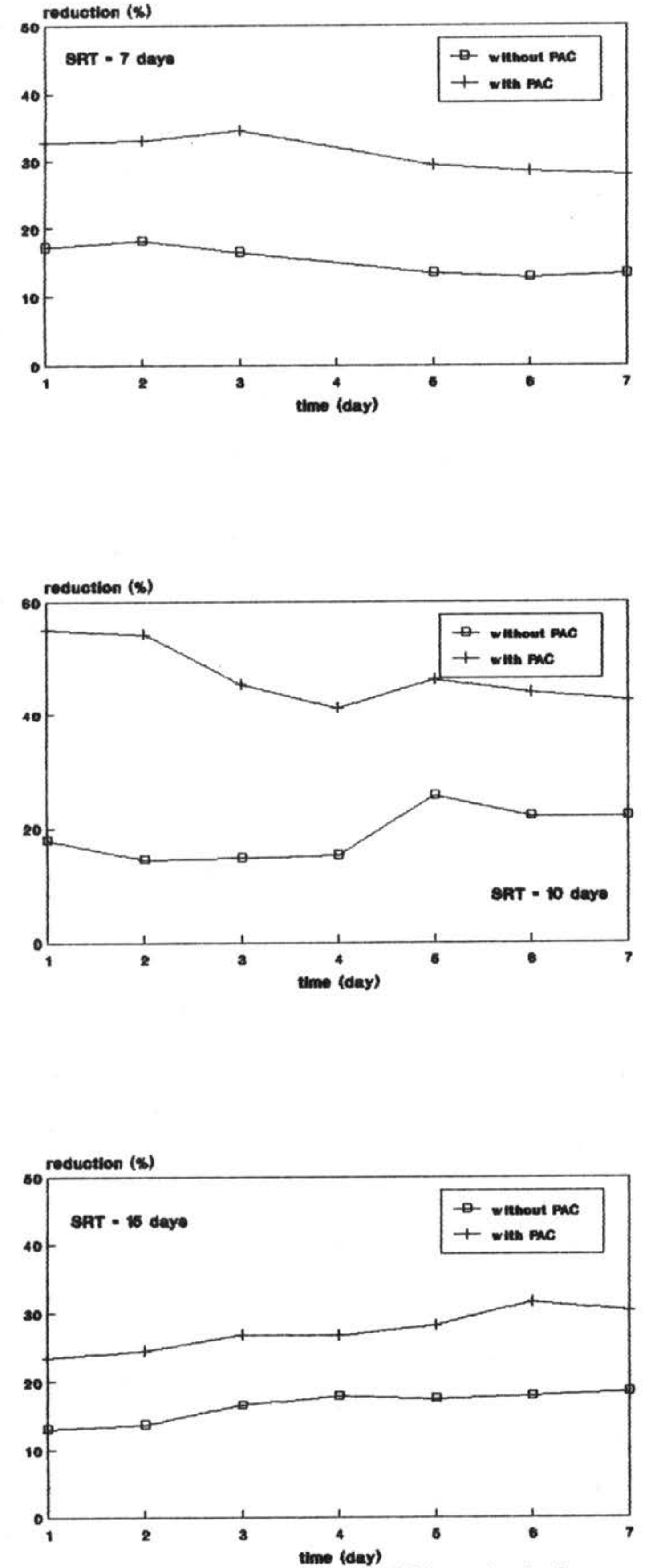

Fig 4.18 Color reduction at different sludge age

the SRT of 10 days showed the highest efficiency at 46.9% followed by 31% at SRT of 7 days and 27.3% at the SRT of 15 days.

Figure 4.18 shows the steady-state color reduction at various SRT.

Throughout the continuous test, sludge bulking problem was encountered in the control unit. Filamentous microorganism also developed in the reactor with PAC but there was no consequent settling problem. Settleability increased with sludge age as shown in Fig 4.19. PAC in the activated sludge improves settling characteristics of the mixed liquor. The attachment of activated sludge on the PAC particles increased its density when saturated in the liquid medium resulting in improved settleability.

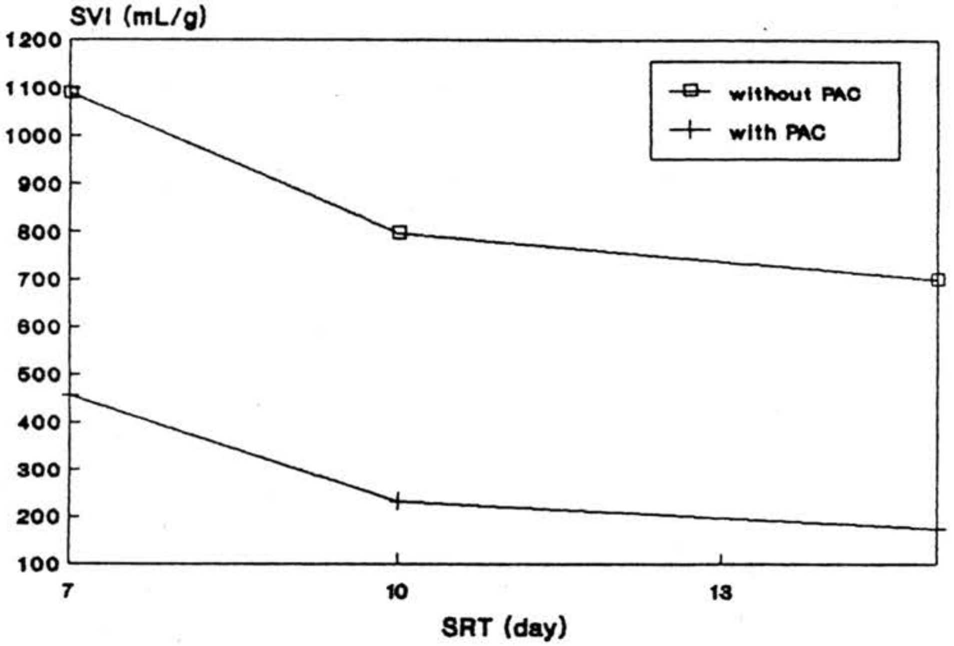

Fig 4.19 Continuous test: SVI variation with sludge age

4.4.4 Effect of loading rate

Lowering the organic loading from an average of 0.92 kg COD/m^3-d (HRT = 24 h) to 0.57 kg COD/m^3-d (HRT = 40 h) resulted in an increased in COD removal for both the control and PAC units. An average 87.4% COD reduction was achieved for the control unit while the PAC unit attained an average removal of 92.5%. Figures 4.20 and 4.21 show the comparison of COD removal at different HRT for the PAC and control units respectively. The reduction in effluent COD in the control unit could be due to absorption of refractory organics by the activated sludge as a result of the longer HRT. Similarly adsorption was enhanced in the PAC unit.

The PAC unit also showed greater color reduction as the wastewater had a longer contact time with the carbon. Color reduction was 37.6% as compared with 27.3% at a HRT of 24 h (Fig 4.22). The control unit did not produce much variation as indicated in Fig 4.23.

Settleability in the PAC unit was slightly better with an average SVI of 156 mL/g. However the control unit did not show any improvement as anticipated. This could be due to the presence of filamentous microorganisms and the short duration of the experiment for the the system to recover. Figs 4.24 and 4.25 show the SVI variation at different HRT for the PAC and control units respectively.

4.4.5 **Effect of PAC dosage**

The PAC dosage was increased to 3 g/L reactor volume. With this addition, average COD removal increased by 5.7 percentage points ie from 89.0% at 1 g/L to 94.7% at 3 g/L (Fig 4.26). LEE et al (1989) obtained close to 95% COD removal using synthetic wastewater and an average steady-state PAC concentration of approximately 4 g/L. The BOD_5 removal was 99.6% which did not differ with that using 1 g/L PAC. This reinforced the earlier suggestion that adsorption of refractory organics was a dominant factor for the higher COD removal in the PAC unit (Section 4.4.1) as more sites were available.

Color reduction improved substantially at the higher PAC dose as shown in Fig 4.27. The effluent was almost water-clear as can be seen from Figs P5 and P6. The average color reduction was 75.6% which compares favorably with the study by PITKAT and BERNDT (1980). These researchers used a mixture of municipal and industrial wastewater and an equilibrium PAC dosage of 4.3 g/L. They reported a color reduction of approximately 86.7%.

Settleability also improved with an increased in PAC dosage. The high particle density of carbon acts as a weighting agent resulting in good settling characteristics. From Fig 4.28 it is observed that the SVI values were below 100 mL/g.

4.4.6 **Effect of gamma irradiation**

10 L of wastewater was irradiated with the CARRIER TYPE GAMMA IRRADIATOR MODEL JS-8900. The radiation source was Cobalt-60 and the dosage used was 2 Mrad. After irradiation it was observed that the color of the wastewater changed from brown to amber as shown in Fig P7. Scanning with the spectrophotometer showed that the minimum transmittance at 330 nm wavelength was lowered from 39.2 %T to 6.95 %T (Fig 4.29). Using the BDH LOVIBOND NESSELERISER MK3, the color was detected as 200 Hazen and 100 Hazen for the wastewater before and after irradiation treatment respectively. The change in COD was insignificant. The COD was 978 mg/L and 968 mg/L before and after irradiation respectively.

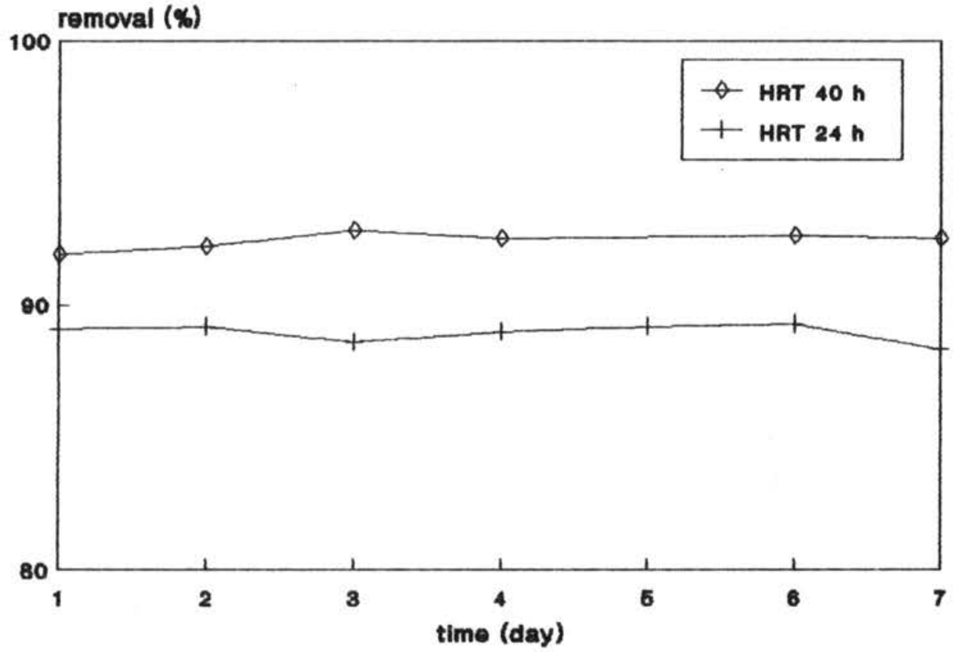

Fig 4.20 COD removal at different HRT (with PAC)

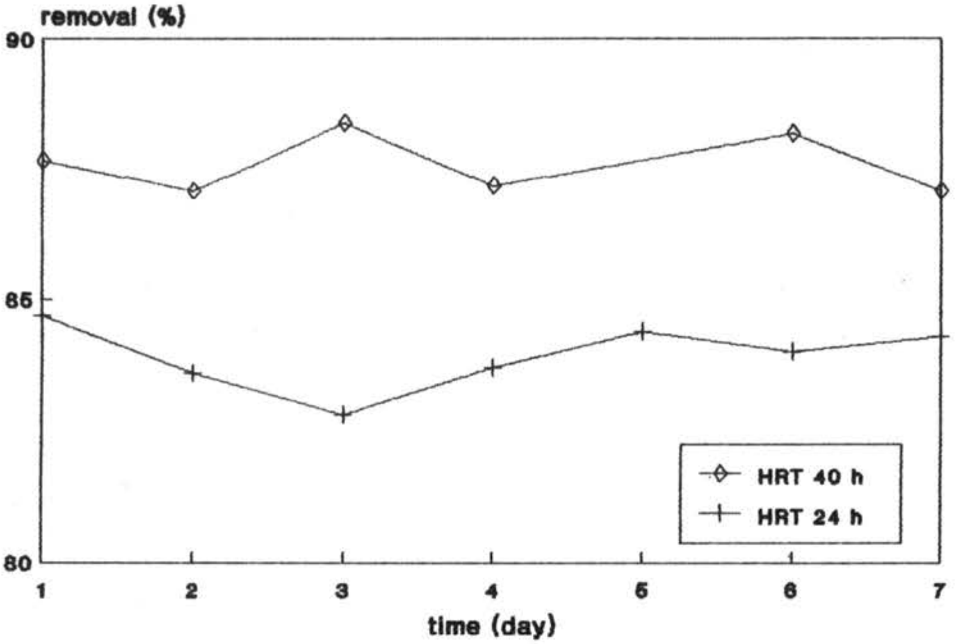

Fig 4.21 COD removal at different HRT (without PAC)

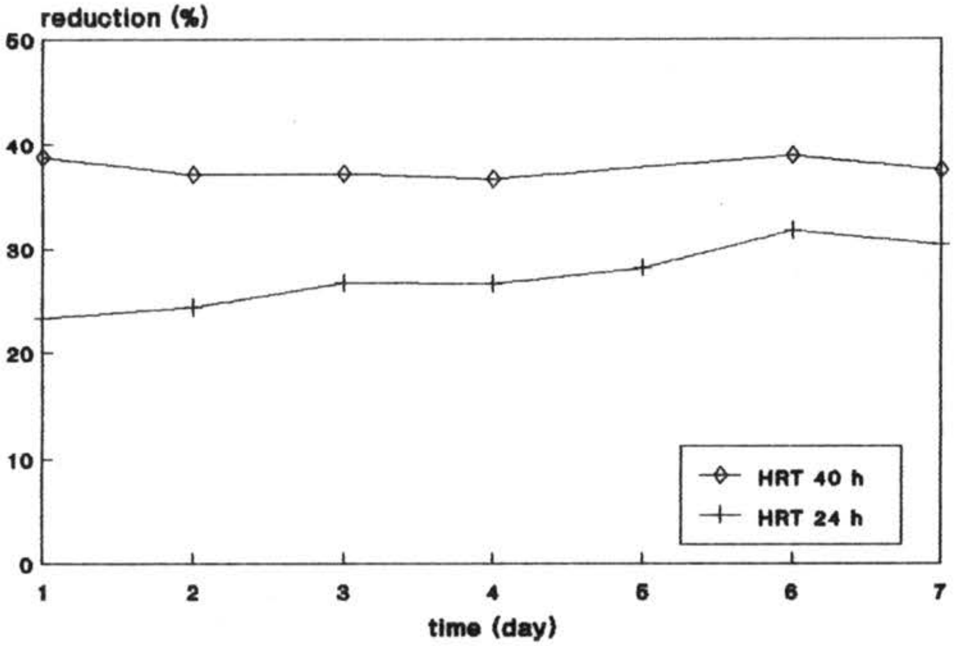

Fig 4.22 Color reduction at different HRT (with PAC)

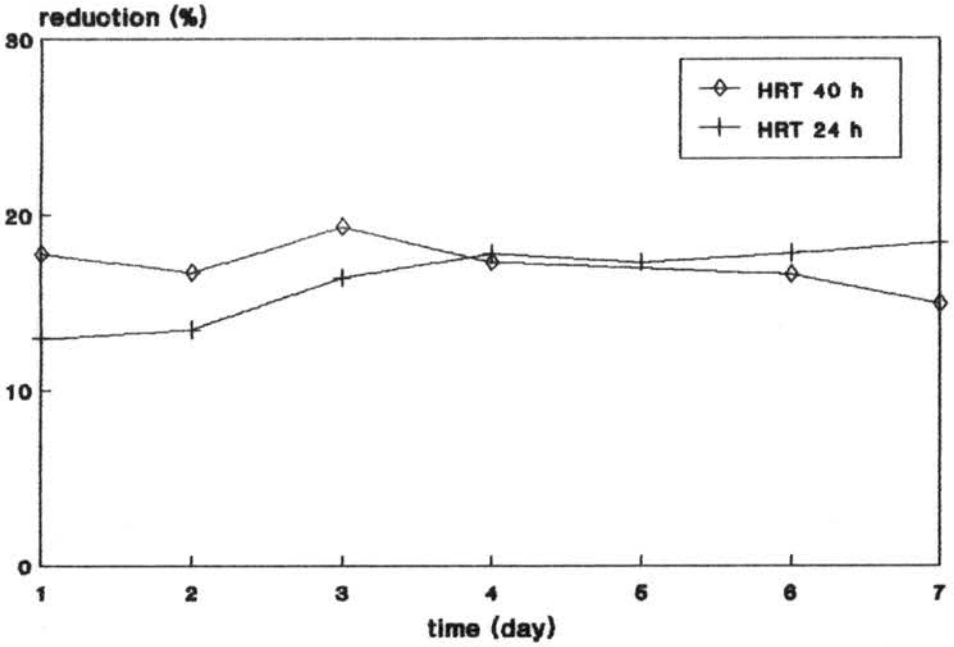

Fig 4.23 Color reduction at different HRT (without PAC)

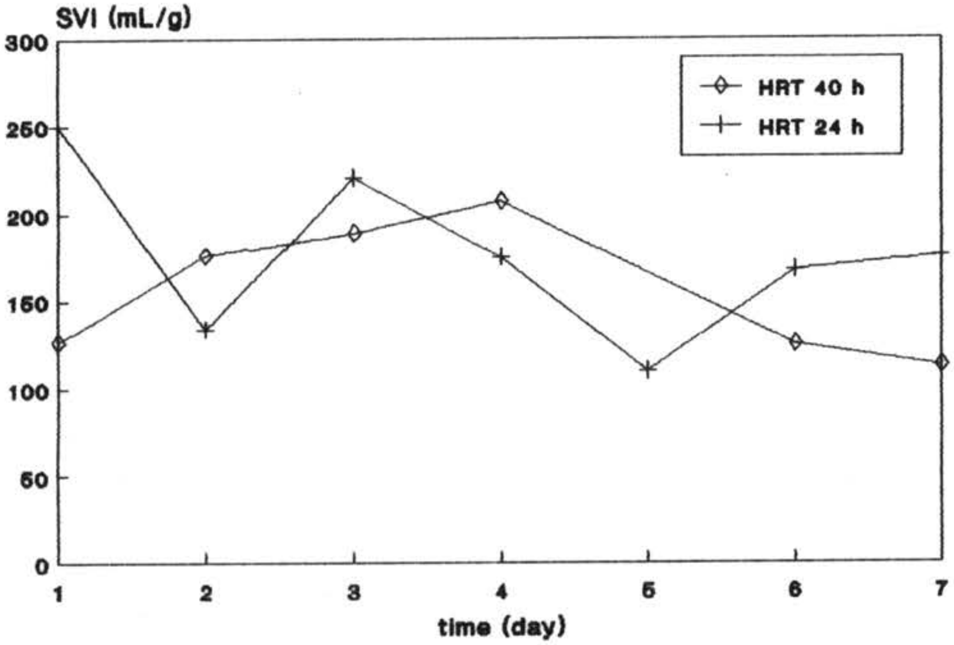

Fig 4.24 SVI variation at different HRT (with PAC)

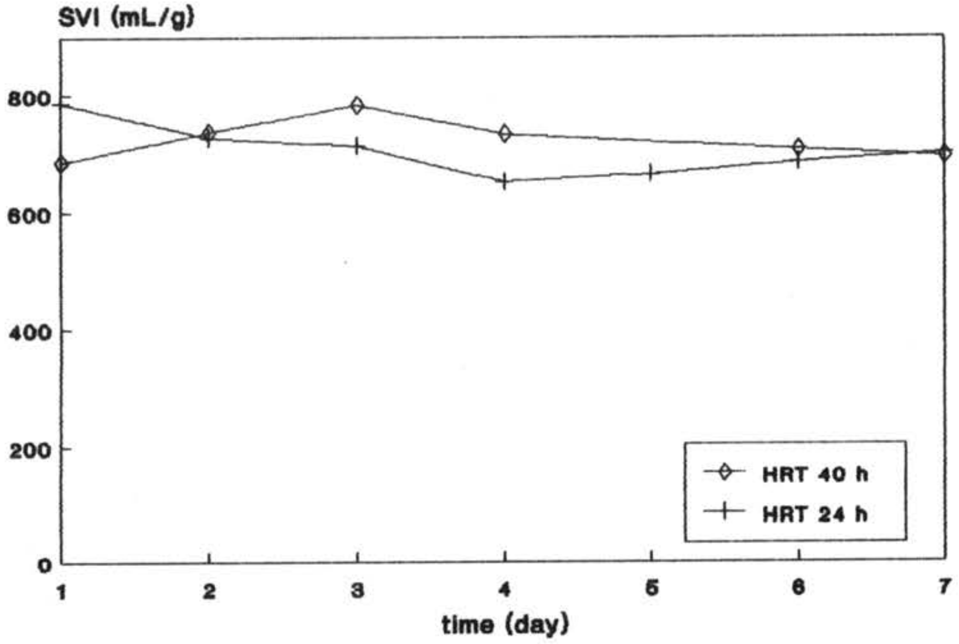

Fig 4.25 SVI variation at different HRT (without PAC)

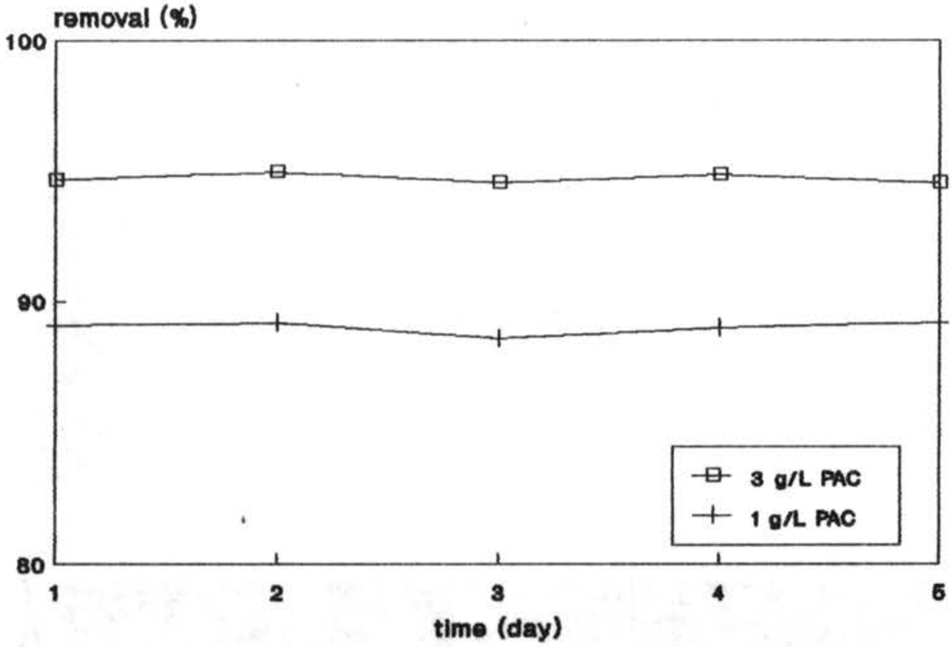

Fig 4.26 COD removal at different PAC concentrations

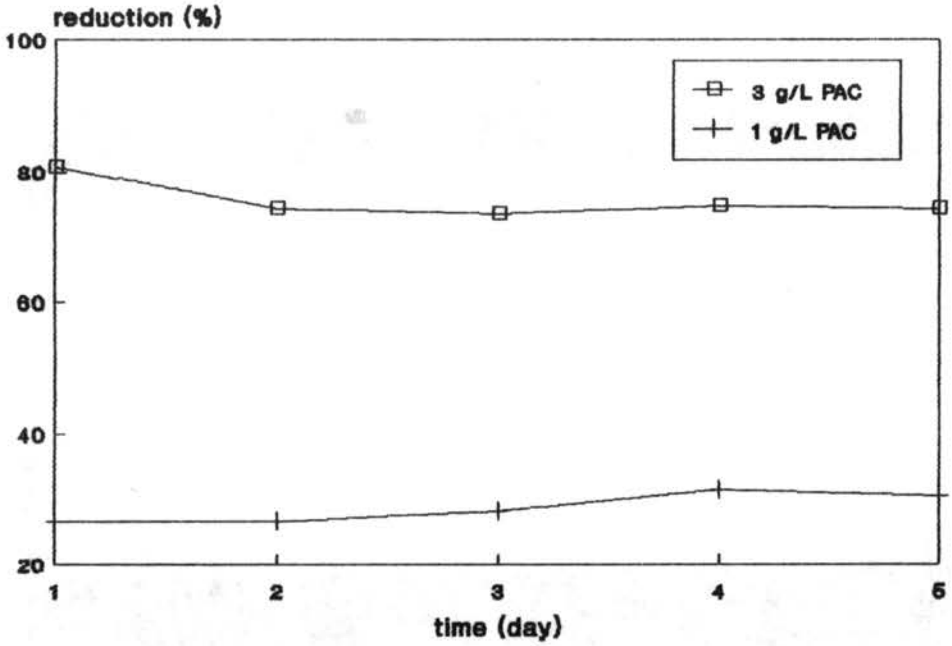

Fig 4.27 Color reduction at different PAC concentrations

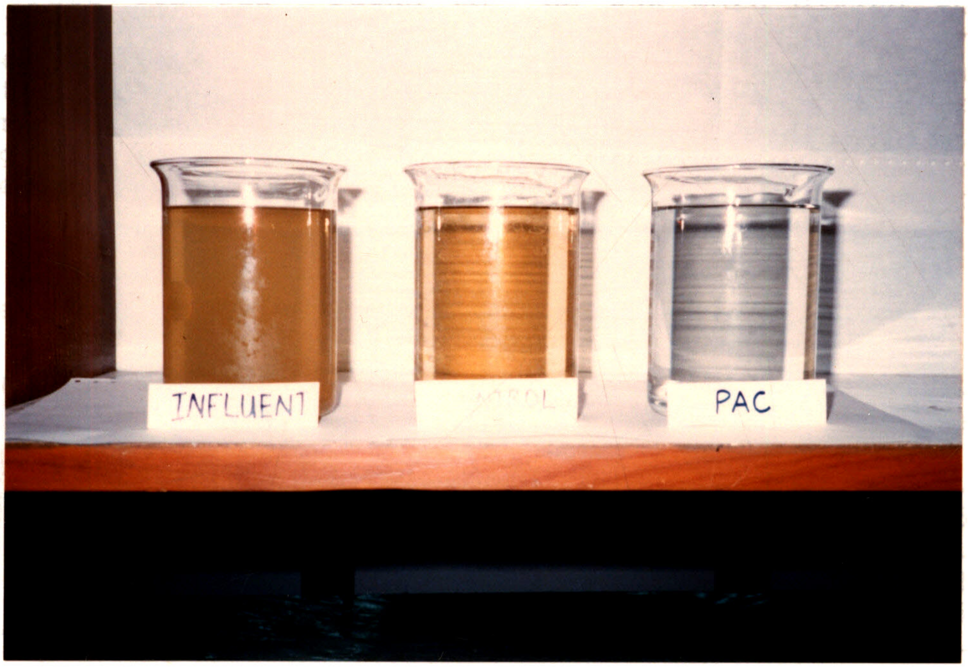

Fig P5 Wastewater samples of influent and effluent at a PAC concentration of 3 g/L

Fig P6 Filtered and unfiltered effluent samples of PAC unit

After feeding the irradiated wastewater to the activated sludge unit, the effluent COD increased considerably when compared with the effluent COD using non-irradiated wastewater. The average COD was found to be 252 mg/L giving an average removal efficiency of 72.3%. BOD_5 removal efficiency however remained unchanged at 99.5%. This indicated that gamma radiation was not toxic to the microorganisms in the activated sludge. The rise in effluent COD could be due to the changed in structure of the organics as a result of rupture of bonds producing new forms that resist biodegradation. Table 4.4 gives the detailed results of the 'gamma irradiated activated sludge process'.

Table 4.4 Results of gamma irradiated activated sludge process

Date	Parameter	influent (mg/L)	effluent (mg/L)	removal (%)
25-02-90	COD	920	207	77.5
26-02-90	COD	904	252	72.1
27-02-90	COD	908	298	67.2
26-02-90	BOD_5	420	2	99.5

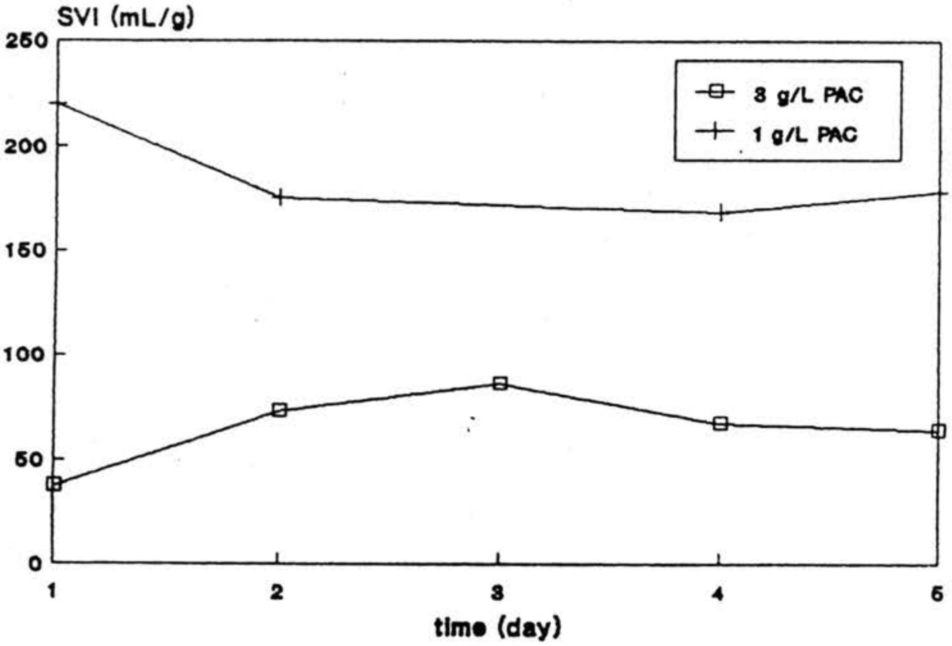

Fig 4.28 SVI variation at different PAC concentrations

Fig P7 Wastewater samples before and after gamma irradiation

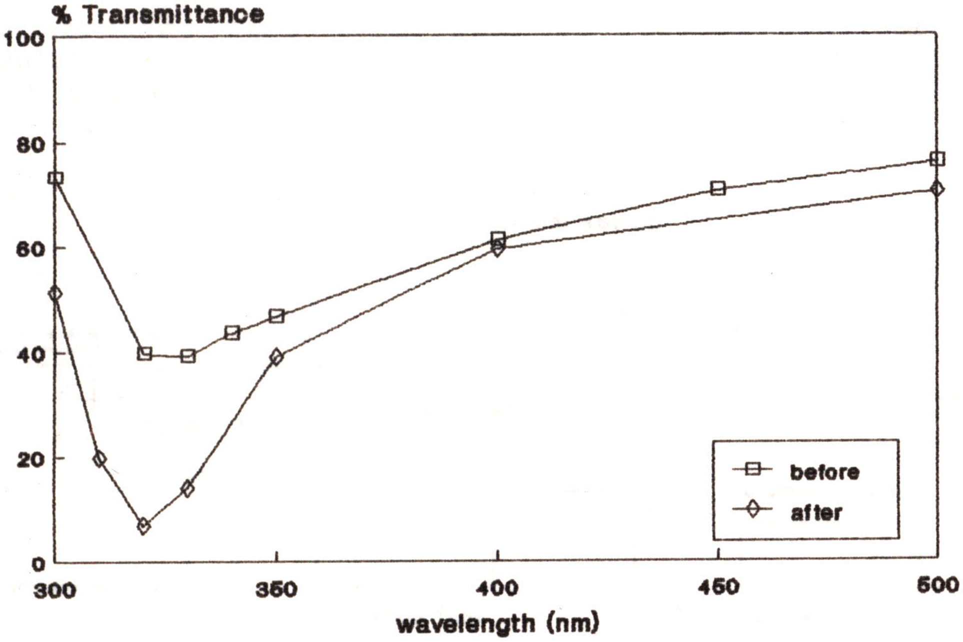

Fig 4.29 Transmittance curve before and after irradiation

4.5 Economics

Preliminary cost estimates revealed that at a PAC dosage of 3 g/L for about 95% removal of COD and 76% reduction in color required 8 Baht/m^3 wastewater treated (at 40 Baht PAC/kg). CHIU et al (1987) reported that 600 mg/L of alum was required to treat combined textile wastewater at a pH of 5.5 to give a color reduction of 97.6%. From a jar test experiment conducted by CHANG (1988) on municipal leachate, it was concluded that 1000 mg/L alum dose and optimum pH of 5.5 resulted in a color reduction of 92% and COD removal of 72.4% but sludge production was large. Alum at a cost of 5 Baht/kg definitely looks more attractive than PAC in the reduction of color but it must be noted that flocculants would be required to assist settling and hence the need for mixing devices and expanded sludge handling facilities which adds on to the cost.

PAC on the other hand provides additional benefits such as reduced foaming in the aeration basin and improved sludge settleability which ease subsequent sludge handling. Futhermore PAC in the activated-sludge can cushioned any toxic effects (LEE et al, 1989) and the system can be subjected to higher organic loading without affecting its stability.

4.6 Wastewater treatment plant modification

The existing treatment system of the factory could be upgraded to improve its COD and color removal efficiency. Foaming in the aeration tank could also be reduced considerably. The only additional units are the carbon bin and delivery facility as shown in Fig 4.30.

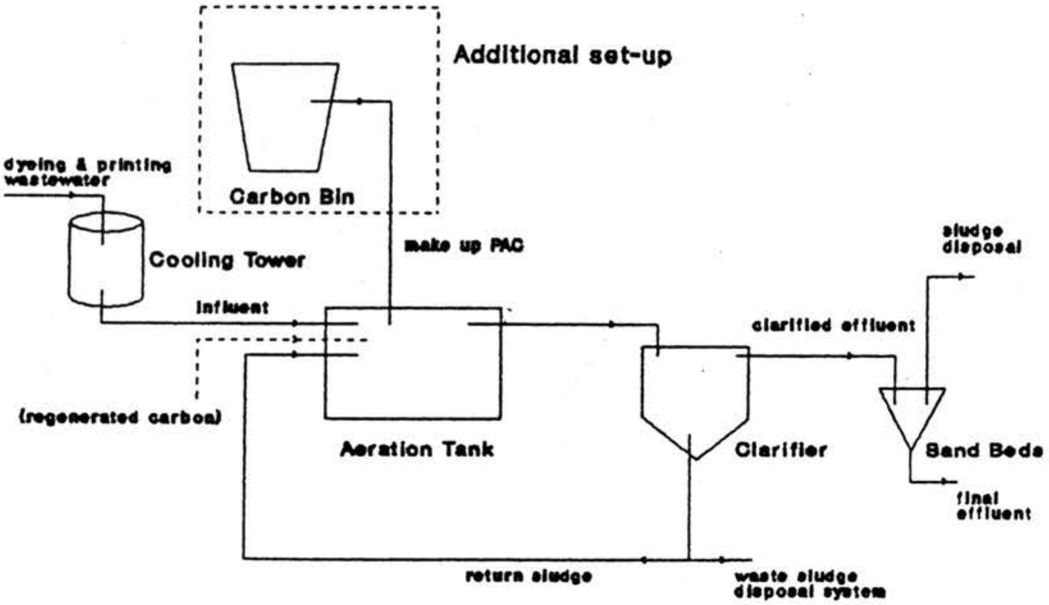

Fig 4.30 Flow diagram of PAC-AS system

V CONCLUSIONS

The following conclusions are drawn from the study:

1. With PAC in the reactor, higher organic loading can be applied without any detrimental effects.

2. PAC addition at a concentration of 3 g/L increased COD removal from 84% to 95% and color reduction increased from 16% to 76%. SVI values were also consistently below 100 mL/g even at a high organic loading of 0.92 kg COD/m^3-d. BOD$_5$ removal showed minimal increase from 98.6% to 99.4%.

3. The main mechanism of increased COD removal was adsorption of non-biodegradable dyes with some degree of enhanced bio-oxidation.

4. COD removal was generally independent of sludge age but color reduction had the highest efficiency at the SRT of 10 days (47%) followed by SRT of 7 days (31%) and 15 days (27%).

5. High mixed liquor suspended solids in the reactor with PAC posed a problem in representative sampling which made the determination of biomass fraction difficult.

6. The main advantages of PAC addition were increased COD and color removal, improved sludge settleability and reduced foaming but cost could be a major disadvantage. A modification to upgrade the factory's activated sludge was proposed.

7. Preliminary studies indicated that color from dyeing wastewater can be reduced by gamma radiation but COD showed insignificant change. Treatability of gamma irradiated wastewater deteriorated in terms of COD removal but remained unaffected in BOD$_5$ removal.

VI RECOMMENDATIONS FOR FUTURE WORK

The following are recommended for future research:

1. Due to the unavailalibity of other types of PAC during the duration of the experiment, other types should be tested to assess its performance vis-a-vis Darco activated carbon.
2. Continuous PAC feeding should be experimented and the performance compared with batch-fed system.
3. A better method to evaluate the biomass fraction in the PAC-AS system needs to be examined and hence the bio-kinetics of this system.
4. More detailed study on the effect of gamma irradiation in the removal of color especially the optimum dose and in the presence of an oxidizing agent such as oxygen, chlorine or sodium hypochlorite in the wastewater. Enhancement of biodegradability under the above condition could also be investigated.

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APPENDIX A

Table A.1 Carbon adsorption: COD, Color variation with time.

Time (min)	COD (mg/L)	Color (%T)
0	860.2	30.0
5	698.9	77.0
10	675.8	80.9
20	668.2	82.4
30	668.2	82.7
40	683.5	83.8
60	668.2	86.2

Table A.2 Carbon adsorption: COD, Color removal with time.

Time (min)	COD (%)	Color (%)
0	-	-
5	18.8	67.1
10	21.4	72.7
20	22.3	74.9
30	22.3	75.3
40	20.5	76.8
60	22.3	80.3

Table A.3.1 Carbon adsorption: COD, Color variation with dose (expt. 1).

Dose (g/200mL)	COD (mg/L)	Color (%T)
0	698.1	49.8
0.1	583.7	66.3
0.2	571.9	75.4
0.4	536.4	84.9
1.0	532.4	93.9
2.0	489.1	96.2
2.5	481.2	98.3
3.0	445.7	98.5

Table A.3.2 Carbon adsorption: COD, Color variation with dose (expt. 2).

Dose (g/200mL)	COD (mg/L)	Color (%T)
0	852.2	30.2
0.5	575.8	78.6
1.0	514.4	83.5
2.0	422.3	90.6
4.0	303.3	93.0
6.0	211.1	95.8
8.0	180.4	96.0

Table A.4.1 Carbon adsorption: COD, Color removal with dose (expt. 1).

Dose (g/200mL)	COD (%)	Color (%)
0	-	-
0.1	16.4	39.2
0.2	18.1	51.0
0.4	23.2	69.9
1.0	23.7	87.8
2.0	29.9	92.4
2.5	31.1	96.6
3.0	36.2	97.0

Table A.4.2 Carbon adsorption: COD, Color removal with dose (expt. 2).

Dose (g/200mL)	COD (%)	Color (%)
0	-	-
0.5	32.4	69.3
1.0	39.6	76.4
2.0	50.4	86.5
4.0	64.4	90.0
6.0	75.2	94.0
8.0	78.8	94.3

Table A.5 Carbon adsorption: Freundlich isotherm (Color).

carbon dose, M (g/200mL)	residual color	Color adsorbed,	x/M,
0	50.2		
0.1	33.7	16.5	165.0
0.2	24.7	25.6	128.0
0.4	15.1	35.1	87.8
1.0	6.1	44.1	44.1
2.0	3.8	46.4	23.2
2.5	1.7	48.5	19.4
3.0	1.5	48.7	16.2

Table A.6 Carbon adsorption: Freundlich isotherm (COD).

carbon dose, M (g/200mL)	residual COD, C, (mg/L)	COD adsorbed, (mg/L)	COD adsorbed, x, (mg)	x/M, (mg/g)
0	852.2			
0.5	575.8	276.4	55.28	110.56
1.0	514.4	337.8	67.56	67.56
2.0	422.3	429.9	85.98	42.99
4.0	303.3	548.9	109.78	27.45
6.0	211.1	641.1	128.22	21.37
8.0	180.4	671.8	134.36	16.80

Table A.7 Batch test: COD (mg/L) variation with time at different PAC doses.

Time (h)	control	500 mg/L	1000 mg/L	2000 mg/L
0	588.8	509.0	437.1	437.1
0.5	512.9	385.2	313.4	305.4
1.0	456.4	246.2	137.1	166.3
2.0	322.4	98.8	54.9	32.9
4.0	208.6	76.8	54.9	38.9
6.0	174.7	60.9	34.9	24.9
8.0	174.7	68.9	38.9	14.9
23.0	138.2	65.1	36.9	14.7

Table A.8 Batch test: COD removal (%) at different PAC doses.

Time (h)	control	500 mg/L	1000 mg/L	2000 mg/L
0	-	-	-	-
0.5	12.9	24.3	28.3	30.1
1.0	22.5	51.6	68.6	61.9
2.0	45.2	80.6	87.4	92.4
4.0	64.6	84.9	87.4	91.1
6.0	70.3	88.0	92.0	94.3
8.0	70.3	86.5	91.1	96.6
23.0	76.5	87.2	91.6	96.6

Table A.9 Batch test: Color (%T) variation with time at different PAC doses.

Time (h)	control	500 mg/L	1000 mg/L	2000 mg/L
0	30.8	30.8	30.8	30.8
0.5	31.6	42.3	54.9	66.1
1.0	34.2	41.9	59.2	74.0
2.0	37.2	50.9	65.0	83.1
4.0	39.6	50.7	65.3	84.8
6.0	42.1	53.9	70.3	87.3
8.0	43.0	56.3	66.5	86.3
23.0	43.6	63.0	79.3	93.0

Table A.10 Batch test: Color removal (%) at different PAC doses.

Time (h)	control	500 mg/L	1000 mg/L	2000 mg/L
0	-	-	-	-
0.5	1.2	16.1	34.3	51.0
1.0	4.9	16.0	41.0	62.4
2.0	9.2	29.0	49.4	75.6
4.0	12.7	28.8	49.9	78.0
6.0	16.3	33.4	57.1	81.6
8.0	17.6	36.8	51.6	80.2
23.0	18.5	46.5	70.1	89.9

Table A.11 Batch test: MLSS (mg/L) variation with time at different PAC doses.

Time (h)	control	500 mg/L	1000 mg/L	2000 mg/L
0	2080	1838	1806	1548
0.5	1991	1920	1816	1440
1.0	1960	2000	1804	1412
2.0	2072	1888	1612	1146
4.0	2134	1978	1626	1412
6.0	2196	2006	1600	1436
8.0	2104	1908	1570	1326
23.0	1906	1830	1394	1234

Table A.12 Batch test: Freundlich isotherm (COD).

carbon dose, M (g/L)	residual COD, C, (mg/L)	COD adsorbed, x, (mg)	x/M, (mg/g)
0	138.2		
0.5	65.1	73.1	146.2
1.0	36.9	101.3	101.3
2.0	14.7	123.5	61.8

Table A.13 Continuous test: COD variation with time.

day	COD (mg/L)			day	COD (mg/L)		
	influent	control	PAC		influent	control	PAC
1	1019.5	248.7	227.9	38	–	–	–
2	976.9	251.5	194.5	39	832.8	126.6	84.8
3	924.6	233.7	198.4	40	1018.1	144.3	106.1
4	867.3	168.5	165.3	41	983.9	144.3	108.7
5	808.7	206.1	174.4	42	–	–	–
6	803.7	165.1	127.7	43	–	–	–
7	802.5	157.2	91.5	44	–	–	–
8	798.3	169.1	108.2	45	–	–	–
9	626.7	170.8	107.8	46	996.1	144.3	116.2
10	624.6	153.5	90.8	47	–	–	–
11	621.2	149.0	85.8	48	1066.9	185.0	122.5
12	–	–	–	49	1000.0	153.2	108.7
13	684.3	139.3	95.5	50	908.0	148.6	98.5
14	710.8	117.4	101.9	51	933.3	160.5	106.4
15	625.8	112.3	82.1	52	931.1	151.3	102.5
16	783.6	135.5	77.7	53	926.7	144.3	100.0
17	747.1	167.4	99.3	54	932.8	149.6	100.2
18	646.9	127.4	90.2	55	923.1	145.0	108.3
19	622.6	140.1	96.1	56	–	–	–
20	670.0	140.0	78.0	57	–	–	–
21	637.9	125.4	57.8	58	–	–	–
22	594.9	124.3	53.5	59	953.5	125.4	93.6
23	628.1	121.4	59.0	60	–	–	–
24	610.9	122.6	64.3	61	950.0	116.6	76.6
25	915.9	123.1	67.8	62	955.9	123.3	74.7
26	914.9	133.2	75.7	63	951.1	110.0	68.5
27	910.7	144.3	79.2	64	942.0	120.2	70.4
28	–	–	–	65	–	–	–
29	932.8	141.4	97.0	66	949.6	112.2	69.8
30	919.8	153.5	92.5	67	932.2	120.7	70.2
31	–	–	–	68	924.2	*	28.2
32	814.7	131.5	84.1	69	955.1	*	29.4
33	–	–	–	70	930.5	*	49.8
34	833.3	127.9	89.2	71	922.1	211.1	46.6
35	834.9	127.9	89.6	72	914.5	161.9	50.9
36	786.3	121.6	85.6	73	914.6	163.1	47.6
37	826.6	156.0	94.4	74	910.6	158.9	50.4

* control fed with gamma irradiated wastewater

Table A.14 Continuous test: COD removal efficiency.

day	removal (%)		day	removal (%)	
	control	PAC		control	PAC
1	75.6	77.6	38	–	–
2	74.2	80.1	39	84.8	89.6
3	74.7	78.5	40	85.8	89.6
4	80.6	80.9	41	85.3	89.0
5	74.5	78.4	42	–	–
6	79.5	84.1	43	–	–
7	80.4	88.6	44	–	–
8	78.8	86.4	45	–	–
9	72.7	82.8	46	85.6	88.3
10	75.4	85.5	47	–	–
11	76.0	86.2	48	82.7	88.5
12	–	–	49	84.7	89.1
13	79.6	86.0	50	83.6	89.2
14	83.5	85.7	51	82.8	88.6
15	82.1	86.9	52	83.7	89.0
16	82.6	90.1	53	84.4	89.2
17	77.6	86.7	54	84.0	89.3
18	82.3	87.5	55	84.3	88.3
19	77.5	84.6	56	–	–
20	79.1	88.4	57	–	–
21	80.3	90.9	58	–	–
22	79.1	91.0	59	86.8	90.2
23	80.7	90.6	60	–	–
24	79.9	89.5	61	87.7	91.9
25	86.6	92.6	62	87.1	92.2
26	85.4	91.7	63	88.4	92.8
27	84.2	91.3	64	87.2	92.5
28	–	–	65	–	–
29	84.8	89.6	66	88.2	92.6
30	83.3	89.9	67	87.1	92.5
31	–	–	68	*	96.9
32	83.8	89.7	69	*	96.9
33	–	–	70	*	94.6
34	84.7	89.2	71	77.1	94.9
35	84.7	89.3	72	82.3	94.5
36	84.5	89.1	73	82.2	94.8
37	81.1	88.6	74	82.5	94.5

* control fed with gamma irradiated wastewater

Table A.15 Continuous test: Color variation with time.

day	Color (%T)			day	Color (%)		
	influent	control	PAC		influent	control	PAC
1	-	-	-	38	-	-	-
2	-	-	-	39	30.5	39.9	50.9
3	-	-	-	40	30.8	39.7	50.4
4	-	-	-	41	30.0	39.4	49.5
5	38.6	41.4	52.2	42	-	-	-
6	39.5	42.4	53.0	43	-	-	-
7	43.9	47.8	56.9	44	-	-	-
8	43.2	45.9	58.2	45	-	-	-
9	45.8	45.6	57.6	46	31.0	39.9	45.0
10	37.8	48.9	62.4	47	-	-	-
11	42.3	51.1	66.5	48	31.5	39.8	46.3
12	-	-	-	49	32.4	38.9	49.5
13	43.0	52.9	64.5	50	31.5	40.4	47.5
14	40.8	52.6	63.8	51	41.4	49.3	55.7
15	41.8	52.4	70.7	52	42.7	52.1	58.0
16	41.6	52.9	72.4	53	43.2	53.3	58.3
17	42.2	52.5	68.2	54	43.5	53.3	59.3
18	42.1	52.4	68.5	55	43.3	53.4	61.3
19	57.0	62.5	73.4	56	-	-	-
20	52.1	63.3	77.4	57	-	-	-
21	54.8	62.9	79.7	58	-	-	-
22	56.9	63.2	80.3	59	38.6	52.0	60.6
23	57.6	63.9	76.8	60	-	-	-
24	57.5	64.0	75.0	61	39.3	50.1	62.8
25	45.1	59.2	70.4	62	41.9	51.6	63.4
26	44.3	56.6	68.8	63	41.5	52.8	63.2
27	44.3	56.6	68.0	64	41.6	51.7	63.0
28	-	-	-	65	-	-	-
29	43.8	56.2	67.4	66	44.7	53.9	66.2
30	44.0	55.0	65.0	67	44.5	52.5	65.4
31	-	-	-	68	44.1	*	88.7
32	36.2	49.8	60.1	69	44.3	*	88.6
33	-	-	-	70	44.5	*	89.4
34	34.5	52.9	61.9	71	44.8	48.9	85.8
35	40.6	50.8	60.0	72	44.6	51.1	85.4
36	39.5	50.5	59.4	73	44.5	52.8	86.0
37	39.8	49.8	60.5	74	44.7	53.7	85.8

* control fed with gamma irradiated wastewater

Table A.16 Continuous test: Color removal efficiency.

day	removal (%)		day	removal (%)	
	control	PAC		control	PAC
1	-	-	38	-	-
2	-	-	39	13.5	29.3
3	-	-	40	12.9	28.4
4	-	-	41	13.4	27.9
5	4.6	22.2	42	-	-
6	13.1	22.3	43	-	-
7	6.9	23.2	44	-	-
8	4.8	26.4	45	-	-
9	0	21.8	46	12.9	20.3
10	17.8	39.5	47	-	-
11	15.3	41.9	48	12.7	22.2
12	-	-	49	9.6	25.3
13	17.6	37.1	50	13.0	23.4
14	19.9	38.8	51	13.5	24.4
15	18.2	49.7	52	16.4	26.7
16	19.3	52.7	53	17.8	26.6
17	17.8	45.0	54	17.3	28.1
18	17.8	45.6	55	17.8	31.8
19	12.8	38.1	56	-	-
20	23.4	52.8	57	-	-
21	17.9	55.1	58	-	-
22	14.6	54.3	59	21.8	35.8
23	14.8	45.3	60	-	-
24	15.3	41.2	61	17.8	38.7
25	25.7	46.1	62	16.7	37.0
26	22.1	44.0	63	19.3	37.1
27	22.1	42.5	64	17.3	36.6
28	-	-	65	-	-
29	22.1	42.0	66	16.6	38.9
30	19.6	37.5	67	14.9	37.4
31	-	-	68	*	79.8
32	21.3	37.5	69	*	79.5
33	-	-	70	*	80.9
34	28.1	41.8	71	7.4	74.3
35	17.2	32.7	72	11.7	73.6
36	18.2	32.9	73	14.2	74.8
37	16.6	34.4	74	16.3	74.3

* control fed with gamma irradiated wastewater

Table A.17 Continuous test: Steady-state COD removal(%) at different SRT and HRT of 24 h.

day	SRT = 7 days		SRT = 10 days		SRT = 15 days	
	control	PAC	control	PAC	control	PAC
1	84.7	89.3	80.3	90.9	84.7	89.1
2	84.5	89.1	79.1	91.0	83.6	89.2
3	81.1	88.6	80.1	90.6	82.8	88.6
4	-	-	79.9	89.5	83.7	89.0
5	84.8	89.6	86.6	92.6	84.4	89.2
6	85.8	89.6	85.4	91.7	84.0	89.3
7	85.3	89.0	84.2	91.3	84.4	88.3
Average	84.4	89.2	82.2	91.1	83.9	89.0

Table A.18 Continuous test: Steady-state color removal(%) at different SRT and HRT of 24 h.

day	SRT = 7 days		SRT = 10 days		SRT = 15 days	
	control	PAC	control	PAC	control	PAC
1	17.2	32.7	17.9	55.1	13.0	23.4
2	18.2	32.9	14.6	54.3	13.5	24.4
3	16.6	34.4	14.8	45.3	16.4	26.7
4	-	-	15.3	41.2	17.8	26.6
5	13.5	29.3	25.7	46.1	17.3	28.1
6	12.9	28.4	22.1	44.0	17.8	31.8
7	13.4	27.9	22.1	42.5	18.4	30.4
Average	15.3	31.0	18.9	46.9	16.3	27.3

Table A.19 Continuous test: Steady-state SVI (mL/g) variation at different SRT and HRT of 24 h.

day	SRT = 7 days		SRT = 10 days		SRT = 15 days	
	control	PAC	control	PAC	control	PAC
1	1165	470	700	266	786	250
2	1190	482	764	244	728	134
3	1195	497	796	208	715	220
4	-	-	764	188	653	175
5	942	370	867	229	666	110
6	1010	480	867	236	688	168
7	1031	439	830	256	703	178
Average	1089	456	798	232	699	176

Table A.20 Continuous test: COD, Color removal and SVI variation at HRT of 40 h and SRT of 15 days.

day	COD (%)		Color (%)		SVI (mL/g)	
	control	PAC	control	PAC	control	PAC
1	87.7	91.9	17.8	38.7	688	126
2	87.1	92.2	16.7	37.0	737	176
3	88.4	92.8	19.3	37.1	784	189
4	87.2	92.5	17.3	36.6	865	207
5	-	-	-	-	-	-
6	88.2	92.6	16.6	38.9	709	125
7	87.1	92.5	14.9	37.4	697	113
Average	87.6	92.4	17.1	37.6	747	156

Table A.21 Continuous test: COD, Color removal and SVI variation at different PAC concentrations.

day	COD (%)		Color (%)		SVI (mL/g)	
	1 g/L	3 g/L	1 g/L	3 g/L	1 g/L	3 g/L
1	89.1	94.6	23.4	80.9	250	38
2	89.2	94.9	24.4	74.3	134	37
3	88.6	94.5	26.7	73.6	220	37
4	89.0	94.8	26.6	74.8	175	73
5	89.2	94.5	28.1	74.3	110	86
6	89.3	-	31.8	-	168	67
7	88.3	-	30.4	-	178	64
Average	89.0	94.7	27.3	75.6	176	57

APPENDIX B

List of dyestuff utilized by the factory

Disperse

Sumikaron Bodeaux SE-BL
Sumikaron Red SE-RPD
Sumikaron Yellow SE-RPD
Sumikaron Blue SE-RPD
Sumikaron Rubine SE-GL
Sumikaron Red E-FBL
Sumikaron Navy Blue S-2 GL
Disperse Red S-RPD
Disperse Yellow S-RPD
Disperse Blue S-RPD
Disperse Navy Blue S-RPD
Dianix Yellow ACE
Dianix Blue ACE
Dianix Black RB-FS
Uvitex EMV
Polyester white
Intrasil Navy Blue HRS
Intrasil Black BA
Intrasil Rubine CK GFL
Intrasil Scarlet HGF
Intrasil Orange YBLH
Intrasil Blue 3RLN
Intrasil Yellow GL
Miketon P Yellow 3GSL

Acid

Lanaeron Red S-G
Irgalan Grey BL
Kayakalan Yellow 143
Kayakalan Grey 167

Reactive

Sumifix Supra Red 3 BF
Sumifix Supra Yellow 3 RF
Sumifix Supra Blue 3 RF
Sumifix Black ENS
Ambifix Red HE-3B
Ambifix Yellow HE-3G
Ambifix Blue HE-4R
Ambifix Turquoise-Blue HA
Ambifix Black VB

APPENDIX C

Prelimimary Cost estimates

From equation 2.15

$$C = C_o \frac{\Theta_c}{\Theta}$$

At an equilibrium PAC concentration of 3 g/L

Taking $\Theta = 1$ day and $\Theta_c = 15$ days

Influent carbon concentration, $C_o = 0.2$ g/L

Carbon cost = 8 Baht/m^3 (PAC at 40 Baht/kg)