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A Cost Effective Solution for Treatment of Rubber Factory Wastewater

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Crepe rubber industry is one of the major water polluting industries in all rubber growing countries. There is a necessity to develop suitable treatment technologies for the management of this problem. Covered Activated Ditch (CAD) type test reactors set with Bio-brush media are very effective in rubber factory wastewater treatment. Out of four organic loading rates (OLR) and five specific surface areas (SSA) of media tested respectively, Bio-brush media with 200 m^2/m^3 SSA under 1.0 COD $kg/m^3/d$ OLR was selected as the best for CAD reactors and the average COD removal achieved was about 89%. Results revealed that at higher OLR, correction of pH could be avoided for an efficient treatment and reactors with higher SSA of media were able to tolerate organic shock loads comparatively. The efficiency of treatment increased with increasing SSA of media and no special cycles were observed in removing biomass from the test reactor under any of the four OLRs tested. During maturation, chemical oxygen demand (COD), pH and suspended solids (SS) of treated effluent with 200 m^2/m^3 SSA were about 100 mg/L, 6.7 – 7.2 and 26 – 43 mg/L respectively which were below the maximum desirable levels stipulated by the Central Environmental Authority of Sri Lanka. Apart from the rubber industry, CAD reactors could also be used for treating biodegradable liquid waste such as waste from the palm oil industry, rice processing industry, sugar industry and others.

Keywords: anaerobic; Bio-brush; water pollution; rubber; specific surface area; wastewater treatment

Raw rubber industry has been identified as one of the largest sources of organic pollution of water in rubber growing countries. Many biological wastewater treatment systems have been investigated and some of them are implemented to minimise the pollution caused by effluents from raw rubber factories.

Several biological systems such as anaerobic pits[1,2] or pond systems[3–6], anaerobic filters[7,8], oxidation ditch and activated sludge systems[9], Upflow Anaerobic Sludge Blanket (UASB) reactor[10], anaerobic and aerobic fluidised beds[11], bio-drum unit[12] and rubberised coir carrier reactor[13,14] were used by many researchers to treat rubber factory wastewater in rubber growing countries.

In 1991, a rotating activated belt system facilitating the growth of aerobic bacteria

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on bottle-brush type coir brushes mounted on rotating belts was tested in Sri Lanka and the system was successful in treating rubber factory wastes[15].

Covered Activated Ditch (CAD) system, a new treatment system configuration was introduced by Warnakula in 1996 for treating raw rubber factory effluent in Sri Lanka[16]. The CAD system is covered with coir based biological odour filter[17] and Bio-brushes; a coir based medium was used as the biomass retainer[18]. Coir has been identified as a suitable raw material for producing such a media[19] with excellent surface properties[20–22] that favours immobilisation of biomass. The system is a cost effective high rate treatment system and this overcomes many inherent drawbacks of the pond process[16].

The first CAD system was constructed with earthen ditches lined with polyethylene sheet for waterproofing. Later, the ditches were constructed with cement blocks reinforced with concrete and lined with polyethylene sheet for waterproofing. It was observed that the Bio-brush media arranged in a vertical position is more effective than the other tested arrangements such as horizontal along the length and horizontal along the width (Warnakula, personal communication). These ditch type reactors were packed with stationary media; CAD system is more related to an anaerobic filter type reactor with cross flow. The practicability and the effectiveness of this new system have been proven at commercial scale treatment systems[16,17,23–26].

Preliminary studies have shown that treatment efficiency of the CAD system could be optimised by changing the packing strategy of Bio-brush medium. However, this has not been fully investigated. Because of the growing demand for CAD system for wastewater treatment, systematic exploration of the possibility of optimisation has become a priority area for investigation.

The objective of this study therefore, was to investigate the effect of different packing strategies of Bio-brush media in covered activated ditches on treatment efficiency with a safe and stable long term operation and acceptable quality of treated effluent.

MATERIALS AND METHODS

Media Design

The bristle fibre coir used in preparation of Bio-brushes was selected from the same batch in order to minimise variations. Mean surface area/unit weight of coir fibre used was 0.015 m^2/g coir. Coir fibre was cut in to 10 cm lengths for preparation of Bio-brushes with 10 cm diameters. Using different amounts of coir fibre, Bio-brushes were prepared to give 50, 100, 150, 200 and 250 m^2/m^3 SSA (*Table 1, Figure 1*) as explained by the Sri Lankan *Patent No. 10951*[19].

Reactor Design

Five identical ditch type test reactors (*Figure 2*) were constructed with cement blocks, supported with concrete reinforcements. The length, width and depth of each reactor were 9.09, 0.3 and 0.69 m respectively. Ditches were lined with a UV stabilised polyethylene sheet for waterproofing and were set with different SSAs of media. Bio-brushes were fixed in a vertical position and anchored to the bottom to prevent uplifting due to gas formation. The final effective volume of each ditch was 1.62 m^3.

Inoculum

Anaerobic biomass collected from a local crepe rubber factory wastewater treatment system was used for preparation of anaerobic seed sludge for test reactors.

TABLE 1. SPECIFICATIONS OF BIO-BRUSHES USED IN DIFFERENT TEST REACTORS

Diameter of Bio-brush media (cm)	Specific surface area (m^2/m^3)	Coir (g)/ brush (m)
10	50	33
10	100	66
10	150	99
10	200	132
10	250	165

Figure 1. Bio-brush media with different specific surface areas (SSA) used in test reactors ($50 \rightarrow 250 m^2/m^3$ from left to right).

Start-up of Reactors

Reactors were filled with water and inoculated with 50 litres of seed sludge mixture with 5000 mg/L of suspended solids content. Dilute rubber factory wastewater was introduced as the feed for a period of 2 weeks. Chemical Oxygen Demand (COD) of the feed increased weekly from 50 mg/L until 750 mg/L.

Feed Characteristics and Organic Loading

Fresh rubber serum was used as the feed. The reactors were tested under four different organic loads; 0.5, 1.0, 2.5 and 3.5 COD kg/m^3/d (*Table 2*). The retention time was set to 2.7 days. Each organic load was introduced until the test reactors reached a steady state.

Analytical Procedure

Samples were collected daily from each test reactor and tested for COD. Closed reflux colourimetric method[27] was used to measure COD. pH of samples was measured daily using Jenway 3305 pH meter calibrated at pH 4 and pH 7. Twenty five mL, homogenised samples, collected daily were measured at 810 nm using a DR/2010 HACH spectrophotometer to determine the suspended solids content. (HACH 8006 method)

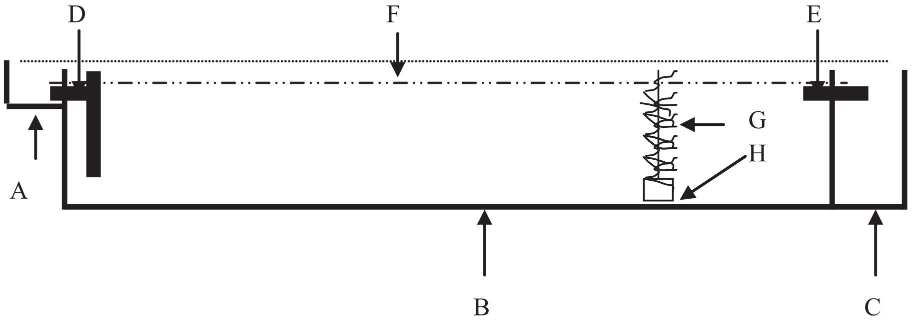
Data Analysis

Means of COD removal efficiency was analysed using analysis of variance. Mean separation was done by performing a Duncan Multiple Range test using statistical software SAS version 8.

RESULTS AND DISCUSSION

By increasing the amount of coir, the SSA of Bio-brush media was increased. In the reactors with five (50, 100, 150, 200, 250 m^2/m^3) different SSA of media, the COD removal efficiency was found to increase with increasing SSA of media under all four OLRs (0.5, 1.0, 2.5 and 3.5 COD $kg/m^3/d$) tested (*Figure 3*). Due to its brush type configuration, Bio-brush media was highly capable in entrapping biomass. By accumulating and entrapping large amounts of micro-organisms on inert support media the solid retention time could be increased and this leads to a high performance in the biological reactors[28,29].

Under all four OLRs tested, reactors with 200 and 250 m^2/m^3 SSA of media performed well. However, reactors with higher SSA (>100 m^2/m^3) showed comparatively higher



A - Inlet chamber B - Test reactor C - Outlet chamber
D - Inlet pipe E - Outlet pipe F - Coir-based odour filter
G - Bio-brush H - Weight

Figure 2. Schematic diagram of a test reactor (not to proportion).

TABLE 2. DIFFERENT ORGANIC LOADS INTRODUCED

Organic loading rate (kg COD/m^3/d)	Concentration of rubber factory effluent (mg/L)	Volume introduced (L)	Time taken to mature (days)
0.5	1350	600	30
1.0	2700	600	40
2.5	6750	600	46
3.5	9450	600	70

COD removal efficiency than the reactors with lower SSA (<100 m^2/m^3) (*Figure 3*). At higher OLRs (2.5 and 3.5 COD $kg/m^3/d$) the COD removal efficiency of the reactors with higher SSA of media did not show a significant difference to each other at an 0.05 probability level (*Table 3*).

Even the highest values of COD removal (93.80%) was observed during the run under 0.5 COD $kg/m^3/d$ OLR (*Table 3*), this OLR was too low and not economically feasible for treating factory effluents with high hydraulic volume. The reactor with 250 m^2/m^3 SSA run under 1.0 COD $kg/m^3/d$ OLR, showed 90% of COD removal, but in long-term operation the possibility of clogging the reactor was high as the coir was densely packed to give the particular SSA. The combination of Bio-brush media with 200 m^2/m^3 SSA under 1.0 COD $kg/m^3/d$ OLR showed a mean removal of COD of about

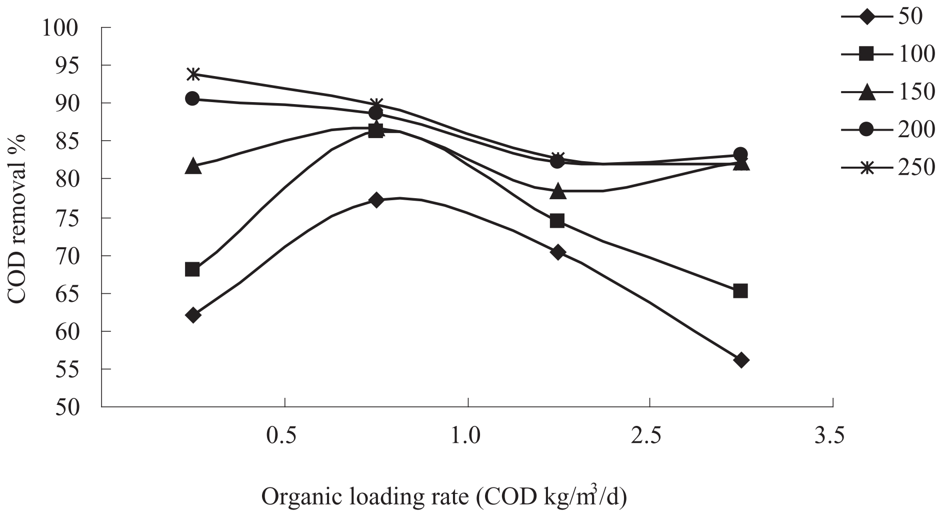


Figure 3. Effect of different OLRs on COD removal efficiency under five different SSA (m^2/m^3) of Bio-brush media.

TABLE 3. COMPARISON OF MEAN COD REMOVAL EFFICIENCY FOR DIFFERENT SSA OF BIO-BRUSH MEDIA FOR FIXED OLRS.

SSA (m^2/m^3)	OLR (COD $kg/m^3/d$) 0.5	1.0	2.5	3.5
50	61.98e	77.19d	70.44d	56.18c
100	68.02d	86.29c	74.40c	65.10b
150	81.82c	86.72c	78.33b	82.29a
200	90.63b	88.63b	82.18a	83.28a
250	93.80a	89.84a	82.73a	82.09a

Means with the same letter are not significantly different at P=0.05 using DMRT

88.63% (*Table 3*) which was quite feasible in the rubber factory wastewater treatment.

Results revealed that reactors with lower SSA of media were highly sensitive to the OLR. The COD removal decreased by 21% in both the reactors with 50 and 100 m^2/m^3 SSA when the OLR was increased from 1.0 to 3.5 COD $kg/m^3/d$. At the same time, the reactor with 150, 200 and 250 m^2/m^3 SSA showed a 5, 6 and 8% decrease in COD removal respectively. These observations showed that the reactors with high SSA of media could tolerate organic shock loads better than the reactors with low SSA of media.

The average SSA of the media used in full-scale anaerobic filters was about 100 m^2/m^3 regardless of the type of media[30]. Results of this investigation revealed the possibility of increasing the COD removal efficiency by increasing the SSA of Bio-brush beyond 100 m^2/m^3 especially in high OLRs. The COD removal efficiency increased significantly with increasing SSA of Bio-brush media (*Figure 3*).

The pH of the reactor with 200 m^2/m^3 SSA which showed the best performances were monitored under all four organic loads during the study. pH of the reactor run under 0.5 COD $kg/m^3/d$ OLR always showed a pH value greater than 6.3. However, during the run with the other three OLRs, the initial pH was below 6.0. At 1.0 and 2.5 COD $kg/m^3/d$ OLR, reactors took about 15 days to increase the pH above 6.0, while under 3.5 COD $kg/m^3/d$ OLR the reactor took about 40 days to achieve the same (*Figure 4*). These results revealed that the efficiency of organic matter removal was high under lower OLRs, hence the possibility of souring the reactor was very low. Nevertheless, when increasing the OLR the reactor took considerable time to increase the pH. This may be due to insufficient growth of biomass at the beginning. After a considerable time period, the reactor reached the optimum pH level for methanogenesis.

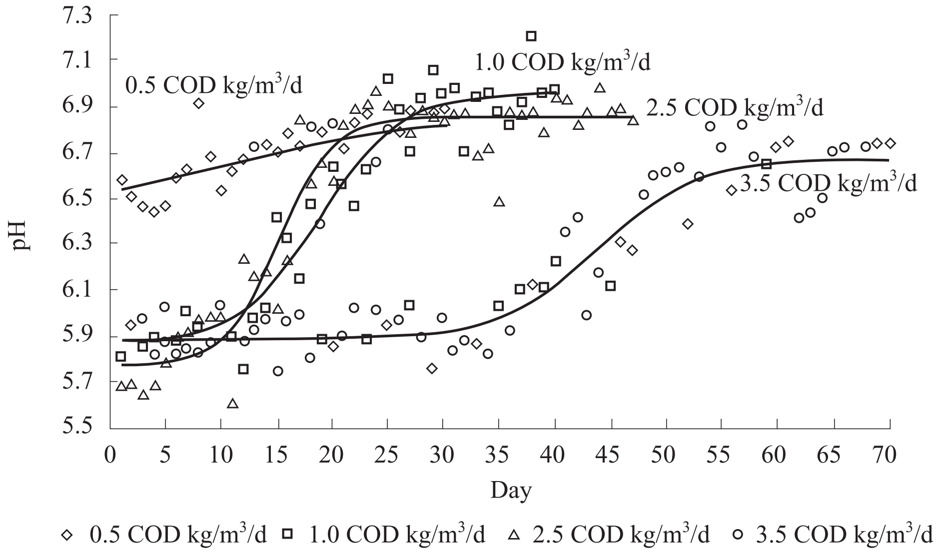


Figure 4. pH of reactor with 200 m^2/m^3 SSA under different OLRs.

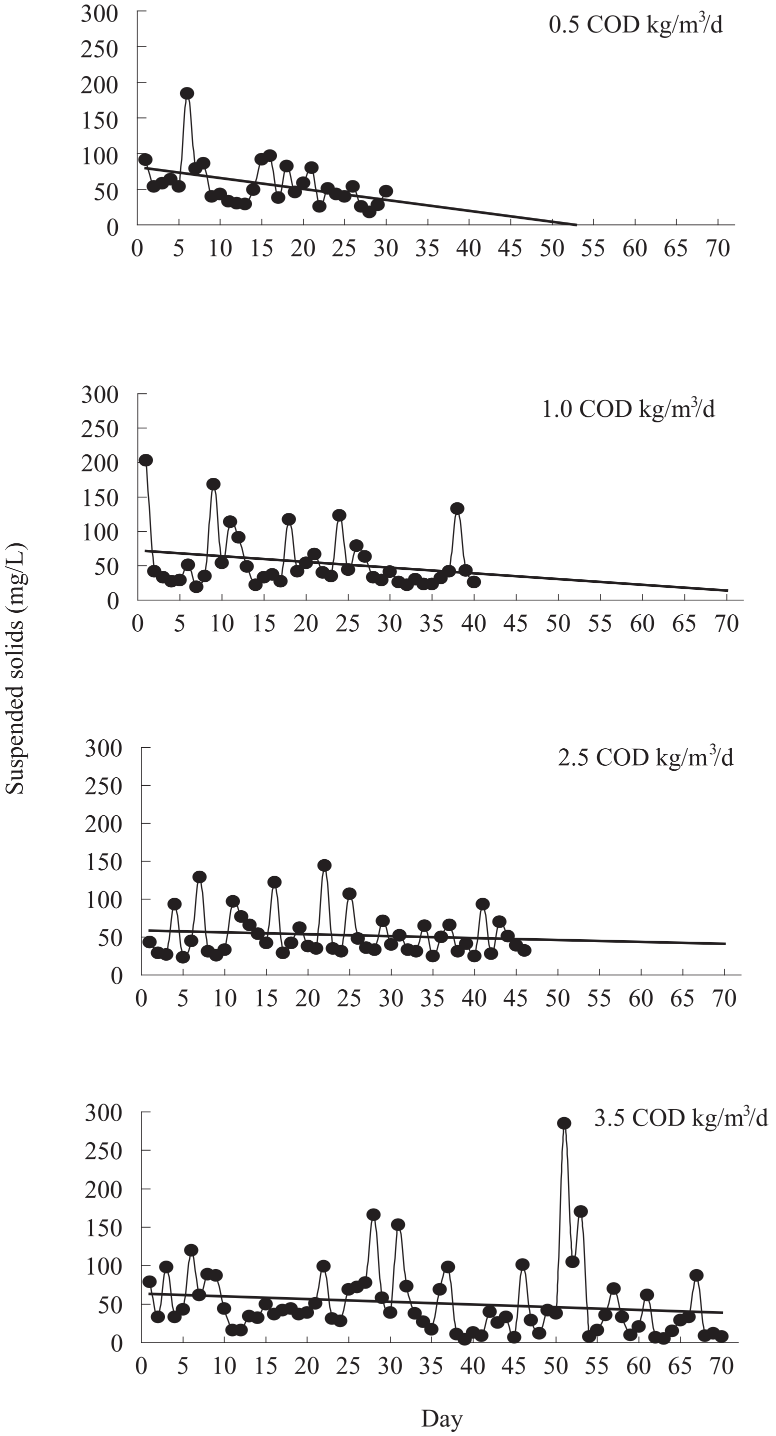


Figure 5. SS of the effluent of reactor with 200 m^2/m^3 SSA under different OLR.

No special patterns were observed in removing biomass from the test reactor under any of the four OLRs. Therefore, the linear trend was analysed. Decreasing trends in SS content were observed under four OLRs tested, which were significant only during 0.5 COD kg/m^3/d OLR at an 0.05 probability level. When increasing the OLR, a high degree of fluctuation was observed in the SS content of effluent (*Figure 5*). This behaviour would be due to low biomass growth with low OLR, resulting in accumulation of biomass while the SSA provided by Bio-brush media would be sufficient to accommodate the biomass growth during the period when the reactor was monitored. Removal of SS during higher OLRs was rather continuous. COD of the reactor with 200 m^2/m^3 SSA and was about 100 mg/L and the pH of reactor varied between 6.7 to 7.2. SS of the effluent was between 26 to 43 mg/L (except in day 38) after maturation of the reactor.

CONCLUSION

The best combination of SSA and OLR for anaerobic filter type CAD reactor was 200 m^2/m^3 SSA and 1.0 COD kg/m^3/d. Under this OLR, correction of pH could be avoided to achieve an efficient treatment. However, correction of pH of reactor was preferred during higher OLRs. Continuous removal of SS from the reactors prevents clogging, especially under higher OLRs.

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REFERENCES

1. HEINISCH, K.F. AND NADARAJAH, M. (1963) Disposal of Factory Effluents from Crepe and Sheet Producing Factories. *1st & 2nd Q. J. Rubb. Res. Inst. Ceylon*, **39(1/2)**, 32–37.

2. PONNIAH, C.D., CHICK, W.H. AND SEOW, C.M. (1975) Treatment of Effluents from Rubber Processing Factories. *Proc. Rubb. Res. Inst. Malaysia Plant. Conf.*, 367–388.

3. IBRAHIM, A., SETHU, S., KARIM, M.Z.A. AND ISA, Z. (1979) Anaerobic/Facultative Ponding System for Treatment of Latex Concentrate Effluent. *Proc. Rubb. Res. Inst. Malaysia Plant. Conf.*, 419–435.

4. ANON (1979) Ann. Rep. Rubb. Res. Inst. Malaysia, 191–193.

5. BAKTI, N.A.K. (1993) Treatment of Rubber Effluent with High Rate Algal Pond. *Plant. Bull. Rubb. Res. Inst. of Malaysia*, **215**, 52–55.

6. KARIM, M.Z.A. (2005) Water Hyacinth System for Examination Glove Factory Effluent Treatment. *J. Rubb. Res.*, **8(4)**, 241–256.

7. ANON (1981) Ann. Rep. Rubb. Res. Inst. Malaysia, 48.

8. ANON (1984) Ann. Rep. Rubb. Res. Inst. Malaysia, 29–30.

9. IBRAHIM, A. AND JOHN, C.K. (1985) Aeration System for the Treatment of Effluent from Latex Concentrate Factories. *Proc. Int. Rubb. Conf.*, Kuala Lumpur, 202–208.

10. ANON (1987) Ann. Rep. Rubb. Res. Inst. Malaysia, 40–42.

11. ANON (1994) Ann. Rep. Rubb. Res. Inst. Malaysia, 49.

12. ANON (1993) Ann. Rep. Rubb. Res. Inst. Malaysia, 38–39.

13. ANON (1991) Ann. Rep. Rubb. Res. Inst. Malaysia, 32.

14. ANON (1992). Ann. Rep. Rubb. Res. Inst. Malaysia, 42–44.

15. WARNAKULA, M.T. (1991) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 61–64.

16. WARNAKULA, M.T. (1996) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 100–103.

17. WARNAKULA, M.T. (1997) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 101–105.

18. WARNAKULA, T., BLISS, P., TILLEKE-RATNE, L.M.K. AND ASHBOLT, N. (1996) A New Medium for Biological Wastewater Treatment. *Proc. IRRDB Symp. Sri Lanka*.

19. WARNAKULA, M.T. (1993) A New Medium for Biological Waste Water Treatment, Sri Lanka *Patent No. 10951*.

20. BHAT, J.V., KUNTALA, K.G., VARADARAJ, P. AND PRABHU, G. N. (1973) Studies of Microbiological Softening of Coir Fibre. *Coir Q. J.*, **18(1)**, 21–26.

21. BHOWMICK, B.B. AND DEBNATH, C.R., (1984) Coir Fibre, Part I: Properties of Coir Fibre. *Indian Cocon. J.*, **15(5)**, 11–14.

22. KULKARNI, A.G., SATYANARAYANA, K.G., SUKUMARAN, K. AND ROHATGI, P.K., (1981) Mechanical Behaviour of Coir Fibres Under Tensile Load. *J. Mat. Sci*., **16**, 905–914.

23. WARNAKULA, M.T. (1998) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 94–98.

24. WARNAKULA, M.T. (1999) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 95–98.

25. WARNAKULA, M.T. (2000) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 84–86.

26. WARNAKULA, M.T. (2001) Annual Review of Department of Biochemistry. *Ann. Rev. Rubb. Res. Inst. Sri Lanka*, 95–96.

27. APHA 5220D, (1998) Standard Methods for the Examination of Water and Wastewater. Published by: American Public Health Association, American Water Works Association and Water Environment Federation. pp. 5-17 – 5-18.

28. KENNEDY, K.J AND DROSTE, R.L. (1991) Anaerobic Wastewater Treatment in Down Flow Stationary Fixed Film Reactors. *Wat. Sci. Tech*., **24(8)**, 157–171.

29. TCHOBANOGLOUS, G. AND BURTON, F.L. (1991) Wastewater Engineering: treatment, reuse and disposal, 3rd Edition. (*Eds. B.J. Clark and John M. Morriss*). McGraw Hills Book Co., Singapore: Metcalf and Eddy Inc.

30. YOUNG, J.C. (1991) Factors Effecting the Design and Performance of Upflow Anaerobic Filters. *Wat. Sci. Tech*., **24(8)**, 133–155.