In situ sludge reduction by microorganisms

S. Banerjee & U. Hooda
Institute of Paper Science and Technology and School of Chemical and Biomolecular Engineering, Georgia Institute of Technology, USA

Abstract

A mixture of facultative microorganisms added to pulp mill aeration stabilization basins is able to reduce sludge *in situ* over several months. Laboratory work shows that pulp fibers exposed to a cell-free extract prepared from the microorganisms are degraded through consumption of their hemicellulosic fraction. However, the process is quite slow; a controlled field study run for seven months did not lead to mineralization of the sludge.
Keywords: sludge, microorganisms, hemicellulose, treatment systems, fiber, ASB.

1 Introduction

Wastewater treatment in the paper industry is done with activated sludge systems or with aerated stabilization basins, ASBs [1, 2]. ASBs need to be dredged periodically and the associated sludge handling and disposal costs are substantial [3, 4]. A recent innovation introduced by Remediation Resources Inc (RRI) of Pembroke, GA, controls the sludge depth *in situ* by introducing a suite of *Pseudonomads* (isolated from oil well corings) into the inlet of the lagoon. The organisms are grown onsite in a fermenter fed by an influent sidestream and are released continuously into the lagoon. The microorganism formulation combines the desiccated *Pseudonomads* with nutrients and is supported on carbon beads, which are continuously dispensed into the fermenter. A number of mills have confirmed that releasing the RRI mcroorganisms into the lagoon leads to a gradual reduction of the sludge bed. In one mill, a sludge inventory of 600,000 m^3 decreased by 90,000 m^3 over a year [5]. In another, the hydraulic retention time increased from 2.5 to 3.4 days over two years [6]. In this paper we review laboratory and field work in light of the mechanism [7] of the process.

WIT Transactions on Biomedicine and Health, Vol 10, © 2006 WIT Press
www.witpress.com, ISSN 1743-3525 (on-line)
doi:10.2495/ETOX060121

2 Results and discussion

The ability of the organism to grow in the influent, which usually contains components toxic to microorganisms, was confirmed in laboratory work. Clarifier overflow was obtained from a mill in Georgia and attempts were made to grow organisms obtained from activated sludge as well as the RRI organisms in this medium. No growth was observed for the activated sludge samples, whereas growth (rod-shaped) was observed with the RRI organisms. The growth rate, measured in a chemostat, was about fivefold lower than that typical of organisms in the back end of an ASB. Hence, the RRI organisms are resistant to influent toxicity, which could be one reason that they are effective.

It seemed likely that the organisms degraded fiber through extracellular enzymes and this viewpoint was tested by exposing pulp fiber (in place of primary sludge) to cell-free extracts prepared from the organisms. The changes in fiber properties were followed with a Fiber Quality Analyzer (FQA). Unbleached and bleached softwood kraft pulps were screened separately through a Bauer-McNett fiber fractionater using 14 and 48 mesh screens, which correspond to openings of 1.6 and 0.4 mm, respectively. The fibers retained by the two screens were designated as long and short fibers, respectively. The fibers were also hydrolyzed in sulfuric acid [8] and the solution analyzed for carbohydrates.

The results, shown in Figures 1 and 2, demonstrate that the fiber length progressively decreases for both brown and bleached fibers, respectively. The results are comparable for the two different fiber lengths used. The curl index also decreases, especially for the long fibers. The results for the brown fibers are illustrated in Figure 3; values for the bleached fibers were very similar. The mixture of fiber and cell-free extract was also sealed between microscope slides. A micrograph illustrating the breakdown of a fiber exposed to the cell-free extract is illustrated in Figure 4. This level of degradation was not observed for all the fibers; some showed extensive damage, while others remained relatively unaffected. Control fibers kept in autoclaved media showed no change whatsoever.

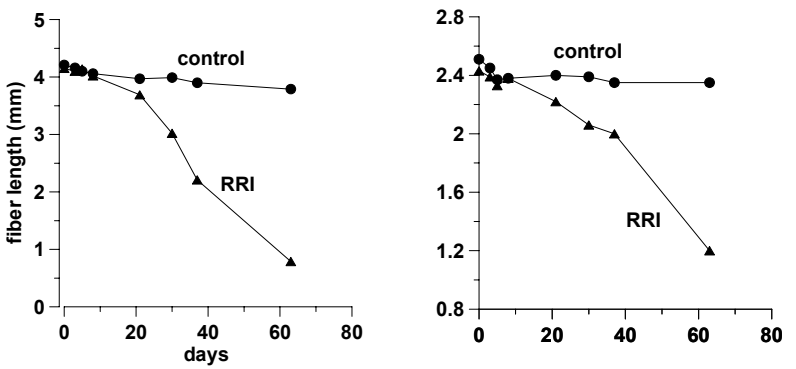

Figure 1: Fiber length changes in long (left) and short (right) brown fiber.

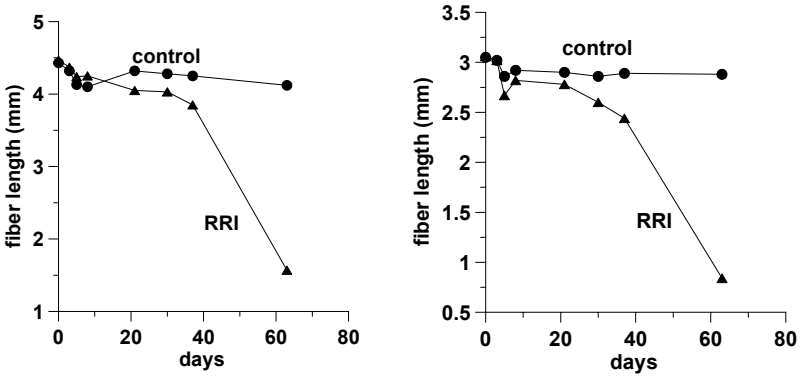

Figure 2: Fiber length changes in long (left) and short (right) bleached fiber.

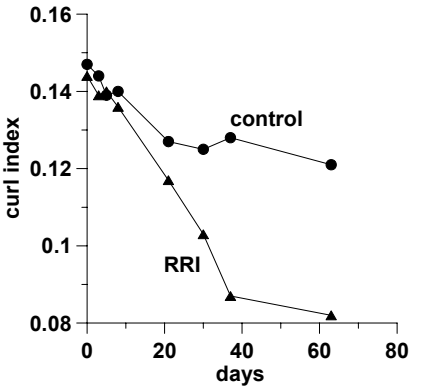

Figure 3: Changes in curl for long brown fiber.

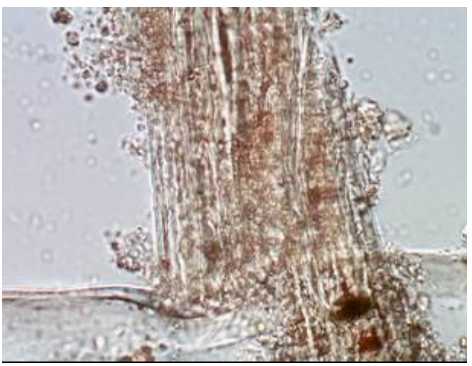

Figure 4: Degradation of a stained fiber in cell-free extract (100X).

Lignin cannot be the principal component involved in the degradation; otherwise the bleached and brown fibers would have behaved differently. Hence, the cellulosic components must be implicated in the disintegration of the fiber. The changes in these components with time are listed in Table 1. The levels of arabinan and xylan in the fiber decrease progressively as illustrated in Figure 5. A similar decrease also occurs with galactan, although there is more scatter. No significant change is seen for either glucan or mannan.

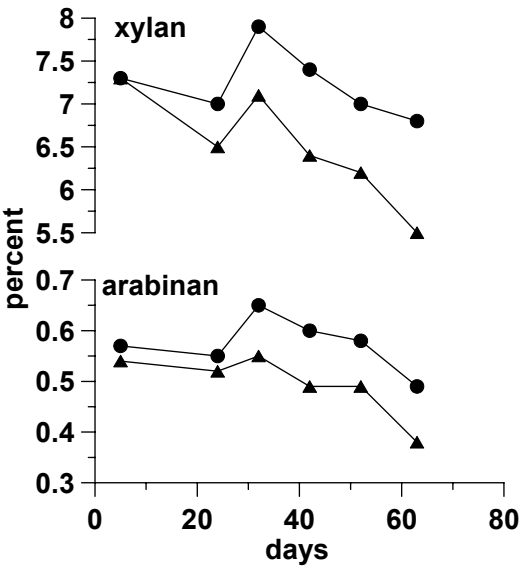

Figure 5: Profiles of arabinan and xylan with (triangles) and without (circles) added organisms.

Table 1: Degradation of cellulose and hemicellulose in the cell-free extract.

day	arabinan (%)		galactan (%)		glucan (%)		xylan (%)		mannan (%)	
	control	RRI	control	RRI	control	RRI	control	RRI	control	RRI
5	0.57	0.54	0.44	0.39	77	79	7.3	7.3		7.3
24	0.55	0.52	0.40	0.41	71	77	7.0	6.5	6.9	7.2
32	0.65	0.55	0.47	0.41	85	84	7.9	7.2	7.9	7.9
42	0.61	0.49	0.44	0.40	75	78	7.4	6.4	7.1	7.5
52	0.58	0.49	0.39	0.40	73	79	7.0	6.2	6.7	7.3
63	0.49	0.38	0.28	0.21	70	66	6.8	5.5	6.3	6.0

It appears that the organisms settle in the sludge bed and release enzymes that gradually degrade the sludge. Given that the organisms are formulated on carbon beads that are denser than water it seemed reasonable to seed the lagoon with the

beads themselves. The beds would sink to the sludge bed and the microorganisms would be delivered directly to the sludge where the enzymes would be more effective. Accordingly, an area of a lagoon in a Georgia mill was seeded with the beads. The sludge bed depth was measured by echosounding as well as with a sludge-light. Depth comparisons made at several locations ranging from 1–5 m showed the correspondence to be within 1.3%. The sludge light went off at a TSS of 3.2% so the sludge bed was operationally defined to begin at this depth. However, surveys taken over three months showed no improvement in the treated region over the others. It is possible that growth of the organisms is too slow under the anoxic conditions prevalent in the sludge bed.

An attempt was made to verify some of the laboratory findings in a controlled field study in a mill in Georgia. The technique used has been described earlier [9, 10] and consists of placing a mixture of sludge and microorganism in a vial capped with semi-permeable membranes and placing it in the lagoon. The membranes allow water to enter the vials but prevent the solids from leaving them. The intent was to determine the rate at which the organisms would mineralize sludge under field conditions.

Sludge was collected from a side of the lagoon just after the inlet and was dosed with the RRI formulation. The vials were then inserted into holders constructed from PVC tubing. Each tube supported five vials and was long enough to ensure that the vials were submerged. Controls were run with sludge but without the added microorganisms. Surprisingly, no change in the sludge mass occurred over 200 days. Evidently, the added organisms did not reduce sludge mass even though they were applied as an overdose. In order to confirm that the RRI organisms were still viable after exposure, a heterotrophic plate count of the 149-day sample was taken. The control contained an average of 2.2×10^6 CFU/mL, whereas the sludge with the added organism showed a higher count of 2.4×10^7 CFU/mL, demonstrating that the added organisms were still alive. Clearly, the process is slow. It is possible that the fibers held in the membrane-capped vials in the field trial were degraded by the RRI microorganisms, but not to the point where they were able to leave the vials. In other words, the fiber length decreased but the fragments were large enough to be held in place by the 0.01 μm membrane.

The sludge bed contains fiber only in the front end of the lagoon; the sludge in the rest of the basin mainly consists of settled microorganisms. The RRI organism is also likely to be effective on this material; otherwise the sludge bed would not have decreased uniformly in the mill applications. While our work does not address this situation, we note that the cell walls of gram-negative bacteria contain polysaccharides, which should be susceptible to degradation.

In conclusion, laboratory trials and full-scale field experience demonstrate that a suite of organisms isolated from oil well corings degrade sludge *in situ* in aerated stabilization basins. Enzymes released from the sludge attack hemicellulose entities in the sludge. The process is effective, but slow, and several months to a year is required before the effect can be quantified in the field.

Acknowledgements

We thank Georgia-Pacific, International Paper, Bowater, and Stora Enso for financial support and Remediation Resources Incorporated for a gift of the microorganism formulation and for conducting the field trial.

References

[1] Fels, M., Pinter, J. & Lycon, D.S., Optimized design of wastewater treatment systems: Application to the mechanical pulp and paper industry. *Can. J. Chem. Eng.*, **75(2)**, pp 437-451, 1997.

[2] Stuthridge, T.R., Campin, D.N., Langdon, A.G., Mackie, K.L., McFarlane, P.N. & Wilkins, A.L., Treatability of bleached kraft pulp and paper-mill wastewaters in a New-Zealand aerated lagoon treatment system. *Wat. Sci. Technol.* **24(3-4)**, pp 309-317, 1991.

[3] Dorica, J.G., Harland, R.C. & Kovacs, T.G., Sludge dewatering practices at Canadian pulp and paper mills. *Pulp and Paper Canada* **100(5)**, 19-22, 1999.

[4] Pickell, J. & Wunderlich, R., Sludge disposal - current practices and future-options - innovative methods are discussed. *Pulp & Paper Canada* **96(9)**, 41-47, 1995.

[5] Massengill D., Pazderski R. & MacDonald S. *Tappi Env. Conf.,* Montreal Canada, 2002.

[6] Bryant C.W., Kloeker J.W., Hege J., Meech M. & Nilsson K. *Tappi Env. Conf.*, Charlotte, NC (2001).

[7] Banerjee, S. & Hooda, U., In-situ reduction of fibrous sludge in a pulp mill aerated stabilization basin. *Tappi J.*, **4 (5)**, pp 3-7 (2005).

[8] TAPPI standard methods T 249 cm-00 Tappi Press, Atlanta, GA, 2000.

[9] Williams, C.L., Banerjee, S., Kemeny, T.E., Sackellares, R., Juszynski, M.D. & Degyansky M.E., In-situ measurement of local biodegradation during secondary treatment: Application to bleached pulp mill chloroorganics. *Environ. Sci. Technol.* **31**, pp 710-716, 1997.

[10] Williams, C.L., Mahmood, T., Corcoran, H., Zaltzmann, M.E. & Banerjee, S., Tracing the efficiency of secondary treatment systems. *Environ. Sci. Technol.*, **31**, pp 3288-3292, 1997.