Acknowledgment

I am deeply indebted to my guide Prof. Babu T. Jose, for persuading me to do this thesis, repeatedly stressing the importance of having a PhD, and bringing me back on track on occasions when I slacked and the morale sagged. I express my heartfelt gratitude to him.

Dr. Renu Pawels, CUSAT spent so much time and effort to help me through all the formalities of the university. Without her help, I would have failed at the bureaucratic gauntlets and no amount of thanks will suffice.

In making this thesis, I have drawn nourishment from various streams. The most important branch is 24 years of research into anaerobic treatment and biological treatment at NIIST, (formerly RRL Thiruvanthapuram). It is only right that I thank first of all, CSIR for all the research support it has provided. CSIR provided a project for scale-up studies on the BFBR. I thank the Director, NIIST for permitting me to register for PhD.

This is the right place to trace my journey in anaerobic technology and remember with gratitude the co-workers, assistants, project staff and students who shared in the successes and failures. My first brush with anaerobic digestion started 30 years ago, as a B.Tech student of Chemical Engineering at IIT Madras, with a few bottle experiments on water hyacinth digestion, with little experimental capability and on shaky theoretical foundations. I resumed the journey after I joined the then RRL Thiruvananthapuram in 1986. My first UASB reactor was built with a borrowed 4 inch dia. 1 m long QVF glass column and metering pumps salvaged from junk. It took years before broken tubing and sludge all over the floor became a rare sight when returning to the laboratory in the morning. Around 1992, I got my first research money came from MOEF for developing a treatment system for centrifuge latex effluent. We could finally buy peristaltic pumps. But, unknowingly we stumbled into the problem of sulphide inhibition of anaerobic treatment. It gave us our first innovation in anaerobic technology, - a process for sulphide inhibition control of anaerobic reactors – still today, the most cost-effective technique available. Dr.P.C Sabumon, now at Vellore Institute of Technology, and Shyam K P, now employed by Singapore University, spent days and nights to run the anaerobic reactor and its sulphide inhibition control system.

Confident, after developing the UASB and granular sludge on centrifuge latex effluent, we tried to run the reactor on palm oil mill effluent. It was a dramatic failure and we learnt what would happen if we run a UASB on a solids and lipid rich wastewater. Since then, the unsolved issue of complex wastewater has been at the back of my mind.

My next project was on sulphide oxidation, and its new concept RFLR reactor. It could not have been done without the efforts of S.Majundar, and Dr.B.Krishnakumar. It was my first experience in developing new reactor concepts. The next major development work was the BFBR. S.Suresh worked literally 24x7 to operate and perfect this reactor. Dr. Manilal, who has been with me since after the first lab UASB, reported seeing protozoa in the BFBR sludge. I said that would be unlikely because protozoa would not get enough energy to run around and grow in an anaerobic reactor. Later it was confirmed, and set me thinking what protozoa were doing...
in the BFBR. Sheela Ravikumar spent so much time to identify and count painstakingly the every day variation in numbers. Priya M. and Nimi Narayanan started their PhD on anaerobic protozoa, guided by Manilal. Krishnakumar set up a microscope that allowed us to see methanogens directly under fluorescence and characterise these using FISH methods. Simi worked on the BFBR filtration studies. Smt. Soosan Pannikar set up and operated modified versions of BFBR with mechanical agitation and sludge settler before the buoyant filter, specifically for the treatment of sewage. She will hopefully write it out for her PhD, after having stood up to the most trying circumstances imaginable in an institute. Abdul Jaleel ran comparative studies on BFBR using two different filter media and came up with intriguing results. KR Chitra developed the protocols and analysed the LCFAs in the BFBR liquor, with unmatched care and precision. Meanwhile I started another stream of anaerobic technology with the leach bed reactor for solids, but that is another story. Everything in the laboratory was made possible by the efforts of my technical assistants, Karunasankar Roat and Shaji Kumar.

In 1995, the World Bank financed our modern Wastewater Technology Laboratory at RRL. I got a chance to spend 3 months at the Wageningen Agricultural University and met Prof Gatze Lettinga and Dr. Look Hulshoff-Pol. Till I saw the lab UASBs at Wageningen, I had never seen one other than my own. I saw a full scale UASB at Eerbek. What more can an anaerobic technologist ask than seeing the UASB in the place of its origin? It gave me the courage to design full-scale UASBs for industrial effluent treatment and later develop the BFBR. Several clients (Bhavani Distilleries, Amitron Pune, KRM C Ltd, EPA Chennai) have put their faith and money in my reactor designs. Each time was a learning process. Sree Sakthi Paper Mills is putting up a variant of the BFBR reactor and I am waiting for the day it will be commissioned. All the design drawings were made possible by the efforts put in by Vijayaprasad. Wageningen confirmed my belief that there are no high-rate reactors for complex wastewaters.

Another stream of knowledge that has gone into this thesis is mathematical modelling. Even while an undergraduate in 1980, we attempted a mathematical model referring to the single publication then available to us (Graef SP, Andrews JF, AIChE Sym. Series, 1973). Those days we punched cards, wrote Fortran, and used the IMSL library subroutines, on IITM’s IBM 370, which was the dream machine in this part of the country. My thesis in graduate school at University of Delaware, USA, had been in then fashionable mathematical modelling, spending months at the text-only CRT terminals of a DEC10 mainframe. Modelling sharpened analysis but I felt it produced no new knowledge and so, at RRL, I worked mainly as an experimenter on biological process development. After doing the anaerobic process model for the BFBR, I am able to see modelling as a tool that can provide insight into complex processes. The BFBR model was based on lectures delivered by Prof. Mark von Loosdrecht (TU Delft) at CUSAT on the ASM model. I thank Prof. Mohandas, former Dean of CUSAT for inviting me to workshops on Environmental Technology conducted at CUSAT by some of the most eminent professors from The Netherlands.

All my colleagues, staff and students have stood by me and helped me in so many ways. I name, in particular, J. Ansari, Dr. Rugmini Sukumaran and Dr. Ramaswamy.

Finally, I would like to dedicate this thesis to the ethics, culture and spirit of science, in its struggle to survive within the country’s scientific establishment.