INTRODUCTION

The Republic of South Africa is rapidly approaching the point of maximum economic exploitation of conventional water resources. In addition, the country is faced with deteriorating water quality which may become a limiting factor in water resources development prior to limitations on water quantity.

The accelerated deterioration of water quality is a result of, amongst others, the discharge of ever-increasing quantities of treated effluents to rivers and streams. Effective removal of pollutants from wastewaters, particularly the nutrients carbon, nitrogen and phosphorus, is therefore of the utmost importance. Furthermore, high quality effluents may serve as an economic source to augment dwindling water resources.

The need for pollution control and indirect reuse of treated wastewater is legally expressed in the Water Act (54 of 1956) and standards promulgated in terms of the Act. The General and Special Standards which were promulgated in 1962, emphasized the adequate removal of carbonaceous material and the transformation of ammonia to nitrate. More recently accelerated eutrophication of many of South Africa's impoundments, with attendant health, water quality and aesthetic problems, has become apparent and resulted in the promulgation in 1980 of an upper limit for effluent phosphates for a number of critical catchments. Furthermore, limiting the total dissolved solids content of treated effluents is now also considered of prime importance. The need to remove nutrients and reduce the increase in dissolved solids during treatment, places difficult demands on future wastewater treatment plants.

Technology for the removal of the nutrients nitrogen and phosphorus from wastewater has been developed to a high level in the Republic of South Africa. Many organizations have been instrumental in this development, including research organizations, universities, consulting engineering firms and local authorities. A wide range of physical, chemical and biological processes and combinations of these are now available both for upgrading of existing works and design of new works. Methods available are: *Physical-chemical*, of particular use for removal of phosphates from the effluents of existing works – the only viable option, in fact, for dealing with biological filter effluents*; *physical-chemical-biological***, for the removal of nitrogen and phosphates, of use where the characteristics of the wastewater are unfavourable for the biological removal of the nutrients; *biological*, for the removal of all or major fractions of the nitrogen and phosphates in the influent, no or only minimal addition of chemicals is needed to produce the required effluent phosphate quality. Biological nutrient removal is particularly attractive for the treatment of municipal wastewaters because treatment costs are generally less than with physical-chemical methods, the salt concentration of the effluent is not raised as with chemical addition and the characteristics of the wastewater usually are amenable to this type of treatment. In consequence, the Water Research Commission has been greatly interested in developing this method of nutrient removal.

The Water Research Commission has stimulated, co-ordinated and financed research and development work in the field of biological nutrient removal in the activated sludge process from about 1973. Since that time it has contracted the National Institute for Water Research of the Council for Scientific and Industrial Research, the Universities of Cape Town and Pretoria and the City Council of Johannesburg to do research and development work in this field on a co-ordinated joint venture basis. A significant amount of information on processes for biological nutrient removal is now available. Much of this information has already been published in local and international journals as well as having been presented at a number of conferences, seminars and open days. However, in the light of the urgent need of local authorities and others who have to meet ever stricter effluent standards, and in particular the effluent phosphate standard of 1 mg/ℓ soluble orthophosphate which is to be strictly enforced in a number of critical catchments from August 1985, it was decided to compile a comprehensive information document on the biological removal of nitrogen and phosphates covering relevant results and findings made under Water Research Commission sponsored projects.

This publication has been compiled as a self-contained document which does not require reference to other publications on wastewater treatment. It is intended primarily for the design engineer and management staff responsible for operation and control of wastewater purification works. The level of presentation assumes that the reader has had tertiary training and/or considerable practical experience in the field of wastewater treatment.

The basic process for the simultaneous biological removal of phosphates and nitrogen was proposed by Barnard in 1976 and is called the Phoredox process in South Africa, and the Bardenpho or Modified Bardenpho in the United States. This process belongs to the single sludge, multi-reactor group of processes. For the phosphate removal aspect the fundamental principle embodied in this process is that an anaerobic state needs to be created at some point in the process in such a way that phosphate is released, a consequence of which is that biological uptake of phosphate in excess of normal metabolic requirements is induced when the sludge is aerated subsequently. In the Phoredox process the endeavour is to create the requisite anaerobic state by mixing the influent waste stream with the

*Phosphate removal by chemical addition: the reader is referred to the Water Research Commission publication "Guidelines for chemical removal of phosphates from municipal effluents."

**For example, the LFB process, the Lime-Flotation-Biological process developed by the National Institute for Water Research, Pretoria, RSA.

sludge recycled from the secondary settling tank without aeration in an anaerobic tank at the head of the works.

This method for promoting the anaerobic state appears in a number of processes that developed from the Phoredox process in order to accommodate wastewaters with unfavourable characteristics or in which nitrification-denitrification is not required. One such development, known as the UCT process, is described in detail in this publication. Some of the other processes which also incorporate the Phoredox principle, are not dealt with, for example, the AO process is not considered since this process is designed to remove phosphate in short sludge age systems where nitrification is prevented from occurring, and is unlikely to find significant application in the RSA. The process developed by Roberts and Kerdachi at Pinetown, Natal, also is not dealt with. This process differs from the others in that nitrification, denitrification and the anaerobic state, to induce P release, all take place in one reactor. Also, the process is oxygen-limited, in consequence, its biological response with regard to sludge production, oxygen demand, nitrification, etc. is not amenable to description by the kinetic models governing non-oxygen-limited processes such as the multi-reactor Phoredox, UCT and AO processes. The writers of this manuscript felt therefore that the Roberts-Kerdachi process falls outside their ambit of competence.

All the above processes are of the main-stream kind. Side-stream processes, of which the Phostrip process is currently the most widely used, are not discussed in this publication. In side-stream processes the anaerobic state is created by passing a fraction of the secondary settler underflow through an anaerobic reactor to release phosphates through endogenous respiration (instead of by the addition of feed waste flow) and precipitating the released phosphates by lime addition. Insufficient data on the behaviour of this process was available to the authors to allow directives to be put forward for design and operation of this process for producing effluents complying with South African effluent regulations with regard to both nitrogen and phosphates.

Guidelines for design set out in this publication are based primarily on about ten years of extensive laboratory investigations at the University of Cape Town on biological nutrient removal from predominantly domestic wastewaters. These guidelines were verified on data generated at pilot scale on the National Institute for Water Research's facility at Daspoort, Pretoria, and at full-scale on the Johannesburg Goudkoppies and Northern Works. The mathematical model for carbonaceous material oxidation, nitrification and denitrification have been shown to give accurate predictions of full scale plant response. The theory for biological phosphate removal is currently still in a development stage with research in this area continuing. Nontheless, tentative but conservative guidelines for process selection and design of biological phosphate removal aspects are presented.

Biological nutrient removal in the activated sludge process has only a short history of application. Currently in South Africa there are of the order of thirty plants designed for and/or being operated to obtain biological nutrient removal, with varying degrees of success. Practical experience on these plants should increase knowledge on the application of the process to a variety of wastewaters under different operating conditions and effluent requirements. Further research is still needed and is continuing in a number of areas where knowledge is still inadequate, for example, the mechanism(s) and factors controlling excess phosphate removal, the role of the anaerobic stage in the process, settling characteristics of the sludge formed in the process and factors which control these, as well as scum formation. This publication therefore does not pretend to be the final word on biological nutrient removal; it is an information document with interim guidelines for design and operation of biological nutrient removal plants.

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