Oxidation Ditches in Wastewater Treatment

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Pitman

PITMAN BOOKS LIMITED
128 Long Acre, London WC2E 9AN

PITMAN PUBLISHING INC
1020 Plain Street, Marshfield, Massachusetts 02050

Associated Companies
Pitman Publishing Pty Ltd, Melbourne
Pitman Publishing New Zealand Ltd, Wellington
Copp Clark Pitman, Toronto

First published in Great Britain 1983

Library of Congress Cataloging in Publication Data
Main entry under title:
Oxidation ditches in wastewater treatment.
Includes bibliographical references and index.
1. Sewage—Purification—Oxidation. I. Barnes, D.
II. Forster, C. F. (Christopher F.) III. Johnstone,
D. W. M. (David W. M.)
TD758.094 1983 628.3'51 82-9026
ISBN 0-273-08527-1 AACR2

British Library Cataloguing in Publication Data
Oxidation ditches in wastewater treatment.
1. Sewage—Purification
I. Barnes, D. II. Forster, C. F.
III. Johnstone, D. W. M.
628.3 TD745
ISBN 0-273-08527-1

National Library of Australia Cataloguing in Publication Data
Oxidation ditches in wastewater treatment.
Bibliography.
Includes index.
ISBN 0 85896 928 9
1. Sewage—Purification—Aeration.
2. Sewage lagoons. I. Barnes, D. (David),
1945–. II. Forster, C. F. III. Johnstone, D. W. M.
628.3'51

ISBN 0 273 08527 1

Filmset and printed in Northern Ireland at The Universities Press (Belfast) Ltd., and bound at the Pitman Press, Bath, Avon.

Preface

The idea for this book was developed when one of us (D B) was on study leave at the University of Birmingham in 1979. Discussions with other research workers, design engineers and practising process scientists revealed that, although oxidation ditch systems were being examined and evaluated at various centres throughout the world, there was no co-ordinated text on the subject. It also became clear that an authoritative text on oxidation ditches would require an edited book with a series of authors to ensure that the expertise and knowledge available throughout the world was adequately presented.

The editors would like to thank all the authors and their ancillary workers (typists, tracers, technicians, students, etc.) and all the regional water authorities, public authorities and industrial organizations who provided operational data so freely. Without their co-operation it would not have been possible to produce this volume. We are particularly indebted to Miss Dora Balis (University of New South Wales), Miss Pauline Tevlin (University of Birmingham) and Mrs Thelma Keen (Thames Water Authority) for their expertise in typing, retyping and correcting portions of the manuscript.

D B would like to thank Dr T H Y Tebbutt of the University of Birmingham for the assistance given to him during his stay in the UK and Professor B W Gould of the University of New South Wales for his encouragement in completing the text. C F F would like to thank both Professor W H Wittrick and Professor M J Hamlin of the University of Birmingham for their help and encouragement during the completion of the text. D W M J would like to thank Mr E C Reed, Director of Engineering, Dr M Dart, Director of Scientific Services, and Mr J L Wilkins, Divisional Manager, Cotswold Division, Thames Water Authority, for their permission to publish the work.

Finally, we would like to thank John Day, formerly of Pitman, for his expeditious handling of the project, as well as our wives and families for their patience, help and co-operation.

March 1981

David Barnes, Sydney
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Introduction

D Barnes, *University of New South Wales*
C F Forster, *University of Birmingham*
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Since the turn of the century wastewater treatment plants, whatever their size, have become increasingly important to local communities. Increasing demands on water mean that constant attention must be paid to its quality in rivers and streams and this, together with increasing industrialization, even in rural areas, and increasing population densities, has resulted in a need for wastewater treatment plants to be both compact and efficient. Furthermore, the ever-increasing costs of labour and energy now mean that the treatment process must be cost effective.

The activated sludge process has been a popular option since its development by Ardern and Lockett, as can be seen from the fact that of the 6 million cubic metres of sewage treated each day in the UK about 50 per cent receives treatment by one or other of the various modifications that have been made to the basic process. This text describes one such modification, the oxidation ditch, which is used in full-scale operation to such an extent that it warrants separate consideration.

Oxidation ditch systems were devised as a low-maintenance option for the treatment of municipal wastewaters from small- and medium-sized communities. The design of an endless channel with surface aerators providing aeration, mixing and propulsion of the liquors around the channel has undergone several modifications since its conception in the 1950s. The simplicity of the reactor, together with its flexibility of operation in achieving carbonaceous oxidation, nitrification and denitrification, has led to the use of the system for a range of municipal and industrial effluents. In some plants even the final settlement stage is carried out in the same tank as the biological reactions, without diversion of the influent wastewater, further adding to the simplicity of construction and operation.

The increased concern with minimizing the discharge of nitrogen to inland waters has led to considerable research interest in those treatment processes which can reduce both ammoniacal and oxidized-nitrogen concentrations in effluents. Ditch systems can achieve this under the proper operational conditions, even without the addition of chemicals. Although full-scale plants have been in regular operation for several decades, published theoretical studies of this type of plant have only begun to be widely available. It is the intention of this text to bring together specialist knowledge about specific aspects of ditches and ditch operation. In doing so, the editors have selected a series of authors whose individual specialities cover the major aspects of ditch design, construction and operation. The book is, therefore, neither a purely theoretical dissertation nor a day-to-day operator's guide. Rather its aim is to provide a concise understanding of the theoretical bases for the solutions of those practical problems which have to be answered when evaluating treatment options and designing and operating ditch systems. As such it should be of use to practising engineers and scientists in research establishments, educational institutes and the water industry, throughout the world.

Contents

1 The historical development of oxidation ditches

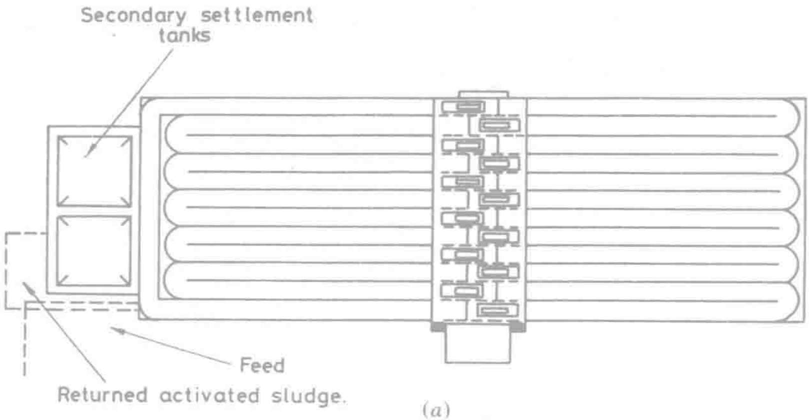
C F Forster, *University of Birmingham*

1.1 Genesis

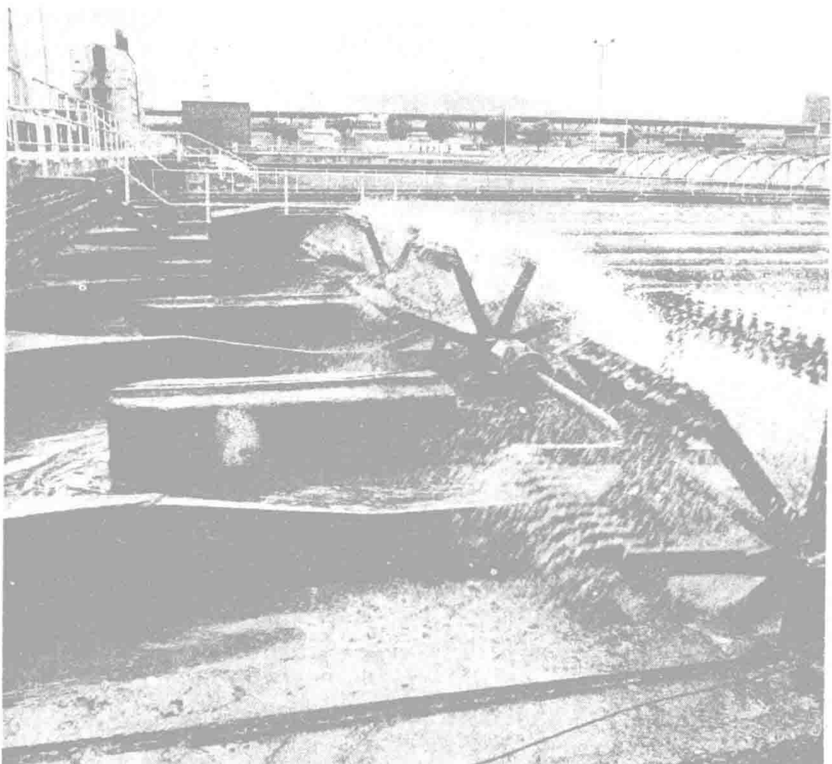
Following the pilot development work at Daveyhulme sewage works, Manchester, the first full-scale activated sludge plant in the UK was built at Worcester in 1916. This plant was based on diffused-air aeration, as were many of the others built later. A common feature of these early aeration tanks was that they were long, narrow, relatively shallow channels. These characteristics resulted from the need for long aeration necessitated by the inefficiencies of the early aerators. Although some of these channels were in total quite long, e.g. 152 m at Manchester, 262 m at Coventry, and could therefore be thought of (almost) as extended aeration channels, they cannot be thought of as a forerunner to the oxidation ditch as:

(*a*) they were not endless channels; and
(*b*) no horizontal impetus was imparted by the aeration mechanism.

At about the same time, mechanical aeration devices were being examined; Joshua Bolton was developing the cone aerator and, of more significance to this discussion, Haworth was persevering with a paddle aerator. On the basis of Haworth's work, the first paddle-aeration plant was commissioned in 1920 at Sheffield's Tynsley works and this plant could indeed be thought of as the precursor to the modern oxidation ditch. Its design was simple but effective (Fig. 1.1)—so effective in fact that the Sheffield system, with some modifications, is still operating. It is an endless channel in which the paddle system achieves both oxygen transfer and momentum transfer. As originally designed, the total channel length was 1080 m, its width was 1.22 m and the depth of the channel was 1.22 m. This gave an overall volume of 1611 m^3 and a hydraulic retention time of 16 hours at DWF (not quite extended aeration). The paddle wheels were 3.05 m in diameter and had a width of 0.76 m. They were driven by electric motors at 15 rpm and imparted a velocity of 0.52 $m.sec^{-1}$ to the mixed liquors. Performance data (see Table 1.1) show



(*a*)



(*b*)

Fig. 1.1 The Sheffield system. (*a*) Schematic diagram. (*b*) Aeration unit in the modern plant (by courtesy of Yorkshire Water Authority, Southern Division).

Table 1.1 Performance data (averages quoted as $mg.l^{-1}$) for the early operation of the Sheffield paddle-aeration plant (Martin, 1927)

	Sewage	*Effluent*
Oxygen absorbed in 4 hours	54	7.6
Ammoniacal nitrogen	34	33
Suspended solids	272	<30
DO uptake (5 days/65°F)	—	10

that although carbonaceous material and suspended matter were removed effectively, the plant did not produce a nitrified effluent.

The success of the paddle-aeration system at Sheffield, particularly at the Blackburn Meadow works, led to the construction of some sixteen other plants based on this principle (Stanbridge, 1977). However, even with improvements to the paddles, e.g. the use of triangular blades, performances were in general disappointing and only a few paddle-aeration systems remain to-day.

1.2 The Dutch school

The initial contribution to this part of the development of oxidation ditches could be said to be that of Kessener who, in 1925, began work on rotating-brush aerators. When fully developed (1935) these were used extensively to aerate individual pockets of aeration tanks. The mode of operation of these tanks was invariably plug-flow and the brushes were mounted so that their horizontal axis was parallel to the flow, thus creating a characteristic spiral motion within the mixed liquor. The first true oxidation ditch, that at Voorschoten, used a Kessener brush 2 m in length, mounted across the flow, to aerate and to circulate the mixed liquors around the ditch. The introduction of this type of treatment by Pasveer (1959) was a significant milestone in the history of sewage treatment. The ditch at Voorschoten, which had a capacity of 100 m^3 and treated the flow from a population equivalent of 360, was operated as an intermittent-flow process, i.e. there were three distinct phases—aeration, sedimentation and a final displacement of treated effluent by the addition of fresh sewage.

Concurrent with the development of the oxidation ditch was the development of a new type of rotor (Baars and Muskat, 1959). This was the cage, or TNO, rotor and it was specifically designed for use in the oxidation ditch. The ditches that were built after Voorschoten, therefore, used TNO rotors. However, for population equivalents of less than 5000, the mode of operation remained the same, i.e. no primary settlement, intermittent feed and aeration, and the use of the main ditch for secondary settlement. It soon became apparent, however, that these early fill-and-draw plants were susceptible to losses of mixed liquor solids during periods of high rainfall. Also, it was often found to be impractical to contemplate an intermittent-feed mode of operation for flows from larger population equivalents. These problems were overcome by using specific clarifiers, either built externally or internally (see Fig. 1.2). With both types of ditch, the flow around the main circuit, the inflow of sewage and the operation of the main rotors was continuous. The side channels, on the other hand, operated alternately as settlement bays, with the rotors being used to scour out solids accumulated during the settlement phase.

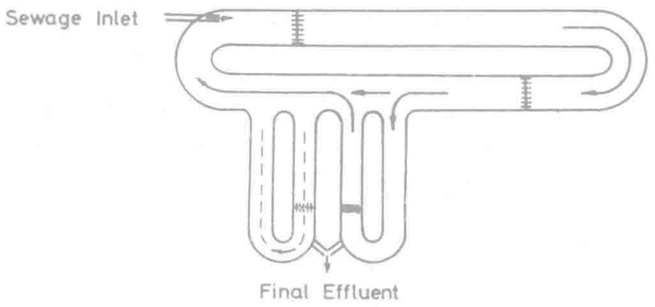


Fig. 1.2 Side ditch layout as developed for continuous operation.

Pasveer's philosophy in developing the oxidation ditch was to provide a system which was both simple to construct and operate and that would also achieve both oxidation and sludge stabilization within one tank. The large volume (relatively speaking) of the ditch resulted in a larger floc mass under aeration than was present in other systems. This had a dual effect. It provided a buffer against BOD variations and resulted in a sufficiently low food to mass (F/M) ratio to achieve sludge stabilization. The simplicity that was achieved in these early ditches is perhaps best demonstrated by the installation costs and operational figures quoted by Pasveer. The former were, on average, £3.5 per capita (£11–16 indexed to 1980) and the latter 18 kWh.capita^{-1}.year^{-1}. These need to be considered against current costs (see Chapter 4) to place them in a proper perspective.

1.3 The widening scene

The success of the Dutch experiments led to the introduction of oxidation ditches in other countries and 1963 saw the commissioning of the first ditch in the UK at Weeley, Essex. By this time it had become clear that the use of separate settlement tanks had distinct advantages, particularly when continuous operation and the treatment of larger flows were required. In addition, ditches were losing their original 'country character' and the full might of civil engineering, e.g. the use of concrete and steel, was being applied to their construction. The ditch at Weeley was a single oval-shaped continuous channel with a separate up-flow settlement tank. The ditch capacity was 245 m^3 and the nominal hydraulic retention time was 3 days. It took some six months for the mixed liquor solids to reach a reasonable working concentration (about 4 $g.l^{-1}$) and once this had been achieved the final effluent conformed to the discharge consent requirements of 20 mg $SS.l^{-1}$ and 15 mg $BOD.l^{-1}$ (Guiver and Hardy, 1968). In addition, almost complete nitrification was achieved. The advantages of the ditch system were so apparent that between 1963 and 1974 nearly 300 were constructed in the UK and over 500 in the USA and Canada. This boom in the construction of oxidation ditches was accompanied by fixed criteria for their design. In the UK this took the form of a Technical Memorandum (Ministry of Housing and Local Government, 1969), while in the USA EPA guidelines were issued (US EPA, 1977) (see Table 4.3). Although the majority of ditches were built to treat domestic sewage, their application to the treatment of industrial wastes was not neglected. Indeed, most of the readily biodegradable trade effluents have been subjected to bio-oxidation in a Pasveer ditch (Denton, 1977). The use of TNO rotors might be considered to have reached its zenith with the installation in 1964 by the Dutch State Mines of an oxidation ditch to treat an industrial effluent from coking and other chemical plant. This treatment plant is 800 m long and 25 m wide, and aeration is achieved by ten rows of TNO rotors, each 25 m long.

1.4 Large oxidation ditches

The criteria for the design of oxidation ditches laid down as a result of Pasveer's work, were a sludge-loading rate of 0.05 kg BOD.kg $MLSS^{-1}.d^{-1}$ and a ditch capacity of 260 $l.capita^{-1}$. These, together with the fact that oxidation ditches using TNO rotors cannot be deeper than 1.5 m, have the effect of making this type of system very 'land hungry'. In addition, economic pressures caused design engineers and planners to be more appreciative of costs, and in particular of per-capita construction costs. Koot and Zeper (1972) have shown that a ten-fold increase in plant size will result in a reduction in the capital investment per capita of 44 per cent. Similar reductions (53 per cent) can be calculated for UK-based plants by using Fig. 4.4. In other words, big, if not necessarily beautiful, is at least more cost beneficial. Large plants however, at least when constructed as TNO-aerated ditches, not only occupy large areas of land, they also require a large number of aeration rotors, which in turn necessitates a significant capital investment. The obvious solution to this problem was to develop aeration devices that would be compatible with the philosophies of ditch operation and yet would enable ditches to be built with greater depths. The main requirements were:

(*a*) to have high oxygen transfer efficiencies; and
(*b*) to generate a sufficiently high velocity within the ditch to maintain solids in suspension.

One solution was the Mammoth rotor. This was a natural extension of the TNO rotor and had a diameter of 1.0 m (see Fig. 4.14). As well as this increased size, modifications were made to the blade configuration, spiral blades being used, radiating from the central shaft. These changes in the rotor design resulted in such an increase in oxygen transfer efficiencies (see Fig. 1.3) that it was possible to contemplate ditch depths of up to 3.0 to 3.6 m. With these depths Mammoth rotors were quite capable of maintaining the mixed liquor solids in suspension. Ditches built with Mammoth rotors also required baffles, flow-dividing walls, or combinations of the two (see Figs. 1.4 and 7.1), to balance the velocities within the ditch.

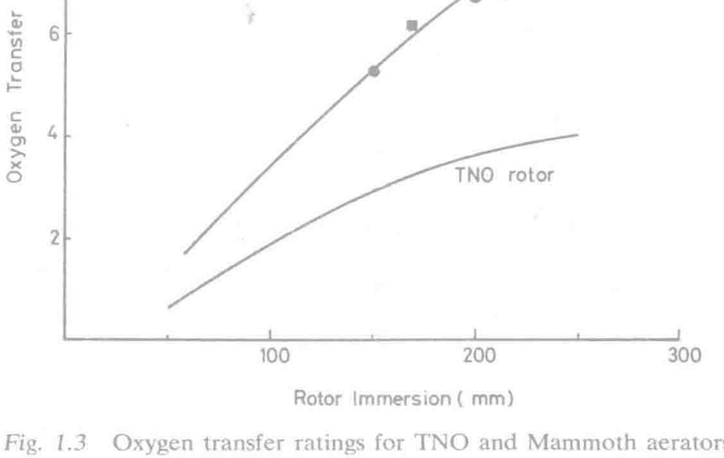


Fig. 1.3 Oxygen transfer ratings for TNO and Mammoth aerators.

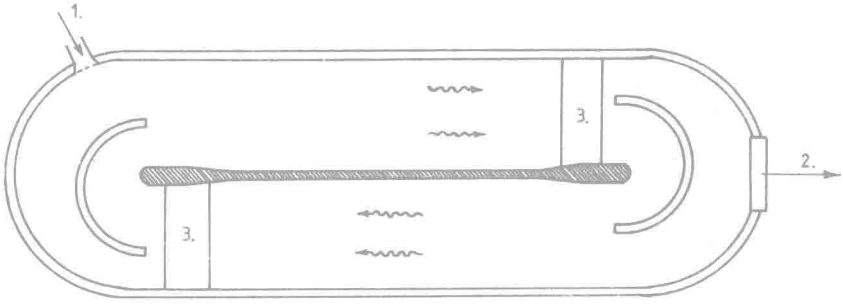


Fig. 1.4 Plan diagram of ditch layout using Mammoth rotors.
1. Sewage inlet. 2. Outflow weir. 3. Rotors.

One of the first Mammoth plants to be reported in detail was the Vienna Blumenthal works (Von der Emde, 1971). This was designed with two ditches, each capable of treating the sewage from a population equivalent of 150,000, i.e. total aeration volume of 12,000 m^3, each ditch being fitted with six pairs of Mammoth rotors 15 m in length. The depth of the ditches was 2.5 m. The performance fully justified the selection of the Mammoth rotors, with the BOD being reduced, on average, from 315 $mg.l^{-1}$ to 17 $mg.l^{-1}$. These data were confirmed as further Mammoth plants were built and evaluated (see Chapter 4). The benefits of the Mammoth rotor in terms of plant size can be seen by considering the TNO plant built by the Dutch State Mines. It has been calculated (Denton, 1977) that, had Mammoth rotors been available for this works, the size (area) could have been reduced by 60%.

An alternative solution, also developed in Holland, was the Carrousel system. The design of this form of the oxidation ditch can best be thought of as a square tank in which one side is extended to form a divided ditch. The aeration was provided within the "original square" by one of the modern cone-aerators which had gradually been developed from Bolton's early work. In addition to transferring oxygen to the mixed liquors, the aerator established a uniform turbulent-flow regime throughout the entire channel section. This has been shown to be the result of interactions between the dividing wall and the spiral flow generated within the square aeration pocket (Zeper and de Man, 1970). It has also been shown that in deep (up to 4 m) Carrousel ditches only about 1 per cent of the energy input for aeration was used to generate flow (Koot and Zeper, 1972). Some of the early development work showed that the depth of the aeration section should be related to the aerator, being at least equal to the aerator diameter. Thus, intermediate-sized Carrousel ditches have aeration zones deeper than the channel, typical figures being 3.5 m for the aeration zone and 2.5 m for the main ditch.

The first Carrousel system to be installed was at Oosterwolde in Holland (1968). Although this was really a prototype, it was capable of treating the flow from a population equivalent of 14,000. The plant performance data (97.5 per cent BOD removal) showed the potential for this type of design and although the Carrousel concept rapidly gained popularity in Europe, it was not until 1976 that a plant of this design was commissioned in the UK (see Chapter 5). The versatility of the Carrousel system can be seen from the range of operational plants (see Fig. 1.5). These data are taken from the UK manufacturer's handbook and cover the UK and Western Europe. They also include ditches treating industrial effluents.

It can be seen from Fig. 1.5 that Carrousel ditches have been built for population equivalents from 500 upwards. One of the largest Carrousel plants treating mainly domestic sewage is currently being constructed in three stages at Belem, in Curitiba, Brazil, each stage serving a population equivalent of 500,000. By far the largest oxidation ditch ever built is a Carrousel plant which treats a combination of domestic sewage and industrial wastewater from the BASF factory at Ludwigshafen in Germany. This has a total population equivalent of 6.5 million.

The introduction of these larger ditches, coupled with an increasing environmental awareness, soon led to investigations into nitrogen removal by ditch systems. Their ability to nitrify was well established (Matsché, 1972; Jacobs, 1975), as was the mechanism by which denitrification could be achieved, and it was soon demonstrated that these ditches could effect a high removal of nitrogen (e.g. Matsché and Spatzierer, 1975; Hanbury *et al.*, 1978). The control of oxygenation, and thus of the anoxic zones necessary for denitrification, and its effect on the energy requirements are discussed in Chapter 3.

1.5 Parallel development

In examining the development of the oxidation ditch, there has so far been a logical progression both in terms of the ditch itself and its rotors, these developments occurring in Western Europe. However in other parts of the world different modifications to the basic ditch design were taking place. In America these were mainly related to aerators. Two systems are worth noting, the jet aerator and the draft-tube aerator. Both systems were the result of a desire to apply the oxidation ditch concept to large flows without incurring an excessive penalty due to large area requirements.

The jet aeration system is essentially an attenuated ejector (see Fig. 4.18) (LeCompte, 1974). A series of these jets are fitted to a manifold placed across a deep (up to 7 m) ditch, the actual number depending on