

TREATMENT OF INDUSTRIAL EFFLUENTS

edited by:

A G Callely C F Forster D A Stafford

TREATMENT OF INDUSTRIAL EFFLUENTS

edited by:

A G Callely C F Forster D A Stafford



HODDER AND STOUGHTON

LONDON SYDNEY AUCKLAND TORONTO

INDUSTRIAL EFFLUENTS TREATMENT OF

edited by:
A G Callely C F Forster D A Stafford

Acknowledgements

The editors wish to thank everyone who co-operated in the production of this book, especially those who were responsible for writing the individual chapters.

ISBN 0 340 19799 4

First published 1977

Copyright © 1977 A G Callely C F Forster D A Stafford

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Phototypesetting by Print Origination
Bootle, Merseyside L20 6NS



Printed in Great Britain for Hodder and Stoughton Educational, a division of Hodder and Stoughton Ltd., Mill Road, Dunton Green, Sevenoaks, Kent by The Pitman Press, Bath.

Authors

- G.K. Anderson, B.Sc., Ph.D., M.I.P.H.E., A.M.Inst.W.P.C.
Department of Civil Engineering, The University of Newcastle-upon-Tyne.
- S. Beastall (Mrs. S. Stafford), B.Sc.
Department of Microbiology, University College, Cardiff.
- R.B. Cain, B.Sc., Ph.D.
Department of Biology, The University of Kent.
- A.G. Calley, B.Sc., Ph.D.
Department of Microbiology, University College, Cardiff.
- C.B. Capper, B.Sc., Ph.D.
Dearbourn Chemicals Ltd., Widnes, Lancashire.
- J.R. Catchpole, B.Sc., M.Inst.W.P.C.
British Carbonisation Research Association, Chesterfield, Derbyshire.
- A.P. Cox, B.A., C.Eng., F.I.Chem.E.
62, Leigh Rd., Hale, Altrincham, Cheshire
- J.G. Everett, B.Sc., Ph.D.
Anglian Water Authority, 12A Lime Street, Bedford.
- N. S. Fisher, Solicitor, Former Town Clerk of Derby,
10, Evans Avenue, Allestree, Derby.
- C. F. Forster, B.Sc., Ph.D., C.Eng., M.I. Chem.E., A.M.Inst.W.P.C.
Wessex Water Authority, Techno House, Redcliffe Way, Bristol.
- A.J. Griffiths, B.Sc., PhD.
Department of Microbiology, University College, Cardiff.
- H.A. Hawkes, M.Sc., M.I.Biol., F.Inst.W.P.C.
Department of Biological Sciences, The University of Aston, Birmingham.
- E.C.Hill, M.Sc., M.I.Biol.
Department of Microbiology, University College, Cardiff.
- Professor D.E. Hughes, B.Sc., M.A., Ph.D., D.Sc., F.I.Biol.
Department of Microbiology, University College, Cardiff.

- R.J. Kiff, M.Sc.
Simon Hartley Ltd., Stoke-on-Trent.
- G.D. Parish, B.Sc., M.Inst.P.
Shirley Institute, Didsbury, Manchester.
- B.D. Peacock, B.Sc., M.I.Biol., F.I.F.S.T.
Co-operative Wholesale Society Ltd., Manchester.
- W.T. Roberts, B.Sc., A.R.I.C.
Wiggins Teape Research and Development Ltd., Beaconsfield,
Buckinghamshire.
- D.A. Stafford, B.Sc., Ph.D., M.I.Biol.
Department of Microbiology, University College, Cardiff.
- W.E. Templeton, A.M.B.I.M., F.I.P.H.E., M.Inst.W.P.C.(Dip).
Welsh National Water Development Authority,
Tawe Sewage Division, 10 The Kingsway Swansea.
- K.C. Wheatstone, M.Sc., L.R.I.C.
Severn-Trent Water Authority,
Abelson House, 2297 Coventry Road, Sheldon, Birmingham.
- J.W.T. Wimpenny, B.A., Ph.D.
Department of Microbiology, University College, Cardiff.

Preface

One of the hallmarks of an advanced civilisation is its concern for the disposal of its society's waste products in a safe and environmentally acceptable manner. The controlled treatment of waste-waters in the UK, as in other countries, had its conception in the aftermath of the epidemics of cholera and other diseases in the middle and late nineteenth century. The major pollutants then were 'natural' compounds which owed very little to the ingenuity of the industrial chemist. This is now not so. In many countries the wastes from industrial processes are not only being produced in ever increasing amounts, but also can contain toxic and poorly degradable compounds. They are often considerably stronger than domestic sewage, which many of the present treatment systems were only designed to handle. In addition, the consumption of water for domestic and industrial use has increased to such a degree that nowadays it is not unusual to find that the rivers receiving treated effluents cannot give the dilution necessary for their survival as good quality watercourses, a problem aggravated during periods of drought.

The technological hardware for treating waste-waters has not kept pace with the changes in the complexity of effluents, though there have been considerable advances in the understanding of the biochemistry and microbiology of the biological processes which still form the main routes for purification. This book examines such developments and how this knowledge should assist the rational development of industrial treatment processes and the control and legislation concerning them. Since each industrial waste can present its own particular set of problems chapters dealing with the peculiarities of many different types of waste have been included besides those involved with general principles. Thus this book was designed to be both a textbook for all students of water resources technology, a guide for water quality engineers practising as multifunctional scientists in Regional Water Authorities and for those involved with or concerned about the effluents which their industry produces.

Contents

PREFACE	xiii
1 MICROBES AND EFFLUENT TREATMENT	1
D E Hughes	
INTRODUCTION	1
POPULATION DYNAMICS	3
ENZYMIC CHANGES	5
2 WASTE WATER TREATMENT—PROBLEMS OF CONTROL AND MANAGEMENT	7
C F Forster, D A Stafford and W E Templeton	
TYPES OF POLLUTION	7
Problems Affecting Treatment	
INDUSTRIAL, COMMUNITY AND MANAGEMENT RESPONSIBILITIES	11
Costing and the Community, Management Structure and Staffing, Effluent Sampling—The Value of Spot Checks, Sampling Methods, Data Collection and Interpretation	
3 LEGAL ASPECTS OF POLLUTION	18
N S Fisher	
INTRODUCTION	18
DISCHARGES TO SEWERS	19
Discharges not Requiring Consent, <i>Prescriptive Rights, Discharges Under Pre-1937 Agreements</i> , Discharges Requiring Consent	
DISCHARGES TO WATERCOURSES OTHER THAN TIDAL WATERS	23
The Riparian's Right of Action at Common Law	
DISCHARGES TO TIDAL RIVERS AND ESTUARIES AND TO THE SEA	26
THE CONTROL OF POLLUTION ACT 1974	27
CONCLUSION	28
4 AN APPRAISAL OF ANALYTICAL TECHNIQUES	30
K C Wheatstone	
INTRODUCTION	30
SAMPLE COLLECTION	31

METHODS FOR THE DETERMINATION OF ORGANIC MATTER	32
Dissolved oxygen, Oxygen demand Tests, <i>Biochemical Oxygen Demand (BOD)</i> , <i>Permanganate Value (PV)</i> , <i>Chemical Oxygen Demand (COD)</i> , <i>Inter-relationship of Oxygen Demand Tests</i> , <i>Total Organic Carbon (TOC)</i>	
SPECIFIC POLLUTANTS	40
Suspended Solids, Phenols, Nitrogen Compounds, <i>Ammonia</i> , <i>Nitrate and Nitrite</i> , <i>Organic Bases</i> , <i>Cyanide and Thiocyanate</i> . Phosphate, Instrumental Methods, <i>Ion-selective Electrodes</i> , <i>Atomic Absorption Spectrophotometry</i> .	
PRECISION AND ACCURACY OF ANALYTICAL METHODS,	53
FUTURE TRENDS	56
5 BIO-OXIDATION	65
C F Forster	
INTRODUCTION	65
BIODEGRADABILITY	65
Testing for Biodegradability	
TRICKLE FILTERS	67
FILTRATION WITH PLASTIC MEDIA	71
ACTIVATED SLUDGE	76
Step Aeration, Tapered Aeration, Contact Stabilisation, Extended Aeration, Aeration Capacity	
ALTERNATIVE BIO-OXIDATION TECHNIQUES	81
Rotating Discs, Submerged Filtration	
TREATMENT COSTS	83
Water Re-use, Waste Utilisation	
6 PHYSICAL TREATMENT	88
C B Capper	
INTRODUCTION	88
PROCESSES USED	88
Settlement, Flotation, Other Processes, Removal of Dissolved Solids	
PROCESS PLANT	89
Settlement, <i>Horizontal-Flow Tanks</i> , <i>Radial-Flow Tanks</i> , <i>Upward-Flow Clarifiers</i> , <i>Inclined Settling</i> , Flotation, <i>Dissolved-air Flotation</i> , <i>Electroflotation</i>	
DESIGN CRITERIA	95
Settlement, Total Treatment, Solids Separation, Sewage Sludge Conditioning, Emulsion Breaking	
ADVANCED PHYSICAL CHEMICAL TREATMENT	99
CONCLUSIONS	101
7 SLUDGE TREATMENT AND DISPOSAL	103
J G Everett	
INTRODUCTION	103
ANAEROBIC DIGESTION	106
CONDITIONING	110
Chemical Conditioning, Physical Conditioning, <i>Heat Treatment</i> , <i>Wet Air Oxidation</i> , <i>Freezing</i> , <i>Elutriation</i>	
DE-WATERING	114
Air Drying, <i>Drying Beds</i> , <i>Lagoons</i> , Mechanical Methods, <i>Vacuum Filters</i> , <i>Filter Press</i> , <i>Roto-Plug Concentrator</i> , <i>Centrifuges</i> . Heat Drying, Performance of Mechanical Filters	
DISPOSAL	120
Liquid Sludge to Agricultural Land, Disposal to Sea, Incineration, <i>Multiple-Hearth Furnace</i> , <i>Cyclone Furnace</i> . Composting, Tipping, Recycling Uses	

8 MICROBIOLOGICAL AND BIOCHEMICAL ASPECTS	129
D A Stafford and A G Calley	
INTRODUCTION	129
COMPOSITION AND STRUCTURE	129
NUTRITION	130
Oxygen Requirements, Other Environmental Factors	
MICROBIAL ACTIVITY	133
MICROBIAL GROWTH	135
BIODEGRADATION	136
CO-OXIDATION AND COMETABOLISM	140
ACTIVATED-SLUDGE FLOCS	141
METHODS OF ASSESSING MICROBIAL ACTIVITY IN ACTIVATED SLUDGE	142
Adenosine Triphosphate and Biomass, Reducing (Dehydrogenase) Activity, Respirometric and Substrate Utilisation Studies	
METABOLIC MANIPULATIONS	144
GENETIC ASPECTS	145
9 BIOLOGICAL AND ECOLOGICAL ASPECTS OF WASTE TREATMENT	149
A J Griffiths	
INTRODUCTION	149
DESCRIPTION OF THE ECOSYSTEM	150
THE MICROBIOLOGICAL APPROACH	153
THE ECOLOGICAL APPROACH	155
SUMMARY AND CONCLUSIONS	156
10 EUTROPHICATION OF RIVERS—EFFECTS, CAUSES AND CONTROL	159
H A Hawkes	
ECOLOGICAL INTRODUCTION	159
EFFECTS	161
Public Supply, In-river Use, Problems—Present and Future	
SOURCES AND CAUSES OF NUTRIENT ENRICHMENT OF RIVERS	166
Nitrogen and Phosphorous in Biogeochemical Cycles, Sources of Nutrient Input Into the Aquatic Environment, <i>Diffuse Sources, Point Sources</i>	
CONTROL	177
Nutrient Removal—Objectives, Nutrient Removal—Methods, <i>Nitrogen Removal, Phosphorus Removal, The Use of Algae for Nitrogen and Phosphorus Removal</i> , In-River and In-Lake Control Measures	
CONCLUSIONS	189
11 WASTES FROM THE PAPERMAKING INDUSTRY	193
W T Roberts	
THE BRITISH PAPERMAKING INDUSTRY	193
THE PAPERMAKING PROCESS	194
COMPOSITION OF PAPER MILL EFFLUENTS	195
THE EFFECT OF PAPER MILL EFFLUENTS ON STREAMS	195
Suspended Matter, Oxygen-Absorbing Substances in Solution, Sewage Fungus	
PURIFICATION OF PAPER MILL EFFLUENTS	197
Sedimentation, Sludge Concentration, Sludge Disposal, BOD Reduction, Sewage Fungus	
SOLVING THE EFFLUENT PROBLEM BY RECYCLING WATER	200

12 DAIRY WASTES	204
B D Peacock	
THE DAIRY INDUSTRY	204
THE ORIGIN OF DAIRY WASTES	204
THE COMPOSITION OF DAIRY WASTES	205
THE VOLUME OF EFFLUENT	206
CONTROL OF WASTE VOLUME AND STRENGTH	206
TREATMENT OF DAIRY WASTES	207
Pre-treatment, Screening, Fat, Curd and Grit Separation, Balancing of Flow, Control of pH, Settlement. Treatment Methods—Biofiltration, Alternate Double Filtration, Filtration with Recirculation, High Rate Filtration. Treatment Methods—Aeration Processes, The Activated-Sludge Process, Extended Aeration. Partial Treatment, Chemical Coagulation, High-Rate Plastic Medium Filters, Activated Sludge. Disposal to Water Authority Sewers, Disposal by Irrigation	
13 THE PETROCHEMICALS AND RESINS INDUSTRY	218
A P Cox	
THE PETROCHEMICALS INDUSTRY	218
THE INDUSTRY'S USE OF WATER	218
HANDLING EFFLUENT WATER	221
IN-PLANT TREATMENT OF PROCESS STREAMS	222
BIOLOGICAL TREATMENT	225
THE USE OF ACTIVATED CARBON	226
WASTE-WATER CONTROL	227
14 TEXTILE AND TANNERY WASTES	229
G J Parish	
THE TEXTILE INDUSTRY	229
THE CHARACTERISTICS OF TEXTILE WASTES	231
TANNERY WASTES	235
EFFLUENT TREATMENT	235
PRE-TREATMENTS AND SPECIAL TREATMENTS	237
Flow Balancing and Mixing, Neutralisation, Sedimentation, Filtration, Addition of Nutrients, Wool Grease, Sulphide Solutions, Chromium and Other Metals	
CHANGING DEMANDS	240
THE REMOVAL OF COLOUR FROM EFFLUENTS	241
THE RE-USE OF EFFLUENTS	242
15 FARM AND FOOD WASTES	245
G K Anderson	
FARM WASTES	245
Sources of Wastes, Quantity and Quality of Wastes, Methods of Treatment, Land Disposal, Aerobic Biological Treatment, Anaerobic Biological Treatment.	
FOOD WASTES	251
Composition and Volume of Food Wastes, Disposal of Wastes, Disposal and Treatment Methods, Biological Treatment, Pre-treatment, Physical and Chemical Processes, Sludge Treatment	

16 THE BIOLOGICAL TREATMENT OF COKE-OVEN LIQUORS	258
J R Catchpole and D A Stafford	
THE EFFLUENT PROBLEM OF THE COKING INDUSTRY	258
PURIFICATION OF COKE-OVEN EFFLUENTS	259
BIOLOGICAL TREATMENT-GENERAL PRINCIPLES	259
The Activated Sludge Process, Application to Toxic Wastes, The Role of Activated Sludge	
MICROBIOLOGY AND BIOCHEMISTRY OF CARBONISATION	262
WASTE TREATMENT	
Phenols, Thiocyanate, Organic Bases	
BIOLOGICAL TREATMENT USING ALTERNATIVE METHODS	263
Percolating filters, Packed Towers	
INVESTIGATIONS INTO COKE-OVEN LIQUOR TREATMENT	264
Residual Permanganate Value, Examples of Liquor Treatment, Laboratory Studies and Liquor Composition	
FULL-SCALE BIOLOGICAL TREATMENT	269
Quantitative Aspects of Treatment, Operation of Biological Treatment Plants, Disposal to Colliery Spoil-heaps	
17 THE TREATMENT OF PHARMACEUTICAL AND FINE CHEMICAL WASTES	273
R J Kiff	
INTRODUCTION	273
WASTE CHARACTERISTICS	273
Carbohydrate Products, Acid and Alkali Effluents, Dissolved Salts, General Process Liquors, Strong Process Liquors, Emulsions	
WASTE ASSESSMENT	277
Site Survey, Chemical Analysis: Effluent Composition, Treatability Studies	
WASTE TREATMENT PROCESSES	279
Segregation and Balancing, Neutralisation and Pretreatment, Dissolved Salt Removal, Pre-Aeration, Biological Treatment, Sludge Treatment	
TYPICAL PLANTS	282
18 SURFACTANT BIODEGRADATION IN WASTE WATERS	283
R B Cain	
INTRODUCTION	283
THE NATURE OF SURFACTANTS	283
THE WASTE-WATER PROBLEM AND SURFACTANT BIODEGRADATION	286
ANALYTICAL METHODS AND TEST PROCEDURES IN SURFACTANT BIODEGRADATION	287
THE MICROBIOLOGY OF SURFACTANT BIODEGRADATION	291
'ACCLIMATION' AS A FACTOR IN SURFACTANT BIODEGRADATION	294
THE METABOLIC FATE OF SURFACTANTS: BIOCHEMISTRY AND ENZYMOLOGY	296
Alkyl Chain Metabolism, Aromatic Ring Metabolism, Metabolism of Sulphate and Sulphonate Groups, The Types and Sequence of Metabolic Attack on Alkylbenzene Sulphonates, Metabolism of Non-ionic Surfactants, Metabolism of Cationic and Amphoteric Surfactants	
GENETIC ASPECTS OF SURFACTANT BIODEGRADATION	318

19	TREATMENT AND NATURAL FATE OF OIL SPILLAGES	328
	S Beastall	
	SOURCES OF OIL POLLUTION IN THE SEA	328
	COMPOSITION OF CRUDE OIL	328
	EFFECT OF ENVIRONMENTAL CONDITIONS ON THE	
	DEGRADATION OF CRUDE OIL	329
	TREATMENT OF OIL SPILLS	332
20	TREATMENT OF INDUSTRIAL OIL WASTES	336
	E C Hill	
	CATEGORIES OF OIL WASTES	336
	OIL CONTAMINATED PROCESS WATER	337
	OIL-IN-WATER EMULSIONS AND DISPERSIONS	337
	Reducing the Need for Disposal by Preservation, Disposal by	
	Biodegradation, Emulsion Cracking, <i>Treatment of the Aqueous Phase</i>	
	PRODUCTION OF BIOMASS	342
	DISCHARGE TO SEWERS, NATURAL WATERS AND TIPS	343
	DISCUSSION	344
21	WATER TRACING	346
	J W T Wimpenny	
	INTRODUCTION	346
	TRACING PROBLEMS	346
	Qualitative Studies, Quantitative Studies, <i>Stream Flow Measurements,</i>	
	<i>Ground Water Movement from Borehole Studies, Diffusion Studies at Sea</i>	
	<i>or in Other Large Bodies of Water</i>	
	CRITERIA FOR THE SELECTION OF A TRACER	350
	Sensitivity of Detection, Safety, Aesthetic Characteristics, Solubility,	
	Cheapness, Stability, Special Characteristics	
	THE AVAILABLE TRACING METHODS	353
	Conductivity Methods, Colorimetric Methods, Fluorescent Labels	
	Flame Photometric Methods, Radioactive Tracers	
	THE USE OF BIOLOGICAL TRACERS	357
	Choice of Organism, Choice of Bacteriophage, Production and Assay of	
	the Phage, Phage Survival Curves, Some Experimental Results	
	CONCLUSIONS	371
	INDEX	376

Chapter One

Microbes and Effluent Treatment

1.1 INTRODUCTION

Some form of biological treatment of human and farm wastes has been well established since late neolithic times, and certainly was a feature of the early cities of the fertile crescent and other centres such as Mohenji-Dara in the Indus basin, where waste treatment relied on its digestion in cess pits. Systems utilising waste in farming were also highly developed early in China. Early septic tanks, sewage farms and self-purification, by dilution into rivers or the sea, were probably based on the empirical observation that the waste slurries became less offensive when so treated, though it is doubtful whether the consequent improvement in community health was associated with these methods of waste disposal until our own time.

Such methods were largely neglected in the medieval cities of the west, and it was not until the population pressures which arose during the industrial revolution that they were taken up and developed. The first activated sludge plants began to be operated by 1900 AD. Although aimed primarily at the disposal of potentially offensive wastes, in recent years an additional objective has been the up-rating of water quality, either because the water courses form the final depository or the water in the effluent is to be reused. Solid residues then became an embarrassment, in contrast to China where they still make an important contribution to agriculture and fish farming.

Until the middle of the last century the main problem of effluent treatment was one of scale. With the growth of industry, especially the chemical industry, new problems appeared owing to the addition of so-called unnatural products to water systems. It is a tribute to the flexibility of microbial genetics and metabolism that our modern biological effluent treatments continue to work efficiently.

Biological treatment of wastes in water is based on the quite simple

and readily repeated observation that polluted water left standing and open to the air undergoes chemical changes which finally can result in clarification; the water can even become potable after decantation or sand filtration. Such changes are chemically similar to putrefaction which was associated with the presence of and later the activities of microbes. All biological effluent treatment systems are based on this seemingly simple process whereby a range of microbes utilise the organic compounds in polluted water as food; they grow, and are then separated from the water, which can then be considered as clean. The engineering developments in recent years have been associated with the preparation of the effluent by separating inorganic and other solids which slow down the purification process, and designing systems in which the microbes and nutrients, including oxygen, are kept in intimate contact and then separated from the water at the end of the process.

Two main systems are used. The first employs microbes which adhere to a solid substrate over which the effluent flows. Rapid-flow synthetic-support systems and more recently fluidised beds are now being employed to improve throughput. The alternative reactor system is analogous to a chemostat with arrangements to return the organisms produced by growth, the biomass, to the treatment tank and the excess to waste. Many plants also include a pretreatment by anaerobic digestion. This reduces many of the larger polymers, such as cellulose, to smaller fragments which are more readily assimilated by microbes. Methane is a useful end-product of anaerobic digestion, but its presence illustrates the fact that in the absence of oxygen little mineralisation of pollutants takes place and they appear as other end-products, such as fatty acids and alcohols. Although not originally a design feature of treatment systems, it is desirable that during treatment most of the pathogens found in human and animal excreta are killed. This is an important factor in environmental health. The higher temperatures at which digesters operate (40–45°C) are less favourable for pathogens and aid their destruction.

A chemostat is a device for growing microbes continuously at rates somewhat below their maximum specific growth rate, μ_{\max} . It applies generally only to organisms that can be maintained in a reproductive growth cycle. This can often be achieved even for organisms such as the fungi, whose life cycles are often more complicated. The underlying principle is that medium in which one essential constituent is made growth limiting is continuously added to a reactor vessel. In effluent treatment the limiting growth substrate is often the carbon source. This means that other nutrients serving as sources of nitrogen, sulphur, phosphorus, etc. are in excess and appear in the effluent, to be either diluted or removed by tertiary treatment. At dilution rates below 0.01–0.02 h⁻¹, the kinetics are complicated by the rate at which the microbes are dying, partly due to lack of energy; this means that the assumption that growth is exponential does not hold.

It must be remembered that often dead organisms (that is those that

have lost the ability to reproduce) can metabolise substrates for considerable periods at rates above those obtaining in viable ones where metabolism is carefully regulated to the requirements of growth.

Although the principles, briefly stated above, are relatively simple in concept, some fundamental biological principles are often neglected. These may be considered by first examining the basic processes as related to the final objectives. The efficiency of any plant may be measured by the rate at which the organic material can be removed with the minimum possible production of microbes, so that the final effluent contains the minimum of dissolved or solid residues. This means that the carbon pollutants are to be completely mineralised to CO_2 and H_2O . Thus the plant is a wet oxidation system in which the catalysts are the microbes. In teleological terms the 'aims' of the microbes are to utilise the substrate to grow and reproduce at the maximum rate. Thus in this respect the aims of the microbes and the desires of the engineer are opposed and a compromise position has evolved empirically. This has been arrived at by feeding the effluent to an established colonial microbial mass at such a rate (often expressed as the residence time) that maximum oxidation of organic carbon takes place. In practice residence times of 20 h are equivalent to quite low dilution rates (0.02 h^{-1}) in a chemostat. This means that very low concentrations of substrates are maintained with a consequence that reproduction rates are also low. These conditions appear to favour the growth of microbes which tend to flocculate but it also means that the death rate is high. For instance, in a typical activated sludge system only about 2–5% of the total microbes present are able to reproduce when placed in favourable conditions. One other consequence of such low dilution rates is that the system is very sensitive to shock conditions such as alteration in the flow rate and changes in the concentration of components. Not only do chemical and population changes take place when such perturbations occur, but the system may take a long time, days or weeks depending on their ability, to recover. One immediate method of overcoming shock changes is to use as buffers holding (and mixing) tanks into which the raw effluent is fed before passing on for treatment; however, this can be employed only on relatively small systems. An understanding of the mechanisms of responses to perturbation of the steady state is essential in plant control and for achieving better efficiency.

1.2 POPULATION DYNAMICS

According to classical ecological theory, a mixture of a wide variety of substrates should support a rich and varied population, while single substrates will, by selective pressure, give rise to a restricted population. It may seem surprising therefore that effluents containing few or even single substrates give rise to a comparatively varied population, often not differing widely from those of normal plants treating domestic sewage. This is mainly because of the release of cell contents upon the

4 Treatment of Industrial Effluents

death of cells under starvation conditions and the support of growth of a variety of heterotrophs by so-called cannibalism (Fig. 1.1). Under such starvation conditions competition is severe. Although heterotrophs will be selected predominantly, the maintenance of a low carbon content means that some autotrophs are able to coexist and to flourish. It is on this that we rely for nitrification and the removal of inorganics such as thiocyanate and cyanide, though heterotrophs can also be involved in some of these processes.

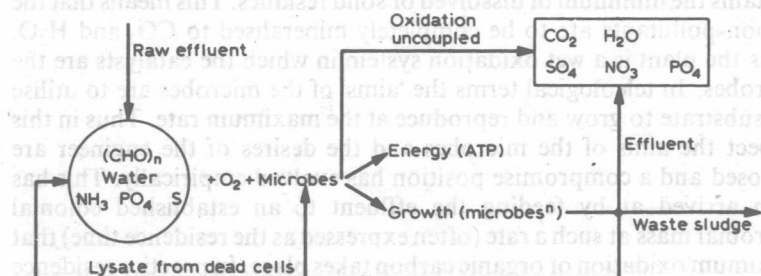


Fig. 1.1 Outline of the transformations which occur during biological effluent treatment

Changes in the concentration of substrates, unless severe, are unlikely to cause marked changes in the population composition. The addition of new substrates is however likely to produce such changes, and throughput will have to be adjusted until the change is accomplished. The source of the new microbe may be from the low numbers already present, by chance contamination or by deliberate inoculation from a rich source of microbes such as soil, mud or an appropriate sludge from another plant. The rate at which the new organism establishes itself will depend on its growth characteristics, mainly on its reproduction time (mean generation time) which may be from about twenty minutes in the case of some pseudomonads to several days for *Mycobacteria* or *Nocardia*. Major changes are rarely found except under 'shock' conditions. For instance, a sudden increase in carbohydrate onto a filter bed often gives rise to a massive overgrowth of micro-fungi, organisms not normally found in large numbers elsewhere in effluent treatment plants.

Short-term fluctuations in oxygen availability are buffered by the presence of facultative anaerobes. However prolonged anaerobiosis will produce marked population changes, not only due to the loss of the aerobes but also to the accumulation of fermentation end-products. Recovery to the state prior to the prolonged anaerobiosis may be slow.

Inter-relations within the mixed microbial population include, in addition to the competitions for substrate, prey-predator relationships and antibiosis. Unlike the soil, antibiosis is not likely to be of major importance in effluent treatment because in such a mixed environment

antibiotics produced by one type of organism are freely available as a foodstuff for another. However, prey-predator relationships are of major importance, and that between the protozoa and the bacteria on which they feed has been the subject of considerable study from which mathematical models have been evolved which evaluate treatment conditions (see Chapter 9). This system is one which readily lends itself to rapid enumeration of the protozoa involved and has therefore proved of use. Most other methods of enumerating specific microbes are too time consuming and difficult to be of use in plant regulation and control. For this reason methods which estimate the activity of the population as if it were composed of a single organism are proving more attractive. They depend essentially on some measurement of enzymic activity and the manner in which this responds to perturbations is now considered below.

1.3 ENZYMIC CHANGES

An assessment of enzyme activity can consist of measuring an overall activity such as CO_2 production, acid production or respiration where oxygen uptake is measured, as in the BOD test. Alternatively single key enzymes may be estimated—for instance, an oxygenase in effluent plants treating phenols. It must be stressed, however, that little has yet been done in this field with single enzymes despite its promise.

Changes in enzyme activity rapidly respond to substrate concentrations, often over a wide range of activities. This may be simply by the laws of mass action, where product and substrate both regulate the rate; the time scale here is seconds or less. In addition, more subtle changes controlling rates are found, particularly in linked enzyme systems where the end-products of a series of reactions feed back and inhibit the first enzyme of the series. Certain key intermediates may also act as regulators of enzyme rates (eg. ATP, NAD, citric acid) (see Chapter 8). Such regulatory systems are of major importance in maintaining the growth of the microbes at their optimum, and are therefore of major importance in the balance between oxidation and biomass production, the central problem of effluent treatment.

In addition to these changes in enzyme rates which occur over periods of seconds and minutes, there are slower changes which may take place over periods of hours or days. These essentially are changes in the enzymic composition of the microbial population which are ultimately determined by the population's genetic composition. Changes in substrate may cause new enzymes to appear (induction) and other enzymes to disappear (repression) (see Chapter 8). The ability of any sludge to respond to changes in substrate composition can therefore be evaluated by measuring its ability to make the necessary enzymes. The best sludges in this respect are those that maintain the widest 'gene bank' and are therefore likely to consist of a wide range of species.

Processes such as contact stabilisation are thought to help establish