

# **Unit Treatment Processes in Water and Wastewater Engineering**

T J Casey

AQUAVARRA RESEARCH LIMITED  
22A Brookfield Avenue  
Blackrock  
Co. Dublin.

October 2006

## Author's Note

Water and wastewater treatment technology is continually evolving in pursuit of better and more economic systems for the production of wholesome drinking water and more effective and efficient systems for the control of water pollution. Advances have been achieved through the combined inputs of many sources including the ever expanding body of fundamental scientific knowledge, advances in process engineering achieved through applied research and innovative design, developments in the fields of instrumentation, process control and electronic data management and, not least, the impact of ever increasing environmental regulations.

This publication presents a comprehensive coverage of the theory, analysis, technology and design of the process engineering used in the production of drinking and other high quality waters, the treatment and disposal of wastewaters and the sludge residues arising therefrom. It was first published in hardcopy format in 1997 by John Wiley & Sons under the title 'Unit Treatment Processes in Water and Wastewater Engineering' as part of the Wiley Series in Water Resources Engineering.

This revised soft copy edition is a free publication of Aquavarra Research Limited (available at [www.aquavarra.ie/publications](http://www.aquavarra.ie/publications)). It is the author's hope that it will be of benefit to students of civil, chemical and environmental engineering as well as design engineers and water industry technical personnel.

T J Casey  
Aquavarra Research Limited  
22A Brookfield Avenue  
Blackrock  
Co. Dublin.

October 2006.

## Preface

Water is one of the prime natural resources, an essential commodity for the living systems that constitute the biosphere, unique in its properties – the only substance to exist in all three phases, solid, liquid and gaseous, within the temperature range of the natural environment, vulnerable to contamination and pollution by human activities, continually renewed by the natural hydrological cycle of evaporation, vapour transportation and precipitation. Water supply and sanitation systems are primary infrastructural needs of communities world-wide, playing a key role in the promotion of public health and the elimination of disease. Water is of course put to many other uses in addition to its drinking water and sanitation uses. High purity waters are used, for example, in the pharmaceutical and semiconductor industries. Water is widely stored and distributed for the irrigation of crops in regions of low rainfall and is used in the electrical power industry for hydropower generation, energy storage and cooling. Thus the engineering associated with water resources management and use is multi-faceted.

This treatise deals with the technologies used to control and modulate water quality to meet the regulatory standards that govern its use for drinking and sanitation purposes and its related use in industrial manufactures. It deals with the range of treatment processes used in the production of drinking and other high quality waters, in the treatment of municipal and industrial wastewaters and in the treatment and disposal of sludge residues. In general, the presentation of the subject matter proceeds sequentially from basic principles through analytical/experimental methods to the development of process design methodologies. Processes are treated as unit operations, emphasising those process fundamentals which can be applied to all process applications.

Chapter 1 presents basic information on water as a substance, with particular reference to the physical and chemical properties of relevance to process technology and design.

Chapters 2 and 3 cover the behaviour of particulate matter in water, including particle settling behaviour, the characteristics of colloidal systems and suspensions and methods for their destabilisation.

Chapters 4, 5 and 6 relate to particle removal processes, including sedimentation, flotation and filtration.

Chapter 7 reviews dissolved species in water. Chapters 8, 9 and 10 relate to dissolved species removal by adsorption, chemical precipitation and ion exchange.

Chapter 11 presents the fundamentals of biological processes and serves as a foundation for the following Chapters 12 and 13 which deal with aerobic suspended floc and biofilm processes technology and design, and for Chapter 15 which deals with the corresponding anaerobic process technologies.

Chapter 14 covers the topic of gas-liquid transfer, the more important process applications of which are to be found in the aeration systems of activated sludge processes and in the air saturation systems associated with dissolved air flotation processes.

The characteristics, treatment and disposal of the sludge residues derived from the various processes used in water and wastewater treatment are the subject matter of Chapter 16.

Chapter 17 covers the topic of water disinfection, which is of critical importance in preventing the spread of waterborne disease.

It is my hope that this treatise will be of benefit to students of civil, chemical and environmental engineering and that it will also serve as a reference work for water system design engineers and water industry technical personnel.

I have endeavoured to acknowledge throughout the text the numerous sources on which I have drawn in the compilation of this treatise. In this context, I would like to make a special reference to the seminal 2-volume publication on the same subject, authored by Fair, Geyer and Okun, published by John Wiley Inc. in 1968, which has had a formative influence on my approach to the subject.

# Contents

- 1. Elements of water science**
  - 1.1 Introduction
  - 1.2 Water Chemistry
    - 1.2.1 Structure and composition of water
    - 1.2.2 Dissolved substances in water
    - 1.2.3 Organic matter in water
    - 1.2.4 Chemical reactions
    - 1.2.5 The carbonate system
  - 1.3 Water physics
    - 1.3.1 Viscosity
    - 1.3.2 Surface tension
    - 1.3.3 Vapour pressure
    - 1.3.4 Density
    - 1.3.5 Diffusivity
    - 1.3.6 Water-dispersed particles
  - 1.4 Gas-water interactions
    - 1.4.1 Gas properties
    - 1.4.2 Gas solubility in water

References
- 2. Settling characteristics of suspensions**
  - 2.1 Introduction
  - 2.2 Settling of discrete particles
  - 2.3 Hindered settling of discrete particles
  - 2.4 Zone settling
  - 2.5 Settling velocity distribution
  - 2.6 Nature of suspensions in sewage treatment
  - 2.7 Nature of suspensions in water treatment

References
- 3. Destabilization of colloidal suspensions**
  - 3.1 Colloidal suspensions
  - 3.2 Coagulation
    - 3.2.1 Effects of electrolytes
  - 3.3 Coagulation with iron and aluminium salts
  - 3.4 Polyelectrolytes
  - 3.5 Determination of the required coagulant dose
    - 3.5.1 Flocculation
    - 3.5.2 The role of velocity gradient in flocculation
    - 3.5.3 Mixing techniques and floc growth
    - 3.5.4 Influence of temperature on coagulation

References
- 4. Separation of suspended solids by sedimentation processes**
  - 4.1 Settling of discrete particles in an ideal flow tank
  - 4.2 Residence time distribution
  - 4.3 Influence of turbulence
  - 4.4 Scouring of deposited particles
  - 4.5 Flow stability
  - 4.6 Sedimentation in wastewater treatment
    - 4.6.1 Grit separation
    - 4.6.2 Primary sedimentation
    - 4.6.3 Secondary sedimentation
  - 4.7 Sedimentation in water treatment
    - 4.7.1 Sludge-blanket clarifiers
  - 4.8 Inclined plate and tube settlers
  - 4.9 Some aspects of hydraulic design

- 4.9.1 Inlet systems
- 4.9.2 Outlet systems
- References

**5. Particle removal by flotation processes**

- 5.1 Introduction
- 5.2 Flotation of suspensions
- 5.3 Determination of design air-solids ratio
- 5.4 Introduction of air
- 5.5 Flotation aids
- 5.6 Design of flotation systems
- 5.7 Comparison with sedimentation
- References

**6. Particle removal by filtration processes**

- 6.1 Introduction
- 6.2 Deep-bed filters
- 6.3 Slow sand filtration
- 6.4 Rapid filters
  - 6.4.1 Rapid filter underdrain systems
- 6.5 Hydraulics of filtration
- 6.6 Removal mechanisms in rapid filtration
- 6.7 Kinetic aspects of suspension removal in rapid filtration
- 6.8 Filter medium selection
- 6.9 Back-washing practice
- 6.10 Cellular sub-division of filtration area
- 6.11 Control of filtration
- 6.12 Membrane filtration
  - 6.12.1 Pressure-driven membrane processes
  - 6.12.2 Membrane fouling
  - 6.12.3 Electrodialysis
- References

**7. Classification of dissolved solids**

- 7.1 Categories of dissolved solids
- 7.2 Inorganic dissolved solids
- 7.3 Organic dissolved solids
  - 7.3.1 Biodegradability of organic substances
  - 7.3.2 Surfactants
- 7.4 Dangerous substances
- References

**8. Adsorption**

- 8.1 Introduction
- 8.2 Activated carbon
- 8.3 Adsorption process
- 8.4 Adsorption equilibrium processes
- 8.5 Design of adsorption systems
  - 8.5.1 PAC process design
  - 8.5.2 GAC process design
- References

**9. Chemical precipitation**

- 9.1 Introduction
- 9.2 Precipitation processes
  - 9.2.1 Precipitation of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$
  - 9.2.2 Precipitation of phosphorus from wastewaters
  - 9.2.3 Reduction and precipitation of  $\text{Cr}^{6+}$
- 9.3 Chemical stabilisation
- References

- 10. Ion exchange**
  - 10.1 Introduction
  - 10.2 Exchange equilibrium
  - 10.3 Selectivity and capacity of exchange resins
  - 10.4 Ion exchange applications
  - References
  
- 11. Biological processes**
  - 11.1 Introduction
  - 11.2 Factors affecting microbial growth
    - 11.2.1 Energy and cell synthesis
    - 11.2.2 Nutrient requirements
    - 11.2.3 Influence of temperature
    - 11.2.4 Influence of pH
    - 11.2.5 Oxygen and microbial growth
  - 11.3 Kinetics of microbial growth
  - 11.4 Biological reactors
  - 11.5 Application of kinetics to a mixed reactor
  - 11.6 Plug-flow reactors
  - References
  
- 12. Activated sludge processes**
  - 12.1 Introduction
  - 12.2 Design considerations
  - 12.3 Oxygen requirements
  - 12.4 Sludge growth
  - 12.5 Physical characteristics of activated sludge
    - 12.5.1 Settleability
    - 12.5.2 Selector tanks
  - 12.6 Separation and recycling of mixed liquor
  - 12.7 Nitrogen removal
    - 12.7.1 Nitrification
    - 12.7.2 Denitrification
    - 12.7.3 Design of nitrogen-removal systems
  - 12.8 Biological phosphorus removal
  - 12.9 Choice of process
  - References
  
- 13. Aerobic biofilters**
  - 13.1 Introduction
  - 13.2 Mode of action
  - 13.3 Ecological aspects
  - 13.4 Seasonal variations
  - 13.5 Process design
  - 13.6 Design of physical facilities
    - 13.6.1 Influent feed
    - 13.6.2 Distribution systems
    - 13.6.3 Filter structure
    - 13.6.4 Ventilation
    - 13.6.5 Filter media
  - 13.7 Comparison of activated sludge and biofilter processes
  - 13.8 Nitrification
  - 13.9 Sludge production in biofilters
  - 13.10 Rotating biological contactor
  - References
  
- 14. Gas-liquid transfer**
  - 14.1 Gas transfer
  - 14.2 Gas solubility

- 14.3 Mechanism and rate of gas transfer
  - 14.4 Oxygen transfer
  - 14.5 Influence of temperature on oxygen transfer
  - 14.6 Aeration system used in the activated sludge process
    - 14.6.1 Dispersed air systems
    - 14.6.2 Mechanical surface aeration systems
  - 14.7 Experimental determination of oxygenation capacity
  - 14.8 Energy consumption and oxygenation efficiency
  - 14.9 Gas stripping
    - 14.9.1 Removal of carbon dioxide
    - 14.9.2 Removal of hydrogen sulphide
    - 14.9.3 Removal of ammonia by aeration
  - 14.10 Gas transfer in packed columns
- References

**15. Anaerobic processes**

- 15.1 Introduction
  - 15.2 Process microbiology
  - 15.3 Environmental influences on the digestion process
  - 15.4 Process kinetics
  - 15.5 Process technology
  - 15.6 Process design
  - 15.7 Digester gas
  - 15.8 Potential uses
- References

**16. Sludge processing and disposal**

- 16.1 Introduction
  - 16.2 Waterworks sludge
    - 16.2.1 Characteristics of alum sludge
  - 16.3 Sewage sludge
    - 16.3.1 Sewage sludge characteristics
  - 16.4 Industrial wastewater sludges
  - 16.5 Processing of sewage sludge
  - 16.6 Solids/water separation processes
    - 16.6.1 Sludge conditioning
    - 16.6.2 Sludge thickening
    - 16.6.3 Sludge dewatering
  - 16.7 Sludge stabilisation
    - 16.7.1 Anaerobic digestion
    - 16.7.2 Aerobic digestion
    - 16.7.3 Chemical stabilization
  - 16.8 Sludge disposal
- References

**17. Disinfection**

- 17.1 Introduction
  - 17.2 Disinfection by chemical agents
  - 17.3 Disinfection by UV light
  - 17.4 Disinfection by heat
  - 17.5 Disinfection by separation processes
  - 17.6 Disinfection with chlorine
    - 17.6.1 Chemical reactions
    - 17.6.2 Chlorine compounds
    - 17.6.3 Trihalomethane formation
    - 17.6.4 Chlorination practice in drinking water treatment
  - 17.7 Disinfection with ozone
- References