Nitrification and Denitrification in the Activated Sludge Process

Michael H. Gerardi

WILEY-INTERSCIENCE

A John Wiley & Sons, Inc., Publication

Nitrification and Denitrification in the Activated Sludge Process

Nitrification and Denitrification in the Activated Sludge Process

Michael H. Gerardi

WILEY-INTERSCIENCE

A John Wiley & Sons, Inc., Publication

This book is printed on acid-free paper. ♾

Published simultaneously in Canada.

For ordering and customer service, call 1-800-CALL-WILEY.

Library of Congress Cataloging-in-Publication Data:

Gerardi, Michael H.
Wastewater microbiology : nitrification/denitrification in the activated sludge process / Michael H. Gerardi.
p. cm.
Includes bibliographical references.
ISBN 0-471-06508-0 (cloth : alk. paper)
1. Sewage—Purification—Nitrogen removal. 2. Nitrification. 3. Sewage—Purification—Activated sludge process. I. Title.
TD758.3.N58 G47 2002 2001046765

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

To
L. Vernon Frye
and
the men and women of the
Williamsport Sanitary Authority
and
Williamsport Municipal Water Authority

The author extends his sincere appreciation to
joVanna Gerardi for computer support
and
Cristopher Noviello for artwork used in this text.

Contents

Preface

Within the last 15 years much interest and use of microbiological principles of wastewater treatment have been successfully applied to the activated sludge process. These principles include the use of the microscope for process control and a better understanding of the microorganisms, especially the bacteria that are involved in the degradation of wastes.

Of special interest to wastewater treatment plant operators are the bacteria that degrade nitrogenous wastes—the nitrifying bacteria—and the bacteria that degrade carbonaceous wastes—the cBOD-removing bacteria. Both groups of bacteria need to be routinely monitored and operational conditions favorably adjusted to ensure desired nitrification. However, operational conditions do change, often in a very short period of time, and an undesired change in operational conditions can adversely affect the bacteria within the activated sludge process and its ability to degrade wastes.

Regardless of discharge permit limitations, activated sludge processes that are and are not required to nitrify and denitrify do nitrify and denitrify. Often these plants develop a form of incomplete nitrification or undesired denitrification that is responsible for an operational upset, an increase in operational costs, and noncompliance with a discharge limitation. Therefore, with a minimum of technical jargon and numerous tables and illustrations, this book addresses the microbiological principles of the bacteria and operational conditions that affect nitrification and denitrification in the activated sludge process. The book is target for operators who are responsible for the daily operation of the activated sludge process regardless if the process is or is not required to nitrify or denitrify. Each chapter is prepared to offer a better understanding of the importance of nitrification and denitrification and the bacteria involved in nitrification and denitrification. The book provides the operator with process control and troubleshooting measures that help to maintain permit compliance and cost-effective operation.

Nitrification and Denitrification in the Activated Sludge Process is the first book in the Wastewater Microbiology series by John Wiley & Sons. This series is designed for operators and provides a microbiological review of the organisms involved in wastewater treatment, their beneficial and detrimental roles, and the biological techniques available for operators to monitor and regulate the activities of these organisms.

Michael H. Gerardi
Linden, Pennsylvania

Part I

Overview

1

Nitrogen: Environmental and Wastewater Concerns

The presence of nitrogenous or nitrogen-containing wastes in the final effluent of an activated sludge process can adversely impact or pollute the quality of the receiving water. Principle nitrogenous wastes that pollute the receiving water are ammonium ions (NH_4^+), nitrite ions (NO_2^-), and nitrate ions (NO_3^-). Ions are chemical compounds that possess a negative (–) or positive (+) charge. Significant pollution concerns related to the presence of nitrogenous wastes include dissolved oxygen (O_2) depletion, toxicity, eutrophication, and methemoglobinemia (Table 1.1).

To reduce the adverse impacts of nitrogenous wastes upon the receiving water, an activated sludge process may be required by state and federal regulatory agencies to lower the quantity of nitrogenous wastes in its final effluent. The activated sludge process would have to nitrify and denitrify the nitrogenous wastes. A nitrification requirement usually is issued as an ammonia (NH_3) discharge limit, and a denitrification requirement usually is issued as total nitrogen or total kjeldahl nitrogen (TKN) discharge limit (Table 1.2).

DISSOLVED OXYGEN DEPLETION

The discharge of nitrogenous wastes to the receiving water results in dissolved oxygen depletion. The depletion occurs through the consumption of dissolved oxygen by microbial activity.

TABLE 1.1 Pollution Concerns Related to Excess NH_4^+, NO_2^-, and NO_3^-

Nitrogenous Ion	Pollution Concerns
NH_4^+	Overabundant growth of aquatic plants Dissolved oxygen depletion Toxicity as NH_3
NO_2^-	Overabundant growth of aquatic plants Dissolved oxygen depletion Toxicity
NO_3^-	Overabundant growth of aquatic plants Dissolved oxygen depletion Toxicity Methemoglobinemia

First, ammonium ions are oxidized to nitrite ions, and nitrite ions are oxidized to nitrate ions within the receiving water (Figure 1.1). The oxidation of each ion occurs as dissolved oxygen is removed from the receiving water by bacteria and added to ammonium ions and nitrite ions. Second, ammonium ions, nitrite ions, and nitrate ions serve as a nitrogen nutrient for the growth of aquatic plants, especially algae. When these plants die, dissolved oxygen is removed from the receiving water by bacteria to decompose the dead plants (Figure 1.2).

TOXICITY

All three nitrogenous ions can be toxicity to aquatic life, especially fish. Ammonium ions and nitrite ions are extremely toxic, and nitrite ions are the most toxic of the three nitrogenous ions.

TABLE 1.2 Permit Requirements for Nitrification and Denitrification

Requirement	Description	Nitrification/Denitrification
NH_3	Ammonia	Nitrification
NH_4^+	Ammonium ion	Nitrification
nBOD	Nitrogenous biochemical oxygen demand	Nitrification/denitrification
NOD	Nitrogenous oxygen demand	Nitrification/denitrification
TKN	Total kjeldahl nitrogen	Nitrification/denitrification

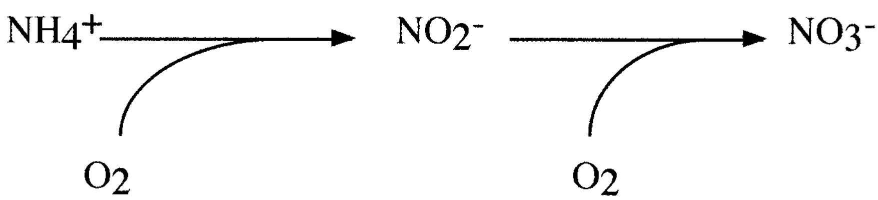

Figure 1.1 Oxidation of ammonium ions and oxidation of nitrite ions. Under appropriate conditions nitrification occurs when oxygen is removed from water, or a water film, and added to ammonium ions to produce nitrite ions, or added to nitrite ions to produce nitrate ions. Although many organisms such as algae, bacteria, fungi, and protozoa are capable of nitrifying ammonium ions and nitrite ions, a specialized group of nitrifying bacteria is primarily responsible for nitrification in water and soil.

Although ammonium ions are the preferred nitrogen nutrient for most organisms, ammonium ions are converted to ammonia with increasing pH (Figure 1.3). It is the ammonia at an elevated pH that is toxic to aquatic life.

EUTROPHICATION

While phosphates (PO_4^{2-}) are the primary source of eutrophication, nitrogenous wastes contribute significantly to this water pollution problem. Eutrophication refers to the discharge of plant nutrients, primarily phosphorus and nitrogen, in undesired quantities to bodies of freshwater, such as lakes and ponds. The presence of undesired quantities of plant nutrients stimulates the rapid growth or blooms of

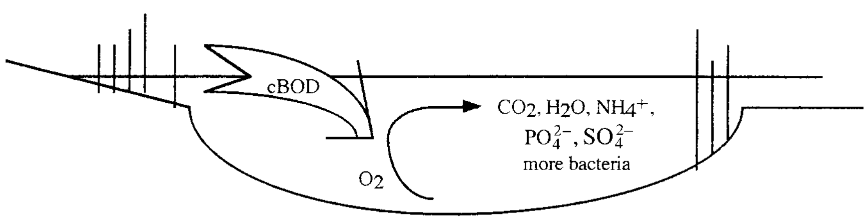

Figure 1.2 Oxygen used during decomposition of dead plants. As large blooms of aquatic plants die in the water, a large diversity of bacteria and fungi quickly remove large quantities of dissolved oxygen and decompose the plant tissue into carbon dioxide, water, ammonium ions, phosphate ions, and sulfate ions. The bacteria and fungi transform some of the organic material from the plant tissue into new bacterial and fungal cells.

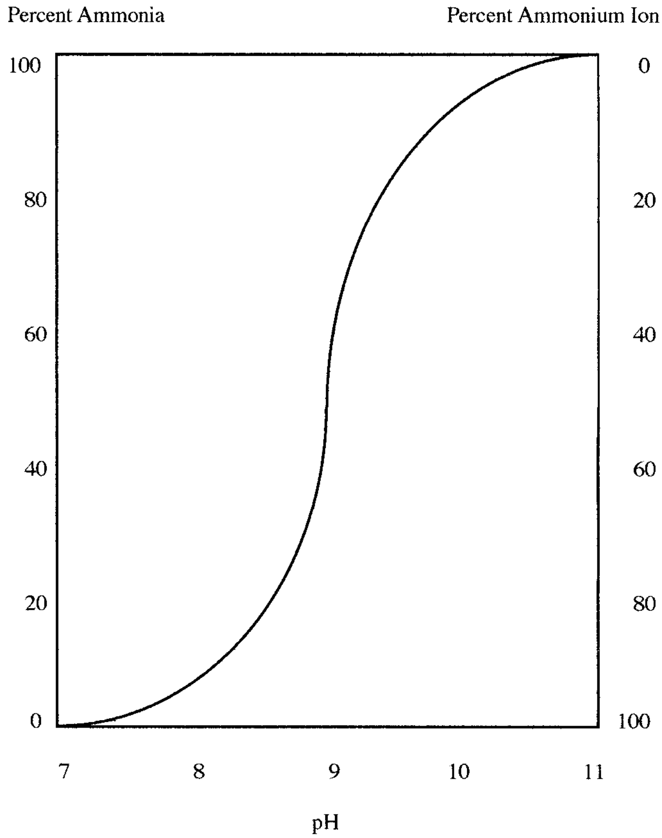

Figure 1.3 *pH and the conversion of ammonia and ammonium ions. The relative quantities of ammonia and ammonium ions in water are determined by the pH of the water. As the pH of the water decreases, ammonium ions are favored. As the pH of the water increases, ammonia is favored. At a pH value of 9.4 or higher, ammonia is strongly favored.*

aquatic plants, including algae. When these plants die, the bodies of freshwater rapidly fill with those parts of the plants that do not decompose. Eutrophication results in the rapid "aging" of the bodies of freshwater as they are lost quickly over time due to the accumulation of parts of plants that do not decompose.

Eutrophication also results in additional water pollution problems. These problems include fluctuations in dissolved oxygen concentration with the growth and death of aquatic plants, the clogging of receiving water caused by the sudden bloom of aquatic plants, and the production of color, odor, taste, and turbidity problems associated with the growth and death of aquatic plants.