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COMPOST ENGINEERING

Principles and Practice

ANN ARBOR SCIENCE

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Paris throws five millions a year into the sea. And this without metaphor. How, and in what manner? day and night. With what object? without any object. With what thought? without thinking of it. For what return? for nothing. By means of what organ? by means of its intestine? its sewer. . . .

Science, after long experiment, now knows that the most fertilising and the most effective of manures is that of man. The Chinese, we must say to our shame, knew it before us. No Chinese peasant . . . goes to the city without carrying back, at the two ends of his bamboo, two buckets full of what we call filth. Thanks to human fertilisation, the earth in China is still as young as in the days of Abraham. Chinese wheat yields a hundred and twenty fold. There is no guano comparable in fertility to the detritus of capital. A great city is the most powerful of stercoraries. To employ the city to enrich the plain would be a sure success. If our gold is filth, on the other hand, our filth is gold.

What is done with this filth, gold? It is swept into the abyss.

We fit out convoys of ships, at great expense, to gather up at the south pole the droppings of petrels and penguins, and the incalculable element of wealth which we have under our own hand, we send to the sea. All the human and animal manure which the world loses, restored to the land instead of being thrown into the water, would suffice to nourish the world.

These heaps of garbage at the corners of the stone blocks, these tumbrils of mire jolting through the streets at night, these horrid scavengers' carts, these fetid streams of subterranean slime which the pavement hides from you, do you know what all this is? It is the flowering meadow, it is the green grass, it is marjoram and thyme and sage, it is game, it is cattle, it is the satisfied low of huge oxen at evening, it is perfumed hay, it is golden corn, it is bread on your table, it is warm blood in your veins, it is health, it is joy, it is life. . . .

Put that into the great crucible; your abundance shall spring from it. The nutrition of the plains makes the nourishment of men.

from *Les Miserables*
by **Victor Hugo** (1862)

PREFACE

My introduction to composting came in 1972 when I was an engineering faculty member at Loyola University. My father then worked for the Los Angeles County Sanitation Districts and was instrumental in implementing a windrow composting facility on anaerobically digested sludge. Until that time, dewatered sludge was placed on the ground in thin layers (about 0.5 m depth) to air dry before reuse. Septic conditions often developed beneath the surface layer and odors were a constant problem. Various techniques had been tried over the years to control odors with only moderate success.

The Districts had conducted considerable research on refuse composting, but it was commonly thought that dewatered sludge cake could not be composted by itself because of the high moisture content. A crisis of odor complaints in late 1971 convinced District management to try the composting approach, even though some concern was expressed that periodic compost turning would only aggravate the odor problem. A key factor which made the operation successful was my father's idea of recycling dry product and blending with dewatered cake to adjust conditions of the starting mixture. The experiment began in February 1972. Within the first few days of composting, previously odorous material was converted to an aerobic condition. Odors were markedly decreased and complaints from the surrounding neighborhood dropped sharply. By July 1972 all dewatered sludge was being windrow-composted. Results were so impressive that the Districts were commended by the county for solving a major community problem.

A number of lessons were learned during this time. First, dewatered sludge cake could be composted using recycled product as the sole amendment. Second, the importance of odor and nuisance control in sludge management was emphasized. No other factor, including economics, seemed as important as odor control, particularly if odors were out of control. Composting was also demonstrated to reduce odor problems compared to certain other management alternatives. Because of this and other experiences with odors, an entire chapter of this book has been devoted to nuisance control.

In 1975 I removed my full-time academic gowns to become senior engineer for the LA/OMA project. The latter was a facilities planning effort to develop a long-range plan for management of sewage sludges generated in the Los Angeles and Orange County metropolitan areas. The project gave me the opportunity to observe sludge management systems throughout the United States, to study alternative systems and to direct technical studies and field experiments designed to gather information in areas where knowledge was lacking. All feasible management alternatives, including sludge composting, were analyzed in depth by the project, and several field-scale demonstration projects were conducted.

It began to appear that our basic knowledge of composting was becoming complete. Just as complacency was about to set in, a sequence of events occurred which profoundly altered my thinking. The first was a letter from a colleague which had been prompted by a presentation on composting I had made recently. The letter asked a rather simple question regarding the effect of product recycle on the energy budget achieved during composting. My inability to answer the question adequately triggered thought processes which eventually led to detailed thermodynamic analysis of the problem. It's interesting to speculate on the small things, such as a question asked at the right time, which trigger sudden insights and result in extensive human endeavors.

A second event was the startup of expanded dewatering facilities by the Los Angeles County Sanitation Districts in 1977. It was intended that all dewatered sludge continue to be windrow composted. Since 1972 the windrow system had successfully processed about 90 dry metric tons per day of digested sludge, dewatered to 30-35% solids. On completon of the new dewatering facilities, sludge tonnage increased to about 270 dry ton/day, but cake solids decreased to only about 23%. When combined with effects of wet weather and other operational difficulties, odor emissions and complaints increased dramatically. Water load on the system increased by a factor of about five as a result of the decrease in cake solids and the increase in dry tonnage. Although it was not known at the time, thermodynamic constraints had been exceeded. This in part led to process failure with subsequent high odor emissions and reduced composting temperatures.

This experience emphasized the need for more fundamental knowledge of the compost process. Indeed, millions of dollars had been spent and much research conducted in designing and constructing the sludge dewatering facility. Unfortunately, similar attention was not given the downstream compost process. I must point out that this judgment is made with the clear vision provided by hindsight. Nevertheless, the experience highlighted the fact that solids content produced from dewatering is an important variable in determining the successful composting of sludge. As it turns out, moisture and volatile solids control and the energy budget for the system are largely influenced by this parameter. Sludge composting has since been described as a problem of moisture control. The reader will note that several chapters of this book are devoted to the subjects of moisture control and system thermodynamics.

Another event which sparked my interest was development of the aerated static pile compost system at Beltsville, MD. This was an entirely different approach to composting compared to the windrow system. Wood chips were used as a "bulking agent" and periodic turning was not used. This prompted several questions. What was the function of the bulking agent? What physical factors influenced the required ratio of wood chips to sludge? What changes in physical properties resulted from use of bulking agents? Were these changes the same as those resulting from use of recycled compost in the windrow system? These intriguing questions spurred further investigations into feed conditioning requirements to produce a starting material with the proper combination of moisture content and free airspace.

Finally, in my position with the LA/OMA project, I had the opportunity to investigate the many enclosed reactor systems available for sludge composting. Some of these systems were designed from the start for sludge composting, while others were originally used on refuse or other relatively dry material. Questions immediately arose in trying to provide a technical assessment of these systems. As one example, required detention times quoted by various manufacturers ranged from as low as 1 day to as high as 14 days. The literature on refuse composting clearly indicated that a one-day detention time was not adequate for stabilization of most organic components. Beyond this, however, the available literature was not particularly helpful. Further analysis of process kinetics was clearly necessary to determine detention time requirements and to identify tradeoffs between detention time, organic stabilization and reactor stability.

It is against the backdrop of these and other experiences that I undertook the study and analysis which culminated in this book. My goal has been to produce a more fundamental engineering approach to the analysis of composting. I hope I have been at least partially successful in achieving this goal. Perhaps the crowning achievement of this effort has been the integration of thermodynamics and process kinetics into a unified model of composting. Although much work remains to improve and further verify the model, its use can guide the analysis and design of present day systems. Preliminary answers can be provided to questions for which experimental data are not available.

In compiling this book, I have drawn heavily on the work of early pioneers and present workers in the field of composting. The reader of this text will become quite familiar with their names. I have tried to represent their data as accurately as possible. Any errors in the analysis are solely my own, as are the comments and opinions expressed in the book.

I owe a great debt of gratitude to those who trained me in the disciplines of engineering. The efforts of Dr. James Foxworthy of Loyola University and Dr. Perry McCarty of Stanford University are most appreciated. I owe a debt to my father, Mr. Lester Haug, which can never fully be repaid. He introduced me to this subject, provided fresh ideas and insights when I needed them, and was the sounding board for numerous theories. In the past eight years, I hardly recall a family meeting which did not end up in a discussion of fundamental aspects of composting, much to the dismay of wives and children. My wife deserves special thanks for the support she provided during the long hours necessary to complete this text and for her proofing of the manuscript. Mrs. Alma Rios and Mrs. Jan Tanori receive my warmest thanks for typing the bulk of the manuscript and Mr. Greg Jowyk for supplying many of the graphics.

Roger Tim Haug

CONTENTS

CHAPTER 1

INTRODUCTION

COMPOSTING–DEFINITION AND OBJECTIVES

There is no universally accepted definition of composting. In this text, composting is defined as the biological decomposition and stabilization of organic substrates under conditions which allow development of thermophilic temperatures as a result of biologically produced heat, with a final product sufficiently stable for storage and application to land without adverse environmental effects. Thus, composting is a form of waste stabilization, but one that requires special conditions of moisture and aeration to produce thermophilic temperatures. Most biological stabilization and conversion processes deal with dilute aqueous solutions, and only limited temperature elevations are possible. Thermophilic temperatures in aqueous solutions can be achieved if substrate concentrations are high and if special provisions for aeration are employed. Aside from such special cases, composting is usually applied to solid or semisolid materials, making composting somewhat unique among the biological stabilization processes used in sanitary and biochemical engineering.

Aerobic composting is the decomposition of organic substrates in the presence of oxygen (air). The main products of biological metabolism are carbon dioxide, water and heat. Anaerobic composting is the biological decomposition of organic substrates in the absence of oxygen. Metabolic end products of anaerobic decomposition are methane, carbon dioxide and numerous intermediates such as low-molecular-weight organic acids. Anaerobic composting releases significantly less energy per weight of organics decomposed compared with aerobic composting. Anaerobic composting has a higher odor potential because of the nature of many intermediate metabolites. For these reasons almost all engineered compost systems are aerobic. Mass transfer limitations, however, may cause anaerobic zones in an otherwise aerobic system. Such subtleties aside, this book will deal primarily with aerobic systems because of their commercial importance to man.

The objectives of composting have traditionally been to biologically convert putrescible organics to a stabilized form and to destroy organisms pathogenic to humans. Composting is also capable of destroying plant diseases, weed seeds, insects and insect eggs. Odor potential from use of compost is greatly reduced because organics that remain after proper composting are relatively stable with low rates of decomposition. Composting can also effect considerable drying, which is of particular value with wet substrates such as municipal and industrial sludges. Decomposition of substrate organics together with drying during composting can reduce the cost of subsequent handling and increase the attractiveness of compost for reuse or disposal.

Compost can be disposed of in a sanitary and usually convenient manner. If the product is reused, it can accomplish a number of additional purposes including:

1. to serve as a source of organic matter for maintaining or building supplies of soil humus, necessary for proper soil structure and moisture-holding capacity;
2. to improve growth and vigor of crops in commerical agriculture or home-related uses; and
3. to reclaim and reuse certain valuable nutrients including nitrogen, phosphorus and a wide variety of essential trace elements.

The nutrient content of compost is related to the quality of the original organic substrate. However, most composts are too low in nutrients to be classified as fertilizers. Their main use is as a soil conditioner, mulch, top dressing or as an organic base with fertilizer amendments. On the other hand, nutrients such as nitrogen are organically bound and slowly released throughout the growing season, making them less susceptible to loss by leaching compared to soluble fertilizers.

PRESENT LIMITATIONS

The most common engineered application of microbes is to treat or convert substrates in aqueous solution. Suspended growth reactors, such as the activated sludge process, or fixed film reactors, such as the trickling filter and rotating biological contactor (RBC), are widely used for treatment of municipal and industrial liquid wastes. Biological engineering is well developed and it is possible to design and operate such systems using a reasoned, engineered approach.

There are a number of biological processes used on solid or semisolid materials including fermentation and ripening of cheese, production of silage and, of course, composting. At least in the case of composting, a reasoned, fundamental approach to analysis has not been fully developed.

Almost every book on the subject of composting begins with the statement that composting is an ancient art, probably practiced by man since before the dawn of recorded history. Although the evidence suggests that man has had a long affair with composting, fundamental scientific studies of the process have generally occurred in the past three decades. Our ability to engineer the process and to understand the numerous competing forces within a composting material is even less well developed. In other words, the theory of composting may be understood and most of the forces involved may be known, yet engineering of systems is still often conducted using a "handbook" approach with little knowledge of how to control these forces to achieve the final end product. It is a goal of this book to develop a more fundamental approach to analysis and design, one that would rely as much as possible on first principles of physics, chemistry, biology, thermodynamics and kinetics.

COMPOSTING SUBSTRATES

The quantity of substrates potentially suitable for composting is indeed large. One estimate of solid and semisolid organic wastes generated and collected in the United States is shown in Table 1-1. Urban refuse, manure and agricultural wastes represent major components of the collected fraction, which totals over 100 million ton/yr. Problems encountered in managing waste materials depend not only on quantity, but also on their characteristics. Thus, municipal and industrial sludges, because of their high moisture

Table 1-1. Estimates of Organic Wastes Generated and Collected in the U.S. in 1971 (10^6 ton/yr, dry wt) [1][a]

Waste Type	Generated	Collected
Urban Refuse	115	65
Manure	180	24
Agricultural Crops and Food Wastes	355	21
Industrial Wastes	40	5
Logging and Wood-Manufacturing Residues	50	5
Miscellaneous Organic Wastes	45	5
Municipal Sewage Solids	11	2
Total	796	127

[a]Values rounded from original reference.

content, may present management difficulties far in excess of their relative tonnage.

There appear to be essentially two basic approaches to resource recovery from organic wastes: (1) use of the organics (and associated nutrients) either directly in the soil or after production of compost material, and (2) conversion of the organics to alternative energy forms. Both paths to resource recovery have noble objectives. Compost is a proven organic supplement which, by supplying humus and nutrients to deficient soils, can greatly improve crop yields. Alternatively, the energy potential of organic wastes is considerable. Development of the resource as an alternative fuel has received economic impetus from worldwide increases in energy prices. Which of these reuse possibilities will win out? To answer this, the characteristics of waste organics must be examined.

Relatively dry wastes, such as municipal refuse, are probably more valuable as energy resources. Energy can be extracted efficiently by thermal processes (e.g., incineration, pyrolysis and gasification) because of the dry nature of the material. Costs of extraction may be high and certain components of a heterogeneous waste, such as refuse, will not be amenable to thermal processing. As moisture content increases, thermal processing becomes much less efficient. For combustion to be self-supporting, it is usually necessary for moisture levels to be less than 60-70%, although the exact value depends on the nature of the organic being burned. If the waste is in the form of a liquid slurry or suspension, anaerobic digestion is the only practical energy recovery method. But what about residues remaining after anaerobic digestion, or other organic wastes too wet for efficient thermal conversion to energy? In the past, fossil fuels were often added to such wastes either to support combustion of the organics or to remove moisture (heat drying). But such processes are energy-intensive, and the use of fossil fuels in this manner is falling into increasing disfavor, as well as becoming very expensive.

High-moisture (greater than about 60%) organic wastes represent a rather unique management problem. Direct application to land is possible, but such practice is usually limited to rural areas where sufficient land is available. Composting can be particularly effective in converting wet materials to a more usable or easily disposable form. At the same time, composting can stabilize putrescible organics, destroy pathogenic organisms and provide significant drying of the wet substrate. All of these advantages are obtained with minimal outside energy input; the major energy resource being the substrate organics themselves. Furthermore, composting is a flexible process: it can be viewed as a conversion process to produce a material suitable for reuse or simply as a stabilization and drying process to provide for easier disposal. Composting is also compatible with a wide variety of feedstocks.

Sludges from municipal and industrial wastewater treatment, certain other industrial processes and animal manures represent a major portion of the high-moisture organic wastes. Estimates of past and future municipal sludge production in the United States are presented in Figure 1-1. Amounts are expected to increase as treatment plants are expanded and upgraded to higher levels of treatment. The present annual production of municipal sludge is about 6-7 million metric tons dry weight. Suler [2] presented the following partial list of organic industrial sludges:

- The food industry generates about 650,000 dry ton/yr of organic sludges which are mostly readily degradable.
- The textile industry produces about 300,000 dry ton/yr, mostly organic and composed of cotton, wool, synthetic fibers, dyes and sizing.

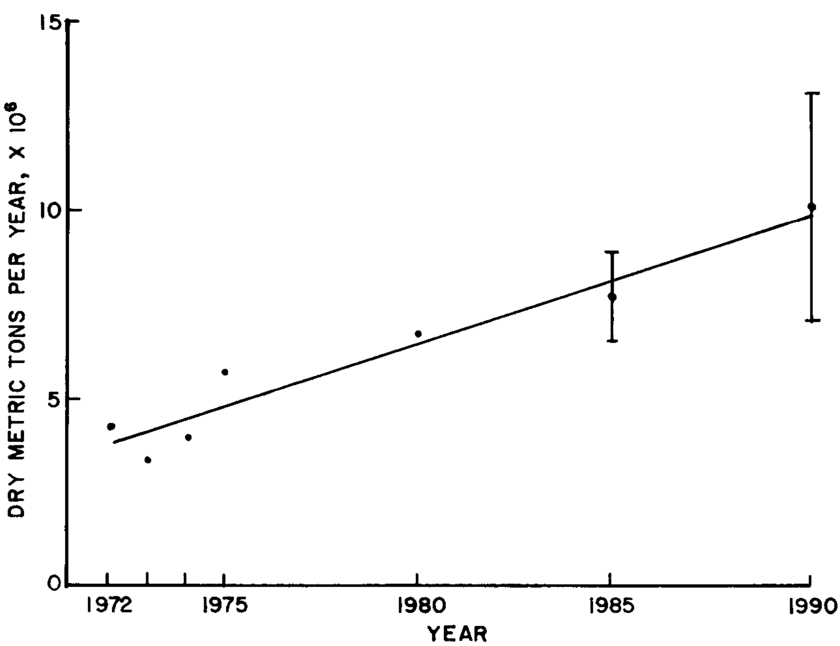

Figure 1-1. Estimates of present total U.S. sludge production and predictions for future sludge production. Values for metric tons dry weight produced in the years 1972–1975 are based on estimates of population served by wastewater treatment and per capita solids production. Projections for 1980, 1985 and 1990 reflect the increase of sludge expected to arise from institution of secondary wastewater treatment at all facilities where it is not now in effect and from construction of new facilities. Ranges are given for 1985 and 1990 estimates. Data presented here indicate that between 1972 and 1990 the amount of sludge produced per capita in the U.S. may more than double. Data compiled by National Research Council of the National Academy of Sciences [3]. See cited reference for original sources of information.