UNIFORM AERATION OF COMPOST MEDIA

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ABSTRACT

Supplying air to aerobic composting systems is essential to provide metabolic oxygen, control process temperatures, and minimize odors. An important objective when designing forced draft aeration systems for composting facilities is providing for the controlled and uniform distribution of air throughout the compost media. Over-aeration of the compost media may remove the heat required for adequate microbial decomposition and pathogen destruction, while too little air can result in excessive temperatures and undesirable anaerobic conditions. The design and performance of a uniform air distribution system for a Washington yard debris composting facility is described.

INTRODUCTION

The controlled, uniform distribution of air within composting media enhances the aerobic composting process. Failure to provide this distribution may result in operational difficulties related to poor media decomposition, low pathogen destruction, and nuisance odors attributed to the formation of anaerobic conditions. This paper describes the design of a combined forced/induced draft ("push/pull") aeration system installed at an 80 ton-per-day yard debris composting facility in Pierce County, Washington. A brief review of the more common methods for aerating compost is presented, followed by a summary of the design basis used to design the facility. The mathematical methods used to hydraulically analyze the aeration system are presented, and relevant construction details described. Finally, the performance of the system to date is presented, including a discussion of recommended design modifications.

AERATION REQUIREMENTS

Aeration is necessary during the yard debris composting process to provide oxygen for microbial activity and to remove excess heat. Aeration is also necessary for reducing the moisture content of the resulting product to an acceptable level (35 to 40 percent) for mechanical screening. The removal of excess heat produced during the process, by an order of magnitude, requires the greatest volume of aeration air. Consequently, aeration systems are designed to meet this aeration demand. Aeration rates required to maintain 55°C temperatures in a composting system are determined by calculating the amount of air required to remove the heat produced by the materials to be composted. The following equation was used for estimating the rate of aeration air required to maintain 55°C.

$$AR_{sf} = \frac{OE_{Btu}H_tFL_{sf}}{PW_{air}} \tag{1}$$

Where

AR_{sf} = Aeration (cfm/ft^2)
O = Oxygen demand
$E/_{Btu}$ = Energy release
H_t = Air demand to maintain 55°C
FL_{sf} = Feedstock loading on aeration floor
P = Period of energy release
W_{air} = Weight of air

For this aeration design, the following assumptions were made:

O = 0.25 lb. microbial O_2 uptake per dry lb yard debris
E_{Btu} = 5,866 MTUs per lb O_2 demand

H_t = lb air per Btu released
FL_{sf} = 0.044 dry tons of yard debris per ft^2
P = 21 days
W_{air} = 0.0748 lb air per ft^3

The value for oxygen demand was based on previous composting projects conducted by E&A Environmental Consultants, Inc., and assumes the maximum dry weight fraction of grass, in the incoming yard debris is 0.3. Values for energy release and air demand are presented in Haug.[1] The value for air demand assumes ambient temperature and humidity are 20°C and 75 percent, respectively, and the exhaust gas is saturated. The feedstock loading value assumes the shredded yard debris has a bulk density of 500 pounds per cubic yard and the pile height is 10 feet. Yard debris is processed for approximately 21 days at the resulting aeration rate of 1.25 cfm per square foot of aeration floor (2,000 CFH/dry ton). During the remaining 45 days of the process, a lower aeration rate of 0.63 cfm per square foot of aeration floor is utilized. This lower aeration rate is justified by the lower oxygen demand of the composting yard debris after 21 days of processing.

TYPES OF AERATION SYSTEMS

Piping systems used to actively aerate compost media are typically classified into moveable or fixed types.

Moveable Aeration Piping Systems

Moveable aeration systems commonly consist of a perforated plastic pipe that is placed at the base of, or within the composting media as it is formed into windrows. The end of the pipe is connected to the outlet of a blower and atmospheric air is applied to the pile or bed. To remove process gas (if desired), the pipe is switched from the blower outlet to the blower inlet, either by disconnecting and re-connecting the pipe, or by utilizing a valve arrangement.

The pipe used in moveable aeration applications is typically corrugated polyethylene (CPE) pipe which has been machine-perforated. Machine-perforated CPE pipe is available in diameters ranging from 4 to 8 inches. The perforation schedules of machine-perforated CPE pipe vary, depending on the pipe manufacturer (Haug, 1993).

The mathematical analysis of machine-perforated CPE pipe for use as a uniform air distribution system is made difficult by the more or less random size and placement of the machine-produced perforations along the length of the pipe. It is possible, however, to utilize non-perforated CPE and specify the diameter and spacing of the perforations to provide a uniform distribution of air. Even so, the issue of how to protect the aeration pipe from damage when the compost must be moved (which can be several times during the composting period) remains with a moveable aeration piping system.

Fixed Aeration Piping Systems

Fixed aeration piping systems use fixed, permanent piping, typically located below the composting floor elevation. Two of the more common methods involve permanently casting the aeration pipe into or beneath the floor, or laying it into concrete channels cast into the floor. The advantage of the latter is that the pipe can be replaced if necessary.

The pipe used in fixed systems may be CPE (factory-perforated or non-perforated), smooth-walled high density polyethylene (HDPE), or polyvinyl chloride (PVC). If the pipe is installed in channels, it is simply perforated, if necessary, and placed into the channel. The channel is then either backfilled with gravel, covered with a steel grate, or both, to provide protection from equipment loads. The channels are typically arranged in a parallel fashion across the composting floor according to material flow and aeration requirements.

If the aeration pipe is permanently cast into, or installed below, the composting floor, risers (nozzles) are required to deliver the air from the pipe to orifices at the top of the floor. The nozzles are usually spaced in a uniform grid across the composting floor.

Fixed aeration piping systems lend themselves well to mathematical analysis for uniform air distribution, as the size and spacing of orifices or nozzles may be specified prior to installation.

DESIGN BASIS

The aeration system design basis memorandum (DBM) for the Pierce County Yard Waste Composting Facility stipulated that the facility incorporate the following design features:

- Fixed Aeration Piping System
- Forced and Induced Draft Capability
- Method for Flushing Aeration Piping
- Non-Clogging, Self-Clearing Orifices
- Multiple Aeration Zones
- Centrally Located Blowers
- Adaptability to Automatic Operation

Fixed Aeration Piping System

A fixed aeration piping system was specified to provide a uniform supply of air to the base of the composting media. All aeration system components were to be installed

[1]Haug, Roger T. *The Practical Handbook of Compost Engineering* (Boca Raton, Lewis Publishers, 1993).

flush with, or below, the concrete composting floor to allow the unimpeded travel of trucks, windrow turners, and front end loaders.

Forced and Induced Draft Capability

The aeration system was to provide the ability to both push (forced draft) and pull (induced draft) air through the composting media. Alternating between the two modes of operation aids to prevent overdrying of the compost, enhances the distribution of air, and helps to control odors (in the pull mode).

Method for Flushing Aeration Piping

The inspection of several operating facilities during the development of the Pierce County facility design basis emphasized the importance of providing a reliable method for flushing the interior of the aeration piping. The lack of an ability to clean the aeration system piping at several facilities resulted in high maintenance costs, reduction of air flow, and in one instance, anaerobic conditions developing within the aeration piping itself. The facility aeration system, then, was to be designed to be easily cleaned.

Non-Clogging, Self-Clearing Orifices

A design requirement that was closely related to the ability to flush the aeration piping, was to provide non-clogging, or if possible, self-clearing, aeration orifices. The thought behind this operator request was to provide a way to allow material that might lodge in an orifice fall into the aeration system piping and be flushed away during routine cleaning.

Multiple Aeration Zones

The amount of air needed varies as the composting media is moved across the floor during the composting period. For this reason, the composting floor was divided into four major aeration zones. Zones 1 and 2 were specified to provide air at a maximum rate of 1.25 cubic feet per minute (cfm) per square foot of floor, while zones 3 and 4 were to provide air at a rate of 0.63 cfm per square foot of floor. The basis for these air flow rates was previously presented in this paper.

Centrally Located Blowers

Rather than installing several small horsepower aeration blowers throughout the facility, a decision was made to centrally locate a few, larger horsepower blowers and distribute the air to the aeration system using a network of below ground ducts. In this way, the control of air could be accomplished from a central location, reducing electrical distribution costs and maintenance issues associated with multiple equipment.

Adaptability to Automatic Operation

The ability to automatically and remotely monitor and modify operating parameters was a future requirement of the facility. Because of this, the blowers were specified to be centrally located to simplify their conversion to automatic operation. Electrical conduits were also requested to be installed within the composting floor connecting the various aeration valve vaults. This was done to provide for the future replacement of manual isolation valves with electrically operated control valves.

HYDRAULIC ANALYSIS

A simplified economic analysis was performed that showed a fixed aeration piping system utilizing a nozzle discharge arrangement to be more cost effective than the channel/pipe configuration when taking into account the cost of concrete form work and steel grating. To further control costs, a decision was made to limit the diameter of the aeration pipes to a maximum of 6 inches, and the spacing between orifices to 6 feet.

A hydraulic analysis was performed, assuming that the aeration pipe would act as a simple sparger in the "push," or forced draft, mode. In designing a sparger, the objective is to get uniform flow distribution along the length of the perforated pipe. Knaebel[2] offers a simplified sparger design that states when the length to diameter ratio of a sparger is 150 or less, the following constraint must be satisfied in order to achieve a sparger maldistribution of less than 5 percent:

$$D_o \preceq 0.7 \frac{D_p}{\sqrt{N}} \qquad (2)$$

Where

D_o = diameter of orifice, feet
D_p = diameter of sparger, feet
N = number of orifices in sparger
L = length of sparger, feet

When the sparger L/D_p ratio is greater than 150, Equation 3 must also be true to achieve a similar uniform distribution.

$$D_0 \preceq \frac{D_p}{\left[1 + \frac{LN^2}{39D_p}\right]^{0.25}} \qquad (3)$$

[2]Knaebel, Kent S. *Simplified Sparger Design* in Calculation & Shortcut Deskbook (New York, Chemical Engineering Magazine, 1986).

A spreadsheet was developed around Equations 2, 3, and the standard square-edged orifice equation:

$$q = YCA\sqrt{\frac{2g(144)\Delta P}{\rho}} \quad (4)$$

Where

q = air flow, cfs
Y = net expansion factor
C = flow coefficient
g = acceleration constant, ft/sec^2
ΔP = differential pressure, ft
ρ = air density, lbs/ft^3
A = area of orifice, ft^2

Knowing the quantity of air needing to be discharged from each nozzle orifice, and assuming a maximum allowable pressure drop across the orifice, a calculation was first made to arrive at an orifice diameter using Equation 4. The calculated orifice diameter D_o was then used in Equations 2 and 3 to see if one or both constraints could be satisfied.

If the constraints could not be satisfied, different values of L, D_o, D_p, N, q, or ΔP were tried until success was achieved.

Table 1 presents the results of the sparger analysis. Sparger pipes in aeration zones 1 and 2 consisted of a 6-inch diameter aeration pipe with thirteen, 0.875-inch diameter orifices delivering 45 cfm each, while zones 3 and 4, with less flow rate required per orifice, used thirteen, 0.625-inch diameter orifices, each delivering 22 cfm of air.

It should be noted that the Equation 3 constraint was never satisfied; however, the design L/D_p ratio was less than 150 in all cases, so it did not require to be satisfied.

TABLE 1 SPARGER ANALYSIS RESULTS

Parameter	Unit	Zone 1	Zone 2	Zone 3	Zone 4
Effective aeration length	FT	75	75	75	75
Effective aeration width	FT	60	60	126	126
Aeration rate	CFM/SF	1.25	1.25	0.63	0.63
Pipe spacing	FT	6.0	6.0	6.0	6.0
Number of pipes	EA	10	10	21	21
Pipe length	FT	75	75	75	75
Pipe inside diameter	IN	6.00	6.00	6.00	6.00
Pipe length/diameter ratio		150	150	150	150
Pipe flow rate	CFM	563	563	284	284
Zone flow rate	CFM	5,625	5,625	5,954	5,954
Hole differential pressure	IN WC	1.37	1.37	1.37	1.37
Hole exit velocity	FT/S	150	150	150	150
Hole spacing	FT	6.00	6.00	6.00	6.00
Number of holes per pipe	EA	13	13	13	13
Hole flow rate	CFM	45.00	45.00	21.85	21.85
Hole diameter	IN	0.9574	0.9574	0.6770	0.6770
Constraint no. 1	IN	1.1879	1.1879	1.1879	1.1879
Constraint no. 2	IN	0.3612	0.3612	0.3612	0.3612
Total number of holes	EA	125	125	273	273
Lineal feet of pipe	FT	750	750	1,575	1,575

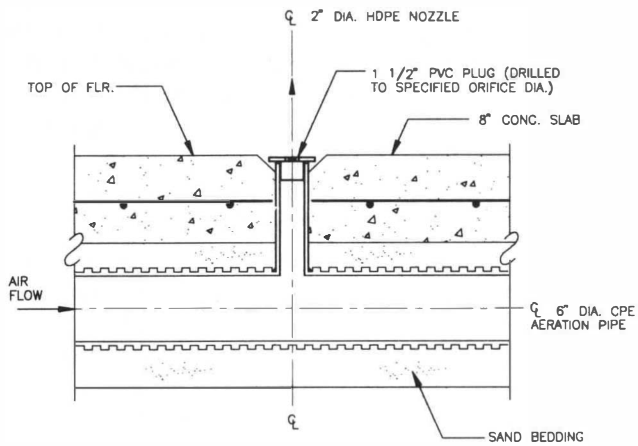

FIG. 1 SECTION THROUGH AERATION NOZZLE

SYSTEM DESIGN

Following the hydraulic analysis, construction details were developed for installing the aeration system. Figure 1 shows a typical cross section through an aeration nozzle. The orifice piece consists of a standard Schedule 40 PVC plug which is drilled to the specified diameter. The nozzles are fabricated from 2-inch diameter HDPE with a standard dimension ratio (SDR) of 9, which results in a snug fit for the PVC plug. The aeration pipe is fabricated from 6-inch diameter CPE (non-perforated, with smooth-wall inner liner), and the nozzles are shop-welded to the CPE.

Figure 2 shows a floor plan of the composting area. Each aeration pipe (sparger) is equipped with thirteen, 2-inch diameter nozzles installed approximately 0.5 to 0.75 inches below the surface of the composting floor. Every two spargers are connected to a 6-inch butterfly valve, which is used to isolate unused sections of the floor. The terminal end of each sparger is fitted with a cleanout to provide access to the aeration piping system during cleaning operations. The spargers slope to drain in the direction of the isolation valves.

An individual CPE header system provides air to each zone. The headers are sloped to drain to a common cleanout pit, where the material that is flushed from the aeration piping is removed. The headers tie into a common plenum, which is fed by the three 50-horsepower blowers, each capable of delivering 6,000 cfm at 30 inches water column pressure. Table 2 shows the header sizing analysis for aeration zone 3.

The blower station piping was installed and valved in such a way as to allow both forced and induced draft operation. Process gases collected during induced draft operation are directed to a biofilter. The design criteria for the biofilter are presented in Table 3.

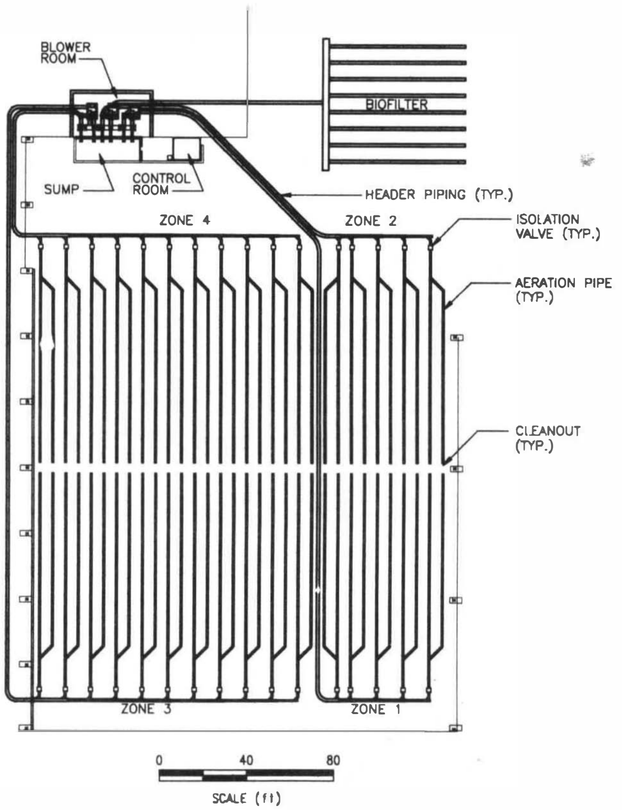

FIG. 2 COMPOST BUILDING FLOOR PLAN

TABLE 3 BIOFILTER DESIGN CRITERIA

Input airflow	12,000 cfm
Static pressure	5 in. water
Detention time	1 minute
Biofilter depth	4 feet
Face velocity	4 feet/min.
Area	3,000 ft²
Biofilter medium	
Composition	1 volume wood chips 3 volumes compost
pH	6.5 - 7.5
Moisture content	55 - 60 percent
Bulk density	600 - 800 lb./yd³
Air filled porosity	≥ 40 percent

TABLE 4 AERATION SYSTEM PERFORMANCE SUMMARY

Temperature control	Temperatures between 55 and 60°C can be readily maintained
Temperature distribution	Monitoring shows equal temperature distribution throughout pile profile
Pile oxygen concentrations	Greater than 10 percent at 2 foot depth
Static pressure	15 in water (meets design criteria)
Airflow impedance	Minimal blockage of air distribution risers and distribution pipe Aeration pipe and risers are readily cleared with air pulsing
Aeration system maintenance	Less than one hour per week
Odor generation	Minimal odor generation 1 off-site odor complaint in 18 months of operation
Final product maturity	Maturity analyses indicate final product is very stable. Respiration rate: <2.0 mg CO_2 carbon per g compost carbon-day Cress seed germination: >80 percent of a deionized water control

TABLE 2 ZONE 3 HEADER SIZING ANALYSIS

SECTION	ITEM	FLOW CFM	FRICTION PER 100'	VELOCITY FPM	VP	LOSS COEFF.	PIPE DIAM	CORR. FACTOR	PRESS. LOSS PER ITEM	TOTAL LOSS
A	30x15 Damper	6,188		4,432	1.22	0.52	16		0.64	31.12
B	5' 30 x 15 Duct	6,188		4,432	1.22	0.10	16		0.12	
C	Inlet Box	6,188		4,432	1.22	0.50	16		0.61	
D	System Effect	6,188		4,432	1.22	0.24	16		0.29	
E	45 Rect Ell	6,188		4,432	1.22	0.13	16	0.60	0.10	
F	Transition	6,188		4,432	1.22	0.52	16		0.64	
G	Entry, Round	6,188		4,432	1.22	0.50	16		0.61	
H	Damper	6,188		4,432	1.22	0.17	16		0.21	
I	90 Ell	6,188		4,432	1.22	0.13	16		0.16	
J	330' Pipe	6,188	1.55	4,432	1.22		16		5.12	
K	90 Ell	6,188		4,432	1.22	0.13	16		0.16	
L	25' Pipe	5,838	1.40	4,181	1.09		16		0.35	
M	25' Pipe	4,718	1.80	4,413	1.21		14		0.45	
N	25' Pipe	3,598	2.30	4,581	1.31		12		0.58	
O	25' Pipe	2,478	3.00	4,543	1.29		10		0.75	
P	25' Pipe	1,358	3.00	3,890	0.94		8		0.75	
Q	10' Pipe	819	4.40	4,171	1.08		6		0.44	
R	45 Wye Branch	560		6,417	2.57	1.05	4		0.00	
S	45 Ell	560		6,417	2.57	0.13	4	0.60	0.20	
T	5' Pipe	560	17.00	6,417	2.57		4		0.85	
U	Damper	560		6,417	2.57	0.17	4		0.44	
V	4 x 6 Transition	560		2,852	0.51	0.39	6		0.20	
W	10' Pipe	560	2.20	2,852	0.51		6		0.22	
X	45 Wye Branch	280		1,426	0.13	0.55	6		0.07	
Y	5' Pipe	280	0.70	1,426	0.13		6		0.04	
Z	45 Ell	280		1,426	0.13	0.13	6	0.60	0.01	
AA	75' Pipe	140	0.17	713	0.03		6		0.13	
AB	90 Wye Branch	23		1,054	0.07	1.70	2		0.12	
AC	Orifice	23		9,394	5.50	0.34	0.67		1.87	
AD	Pile Losses								15.00	

SYSTEM PERFORMANCE

The Pierce County Yard Waste Composting Facility has been in continuous operation since May 1992. Based on the measured ability to control process temperatures, the aeration system has performed quite successfully to date. The non-clogging orifice design, along with the aeration pipe flushing capability, has resulted in minimal operating problems associated with the poor distribution of air. The performance of the aeration system is summarized in Table 4. However, as with all designs, there is room for improvement. One suggested modification to the original design would be to structurally tie the nozzles into the concrete composting slab to prevent equipment loads from punching a nozzle downward, through the CPE aeration pipe, breaking the CPE-to-nozzle weld. This condition has occurred on a few occasions, but does not appear to greatly affect the aeration system performance, as a majority of the air continues to travel up through the nozzle.

SUMMARY

Systems for supplying a uniform quantity of air to composting media may be mathematically analyzed, readily designed applying standard engineering principles, and successfully implemented using common construction techniques.