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Design of Composting Ventilation System For Uniform Air Distribution

A key to this design for uniform air distribution is a computer program which helps determine the number of holes needed per section of pipe.

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VENTILATION is at the center of our approach to composting process control *(1-4)*. The strategy is to manage ventilation as a means of heat removal, to prevent excessive accumulation leading to inhibitive temperatures. The main mechanism of heat removal is the vaporization of water, thus the material tends to dry. Since the vaporization is driven by heat, and the heat is generated through waste decomposition, the drying represents the progress of processing. The strategy is implemented via a temperature feedback control system, which communicates demand for heat removal from the composting mass to a blower. This constitutes a time-variable, interactive, control system. Because the amount of air needed for heat removal exceeds that needed to supply oxygen, the mass is well oxygenated. Forced-pressure ventilation is preferred, rather than the vacuum-induced mode, as it removes heat and water more efficiently *(1, 5-6)*.

If the composting mass is in the form of a lengthy pile, a problem arises involving the uniform delivery of air in the longitudinal dimension. A means of providing air uniformly is developed in the present paper.

Distribution of Air

If the area of air holes is uniform along the length of the duct, delivery of air to the pile is non-uniform in the longitudinal dimension. This is because more air exits from the part of the duct close to the blower than from the distant part. Consequently, the part of the pile close to the blower is overventilated (too cool) and the more distant part underventilated (too hot). Moreover, it is desirable to place blowers at only one end of the pile, to simplify the installation and to economize on space.

A means of providing air uniformly in the longitudinal dimension is to vary the size and/or spacing of the air holes along the length of the duct, such that the amount of air vented is similar regardless of distance from the blower. A computer program is presented herein which permits the user to determine the number of evenly spaced holes—of a given hole size—necessary to supply a given amount of air to a 5 foot section of pipe. Each succeeding 5 foot section is treated separately. A spacing scheme for one to 20 holes per section is stored in the program. Depending on the length of the pile, it may be advantageous to increase the size of the holes in progressive sections of the pipe.

Airflow Calculation

The airflow out of each hole in the duct is calculated through the use of two equations. The first involves the pressure drop in the pipe, as follows:

$$\Delta P = \frac{fL\rho V^2}{2D} \; ; \qquad \text{(i)}$$

where,

f = the Moody friction factor (dimensionless);
L = the length of pipe (ft);
ρ = fluid density $\left(\frac{\text{slugs}}{\text{ft}^3}\right)$;
V = velocity $\left(\frac{\text{ft}}{\text{sec}}\right)$; and,
D = pipe diameter (ft).

Comments on these factors are as follows:

Moody friction factor (f). Tables of values of this factor are found in fluid dynamics textbooks (e.g., 7). Also, the Fanning friction factor may be used (Fanning factor = Moody factor/4). For the present application (commercial pipe, high velocity) the Moody friction factor is roughly 0.02.

Length of pipe (L). This refers to the total length of pipe, including parallel lengths where appropriate.

Fluid density (ρ). The value used in the program is $\rho = 0.00238$ slugs per foot.

Velocity (V). This is the mean cross-sectional velocity.

Diameter (D). The user selects the pipe diameter.

The second equation is used to calculate the airflow out of each hole, as follows:

$$V_e = \frac{(P_{duct}-P_{exit})^2}{K} \; ; \qquad \text{(ii)}$$

where,

V_e = the exit velocity $\left(\frac{\text{ft}}{\text{sec}}\right)$;
P_{duct} = the pressure in the duct at that point $\left(\frac{\text{lb}}{\text{ft}^2}\right)$;
P_{exit} = the pressure in the pile; and,
K = constant (dimensionless).

Comments on these factors are as follows:

Pressure in the pile. Since instantaneous pressure should not vary along the length of the pile, it is set equal to zero.

Constant. In this program K is set equal to 0.34. This is based on the assumption that the pressure drop occurs mainly at the entrance to the hole, and that the hole is circular and square-edged.

Computer Program Background

User Knowledge

Here is a list of things the user must know to enter the program:

Pressure at entrance to duct (lb/ft^2). The pressure at the entrance to the first section of pipe must be known. The pressure at this point is the pressure at the blower (e.g., as specified by the manu-

The pressure at the blower must provide adequate pressure to the terminal section of pipe.

facturer) minus the pressure drop over the distance to the first section. The user should also subtract the pressure loss from the ductwork to the outer edge of the pile (the pile backpressure). If this is not known, a conservative estimate is 1.0 lb/ft^2. The pressure at the exit of the first section is the entrance pressure at the second section—etc. The pressure at the blower must provide adequate pressure to the terminal section of pipe. This is satisfied when the number of holes required in the terminal section is <20, and the required hole diameter is reasonably less than the pipe I.D. Use of a blower delivering higher pressure than necessary yields a solution involving fewer holes and/or smaller holes, but this represents an uneconomical approach. A suggested first approximation for pressure at the blower is 6.0 lb/ft^2.

Flow at entrance to duct (cfs). Like pressure, the initial air flow is selected on the basis of blower specifications. The entrance flow to the second pipe section is that of the exit flow from the first section, etc.

Exit flow from the holes (cfs). Estimation of the required airflow from the holes into the composting mass is based on the behavior of pile 9A *(8-9)*, which is the largest relevant pile in our experience (approximately 40 initial wet tons of a mixture of primary sewage sludge and woodchips). This pile was ventilated by six 1/3 h.p. blowers, with three blowers at each end of the pile. The blowers were operated in unison. Each blower discharged into a 20 foot length of perforated duct, which was capped at the distal end. Since the total length of perforated duct was 120 feet, for calculation purposes there are twenty-four 5 foot sections.

Pile 9A exerted a peak demand for ventilation of 71.3 cubic feet per minute per wet ton, and a total demand (12.9 day composting period) of 307,000 cubic feet per wet ton. (Demand is exerted via a temperature feedback control system — see *1-4.*) The value needed herein is that of peak demand, and for present purposes this is rounded off to 80 cfm per wet ton. Taking the pile weight as 40 wet tons, the peak demand for the entire pile was 3200 cfm. Thus, each 5 foot section required 133.3 cfm. For use in the program this is converted to cfs (2.22 cfs).

Duct pipe diameter (ft). The use of standard pipe ID's is recommended.

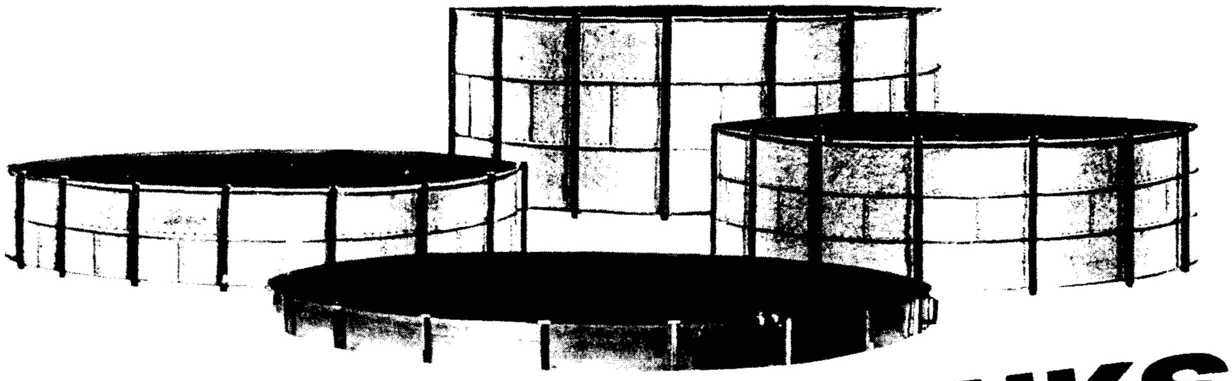
Friction factor. This depends on pipe size, material, and airflow, as described above.

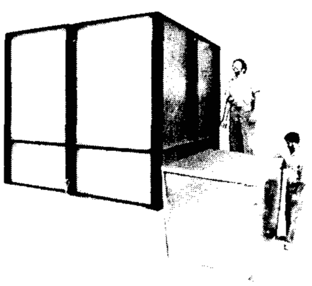
Hole diameter, in 32nds of an inch. Different values should be entered in different runs of the program to find the best combination of number and size of holes for each 5 foot section of pipe. An input of 99 will end the program.

Output

XXXX/32 inch	XX holes	XXX.XXCFS	XXX.XXPSF
The hole size (inputted)	The number of holes selected by computer	Exit flow from the holes	Pressure at the end of the section

Two output values are provided each time the program is run. The first is the value for the number of holes giving slightly less than the desired exit flow. The second is the value for the number of holes giving slightly greater than the desired exit flow.





Notes

The first step in putting the program on line is to establish the file on hole spacing. This is provided in Table 1 (the "H.DAT" file).

All of the values inputted to run the program must be real numbers, rather than integers. Always include a decimal point.

List of Variables

AL (20,21)	Array storing spacing between each hole for 1-20 holes. Does not change through the program.
PREF	Duct pressure in PSF. Changes in lines 290, 330 and 240
PREM	Duct pressure in PSF. Does not change. Used for program to remember initial pressure.
CFS	Flow in pipe (CFS). Changes in lines 270 and 310.
CFSM	Flow in pipe (CFS). Does not change (used like PREM)
FF	Friction factor. Does not change.
DUCT	Duct diameter in feet. Does not change.
EXF	Exit flow from holes in CFS. Does not change.
I (First use)	Counter for filling "AL" array (Line 150).
J	Counter for filling "AL" array (Line 150) and line 320.
DIA	Exit hole diameter (32nd's of an inch). Changes in line 180.

Table 1. "H.DAT" (hole data) file

```
0. 5. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 2.5 2.5 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 1.667 1.667 1.667 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 1.25 1.25 1.25 1.25 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 1.667 0. 1.667 0. 1.667 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. .7083 .7083 .7083 .7083 .7083 .7083 .7502 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 1.25 0. 1.25 0. 1.25 0. 1.25 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. .5521 .5521 .5521 .5521 .5521 .5521 .5521 .5521 .5832 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 1. 0. 1. 0. 1. 0. 1. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. .4583 .4583 .4583 .4583 .4583 .4583 .4583 .4583 .4583 .4583 .4170 0. 0. 0. 0. 0. 0. 0.
   0. 0.
0. 0. .8333 0. .8333 0. .8333 0. .8333 0. .8333 0. .8335 0. 0. 0. 0. 0. 0. 0. 0.
0. .3854 .3854 .3854 .3854 .3854 .3854 .3854 .3854 .3854 .3854 .3854 .3854 .3752 0. 0. 0.
   0. 0. 0. 0.
0. 0. .7083 0. .7083 0. .7083 0. .7083 0. .7083 0. .7083 0. .7502 0. 0. 0. 0. 0. 0.
0. .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333
   .3338 0. 0. 0. 0. 0.
0. 0. .625 0. .625 0. .625 0. .625 0. .625 .0 .625 0. .625 0. .625 0. 0. 0. 0.
0. .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917 .2917
   .2917 .2917 .3328 0. 0. 0.
0. 0. .5521 0. .5521 0. .5521 0. .5521 0. .5521 0. .5521 0. .5521 0. .5521 0. .5832 0. 0.
0. .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604 .2604
   .2604 .2604 .2604 .2604 .3128 0.
0. 0. .5 0. .5 0. .5 0. .5 0. .5 0. .5 0. .5 0. .5 0. .5 0. .5
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
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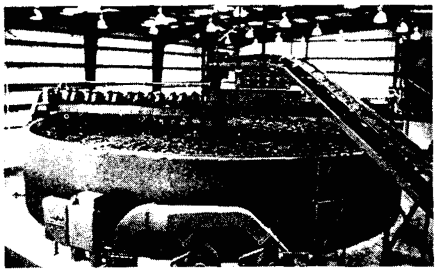

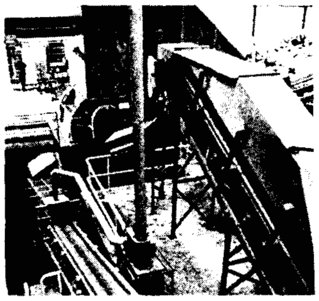

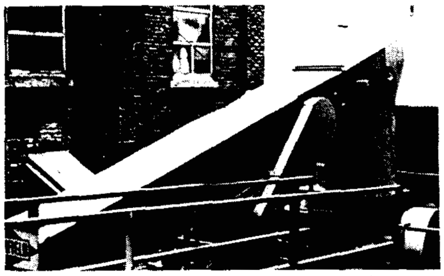

N	Counter used in "AL." (Depicts Changes in lines
FL	Exit flow from h Changes in lines
FS	Exit flow from h to remember mos "FL". Changes i
PRES	Duct pressure in "FS". Changes in
I (Second use)	Counter to pull da Changes in line 28
NC	Simply N-1 used to of line 370. Chang

The Program

@ Type Pipes, for

```
 10  REAL AL(20,21)
 20  WRITE(5,440)
 30  READ(5,*)DUCT
 40  WRITE(5,450)
 50  READ(5,*)EXF
 60  WRITE(5,400)
 70  READ(5,*)PREF
 80  PREM=PREF
 90  WRITE(5,410)
100  READ(5,*)CFS
110  CFSM=CFS
120  WRITE(5,420)
130  READ(5,*)FF
140  OPEN(UNIT=29,DEVICE='dsk:
     'H.DAT')
150  READ(29,*) ((AL(I,J),J=1,21),I=
160  CLOSE(UNIT=29)
170  WRITE(5,430)
180  READ(5,*) DIA
190  IF(DIA.EQ.99.)GO TO 390
200  N=1
210  GO TO 250
220  N=N+1
230  FS=FL
240  PRES=PREF
250  FL=O
260  PREF=PREM
270  CFS=CFSM
280  DO 310I=1,N
290  PREF=PREF-(AL(N,I)*(CFS**2)/
     (DUCT**5)*FF/559.0)
300  FL=FL+(0.000275*(DIA**2)*(PREF**0.5))
310  CFS=CFSM-FL
320  J=N+1
330  PREF=PREF-(AL(N,J)*(CFS**2)/
     (DUCT**5)*FF/559.0)
340  IF(FL.LT.EXF)GO TO 220
350  WRITE(5,460)N,DIA,FL,PREF
360  NC=N-1
370  WRITE(5,460)NC,DIA,FS,PRES
380  GO TO 170
390  STOP
400  FORMAT('     ','INPUT ENTRACE
     PRESSURE IN PSF')
410  FORMAT('     ','INPUT ENTRANCE
     FLOW IN CFS')
420  FORMAT('     ','INPUT FRICTION
     FACTOR')
430  FORMAT('     ','INPUT DIA IN 32NDS
     OF AN INCH OR 99 TO END')
 40  FORMAT('     ','INPUT DUCT
     DIAMETER IN FEET')
 50  FORMAT('     ','INPUT EXIT FLOW PER
     5 FT OF DUCT IN CFS')
 60  FORMAT('     ',I2,'     HOLES',F4.0,'/32
     IN.',F7.2', CFS',F8.2', PSF')"
 70  END
```

Discussion

Use of a temperature feedback control system and forced pressure ventilation to regulate temperature, as summarized in the introduction, is the basis of the Rutgers Static Pile Composting Process *(1-4, 8-9)*. The preference for the forced pressure mode of ventilation is based on a comparative field trial and theoretical consideration *(1,5)*, as reiterated in an independent theoretical consideration *(6)*. The advantage of basing process control on temperature feedback and forced pressure, in reference to temperature regulation, was verified in an independent comparative trial *(10)*.

In the developmental phase of the Rutgers Process, non-uniform distribution of air was not a significant problem. This probably reflects the use of relatively small, pilot scale, piles (4 to 40 initial wet tons). Furthermore the larger piles, including the one used as the model herein, were served by blowers at both ends of the pile, and the longest continuous length of perforated duct was only 20 feet. Routine operation, however, would involve longer piles, and it is desirable to place the blowers at only one end. This would result in non-uniform ventilation, leading to poorer process performance.

Hence the need for the design protocol for uniform air distribution presented herein.

In the Beltsville Static Pile Process *(11-13)* the problem of air distribution is insignificant, even at large scale facilities. This is because temperature is not determined by ventilation; rather, it is determined by the upper limit of the composting ecosystem's tolerance to harsh temperature *(2)*. Consequently the ecosystem experiences uniform, self-imposed, inhibitive temperatures, retarding decomposition. One of the manifestations of inhibited activity is inhibited consumption of oxygen. Hence, the prescribed ventilation, though slight, suffices to maintain an oxygenated condition. In this circumstance non-uniformity of ventilation does not significantly affect process performance. ■

Acknowledgments

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References

1. Finstein, M.S., Cirello, J., MacGregor, S.T., Miller, F.C., Psarianos, K.M. 1980. Sludge Composting and Utilization: Rational Approach to Process Control. Final Report to USEPA, NJDEP, CCMUA. (Available through U.S. Dept. Commerce, NTIS, Springfield, VA., Accession No. PB82 136243).
2. MacGregor, S.T., Miller, F.C., Psarianos, K.M., Finstein, M.S. 1981. "Composting Process Control Based on Interaction Between Microbial Heat Output and Temperature." *Appl. Environ. Microbiol.* 41:1321-1330.
3. Finstein, M.S. 1980. "Composting Microbial Ecosystem: Implications for Process Design and Control." *Compost Science/Land Utilization.* 21(4):25-39.
4. Miller, F.C., MacGregor, S.T., Psarianos, K.M., Finstein, M.S. 1982. Static-Pile Sludge Composting with Recycled Compost as the Bulking Agent. *Fourteenth Mid-Atlantic Conference on Industrial Waste,* p. 35-44. Ann Arbor Science, Michigan.
5. Miller, F.C., MacGregor, S.T., Psarianos, K.M., Cirello, J., Finstein, M.S. 1982. "Direction of Ventilation in Composting Wastewater Sludge." *J. Water Pollut. Control Fed.* 54:111-113.
6. Higgins, A.J. 1982. "Ventilation for Static Pile Composting." *BioCycle* 23(4):36-41.
7. Streeter, V.L., Wylie, E.B. 1979. *Fluid Mechanics.* Seventh Edition, McGraw-Hill, New York.
8. Finstein, M.S., Miller, F.C., MacGregor, S.T., Psarianos, K.M. Sewage Sludge Composting: Process Design and Control. Draft Final Report to USEPA-MERL, Cincinnati (Feb. 1982).
9. Finstein, M.S., Miller, F.C., MacGregor, S.T., Psarianos, K.M. 1982. Composting Sludge: A Means of Linking Decomposition and Water Removal. *Sixth Mid-America Conf. on Environmental Engineering Design,* p. 112-119. Engineering Conf. Unit, University of Missouri, Columbia.
10. DeBertoldi, M., Vallini, G., Pera, A., Zucconi, F. 1982. "Comparison of Three Windrow Compost Systems." *BioCycle* 23(2):45-50.
11. Epstein, E., Willson, G.B., Burge, W.D., Muller, D.C., Enkiri, N.K. 1976. "A Forced Aeration System for Composting Wastewater Sludge." *J. Water Pollut. Control Fed.* 48:688-694.
12. Sikora, L.J., Willson, G.B., Colacicco, D., Parr, J.F. 1981. "Materials Balance in Aerated Static Pile Composting." *J. Water Pollut. Control Fed.* 53: 1702-1707.
13. Willson, G.B., Parr, J.F., Epstein, E., Marsh, P.B., Chaney, R.L., Colacicco, D., Burge, W.D., Sikora, L.J., Teste, C.F., Hornick, S. 1980. Manual for Composting Sewage Sludge by the Beltsville Aerated-Pile Method. EPA-600/8-80-022, MERL/ORD, Cincinnati.