한국농업기계학회지 제23권 제1호. pp. 31~48. 1998

연속 및 간헐통기가 돈분 퇴비화 및 생퇴비 탈취에 미치는 영향

The Effect of Continuous and Intermittent Aeration on Hog Manure Composting and Odor Control through Fresh Compost

홍 지 형* 최 병 민* 박 우 룡*
정회원 정회원 정회원
J. H. Hong B. M. Choi W. L. Park

摘 要

가축분뇨, 음식쓰레기 등의 유기성 고형 폐기물의 퇴비화처리 과정의 성능 향상과 암모니아 가스 발생을 저감화하려는 연구의 일환으로서 파이로트 규모의 원통형 회분식 분해조 및 숙성조를 설계, 제작하여 퇴비화 성능과 탈취효과를 분석하였다. 고형퇴비화 처리에 미치는 주요요인은 초기재료의 수분, 탄질비, 수소이온농도, 발효온도 및 통기조건 등이다. 돈분에 부자재인 톱밥을 혼합하여 초기재료의 수분, 탄질비, 수소이온농도 등을 동일한 재료로서 같은 수준에 유지하고 연속통기와 간헐통기 방식으로 퇴비화하는 동안에 분해 및 숙성단계의 부위별 발효온도의 변화, 산소흡수 및 탄산가스 배출농도의 변동, 평균통기량, 재료의 평균온도 변화, 암모니아가스 배출농도의 변화 등을 분해 및 숙성 전기간을 통해 측정하고 초기재료와 숙성재료의 주요 이화학적 성분을 분석하여 퇴비화 성능과 퇴비 탈취 효율을 비교하였다. 주요 연구결과는 다음과 같다.

1. 숙성과정 8일 이후의 암모니아가스 탈취효율은 연속통기법이 90%이고, 간헐통기법이 70%였으며, 분해 및 숙성과정의 발효온도, 탄산가스 발생, 암모니아가스 배출농도 및 숙성퇴비의 성분 등의 결과로서 판단할 때에 퇴비화 소요기간은 6주간이었다.
2. 탄산가스 배출농도 변화로서 간헐통기 퇴비화 방식은 연속통기법에 비하여 분해과정이 7일 정도 빠르고, 숙성과정이 10일 정도 단축되었으며 암모니아가스 농도도 적게 나타나고 있었다.
3. 퇴비화 분해과정이 지난 후 숙성과정 도입단계에서 퇴비재료의 혼합 교반에 따른 재료의 고온상승으로 인한 암모니아가스의 고농도화 현상의 억제대책이 필요하다고 판단되었다.

주요용어(Key Words): 돈분(Hog Manure), 고형퇴비(Solid Compost), 분해(Decomposition), 숙성(Stabilization), 연속통기(Continuous Aeration), 간헐통기(Intermittant Aeration), 퇴비탈취(Compost Odor Control)

* Dept. of Agricultural Machinery Eng., Sunchon Nat'l University, Republic of Korea

1. INTRODUCTION

Composting is a process which deals with the biological decomposition and stabilization of organic substrates. Microorganisms in composting systems utilize degradable constituents and oxygen to produce carbon dioxide, water vapor, ammonia and biological heat as major products. The rate of composting, like the rate of plant or animal growth, can be affected by C/N ratio, pH, moisture content(MC), temperature and aeration(Hong, 1994; Matsuda, 1987).

Composting is usually successful when the mixture of organic materials consists of 20 to 40 parts of carbon to 1 part of nitrogen. However, as the ratio exceeds 30, the rate of composting decreases. As the ratio decreases below 25, excess nitrogen is converted to ammonia. This is wasted into the atmosphere and results in undesirable odors(Hansen et al., 1990). High pH levels increases the loss of ammonia. The initial pH of the mixture should be as close to neutral as possible(Composting council, 1995).

Depending on the components of the mixture, initial moisture content can range from 55 to 70 percent. However, as the moisture content exceeds 60 percent, oxygen movement is inhibited(Keener et al, 1993). Composting rate is generally measured by rate of carbon dioxide production. The maximum rate occurs where compost temperatures range from 45 to 65℃. As the temperature exceeds 65℃, the composting rate drops rapidly and becomes negligible at temperatures higher than 70℃. Most composting should include temperatures in the thermophilic range (38~65℃). At these temperatures the rate of organic matter decomposition is maximum, and weed seeds and most microbes of pathogenic significance can not survive. It takes three days at 55℃ to kill parasites, and fecal and plant pathogens(Hansen et al., 1995).

Aeration is a key element in composting. Proper aeration is needed to control the environment required for biological processes to thrive with an optimum efficiency. A number of controllable factors are involved: a) temperature should be controlled to a 60 to 65℃ upper limit, b) moisture is removed naturally from the compost medium, c) carbon dioxide must be removed from the compost microenvironment to avoid toxic concentrations and d) aeration must be available to microbes in sufficient quantities to ensure vitality of the aerobic types and to minimize odors(Hansen et al., 1995).

The composting process is usually separated into two phases: decomposition and stabilization phase. Air may be forced through the pile to speed up the process. However, the forced aeration adds complexity to the process. Odor control is more feasible for composting facilities that use forced aeration. The exhaust air leaving the pile or bin can be directed into an odor absorbing biofilter such as fresh or stabilized compost. Biofilters must operate with as high a moisture content as possible, generally in the range of 50~70% and with a temperature between 10 and 40℃(Hong, 1993; Leson and Winer, 1991). Biofilters should have a pH between 6.5 and 7.5 for proper microbial activity (Toffey, 1997).

This paper is intended to evaluate temperature in compost, oxygen uptake, carbon dioxide evolution and ammonia gas concentrations to maximize decomposition rate of compost while minimizing ammonia nitrogen loss under both continuous and intermittent aeration during composting decomposition and stabilization process.

2. MATERIALS AND PROCEDURES

For this study, the experimental treatment examined the effects of aeration through raw and fresh compost during its decomposition and stabilization composting process. This pilot scale work was conducted in barrels that have been described elsewhere in greater detail(Hansen et al., 1989; Elwell et al., 1994). A preliminary run(Hong et al., 1997c) had composted a fresh hog manure and sawdust mix under continuous aeration(CA) and intermittent aeration(IA) replicated in two barrels each. Then, for the work reported here, the barrels were paired as shown in Fig. 1 so that the air supplied by the fans would first pass through a second barrel in which the fresh compost from the preliminary run was stabilizing. The first of the two pairs of barrels was operated in the CA mode and the second pair was operated under IA control with an additional thermostatic override such that for much of the time(see airflow results as shown in Fig. 7) the IA pair operated very similarly to the CA pair.

Fresh hog manure was collected from a facility at the Agricultural Technical Institute of the Ohio State University on April 4 and April 25, 1997 and mixed with sawdust on a concrete floor using shovels. A total of 97 kg(75 kg hog manure and 22 kg sawdust) of raw compost mixture was loaded into each barrel. The physicochemical components of the raw material, initial mixture(Di), final fresh compost(Df) during decomposition process and the initial fresh compost(Si), final stabilized compost(Sf) during stabilization process are shown in Table 1. Runs under CA and IA lasted 3 weeks and no remixes were done during the runs. Approximately 0.8 kg samples were collected from six arbitrarily selected points for each barrel at the start and at the end of each run. The samples were analyzed for pH, total carbon, total nitrogen, C/N ratio, volatile solids(VS) by the Research, Extension and Analytical Laboratory at the Ohio Agricultural Research and Development Center using standard laboratory techniques. Two additional samples for each barrel were obtained at the start and the end of each run and analyzed for moisture and particle size distribution. Moisture content was determined by drying the samples at 100℃ for two days. Particle size distribution was analyzed in accordance with ASAE Standards(1997). All analyses were carried out in duplicate.

Briefly, each pilot-scale composter was a 208 liter and was 57 cm in diameter and 73 cm deep(see Fig. 1). Each barrel had 50 mm of polystyrene insulation around it, in the base on which it sits, and in its cap in

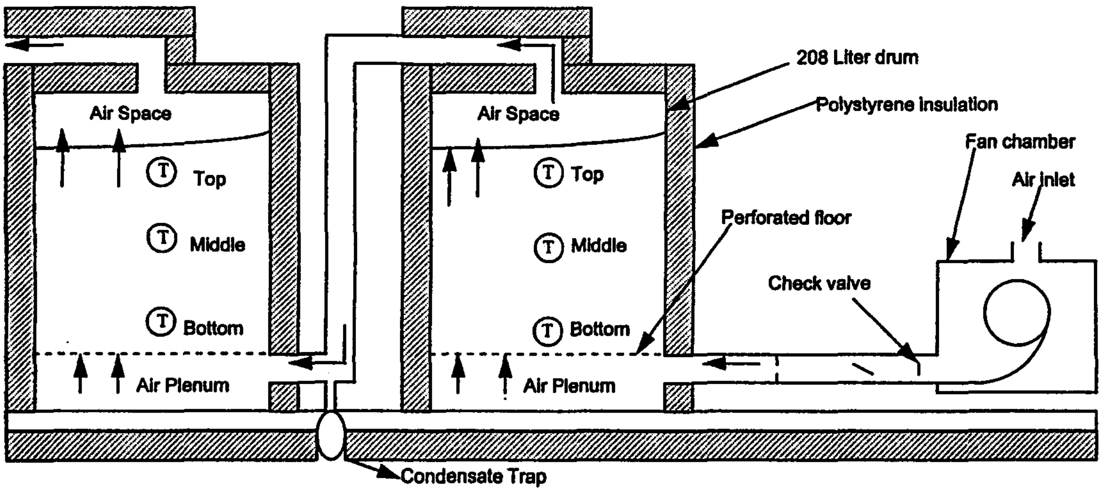

Fig. 1 Schematic drawing of the pilot-scale composting set up.

Table 1 Physicochemical components of raw material, mixture, fresh, and stabilized compost for both decomposition(D) and stabilization(S) process using continuous(CA) and intermittent(IA) aerated composting

Component	PH (-)	MC (%, wb)	T-C (%, db)	T-N (%, db)	C/N Ratio	VS (%, db)	Weight (kg, wb)	Density (kg/m^3, wb)
Hog manure	6.5	75.0	43.2	3.62	12	82.8	75	940
Sawdust	3.9	5.4	43.3	0.21	215	99.0	22	270
Mixture (Di)								
CA	5.6	59.8	45.8	2.32	19.7	91.6	94.7	592
IA	5.9	56.0	45.4	2.12	21.4	91.2	94.9	527
Fresh compost (Df)								
CA	7.6	58.5	42.9	2.46	17.4	90.1	68.5	489
IA	7.6	56.1	42.1	1.98	21.3	89.6	59.8	427
Fresh compost (Si)								
CA	7.6	54.6	43.0	2.36	18.2	89.0	70.3	391
IA	7.5	57.7	42.9	2.45	17.5	89.0	83.0	461
Stbilized compost (Sf)								
CA	8.5	61.3	41.0	2.42	16.9	89.6	60.5	403
IA	8.2	62.0	39.8	2.06	19.3	87.3	73.3	489

order to reduce heat loss and water condensing in the exit air stream and dripping back on the compost. A perforated, galvanized steel grate formed a plenum at the barrels base to distribute air uniformly through the compost. Two fans were connected to provide air to each barrel through a 4.76 cm(ID) PVC pipe that was equipped with an orifice plate. Daily, manual readings of the pressure drop across the plate were obtained for each fan of each barrel and used to determine air flow rate(Keener et al., 1992; Marugg et al., 1993). For the CA barrels, the low flow fan provided about 11 ℓ/min of air for oxygenation of the compost until a thermistor controlled thermostat(set point 60℃) switched to the high flow fan at about 36 ℓ/min of air for cooling. For the IA barrels, the low flow fan was left off and there was no air flow for 55 minutes in each hour, then a timer switched on the high flow fan for 5 minutes to provide air at about 37.5 ℓ/min. However, thermostatic control provided high airflow when compost temperature in the initial barrel was above 60℃.

Gas samples were drawn from each barrel in succession and dew point temperature(EG & G Model 911 Dew All Digital Humidity Analyzer) of the input air and carbon dioxide and oxygen concentrations (Beckman Model 864 Infrared Analyzer and MSA Oxygen Analyzer 4000, respectively) of the outlet air for each barrel were obtained and recorded once each hour. Each barrel had five Type-K thermocouples in it. There was one above the compost, three in the compost material and one in the air plenum. There was also a thermocouple to measure room temperature. Thermocouple wires fixed to a support were inserted into the material heights of 24, 48 and 73 cm in the compost material and the temperature was monitored during the composting period. Temperature readings and fan operating times were recorded for each barrel every 15 minutes with a Digi Ⅲ Kaye Data Logger and a MFE tape recorder.

Ammonia concentrations of exhaust gas from the composting process were obtained for each barrel once a day. Boric acid traps of 200 mℓ were used to trap the ammonia as described by Elwell et al(1994). Ammonia produced during composting was collected in a 200 mℓ acid trap(see Fig. 2). The acid trap was a solution containing 42gr/ℓ of boric acid plus a bromocresol green-methyl red indicator(Keeney and Nelson, 1982). The flow rate through the trap was 1 ℓ/min. which represented 7 percent of the total airflow(at low fan rate) through the barrel. Traps were changed approximately every 24 hours. To determine the amount of ammomia in the trap, the boric acid solution was titrated with 0.7N hydrochloric(HCL) with the end point defined as the color change of the solution from green to pink. Each milliliter of hydrochloric acid consumed during the titration represents 9.29 mg of NH_3-N.

Ammonia concentrations was calculated as:

$$NH_3\,(ppm) = \frac{HCL(ml) \times 9.29\ \mathrm{mg}(NH_3-N)/ml}{FlowRate(Ammonia\ Sampling; l/min) \times time(\mathrm{min})} \times \left(\frac{mole}{14g \cdot N}\right) \times \left(\frac{22.4l}{mole}\right)$$

Finally, at the end of a run all data were put into computer files. This data was processed by computer programs written for this purpose(Marugg, 1992). These programs computed heat and air flows, ammonia nitrogen lost and material balances throughout the composting runs.

3. RESULTS AND DISCUSSION

An analysis of the mean values for the physicochemical components of the raw material, mixture, fresh and stabilized compost for both decomposition and stabilization process before and after composting is presented in Table 1. The hog manure had a C/N ratio of 12 and moisture content of 75%(wb). To adjust these parameters manure was mixed with sawdust. The main reasons for choosing sawdust as the amendment were (1) sawdust is rich in carbon(C/N=215) and can be used to adjust C/N ratio of the raw manure; (2) sawdust is acidic(pH=3.9) and helps conserve nitrogen; (3) sawdust has the ability to absorb large amounts of water because of low wet density(density=270 kg/m^3) and much fine particle size which facilitates the aeration. In this study, the initial MC and C/N ratio of the mixture were 56~59.8% (wb) and 19.7~21.4, respectively. Almost 60% of the

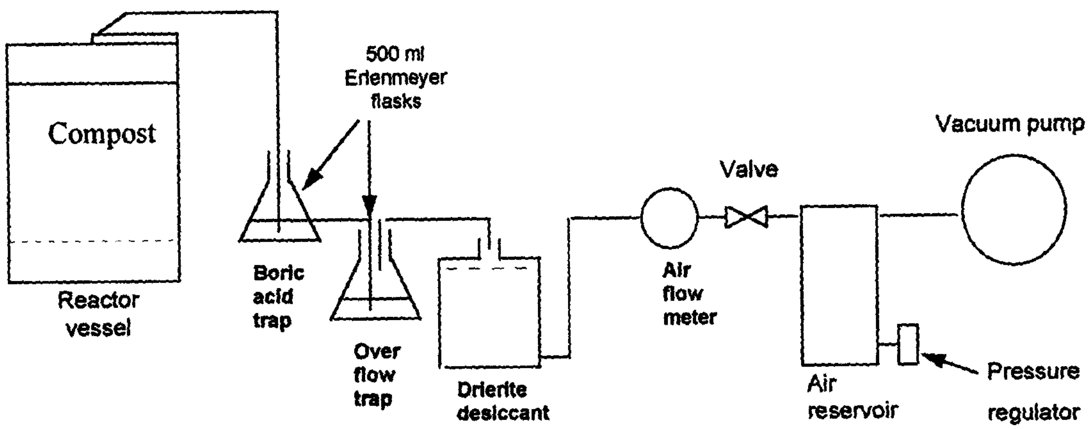

Fig. 2 Schematic illustration of the ammonia sampling system.

particle size was less than 0.2 cm from the mixture, fresh and stabilized compost(not shown). However, the ideal particle size ranges from 0.1 to 1.0 cm from the point of view of free air space(Haug, 1993). Initial mixture and fresh compost had a good condition for aeration. The C/N ratio, volatile solids(VS), wet weight and density decreased as the mixture was composted, while the pH increased. There was no difference between CA and IA composting process in terms of the physicochemical indicators.

Figs. 3 and 4 show the actual temperatures recorded for each location the duration of the composting decomposition process(barrel #1 and #3) and stabilization process(barrel #2 and #4), while Fig. 7 (b) shows the average temperature in compost during biological process. Temperature was found to vary with aeration management and location in the barrel. The biological decomposition process in barrel #1 and #3 reached average temperature in compost of over 60℃ within 5 days after aeration began and the highest temperature reached in the aerated piles were over 65℃. The average temperature of the compost material in barrel #2 and #4 decreased rapidly to 40℃ on the 8th day after turning the fresh compost and dropped to near room temperature for compost odor removal.

The fluctuation in the temperature of compost followed those of the top surface, but the temperatures of the IA method were lower than that of CA method, because of oxygen and cooling were not constantly supplied. The IA composting was very successful in reaching sufficient temperature above 55℃ long enough for pathogen kill.

The rise in temperature was the result of organic matter biological decomposition as indicated by the CO_2 evolution data as shown in Figs. 5 and 6. CO_2 evolution peaked and then declined when the temperatures reached their maximum, which indicated the possibility that high temperature had an adverse effect on the microbial decomposition process. Depletion of substrate also may have resulted in CO_2 decline but secondary CO_2 peaks in stabilization process as shown in Figs. 5B and 6B are indicative of substrate still available. CO_2 evolution during decomposition phase in barrel #1 and #3 declined after the 14th day in CA method and the 7th day in IA method, respectively. The CO_2 evolution time in CA was longer than that in IA. The fact that CO_2 did not rise again on the 7th day after decomposition and on the 6th day after stabilization(see Figs. 6A and 6B) showed that the IA method required shorter time to reach stability.

The pattern of average air flow rates and NH_3 gas concentrations during the composting process versus time are shown in Fig. 7(a) and (c). Average air flow rate during decomposition and stabilization phase varied between 0.06~0.68 ℓ/min·kgDM(IA) to 0.17~0.56 ℓ/min·kgDM(CA) and 0.05~0.85 ℓ/min·kgDM (IA) to 0.15~0.59 ℓ/min·kgDM(CA), respectively. The average air flow rates during composting were nearly the same for both aeration management systems.

The curve pattern of the NH_3 gas concentrations was greatly affected by the compost temperature. NH_3 gas readings during the biological decomposition phase on the 7th to 21th day for the CA method showed values between 182 and 1,103 ppm which were more higher than those observed in the IA method. The NH_3 gas concentrations were similar for the NH_3 gas emitted during high rate composting of dairy manure and rice hulls mixtures(Hong et al., 1997b). NH_3 gas removal efficiency through fresh compost during the stabilization period ranged from 70%(IA) to 90%(CA) of total NH_3 gas evolution after the 8th day, respectively. The NH_3 gas concentrations at the end of composting were 39 ppm(IA) and 29 ppm(CA), respectively. It was possible to use this product as an organic fertilizer after 6 weeks composting. This result was similar for the intermittently aerated static pile

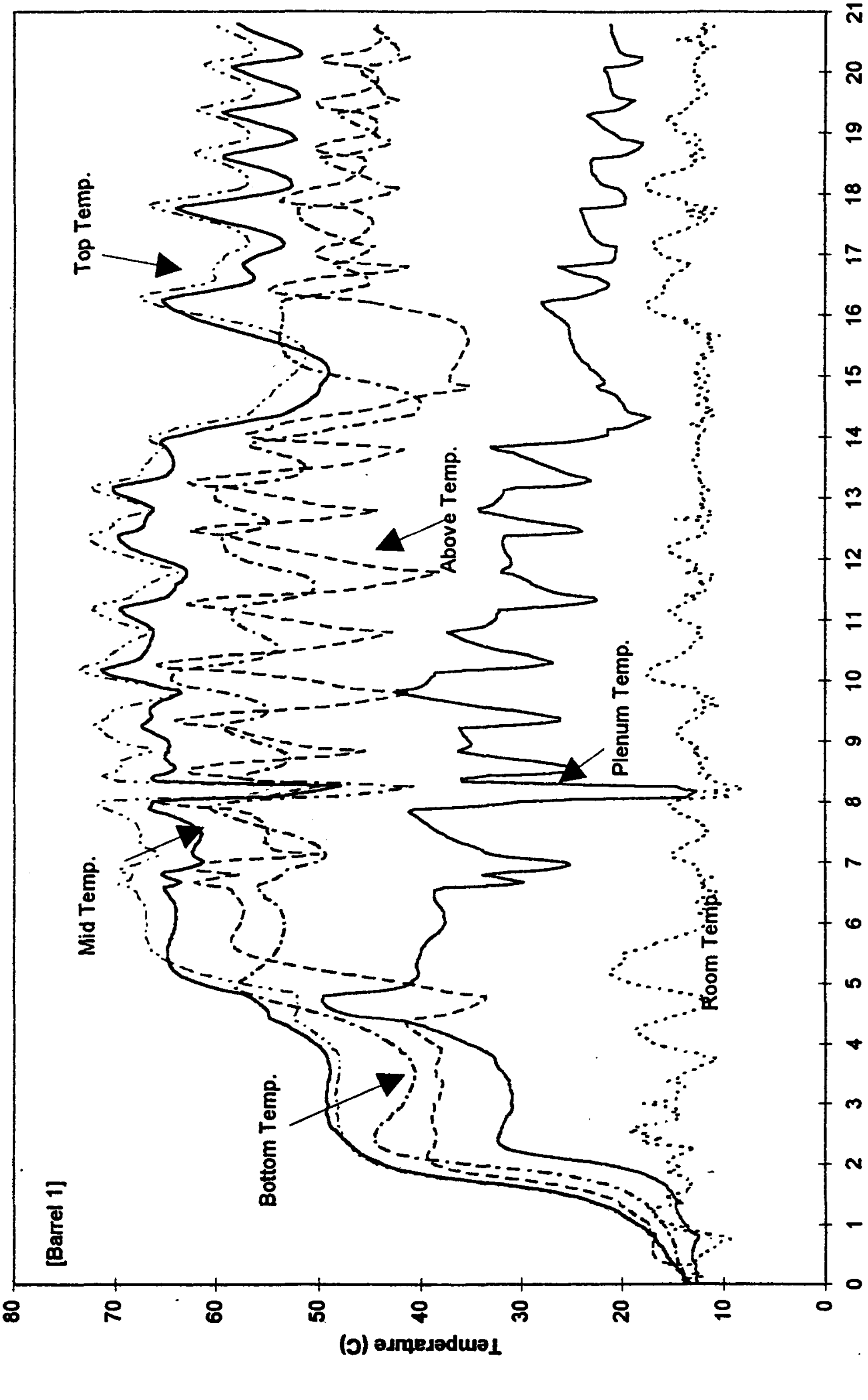

Fig. 3A Change in temperature at various pile locations using a continuously aerated decomposition process.

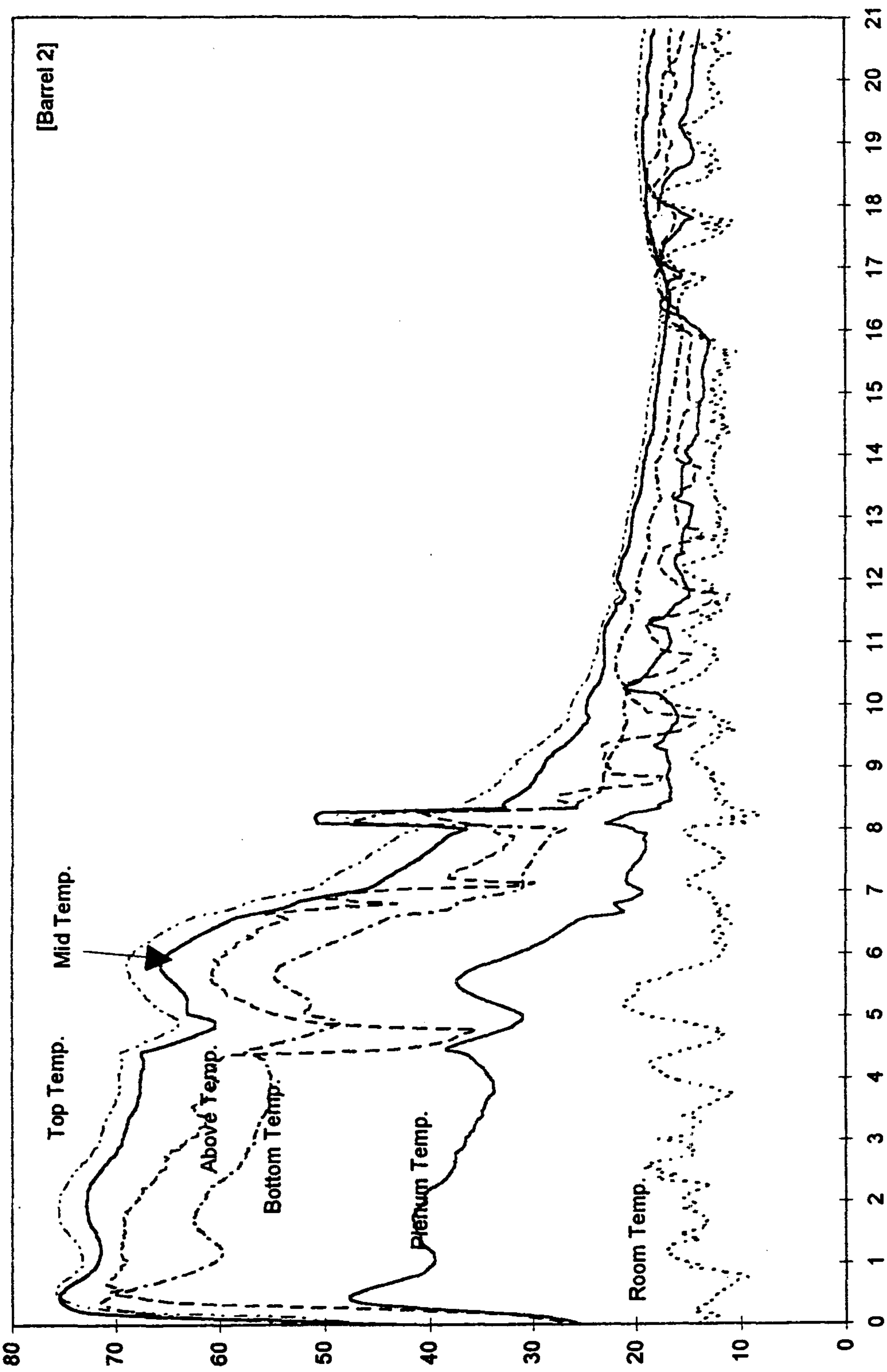

Fig. 3B Change in temperature at various pile locations using a continuously aerated stabilization process.

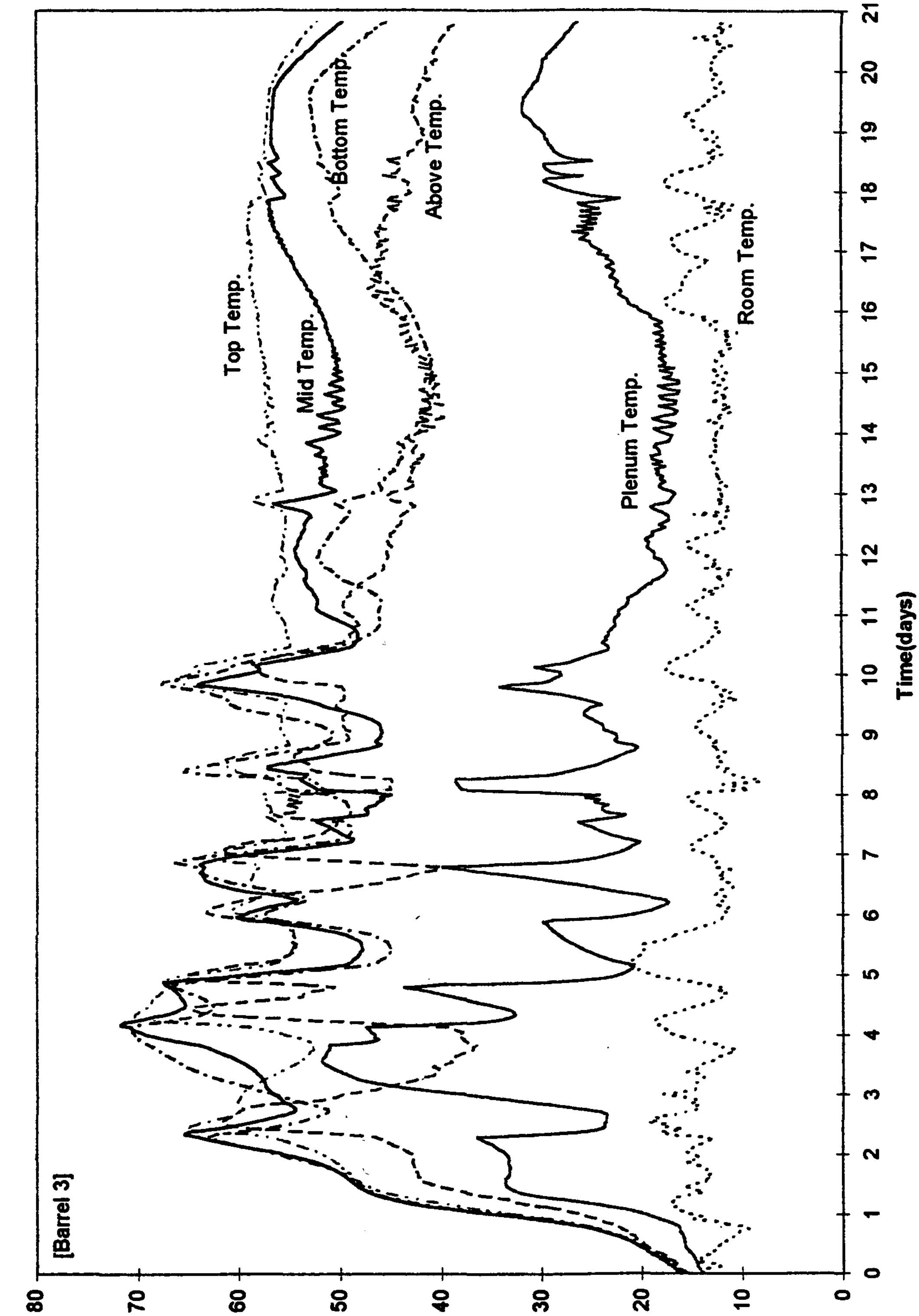

Fig. 4A Change in temperature at various pile locations using an intermittently aerated decomposition process.

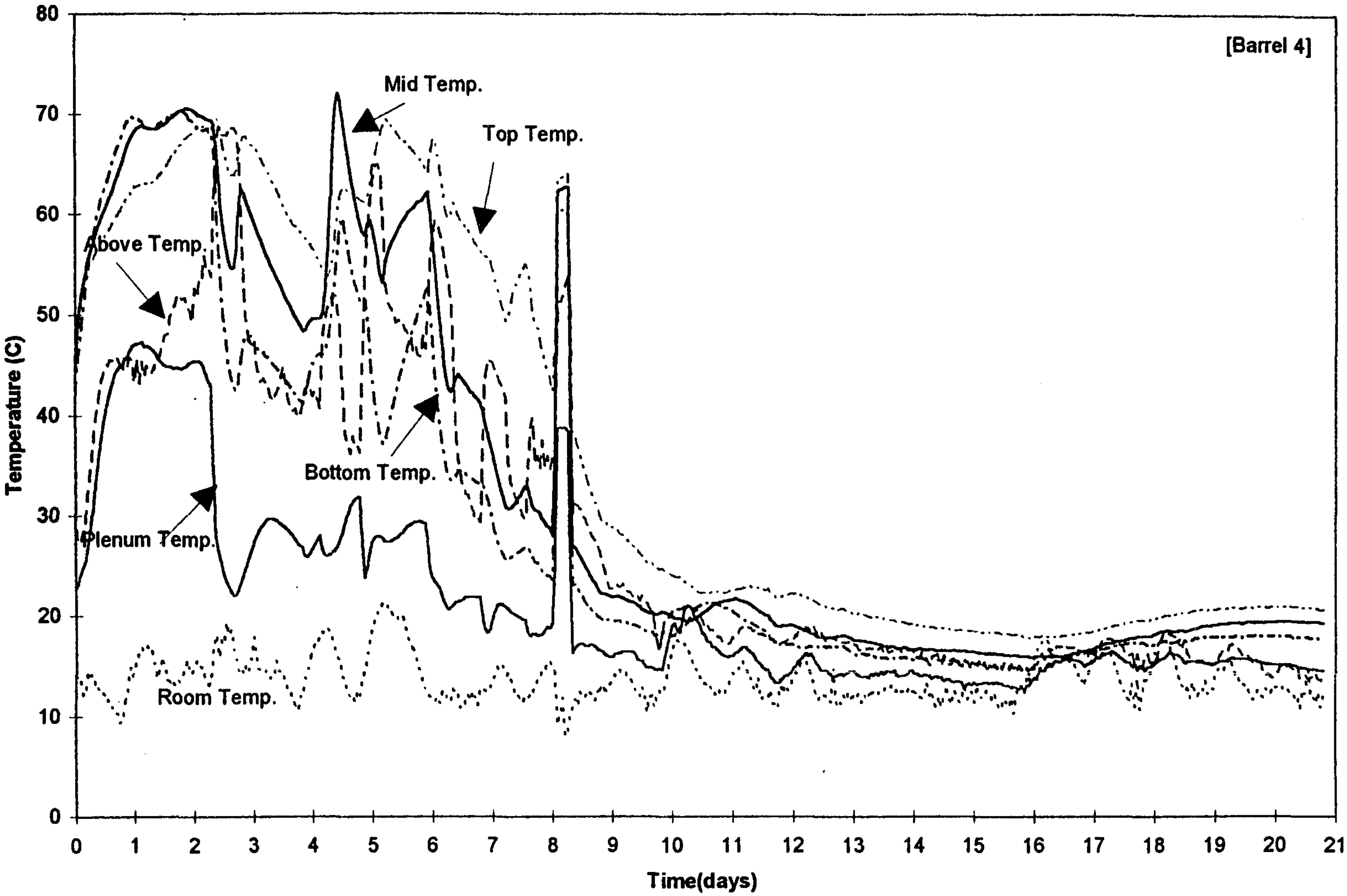

Fig. 4B Change in temperature at various pile locations using an intermittently aerated stabilization process.

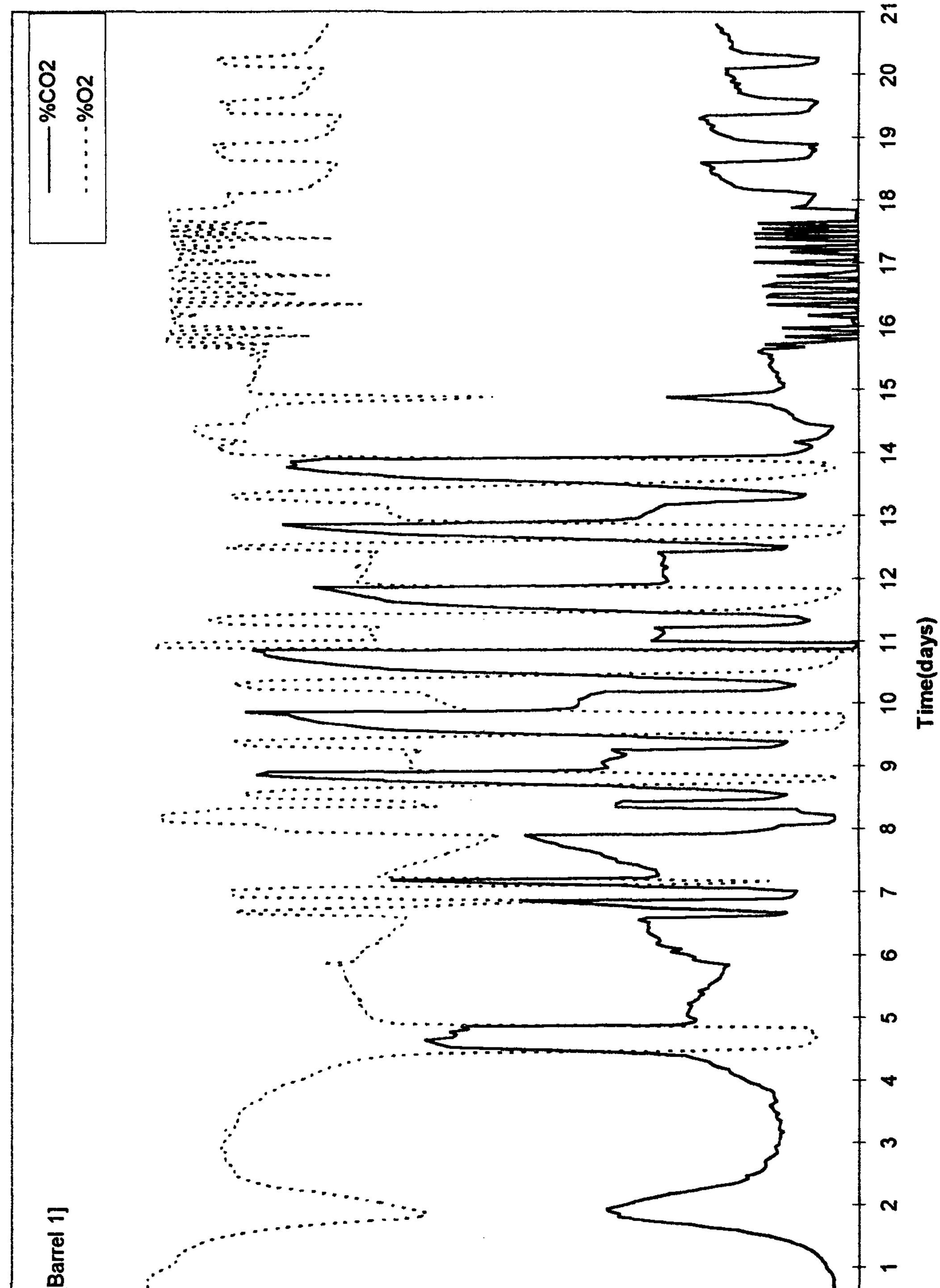

Fig. 5A Oxygen and carbon dioxide histories obtained during the continuously aerated decomposition process.

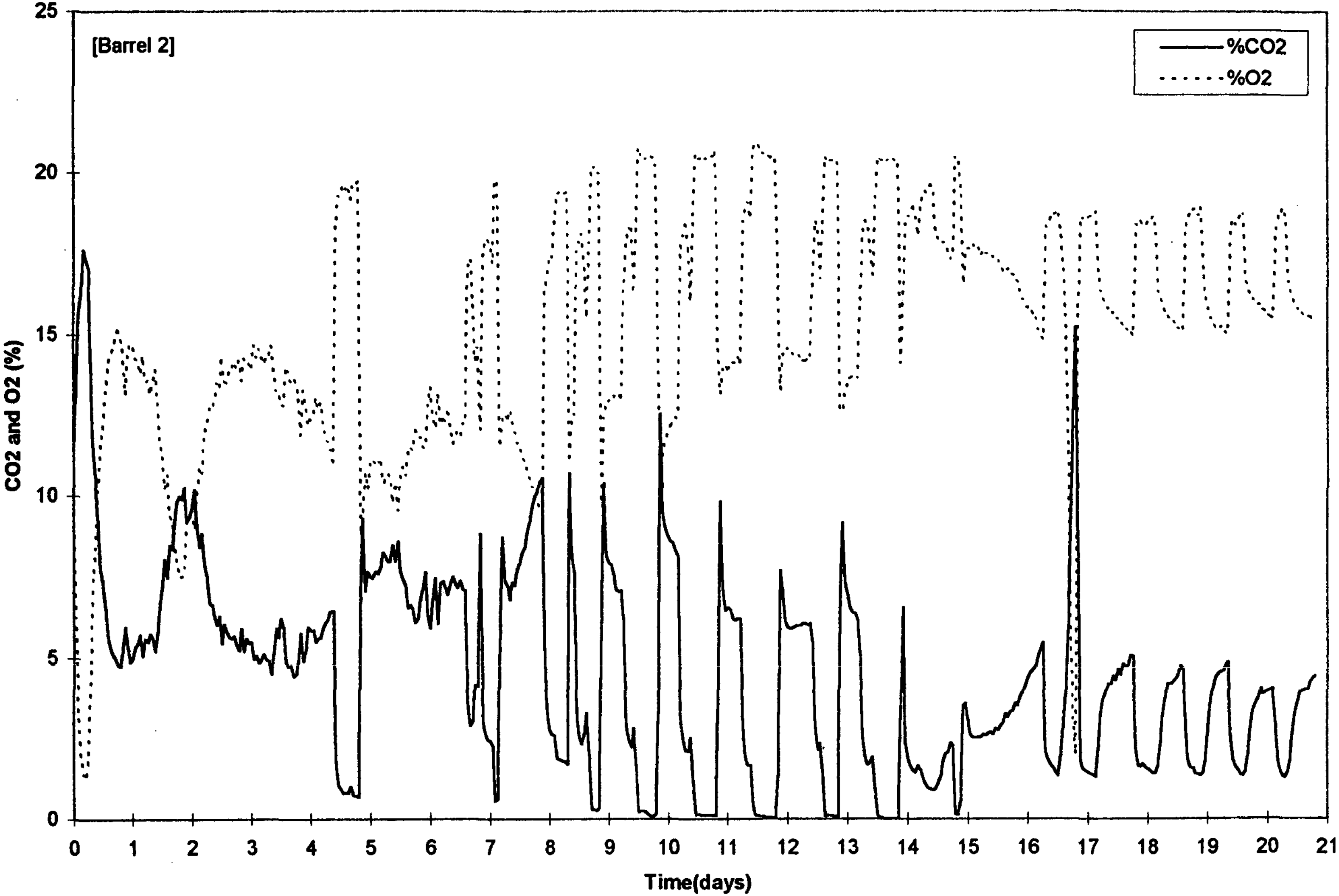

Fig. 5B Oxygen and carbon dioxide histories obtained during the continuously aerated stabilization process.

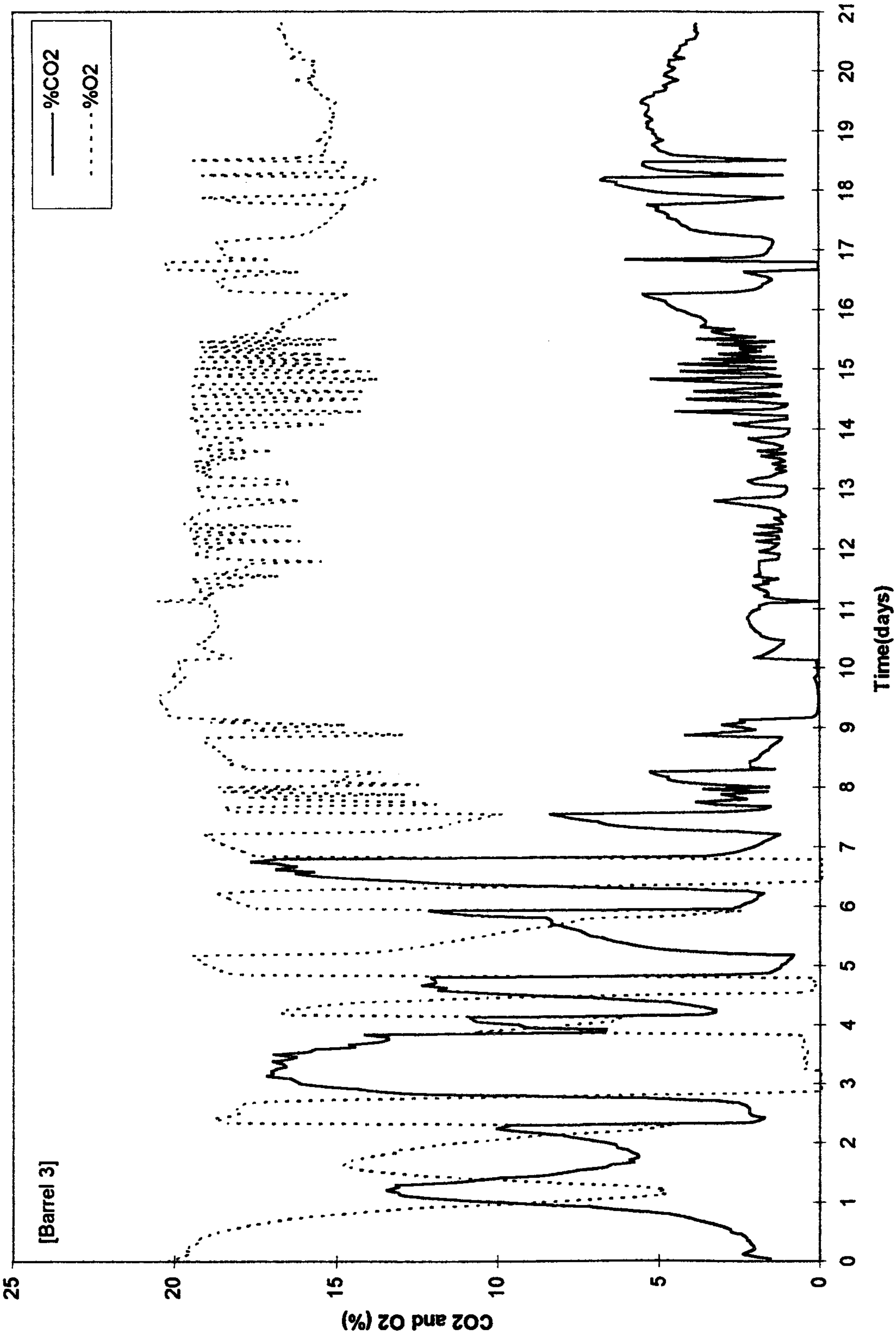

Fig. 6A Oxygen and carbon dioxide histories obtained during the intermittently aerated decomposition process.

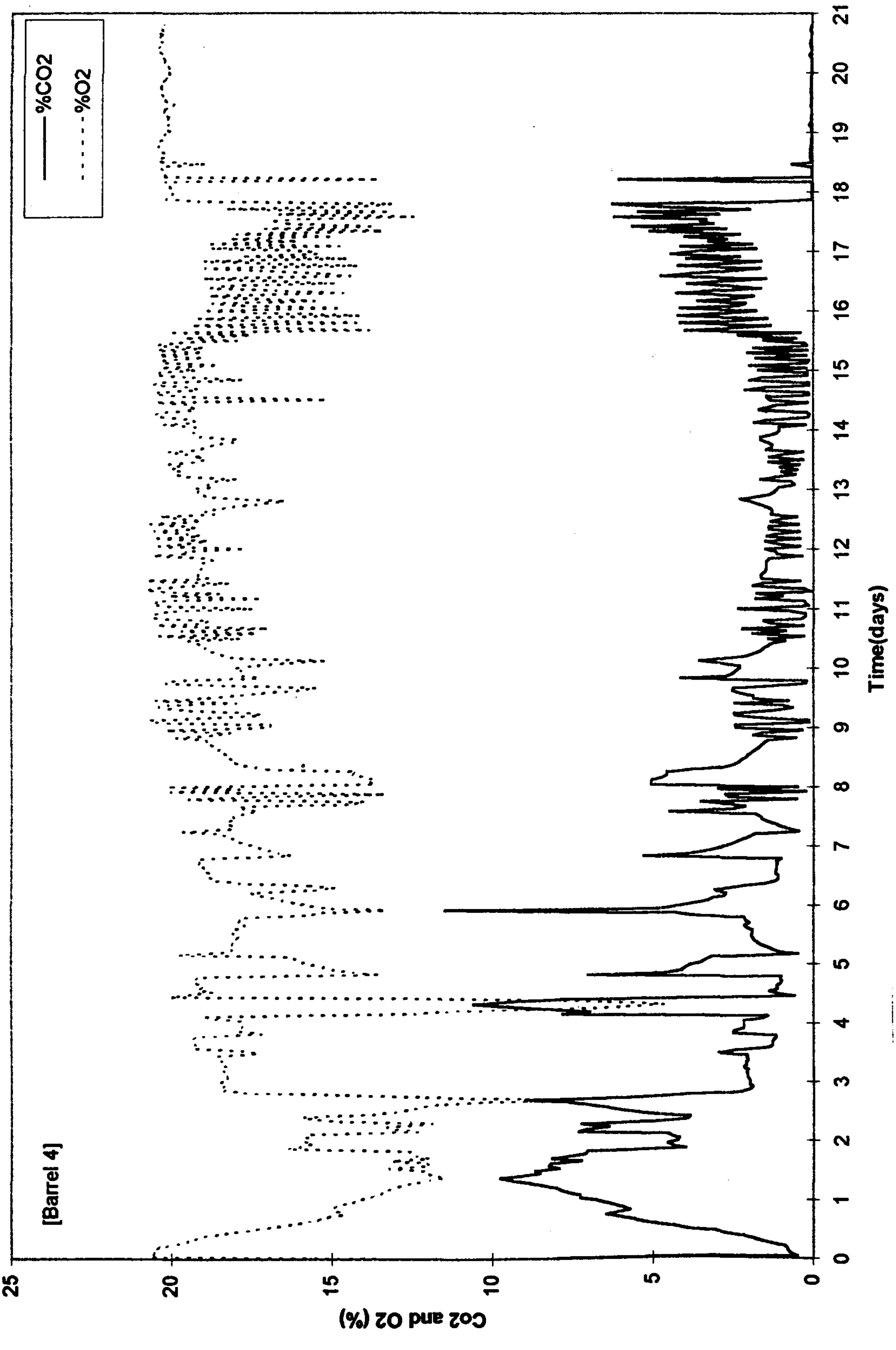

Fig. 6B Oxygen and carbon dioxide histories obtained during the intermittently aerated stabilization process.

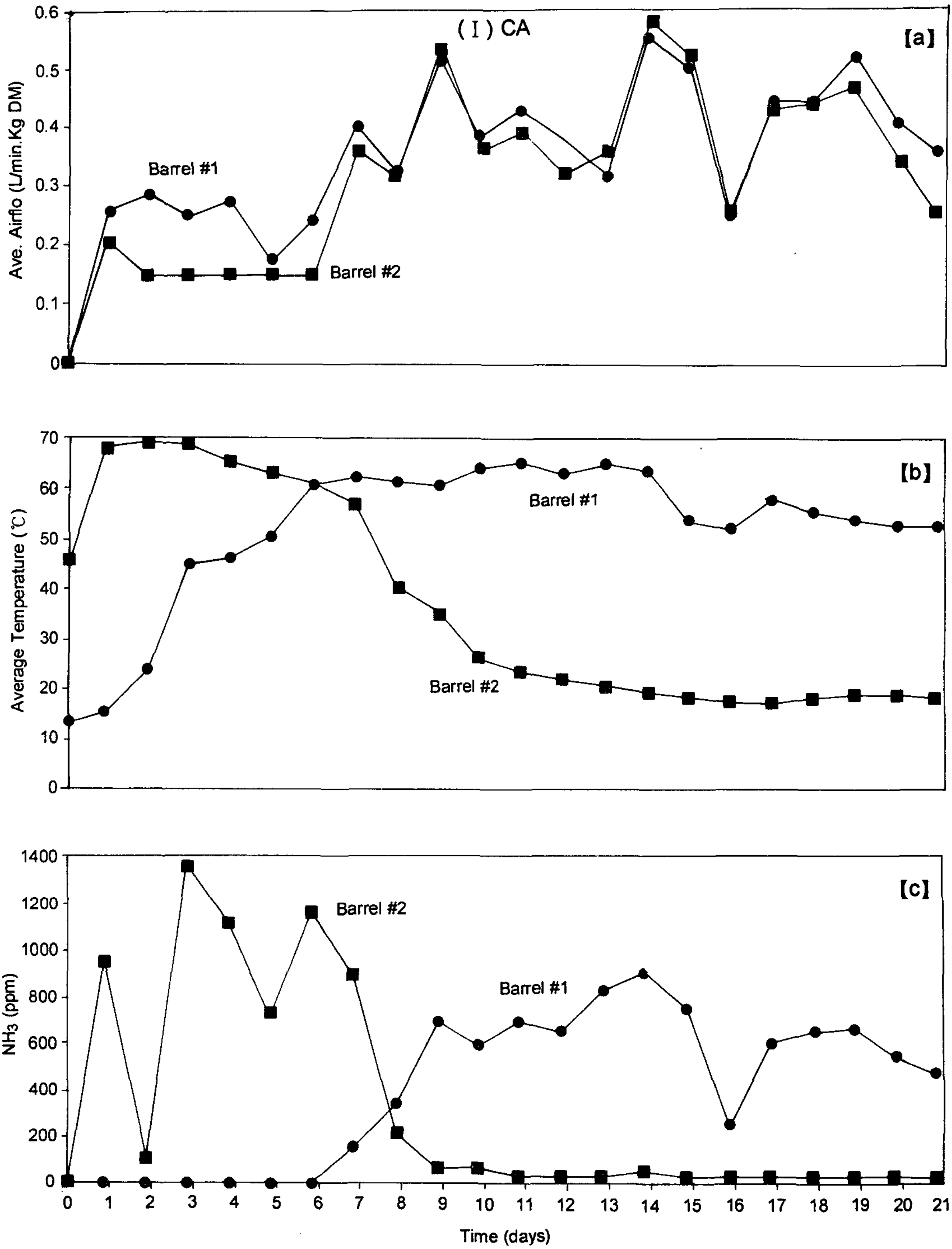

Fig. 7A Graphical records of average airflow rates, compost temperatures and ammonia concentrations during continuously aerated composting decomposition(#1) and stabilization (#2) processes.

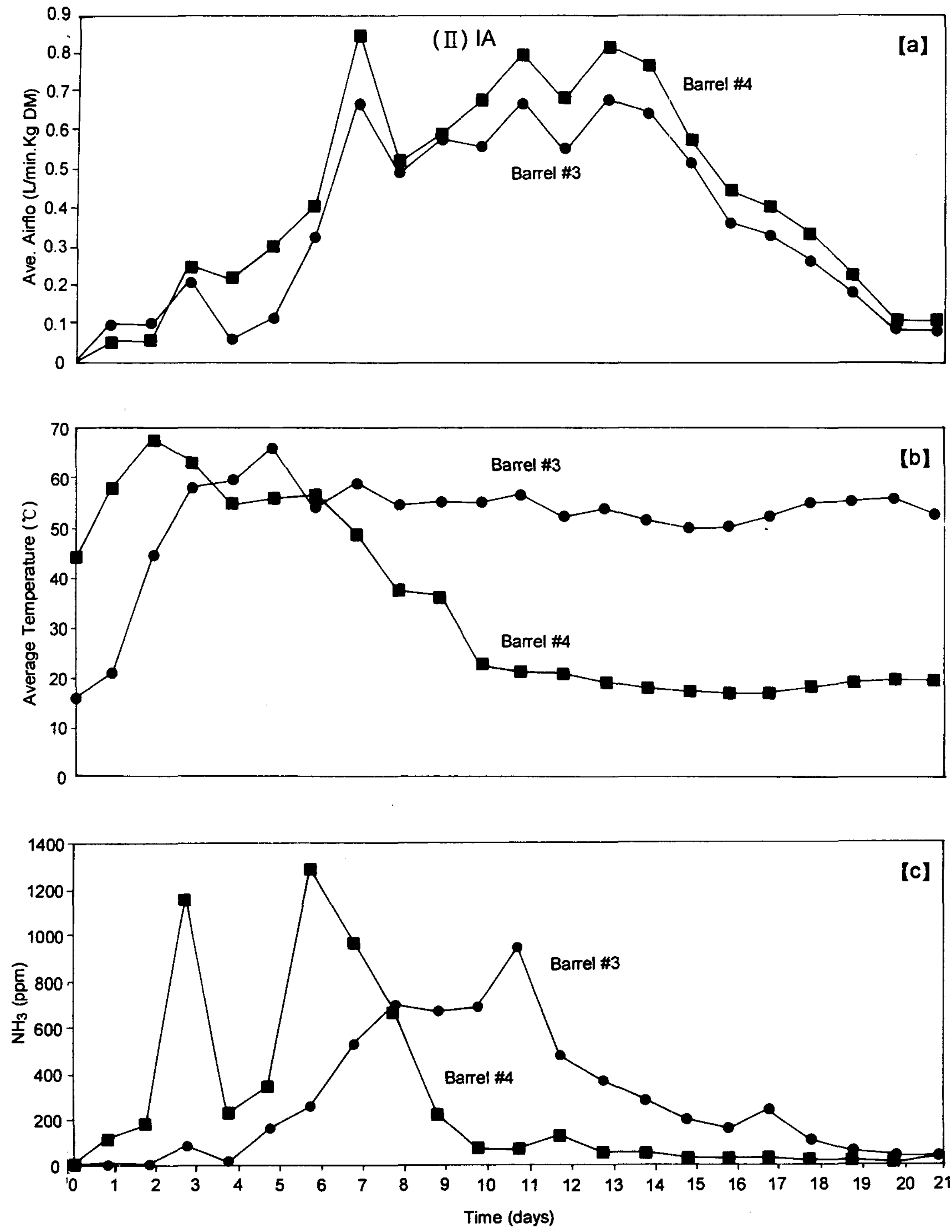

Fig. 7B Graphical records of average airflow rates, compost temperatures and ammonia concentrations during intermittently aerated composting decomposition(#3) and stabilization (#4) processes.

composting(Hong et al., 1997a).

4. CONCLUSIONS

The effects of temperature, air flow rate, O_2 consumption, CO_2 evolution and NH_3 gas concentration on the composting reaction were examined while raw hog manure amended with sawdust was composted by continuous aeration(CA) and intermittent aeration(IA) management using pilot-scale in a barrel composting system.

Major findings are summarized as follows:

1. The ammonia removal efficiency through fresh compost during stabilization process ranged from 70% (IA) to 90%(CA) of total NH_3 gas evolution after 8^{th} day, respectively.

2. The IA composting was very successful in reaching sufficient temperature above 55℃ long enough for pathogen kill.

3. CO_2 evolution during the biological decomposition phase declined after the 14^{th} day in the CA method and the 7^{th} day in the IA method, respectively. IA required less time to reach stability than CA.

4. Temperature, CO_2 evolution, NH_3 gas concentration and composition of the stabilized compost, hog manure amended with sawdust can be composted after 6 weeks.

5. ACKNOWLEDGEMENTS

This research was supported in part by the Korea Science & Engineering Foundation under the KOSEF/NSF Senior Scientist Exchange Program Agreement.

The authors want to acknowledge the contributions of Dr. Harold M. Keener, associate professor, and Kamil Ekinci, graduate student for assisting with the composting experiments. And the authors are very grateful to the OARDC/OSU for sponsoring this work and to the staff of the Dept. of Food, Agricultural and Biological Engineering for Their cooperation.

REFERENCES

1. ASAE. Standards(44^{th} Ed.). 1997. S319.3. Methods of determining and expressing fineness of feed materials by sieving. St. Joseph, MI. ASAE.
2. Composting Council. 1995. Compost Facility Operating Guide, The Composting Council, Alexandria, Virginia, 22314.
3. Elwell, D. L., H. M. Keener, H. A. J. Hoitink, R. C. Hansen and J. Hoff. 1994. Pilot and full scale evaluation of leaves as an amendment in sewage sludge composting. Compost Science and Utilization 2(2):55-74.
4. Hansen, R. C., K. M. Mancl, H. M. Keener and H. A. J. Hoitink. 1995. The composting process- A natural way to recycle wastes- The Ohio State University, Ohio State Extension.
5. Hansen, R. C., H. M. Keener, W. A. Dick, C. Marugg and H. A. J. Hoitink. 1990. Poultry manure composting: Ammonia capture and aeration control. ASAE paper No. 904062.
6. Hansen, R. C., H. M. Keener and H. A. J. Hoitink. 1989. Poultry manure composting: Design guidelines for ammonia. ASAE paper No. 894075.
7. Haug, R. T. 1993. The Practical Handbook of Compost Engineering, Ann Arbor, Mich; Lewis Publishers.
8. Hong, J. H., K. J. Park and B. K. Sohn. 1997a. Effect of composting heat from intermittent aerated static pile on the elevation of underground temperature. Applied Engineering in Agriculture, ASAE, 13(5):679-683.
9. Hong, J. H., K. J. Park and B. K. Sohn. 1997b. Influence of aeration rate on ammonia emission in high rate composting of dairy manure and rice hulls mixtures. ASAE paper No. 974114.
10. Hong, J. H., H. M. Keener and D. L. Elwell.

1997c. Preliminary study of the effect of continuous and intermittent aeration on composting hog manure. Unpublished thesis, Dept. of FABE, OARDC/OSU, Wooster, OH.

11. Hong, J. H. 1994. Controlling factors in open composting process. Proc. of the 12th world congress on Agricultural Engineering Vol. 2:1553-1559.
12. Keener, H. M., C. Marugg, R. C. Hansen and H. A. J. Hoitink. 1993. Optimizing the efficiency of the composting process. In: Science and Engineering of Composting, pp. 55-94. Worthington, OH; Renaissance Publications.
13. Keener, H. M., D. L. Elwell and T. Pang. 1992. Effect of temperature and weekly turning on composting rates-phase 1. Unpublished thesis, Dec. 30 Written for Buhlers Inc.
14. Keeney, D. R. and D. W. Nelson. 1982. Nitrogen-inorganic forms. pp. 643-698. In: A. L. Page et al. (eds.), Methods of Soil Analysis, Part 2. American Soc. of Agronomy, Madison.
15. Leson, G. and A. M. Winer. 1991. Biofiltration: an innovative air pollution control technology for VOC emission. Air and Waste Management Association 41(8):1045-1054.
16. Marugg, C., M. Grebus, R. C. Hansen, H. M. Keener and H. A. J. Hoitink. 1993. A kinetic model of the yard waste composting process. Compost Science and Utilization 1(1):38-51.
17. Marugg, C. 1992. Handbook of Analysis Procedures for Compost Laboratory Data, Dept. of FABE., OARDC/OSU, Wooster, OH.
18. Matsuda, J. 1987. Forced air for compost making. Farming Mechanization, 2839:13-15.
19. Toffey, W. E. 1997. Biofiltration-Black box or biofilm? BioCycle 38(6):58-63.