

猪粪快速好氧堆肥过程中氧气浓度的变化

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摘要 采用自主设计开发的氧气测量设备,测定堆体不同部位的氧气浓度,从而对猪粪堆肥过程中氧气浓度的变化、通风对氧气浓度的影响、堆体不同部位氧气浓度的差异进行了分析。结果表明,堆肥过程中氧气浓度呈升高的趋势,中后期氧气浓度增加比前期明显,停止通风后 10min 内氧气消耗速率最快,之后消耗速度较慢,堆体四周和顶部氧气浓度较高,中部较低。

关键词 猪粪 堆肥 氧气 氧传感器 强制通风

Oxygen Variation in Aerobic Composting Process of Pig Manure

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Abstract Aerated static composting is one of the best choices to treat animal wastes. Oxygen is an important factor influencing the composting process. The growth of aerobic microorganism, the composting duration and the quality of final product depend largely on the oxygen concentration in the pile and the oxygen supplying process. In order to control the oxygen concentration and optimize the composting process, it is necessary to study the spatial distribution and variation of oxygen in the composting process.

Experimented composting pile was placed in a building in one 1.5m × 1.0m bay with cement floor and walls. Aeration board was laid on the bottom of the bay. The pile contained pig manure, recycled compost and bulking agent. A bulking agent layer on the aeration board dispersed air through the 1.5m high mix layer. Pile was covered with a 20cm insulating layer of recycled compost. The bay had an aerator to supply air. The composting experiment was carried out from Nov. 28, 2000 to Dec. 20, 2000. Five sampling sites were set in the pile and the oxygen concentrations were monitored during the composting process.

The equipment used to measure the oxygen concentration was designed and made by Laboratory of Environmental Remediation. Before the composting experiment, all oxygen sensors and the whole equipment were tested. The results showed that the stability and the precision of sensors were perfect. Other gases produced in the composting process possibly interfered the measured result of oxygen sensor, so all oxygen sensors were placed in the circumstances full of NH₃, H₂S and H₂O with different concentrations. The results showed that those gases did not affect the measuring sensibility of sensors. The responding time of the sensor was less than two seconds and the equilibrium time of the whole equipment was less than four seconds.

The oxygen concentrations were measured at 0, 10, 20 and 30 minutes later after the stopping ventilation, respectively. In order to study the oxygen dynamics, the oxygen concentrations were monitored at the same time every day, and the measured data were used to analyze the oxygen variation during the composting process.

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The oxygen decreasing speed in the pile was fast during the first 10 minutes and then decreased slowly. Oxygen concentrations at the edge parts and upper parts were high in different sampling sites, almost at the same level. Ventilating for 10 minutes and stopping ventilating for 40 minutes kept the oxygen concentration increase to 15%, which made microorganism degrade organic matter successfully in most parts of the pile except for the central part where oxygen concentration was far lower than the edge parts. It showed that supplied oxygen was not enough for the growth of microorganism and ventilating had little effect on the supplying process of oxygen for the central part.

Key words pig manure; compost; oxygen; sensor; ventilation

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近年来,我国畜禽的规模化、集约化饲养发展很快,并导致严重的畜禽粪便污染。好氧高温堆肥技术,不易产生二次污染,是一种比较彻底的畜禽粪便处置方式。

氧气是影响畜禽粪便好氧堆肥进程的关键因素之一,是判断堆肥是否进行完全的重要参数^[1]。充足的氧气供给是保证好氧微生物群体繁殖发育的重要条件,对堆肥进行时间、堆肥产品质量有重要影响^[2]。研究堆体不同部位氧气分布状况和整个堆肥过程中氧气变化规律,对于调节堆肥过程中的氧气浓度、适时培养好氧微生物群体、控制恶臭气体、CO 的排放^[3],从而实现整个堆肥控制过程的优化具有重要的意义。

目前,国内关于堆肥的研究主要集中在堆肥方法、设备等方面,高温好氧堆肥堆体中氧气浓度的研究较少。国外关于堆肥及堆体中氧气浓度的研究开展较早。Randle 等^[4]研究了堆肥过程中氧气的消耗和供给之间的关系,结果表明堆肥全过程中堆体 86% 的位置氧气浓度大于 5%。Hansen 等^[5]研究了在静态垛堆肥中通入浓度 95% 的氧气对堆体 C/N 比、颜色、气味、部分重金属含量以及湿度变化的影响。Joshua 等^[6]试验发现,在各种条件适宜的情况下,条垛式静态堆肥系统中,堆体中氧气最低浓度为 14.4%。Jackson 等^[7]研究证明,采用鼓风和抽风间隔进行的方式堆肥,堆体通风效果好。Niemi 等^[8]探讨了建立氧气消耗和氧气供给关系模型。其他学者,如 Kermarrec^[9],Lasaridi^[10]等也都对通风与堆体氧气含量的关系,氧气与堆体气体释放的关系等进行了研究。但是,以往对堆肥过程中氧气浓度的动态变化研究较少,对于短时间内氧气的消耗状况研究也比较少。本文则旨在探讨堆肥过程中氧气浓度的变化过程,以进一步提高堆肥效率和堆肥产品的质量。

1 材料和方法

1.1 试验材料和方法

供试材料为北京市朝阳区王四营养猪场猪粪,填充料采用 CTB 调理剂、回流猪粪。调理剂的含水率和饱和吸水率为 2.68%、65.69%。堆肥于 2000 年冬季进行(11 月 28 日开始,12 月 20 日结束),共 23d,堆肥方式为强制通风静态垛高温好氧堆肥。

堆肥池的几何尺寸为 $150 \times 100 \times 150 \text{ cm}^3$ 。试验采用温度反馈自动控制系统进行自动控制。该系统可根据堆体温度变化情况,通过堆肥专用软件 Compsoft 对通风方式和通风量进行控制,控制方式为强制通风 10min,停止 40min。在该自动控制系统运作下,测量堆体不同部位的氧气浓度。

1.2 设备及可靠性检验

氧传感器原理为电化学传感器,传感器外观呈圆柱形,直径 18mm,长 30mm。测量采用抽气法,气路内径 0.8mm(该装置正在申请专利)。为了保证测量的准确性,对传感器及氧气测量装置进行了可靠性检验。

在封闭容器内将 N_2 和 O_2 按不同比例混合,得到不同浓度的混合气体,将测量值与混合气体实际值比较来验证传感器的精度、响应时间等参数。传感器的实验结果见图 1,从图 2 可知,该传感器 3 次测定的稳定性良好,通过相关分析发现,3 次测量结果与混合气体真实值之间的相关系数 r 分别为 0.999, 1.000, 1.000, 均达到 99.9% 的置信度,因此传感器的测量精度和重现性良好。将传感器放置于 NH_3 、 H_2S 、水蒸气等气体环境中检测堆体实际环境中可能存在的气体对它的干扰,证明以上气体对传感器没有明显的影响。

多次试验的结果表明,该传感器的稳定性也良好,传感器的响应时间 $<2s_0$ 。氧气测量设备在空气中的平衡时间 $<4s_0$ 。

1.3 样点分布

1号、2号、3号、4号样点在同一个水平面上,其中1号、2号、3号样点在一个对角线上,5号样点高于其他4个样点(如图2)。1号、3号、4号样点位于堆体边缘,2号样点位于堆体中部,5号样点位于堆体中上部距堆体表面1/3处。

2 结果与讨论

2.1 堆肥过程中氧气动态变化

为测定堆肥过程中氧气浓度的变化,于鼓风停止后0、20min时分别测定各个样点氧气浓度,其结果如图3。

从整个堆肥过程来看,堆体各部分氧气浓度总体上呈现增加趋势。但是,开始几天内氧气浓度有一个不明显的减少过程,之后开始增加,表明早期氧气消耗量较大。堆体边缘和中上部氧气浓度变化趋势基本一致,中部氧气变化规律不明显。据试验观察,造成这种差异的原因可能与不同样点的水分含量差异有一定关系,虽然中部2号样点与四周1号、3号、4号样点的深度一致,但是中部2号样点的水分含量高,堆体孔隙充满液态水分,气体交换不畅,因而氧气浓度低,而中上部5号样点距离堆体顶部近,通气状况良好,因而其变化趋势与堆体边缘的1号、3号、4号样点基本一致。

鼓风停止20min后,堆体各部位氧气的变化规律与鼓风停止时各部位的变化规律一致,但是鼓风停止20min后的升幅大于鼓风停止时。这可能是因为在堆肥开始的一段时间内微生物活动旺盛,氧气消耗量大,而后期堆体物质基本稳定,微生物活动减弱,氧气消耗量逐渐减少,因而 O_2 浓度逐渐增大。

2.2 停止鼓风后氧气的消耗过程

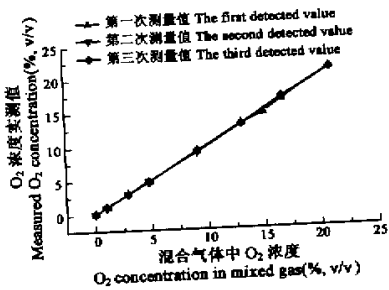


图1 氧传感器的稳定性实验结果
Fig.1 Stable test for oxygen sensor used in the experiment

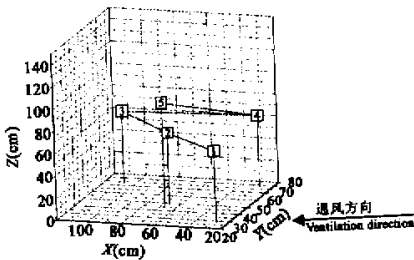


图2 样点(1~5)位置示意图
Fig.2 Sketch map of the sample point(1~5)

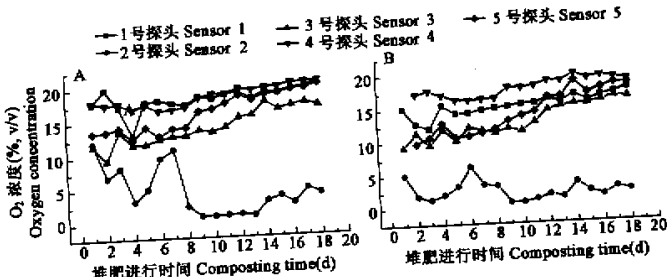


图3 堆肥过程中氧气浓度变化
Fig.3 Oxygen variation

A: 鼓风停止时的氧气浓度变化 Oxygen variation right after stop ventilation ;B: 鼓风停止 20min 后的氧气浓度变化 Oxygen variation 20 min after stop ventilation

每次鼓风停止后,分别于 0、10、20、30min 测定 O₂ 浓度,结果见图 4。

由图 4 分析可见,各样点的氧气浓度都呈现减少的趋势,这是鼓风停止后,氧气消耗的结果。减少的趋势表明各点氧气消耗的速率,从测量结果看,氧气消耗速度在前 10min 最快,可占鼓风停止后 40min 内氧气消耗量的 1/24/5,之后消耗速度逐渐减缓。从各部位氧气浓度看,堆体边缘部位的 1 号、3 号、4 号各样点和中上部的 5 号样点氧气浓度较高,基本处于同一水平。强制通风 10min,然后自由发酵 40min 的通气方案基本可以保证氧气浓度高于 15%,因此可以满足好氧发酵的要求,但是,堆体中心部位的 2 号样点,无论通风前后均不能满足好氧发酵的氧气浓度要求,说明鼓风对该点氧气的补充没有明显的作用。因此,改变堆体的结构,改善堆体中部的通风条件,是进一步提高堆肥效率的关键。

2.3 堆体不同部位的氧气浓度差异

从图 4 还可以看出,虽然堆体边缘的 1 号、3 号、4 号样点和位于堆体中心的 2 号样点处于同一水平面,5 号样点高于前 4 个样点,但在各时间段内边缘部位和中上部的氧气浓度相近,而中心部位的氧气浓度远远小于其他样点。形成这种分布规律的主要原因可能是水分含量影响的缘故^[1]。试验中观察堆体中心部位水分含量远远高于其他样点,水分的存在填充了堆体孔隙的大部分自由空间,并且使调理剂大量吸水饱和,因此通气性极差,使得该部位氧气浓度极低。其次,堆体中心部位的 2 号样点由于堆体自身重力致使该点密度较大,孔隙度较小,因此其位置虽然与 1 号、3 号、4 号处于同一水平面,但是它的通气性却低于其他样点,从而使该点氧气浓度低。中上部 5 号样点位于 2 号样点的正上方,高于边缘 1 号、3 号、4 号样点,但是其氧气浓度却与 1 号、3 号、4 号样点相当,远远高于 2 号样点,这可能是由于其距离上部的气-固界面较近,容易与大气中的空气进行直接交换。

2.4 结论

在堆肥过程中,堆体边缘部位的氧气浓度有随堆肥时间的推移而逐渐增加的趋势;在间歇性鼓风方案中,停止鼓风 10min 内堆体氧气消耗速度最快,之后的 30min 内消耗速度较慢。堆体中氧气的分布规律是中心部位氧气浓度较低,而四周以及上部氧气浓度较高。因此在改进堆肥工艺时应注意提高堆体中部的通气性。

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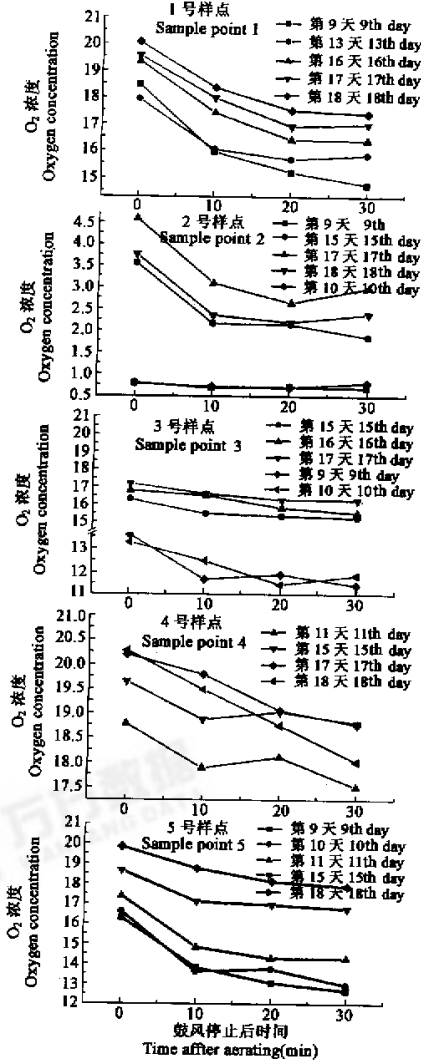


图 4 鼓风停止后堆体的氧气消耗过程
Fig.4 Oxygen variation after ventilation

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