中文摘要

豬糞尿在厭氧條件下會產生揮發性有機臭氣(VOC 臭氣)，為研擬其在異質混合通風空間中之動態傳輸過程，本文以對甲酚(p-cresol)、甲苯(toluene)及對二甲苯(p-xylene)三種 VOC 臭氣作為研究對象，考慮 VOC 衰減過程及豬糞尿分層現象。VOC 主要分佈於糞尿坑下方污染層，其上有一層較為清澈之澄清層，假設糞漿未經攪動，VOC 臭氣由豬糞尿污染層產生，穿過澄清層及空氣邊界層，將 VOC 臭氣的濃度變化表示成傳輸擴散方程式，經由理論推導，計算畜舍內對甲酚、甲苯及對二甲苯三種 VOC 臭氣濃度隨時間變化，求出工作人員在畜舍內 10 年暴露時間所吸入的 VOC 臭氣總劑量，並與安全標準劑量相較，訂立畜舍惡臭清除準則。由於畜舍通風型態差異影響 VOC 臭氣濃度分佈，本研究基於停留時間分佈(residence time distribution，RTD)及三參數 gamma 分佈之統計理論推導多氣流區 gamma 模式(multiple airflow regions gamma model，MARGM)，將通風空間內部視為由完全混合(complete mixing)、不完全混合(incomplete mixing)及栓塞流(piston flow)三種氣流型態所組成，以此模擬異質混合通風畜舍內部氣流混合型態。將 VOC 傳輸模式推求之濃度對時間分佈資料以 MARGM 進行擬合，求出 VOC 臭氣平均停留時間及混合因子(mixing factor)，由此探討 VOC 臭氣在時間及空間分佈特性，預測通風空間氣流的異質混合行為。以台南新市一機械通風畜舍為對象，並考慮豬糞尿含水量 60、70 及 80%，澄清層厚度為 1 公分及污染層厚度 4 公分與澄清層厚度為 2 公分及污染層厚度 8 公分兩種豬糞尿層厚度進行模式模擬，模擬結果顯示對甲酚尖峰濃度於含水量 60%時最高，當含水量增加時濃度降低；甲苯及對二甲苯尖峰濃度則隨含水量增加而增高，當澄清層厚度增加會延長尖峰濃度到達時間。由工作人員在畜舍內 10 年暴露時間所吸入的 VOC 臭氣

總劑量，與安全標準劑量相較，訂立畜舍惡臭清除準則顯示對甲酚、甲苯及對二甲苯所允許的初始濃度值分別為 10.10、6.13 及 6.69 g m-3。MARGM 模擬對甲酚於通風流量為 3.75 m3 s-1，含水量 70±10%時，在畜舍平均停留時間為 44.45±0.91 小時，平均混合因子 0.20±0.05；甲苯於通風流量為 7.5 m3 s-1，含水量 70±10%時，在畜舍平均停留時間為 267.30±58.90 小時，平均混合因子 0.81±0.17；對二甲苯於通風流量為 5 m3 s-1，含水量 70±10%時，在畜舍平均停留時間為 332.38±129.83 小時，平均混合因子 0.81±0.19。以 MARGM 模擬通風空間氣流之混合行為，可將氣流混合型態經由 VOC 臭氣濃度之擬合，推求平均停留時間以掌握 VOC 臭氣在畜舍內部時間分佈特性，並由平均混合因子瞭解空間分佈特性，以此作為異質混合環境模擬之指標，其強韌性可提供做為室內通風改善參考。

關鍵詞：揮發性有機臭氣；異質混合；停留時間分佈；混合因子；清除準則

Abstract

Odors causing volatile organic compounds (VOC-odors) are released as the result of mass transfer from stored pig slurry under anaerobic decomposition. This research proposes a VOC-odors-transport-model to simulate the diffusion behavior of p-cresol, toluene, and p-xylene, (the three intense VOC-odors found in swine housing) and to study their dynamic transport processes in a ventilated airspace with mixing heterogeneity. A hypothetical scenario is used which assumed that pig slurry as undisturbed followed by the release of VOC-odors in contaminated layer, transported through a clean layer and as well as an air-boundary layer. The variation of VOC-odor concentration could be presented as a diffusion equation to simulate its transport processes. Swine manure clean-up criteria based on non-excess of the total hazardous dose corresponding to an acceptable risk from indoor inhalation for 10 years could then be calculated. We developed a multiple airflow regions gamma model (MARGM) to simulate airflow patterns in a ventilated airspace with mixing heterogeneity based on residence time distribution and gamma distribution statistics. The residence time distribution function takes the form of the three-parameter gamma distribution and account for different mixing types such as complete mixing, piston flow, incomplete mixing, and various combinations of the above types. By fitting the VOC-odor concentration profiles with three-parameter gamma distribution, we can characterize the extent of mixing and provide information for predicting mixing heterogeneity in a ventilated livestock through mixing factor and mean residence time of selected VOC-odors. The typical swine unit with mechanical ventilation system in Tainan was selected for model simulation. The moisture content varied from 60 to 80%; the depth of clean layer varied from 1 to 2cm as well as contaminated layer from 4 to 8cm. The results show that the peak concentration of p-cresol at moisture content 60% is higher than that of 70% or 80%. Moisture content shows different effects to the peak concentration of toluene or p-xylene. Increase in thickness of clean layer will delay the time to peak concentrations. Calculated swine manure clean-up criteria of p-cresol, toluene and p-xylene are 10.10, 6.13, and 6.69 g m-3, respectively. Results from MARGM simulation demonstrate that the mean residence time of p-cresol is 44.45±0.91 h and mean mixing factor is 0.20±0.05 corresponding to a ventilation rate of 3.75m3 s-1 and manure moisture content of 70±10%. When ventilation rate is 7.5 m3 s-1 and manure moisture content is at 70±10%; resulting in a mean residence time of toluene of 267.30±58.90 h with a mean mixing factor of 0.81±0.17. When ventilation rate is 5 m3 s-1 and manure moisture content is at 70±10%; resulting in a mean residence time of p-xylene of 332.38±129.83 h and a mean mixing factor of 0.81±0.19. Our results give additional physical information to characterize mixing behavior temporally and spatially with mean residence time and mixing factor, respectively. The robustness of MARGM can offer designers to reconsider the efficiency of ventilation systems though different mixing flow pattern in place of complete mixing.

Keywords ： Odors causing volatile organic compounds; Mixing heterogeneity; Residence time distribution ; Mixing factor ; Clean-up criteria