中文摘要

本研究探討具室內 PM 來源之生物環境中不同粒徑顆粒物質(Particulate matter，PM)室內/室外/人體暴露之關聯性。於台灣北部(台北縣三重市)、中部(彰化縣竹塘鄉)、南部(台南縣新市鄉)地區各選取一機械式通風豬舍及於中部(彰化縣溪湖鎮)選取一住戶進行探討，結果顯示北部(以 NS 豬場稱之)、中部(以 CJ 豬場稱之)、南部(以 SH 豬場稱之)豬舍及中部住家中，PM 粒徑特性可以對數常態分佈表示，幾何平均粒徑分別為 2.15、3.11、2.23 及 1.71 μm；幾何標準偏差分別為 1.75、2.26、1.76 及 2.47；質量濃度則分別為 70.79 ± 12.74 (mean ± sd)、2529.43 1138.24、3802.14 1178.66 及 513.24 132.63 μg m^{-3}。室內 PM 之主要移除機制包括通風及沈澱損失，來源則為室外引入及室內飛揚，以質量平衡觀點考慮穩定濃度則可推求不同粒徑之 PM 來源濃度。NS、CJ、SH 豬場及 CS 住戶 PM 質量室內/室外(Indoor/Outdoor，I/O)比在具室內 PM 來源時分別為 1.6 — 24.5、0.02 — 4.97、1.36 — 35.5 及 4.66 — 20.8；無室內 PM 來源時分別為 0.3 — 0.99、0.01 — 0.47、0.02 — 0.58 及 0.42 — 0.99。PM 於人體肺部之沉積以 5 區塊模式模擬：(i)鼻腔區(Nasal passage，ET1)；(ii)口腔咽喉區(Pharynx，ET2)；(iii)氣管/支氣管區(Bronchial region，BB)；(iv)細微支氣管區(Bronchiolar region，bb)，及(v)肺泡區(Alveolar-interstitial region，AI)。肺部 PM 之主要移除機制包括呼吸、重力沈降、紊流擴散沈澱、慣性衝擊、接觸附著損失及巨噬細胞(Macrophage)對 PM 之清除等，研究結果以慣性衝擊損失為主要沈澱機制(1.28×10^{-2} — 5.89×10^{-1} s^{-1})。NS、CJ 豬場及 CS 住戶中，具室內 PM 來源時質量肺部/室內(Lung/Indoor，L/I)比分別為 0.03 — 0.85、0.01 — 0.81 及 0.02 — 0.82；無室內 PM 來源時分別為 0.008 — 0.76、0.006 — 0.71 及 0.009 — 0.77，以上差異主要因為 PM 粒徑不同及肺部不

同區塊之生理變化所造成。模擬得之沈澱分量與 ICRP66 結果比較之均方根誤差(Root mean square error，RMSE)為 0.17，與非 ICRP66 結果比較之 RMSE 為 0.05。此區塊模式計算人員暴露於 NS、CJ、SH 豬場及 CS 住戶內 HRT 之 PM 累積總劑量達穩定時分別為 86.84、2605.15、4386.93 及 607.38×10^{-8} μg cm^{-2}。

關鍵詞：生物環境；機械通風豬舍；住家；顆粒物質；室內/室外比；肺部/室內比；區塊；暴露劑量

Abstract

The purpose of this research is to investigate the size-dependent particulate matter (PM) indoor/outdoor/personal exposure relationships in bioenvironmental enclosures. Both the mechanically ventilated swine buildings located at Sanchung city, Jutang county, and Hsinshi county, respectively, in north, central, and south Taiwan region and the residence house located at Hsihou county in central Taiwan region were selected as study sites and were designated as NS, CJ, SH, and CS, respectively. Measured PM size distributions followed a lognormal distribution with geometric mean diameters of 2.15, 3.11, 2.23, and 1.71 μm and geometric standard deviations of 1.75, 2.26, 1.76, and 2.47, respectively, in swine buildings NS, CJ, SH, and residence CS. Measured mass concentrations were 70.79 ±12.74 (mean±sd), 2529.43 2238.24, 3802.14 1178.66 and 513.24 132.63 μg m^{-3}, respectively, in swine buildings NS, CJ, SH, and residence CS. Transport mechanisms of indoor PM include turbulent diffusive deposition, gravitational settling, and ventilation. The size-dependent PM source concentrations can be evaluated from the mass balance point of view under steady-state conditions. Calculated PM mass indoor/outdoor (I/O) ratios with indoor PM source were 1.6 — 24.5, 0.02 — 4.97, 1.36 — 35.5, and 4.66 — 20.8, whereas 0.3 — 0.99, 0.01 — 0.47, 0.002 — 0.58, and 0.42 — 0.99 without indoor PM source, respectively, in swine buildings NS, CJ, SH, and residence CS. The PM deposition in human respiratory tract (HRT) was described based on a five-compartment lung model including nasal passage (ET1), pharynx (ET2), bronchial region (BB), bronchiolar region (bb), and alveolar-interstitial (AI) compartments. Transport mechanisms of PM in HRT include inhalation, gravitational settling, turbulent diffusive deposition, inertial impaction, interception, and PM clearance, whereas inertial impaction is the dominant mechanism (ranged from 1.28×10^{-2} — 5.89×10^{-1}

s^{-1}). Calculated PM mass lung/indoor (L/I) ratios with indoor PM source of swine buildings NS and CJ and residence CS were 0.03 — 0.85, 0.01 — 0.81, and 0.02 — 0.82, respectively, whereas 0.008 — 0.76, 0.006 — 0.71, and 0.009 — 0.77 without indoor PM source. The study reveals that significant variations result from PM wide size range and physiological factors in lung. The root mean square error of deposition efficiency between model prediction and ICRP66 is 0.17, whereas 0.05 between model prediction and non-ICRP66. Calculated steady-state integrated exposure dose in HRT were 86.84, 2605.15, 4386.93, and 607.38 $\times 10^{-8}$ μg cm^{-2} for a person in swine buildings NS, CJ, SH, and residence CS, respectively.

Keywords：Bioenvironmental enclosures; Mechanically ventilated swine building; Residence; Particulate matter; Indoor/Outdoor ratio; Lung/Indoor ratio; Compartment; Exposure dose