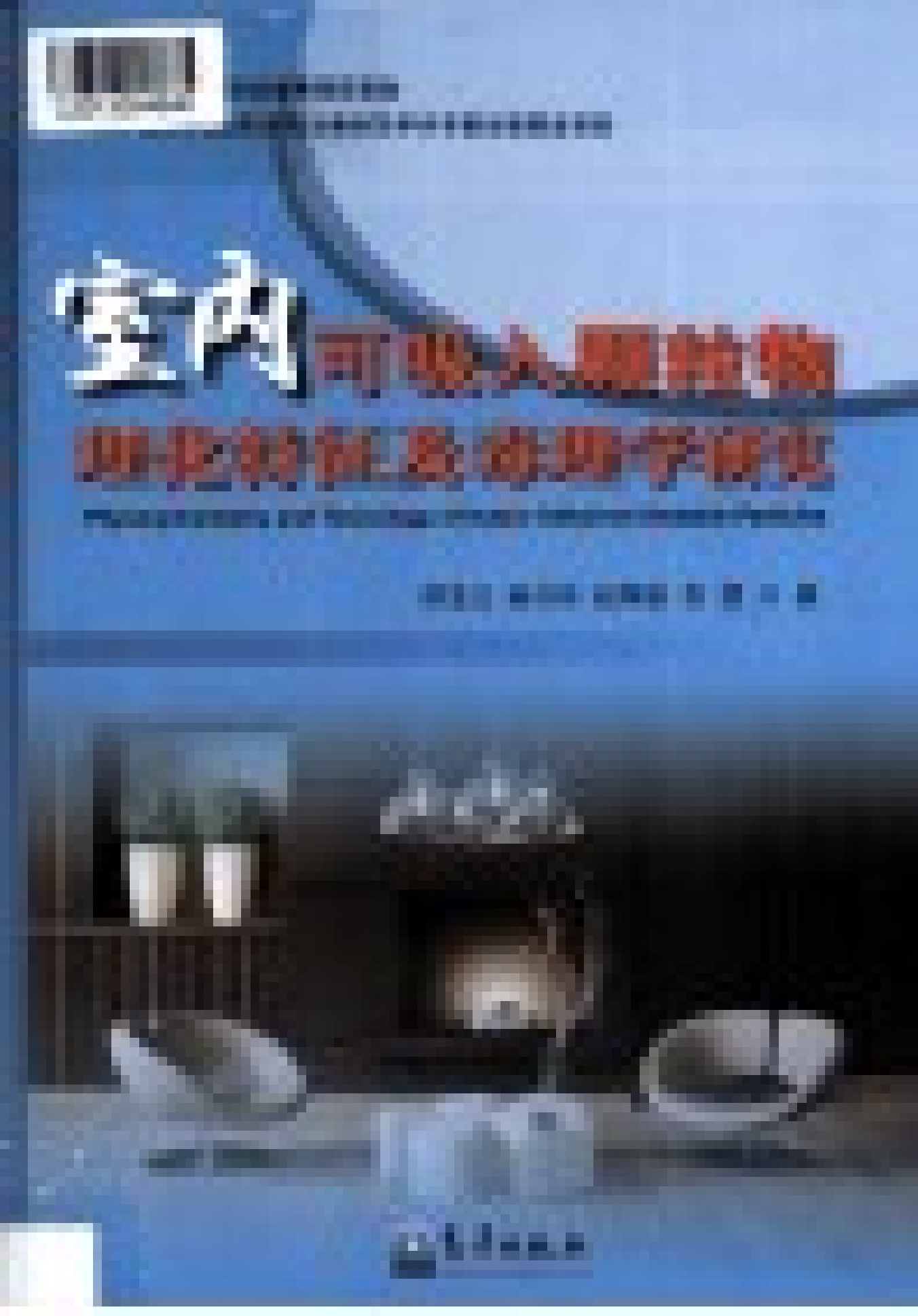
研业务费项目资助
(北京)研究生教材及学术专著出版基金资助

室内可吸入颗粒物理化特征及毒理学研究

Physicochemistry and Toxicology of Indoor Airborne Inhalable Particles

邵龙义 杨书申 赵厚银 李 慧 ◎ 著

气象出版社
China Meteorological Press



中央高校基本科研业务费项目资助
中国矿业大学(北京)研究生教材及学术专著出版基金资助

室内可吸入颗粒物理化特征及毒理学研究

邵龙义　杨书申　赵厚银　李　慧　著

气象出版社
China Meteorological Press

内容简介

人们平均80%以上的时间是在室内度过的，所以每天呼吸的空气绝大部分来自于室内。室内空气污染不仅破坏人们的工作和生活环境，而且直接威胁着人们的身体健康。本书以北京市居室及校园公共场所室内空气为例，分析了室内 PM_{10} 和 $PM_{2.5}$ 在不同季节、不同时间段的质量浓度变化特征及其影响因素；利用场发射扫描电镜、透射电镜及能谱等单颗粒分析方法揭示出可吸入颗粒物的主要微观形貌类型及其来源，结合图像分析及分形维数提出不同类型颗粒物的粒径分布特征；利用质子激发X荧光分析测定了不同污染源和不同类型的居室室内 PM_{10} 中化学元素的质量浓度，并利用富集因子法进行了颗粒物的源解析，同时使用电感耦合等离子体质谱法测定了室内大气中 PM_{10} 样品重金属元素组成特征；最后还通过质粒DNA损伤评价研究了可吸入颗粒物的潜在健康效应等。全书数据翔实、内容丰富、方法先进，具有很强的科学性、资料性和实用性。

本书可供大气科学、环境科学、大气环境化学及环境地质学等领域的科技人员、有关专业师生以及从事环境保护事业的管理人员参考。

图书在版编目(CIP)数据

室内可吸入颗粒物理化特征及毒理学研究/邵龙义等著.
—北京：气象出版社，2012.4
ISBN 978-7-5029-5464-2

Ⅰ.①室… Ⅱ.①邵… Ⅲ.①室内空气-空气污染-粒状污染物-物理化学-特征-研究 ②室内空气-空气污染-粒状污染物-毒理学-研究 Ⅳ.①X513.31

中国版本图书馆CIP数据核字(2012)第057632号

Shinei Kexiru Keliwu Lihua Tezheng ji Dulixue Yanjiu

室内可吸入颗粒物理化特征及毒理学研究

邵龙义 杨书申 赵厚银 李 慧 著

出版发行：气象出版社
地　　址：北京市海淀区中关村南大街46号　　**邮政编码**：100081
总 编 室：010-68407112　　**发 行 部**：010-68406961
网　　址：http://www.cmp.cma.gov.cn　　**E-mail**：qxcbs@cma.gov.cn
责任编辑：王元庆　　**终　　审**：黄润恒
封面设计：博雅思企划　　**责任技编**：吴庭芳
责任校对：永 通
印　　刷：北京中新伟业印刷有限公司
开　　本：787 mm×1092 mm 1/16　　**印　　张**：15
字　　数：384千字
版　　次：2012年6月第1版　　**印　　次**：2012年6月第1次印刷
定　　价：58.00元

前 言

人们有平均80%以上的时间是在室内度过的，室内空气污染不仅破坏人们的工作和生活环境，而且直接威胁着人们的身体健康，尤其是对孕产妇、婴幼儿、老弱病残等敏感人群身体健康的影响更为明显。近年来，室内可吸入颗粒物污染及其造成的健康问题已逐渐引起人们重视。世界卫生组织最近报道(2011年9月)，全世界约有200万人因使用家用固体燃料造成的室内空气污染所致疾病而过早死亡，由肺炎导致的五岁以下儿童死亡中，几乎有50%是因为吸入了室内空气污染带来的颗粒物，每年有100多万人死于因接触此类室内空气污染而导致的慢性阻塞性肺病(http://www.who.int,Indoor air pollution and health)。在继“煤烟型”、“光化学烟雾型”空气污染后，“室内空气污染”亦越来越受到人们的关注。调查统计，世界上30%的建筑物中存在有害健康的室内空气，受污染的室内空气中存在着30余种致癌物(Ozkaynak 等 1996)，这些有害气体已经引起全球性的人口发病率和死亡率的增加。为此，美国环保局、欧共体国家、世界卫生组织以及我国都先后组织制定了室内空气质量标准，以控制室内空气污染。因此，从健康的角度出发，研究与防治室内空气污染已经是环境与健康学科的重点研究方向。

本书以北京市居室环境和校园公共室内环境为例，对室内PM_{10}和$PM_{2.5}$不同季节、不同时间段的质量浓度、单颗粒微观特征、粒度分布和微量元素组成等物理化学特征及变化规律，并用质粒DNA评价法方法，研究了室内/外颗粒物的生物活性大小及变化规律。使用重量—撞击法采集不同季节、不同时间段室内可吸入颗粒物(PM_{10}和$PM_{2.5}$)样品，称量样品质量，计算得出其质量浓度；使用场发射扫描电镜(FESEM)及透射电镜(TEM)、能谱技术、图像分析、电感耦合等离子体质谱(ICP-MS)、质子激发X荧光光谱(PIXE)等技术手段分析单颗粒微观特征、颗粒物来源、颗粒物数量-粒度分布、体积-粒度分布和微量元素组成等物理和化学特征，并使用质粒DNA评价法研究室内大气颗粒物对超螺旋DNA的氧化性损伤即毒性特征。希望研究成果对推动我国室内可吸入颗粒物的研究，特别是颗粒物物理和化学性质及健康效应评价等的研究有所帮助，为我国室内大气环境质量的提高做出贡献。

本书获中央高校基本科研业务费项目资助和中国矿业大学(北京)研究生教材及学术专著出版基金资助。此外，本书研究课题受北京市自然科学基金“北京市室内可吸入颗粒物的物理化学特征及生物活性研究”(项目号8073030，项目负责人：邵龙义)和建设部科学技术项目“室内可吸入颗粒物对DNA氧化性损伤能力的研究”(项目号05-K4-38，项目负责人：邵龙义)资助；同时本书研究课题还受到国家自然科学基金项目(项目号：41030213，41175109)和国家自然科学基金委与英国皇家学会共同资助的中英国际合作项目、北京市共建项目——北京市优秀博士学位论文指导教师科技项目以及教育部高等学校科技创新工程重大项目培育资金项目(项目号：705022)的资助。

本书共分七章，撰写分工如下：第1章由邵龙义、杨书申执笔，第2章由李慧、赵厚银和孙

珍全执笔，第 3 章由邵龙义、李金娟和宋晓焱执笔，第 4 章由杨书申和沈蓉蓉执笔，第 5 章由赵厚银、孙珍全执笔，第 6 章由邵龙义、李慧和吕森林执笔，第 7 章由杨书申和肖正辉执笔。全书最后由邵龙义统稿。

本书的研究工作及编著得到中国矿业大学（北京）地球科学与测绘工程学院以及煤炭资源与安全开采国家重点实验室师生的大力支持，除署名作者外，还有博士生李卫军、李凤菊、牛红亚、樊景森，硕士生贺桃娥、刘昌凤、杨园园、张涛、王伟、刘君霞、付小娟、王静、王建英、李泽熙、胡颖等参加了样品采集及室内实验研究。采样工作还得到中国矿业大学（北京）图书馆、学生餐厅、居委会等部门的领导及同志们的协助。研究工作还得到魏复盛院士、任阵海院士、何兴舟教授、王庚辰研究员、柴发合研究员、张金良教授、王跃思研究员、徐永福研究员、张远航教授、胡敏教授、潘小川教授、姚强教授等的帮助和指导，中国矿业大学（北京）张鹏飞教授、金奎励教授、任德贻教授及彭苏萍院士对研究工作一直给予了关注，并审阅了部分章节。需要特别指出的是英国 Cardiff 大学地球科学系 Tim Jones 博士和生命科学系 Kelly BéruBé 博士在与课题组的长期合作过程中给予了大力支持和帮助。笔者在此对上述单位及专家表示衷心的感谢。

由于作者水平有限，文中错误或欠妥之处，敬请读者不吝指正。

邵龙义

2012 年 3 月谨识

Foreword

People typically spend over 80% of their time indoors, and thus, indoor air pollution not only destroy their working and living environments, but also threaten their respiratory health, especially threatening the health of those sensitive populations such as pregnant women, children, the elderly, and the infirm. In recent years, indoor inhalable particulates and related health problem have attracted wide attention from the public. World Health Organization reported in September 2011 that nearly 2 million people die prematurely from illness attributable to indoor air pollution from household solid fuel use, nearly 50% of pneumonia deaths among children under five are due to particulate matter inhaled from indoor air pollution, and more than 1 million people a year die from chronic obstructive respiratory disease (COPD) that develop due to exposure to such indoor air pollution (http://www. who. int, Indoor air pollution and health). After "coal smoke pollution", and "photochemical smog pollution", the "indoor air pollution" is becoming a more and more important issue. Investigation has shown that 30% of buildings in the world have poor quality indoor air which harms human health, and more than 30 species of carcinogens exist in the polluted indoor air (Ozkaynak et al. , 1996). These harmful pollutants have caused increased morbidity and mortality of world population. Therefore, United States Environmental Protection Agency, European Union countries, World Health Organization and Chinese government have established the related standards of the indoor air quality in order to control the indoor air pollution. It can be seen that, in terms of human health, the prevention and remediation of indoor air pollution is now a major research direction for the environment and health subject.

This book takes the indoor environments of the residential rooms and the campus public rooms in Beijing as an example, and studies the physicochemistry and toxicity of the indoor PM_{10} (particles with a mean aerodynamic diameter less than 10 μm) and $PM_{2.5}$ (particles with a mean aerodynamic diameter less than 2. 5 μm) of the different functional rooms in different seasons. Physicochemistry of indoor PM_{10} and $PM_{2.5}$, such as mass concentrations, individual particle morphology, size distribution and elemental chemistry especially heavy metal compositions, was studied using Field Emission Scanning Electron Microscopy (FESEM), Transmission Electron Microscopy (TEM), image analysis (IA), proton induced X-ray emission (PIXE) and inductively coupled plasmas mass spectrometry (ICP-MS). Toxicity, represented by bioreactivity, of these inhalable particles was investigated using plasmid DNA assay. We hope the results presented in this book will be of help to the promotion of the study of indoor inhalable particulate pollution, especially the study of physicochemical characterization and health impact assessment of these indoor particles. We also hope this book can contribute to the improvement of the indoor air quality in our country.

The research for this book has been supported by a number of funding sources, including Beijing Natural Science Foundation project "Physicochemistry and bioreactivity of indoor inhalable particles in Beijing (Grant No. 8073030, project leader: Shao Longyi)", the Science and Technology Project of the Ministry of Construction "Assessment of oxidative capacity on plasmid DNA induced by indoor inhalable particles (Grant No. 05-K4-38, project leader: Shao Longyi)". The research is also supported by National Natural Science Foundation of China (NSFC Grants 41030213 and 41175109), Sino-UK collaboration project supported by the NSFC and the UK Royal Society, The Joint Program for Scientific Research and Graduate Training of Beijing Education Commission - Awards of Excellent PhD Thesis Supervisor (YB20101141301), and the Cultivation Fund of the Key Scientific and Technical Innovation Project of the Ministry of Education of China (No. 705022)..

The present book was organized by the Geo-Environment Research Group of the China University of Mining and Technology (Beijing) (CUMTB). Chapter 1 was contributed by Shao Longyi and Yang Shushen; Chapter 2 by Li Hui, Zhao Houyin and Sun Zhenquan; Chapter 3 by Shao Longyi, Li Jinjuan and Song Xiaoyan; Chapter 4 by Yang Shushen and Shen Rongrong; Chapter 5 by Zhao Houyin and Sun Zhenquan; Chapter 6 by Shao Longyi, Li Hui and Lv Senlin; Chapter 7 by Yang Shushen and Xiao Zhenghui. The final version of the whole manuscript was completed by Shao Longyi.

The authors of this book would like to thank the staff and students at the School of Geosciences and Surveying Engineering and the National Key Laboratory of Coal Resources and Safe Mining of the CUMTB for their support and help. In particular, Ph. D. students including Li Weijun, Li Fengju, Niu Hongya and Fan Jingsen, as well as MSc students including He Tao-e, Liu Changfeng, Yang Yuanyuan, Zhang Tao, Wang Wei, Liu Junxia, Fu Xiaojuan, Wang Jing, Wang Jianying, Li Zexi and Hu Ying have attended the site sampling campaign and laboratory experiments. Access to the sampling sites has been kindly permitted by the administration departments of the campus of CUMTB. Many thanks are also due to Academician Wei Fusheng, Academician Ren Zhenhai, Professor He Xingzhou, Professor Wang Gengchen, Professor Chai Fahe, Professor Zhang Jinliang, Professor Wang Yuesi, Professor Xu Yongfu, Professor Zhang Yuanhang, Professor Hu Min, Professor Pan Xiaochuan and Professor Yao Qiang for their kind advice and discussions. Professor Zhang Pengfei, Professor Jin Kuili, Professor Ren Deyi and Academician Peng Suping of CUMTB have paid much attention to the research, and examined and revised part of this book. Special thanks go to Dr Tim Jones, Dr Kelly BéruBé and all their Research Group at Cardiff University (UK) for their constant support and guidance during our long-term collaboration.

Shao Longyi

March 4, 2012

目 录

前言
1 绪 论 …… (1)
1.1 室内可吸入颗粒物研究意义 …… (1)
1.2 室内可吸入颗粒物的研究现状 …… (2)
1.2.1 室内可吸入颗粒物物理化学特征的研究 …… (2)
1.2.2 室内大气颗粒物的来源分析 …… (6)
1.2.3 室内大气颗粒物的健康效应研究 …… (7)
1.2.4 可吸入颗粒物的单颗粒表征方法 …… (9)
1.3 室内可吸入颗粒物研究中存在的问题 …… (10)
2 室内 PM_{10} 及 $PM_{2.5}$ 的污染水平 …… (12)
2.1 研究工作概况 …… (13)
2.1.1 研究区概况 …… (13)
2.1.2 采样设备的选择 …… (15)
2.1.3 采样滤膜的选择 …… (16)
2.2 北京市居室室内颗粒物污染水平 …… (17)
2.2.1 北京市市区和郊区室内 PM_{10} 的污染特征 …… (17)
2.2.2 室内 PM_{10} 质量浓度变化原因探讨 …… (22)
2.3 校园公共场所室内 PM_{10} 的污染水平 …… (30)
2.3.1 校园公共场所室内 PM_{10} 和 $PM_{2.5}$ 质量浓度的季节性变化 …… (32)
2.3.2 校园室内昼夜 PM_{10} 和 $PM_{2.5}$ 质量浓度的对比 …… (38)
2.3.3 校园室内 PM_{10} 的质量浓度与气象条件之间的关系 …… (40)
2.4 小结及建议 …… (45)
2.4.1 小结 …… (45)
2.4.2 控制室内 PM_{10} 污染的建议 …… (45)
3 居室及公共场所室内 PM_{10} 的微观形貌及来源分析 …… (47)
3.1 扫描电镜工作原理及在大气颗粒物研究中的应用 …… (47)
3.1.1 扫描电镜及 X 射线能谱仪的结构与原理 …… (47)
3.1.2 扫描电镜在大气颗粒物研究中的应用 …… (50)
3.2 居室室内及公共场所室内 PM_{10} 的微观形貌 …… (50)
3.2.1 样品制备 …… (50)

3.2.2 居室室内及公共场所室内 PM_{10} 的主要单颗粒类型 …… (52)
3.3 北京市不同地区、不同时间居室室内/外 PM_{10} 的显微形貌对比 …… (63)
3.3.1 郊区吸烟和无吸烟室内/外 PM_{10} 的显微形貌对比 …… (63)
3.3.2 市区吸烟和无吸烟室内/外 PM_{10} 的显微形貌对比 …… (64)
3.3.3 同一家庭厨房、客厅的 PM_{10} 的显微形貌对比 …… (65)
3.3.4 不同燃料燃烧产生的 PM_{10} 的微观形貌对比 …… (66)
3.4 校园公共场所室内 PM_{10} 微观形貌的时空变化及来源分析 …… (66)
3.4.1 图书馆室内 PM_{10} 微观形貌的季节变化及来源分析 …… (67)
3.4.2 餐厅室内 PM_{10} 微观形貌的季节变化及来源分析 …… (68)
3.4.3 白天和晚上室内 PM_{10} 微观形貌类型及变化规律 …… (70)
3.5 PM_{10} 中典型单颗粒的微区成分分析 …… (71)
3.5.1 实验设备的选择与样品的制备 …… (71)
3.5.2 烟尘集合体的微区成分 …… (72)
3.5.3 球形颗粒的微区成分 …… (73)
3.5.4 矿物颗粒的微区成分 …… (73)
3.5.5 生物质颗粒的微区成分 …… (75)
3.5.6 不可识别的颗粒的微区成分 …… (75)
3.6 小结 …… (75)
4 居室及校园公共场所室内 PM_{10} 的粒度分布特征 …… (77)
4.1 大气颗粒物粒度分布分析 …… (78)
4.1.1 样品信息 …… (78)
4.1.2 大气颗粒物图像分析基本步骤 …… (79)
4.2 不同燃料燃烧排放室内 PM_{10} 的粒度分布特征 …… (81)
4.2.1 燃柴、燃煤、燃气排放室内 PM_{10} 的数量-粒度分布 …… (81)
4.2.2 燃柴、燃煤、燃气排放室内 PM_{10} 的体积-粒度分布 …… (83)
4.3 居室室内 PM_{10} 的粒度分布 …… (85)
4.3.1 市区居室室内/外冬季和夏季 PM_{10} 的数量-粒度分布 …… (85)
4.3.2 市区居室室内/外冬季和夏季 PM_{10} 的体积-粒度分布 …… (89)
4.3.3 郊区居室室内/外 PM_{10} 的数量-粒度和体积-粒度分布 …… (90)
4.3.4 市区和郊区居室室内/外 PM_{10} 的数量-粒度及体积-粒度分布对比 …… (93)
4.4 校园公共场所室内 PM_{10} 的粒度分布特征 …… (94)
4.4.1 冬季校园公共场所室内 PM_{10} 的粒度分布 …… (94)
4.4.2 春季校园公共场所室内 PM_{10} 的粒度分布 …… (97)
4.4.3 夏季校园公共场所室内 PM_{10} 的粒度分布 …… (99)
4.4.4 秋季校园公共场所室内 PM_{10} 的粒度分布 …… (100)
4.4.5 不同季节校园公共场所室内 PM_{10} 的粒度分布比较 …… (102)
4.4.6 昼夜校园公共场所室内 PM_{10} 的粒度分布比较 …… (102)
4.5 小结 …… (104)

5 居室及公共场所室内 PM_{10} 中化学元素组成特征 …… (105)
5.1 化学成分分析原理 …… (106)
5.1.1 质子激发 X 荧光分析原理及应用 …… (106)
5.1.2 ICP-MS 的原理与仪器设备 …… (107)
5.2 制样和分析 …… (108)
5.2.1 PIXE 分析样品处理 …… (108)
5.2.2 ICP-MS 分析样品处理 …… (109)
5.2.3 富集因子法分析颗粒物来源 …… (112)
5.2.4 因子分析(Factor Analysis)在大气环境中的应用 …… (112)
5.3 北京市居室室内 PM_{10} 的化学元素组成分析 …… (114)
5.3.1 不同燃料源排放颗粒物的化学元素组成及富集因子分析 …… (114)
5.3.2 市区吸烟和非吸烟室内 PM_{10} 的化学元素分析 …… (116)
5.3.3 郊区吸烟和非吸烟室内 PM_{10} 的化学元素分析 …… (118)
5.3.4 室内和室外 PM_{10} 的化学元素对比分析 …… (120)
5.3.5 PM_{10} 和 $PM_{2.5}$ 中化学元素特征分析 …… (121)
5.3.6 居室室内 PM_{10} 化学元素的因子分析 …… (122)
5.4 校园公共场所室内 PM_{10} 中微量元素分析 …… (123)
5.4.1 校园公共场所室内 PM_{10} 中微量元素来源分析 …… (123)
5.4.2 图书馆和餐厅室内冬季和春季 PM_{10} 的富集因子分析 …… (125)
5.4.3 图书馆和餐厅室内微量元素的因子分析 …… (127)
5.5 小结 …… (129)
6 居室及公共场所室内 PM_{10} 的基于 DNA 氧化性损伤评价的毒理学研究 …… (130)
6.1 大气颗粒物毒理学的质粒 DNA 评价 …… (130)
6.1.1 质粒 DNA 评价方法原理 …… (130)
6.1.2 质粒 DNA 评价实验 …… (131)
6.1.3 质粒 DNA 评价实验中的常见问题 …… (133)
6.2 居室室内 PM_{10} 对质粒 DNA 的氧化性损伤能力研究 …… (141)
6.2.1 不同类型的 PM_{10} 对质粒 DNA 氧化性损伤能力研究 …… (141)
6.2.2 居室室内 PM_{10} 致 DNA 损伤的原因分析 …… (145)
6.3 校园公共场所室内 PM_{10} 对质粒 DNA 的氧化性损伤能力研究 …… (151)
6.3.1 不同季节校园公共场所室内 PM_{10} 的氧化性损伤能力比较 …… (152)
6.3.2 白天和晚上校园公共场所室内 PM_{10} 的氧化性损伤能力比较 …… (158)
6.3.3 校园公共场所室内 PM_{10} 和 $PM_{2.5}$ 的氧化性损伤能力比较 …… (159)
6.3.4 校园公共场所室内 PM_{10} 的氧化性损伤能力来源分析 …… (160)
6.3.5 校园公共场所室内 PM_{10} 氧化性损伤能力大小与其质量浓度的相关性分析 ……
…… (178)
6.4 小结 …… (178)

7 颗粒物物理特征的分形表征及其应用 …… (180)
7.1 分形理论概述 …… (180)
7.1.1 分形理论的基本概念 …… (181)
7.1.2 分形的定量表示 …… (182)
7.2 分形几何在环境科学中的应用 …… (182)
7.2.1 生态学方面 …… (182)
7.2.2 混凝过程 …… (183)
7.2.3 大气环境 …… (183)
7.3 分形理论在颗粒物研究中的应用及进展 …… (183)
7.3.1 大气颗粒物凝聚状态的分形研究 …… (183)
7.3.2 大气颗粒物形貌的分形研究 …… (188)
7.3.3 大气颗粒物粒径分布的分形研究 …… (191)
7.4 大气颗粒物粒径分布分形维数分析 …… (194)
7.4.1 大气颗粒物粒径分布分形维数分析步骤 …… (194)
7.4.2 大气颗粒物粒径分布分形维数结果分析 …… (196)
7.4.3 室内颗粒物粒径分布分形维数与颗粒物化学元素组成关系分析 …… (197)
7.4.4 室内颗粒物粒径分布分形维数与颗粒物氧化性损伤能力关系分析 …… (201)
7.5 小结 …… (202)
参考文献 …… (204)

Contents

Foreword

1 Introductions …… (1)

1.1 Implications of the study on indoor inhalable particles …… (1)

1.2 Current situation of the study on indoor inhalable particles …… (2)

1.2.1 Physicochemical characterization of indoor inhalable particles …… (2)

1.2.2 Source apportionment of indoor inhalable particles …… (6)

1.2.3 Health effect of indoor inhalable particles …… (7)

1.2.4 Individual particle analysis methodology of indoor inhalable particles …… (9)

1.3 Some limitations of study on indoor inhalable particles …… (10)

2 Pollution levels of the indoor PM_{10} and $PM_{2.5}$ in Beijing …… (12)

2.1 Outline of the sampling campaign …… (13)

2.1.1 Outline of the sampling sites …… (13)

2.1.2 Selection of sampling equipment …… (15)

2.1.3 Selection of sample filters and substrates …… (16)

2.2 Pollution levels of the indoor airborne particles of residential rooms in Beijing …… (17)

2.2.1 Pollution characteristic of the indoor PM_{10} of urban and suburban residential rooms in Beijing …… (17)

2.2.2 Cause of variation in indoor PM_{10} mass concentrations …… (22)

2.3 Pollution levels of the indoor PM_{10} of the campus public places …… (30)

2.3.1 Seasonal variation of mass concentrations of indoor PM_{10} and $PM_{2.5}$ in the campus public places …… (32)

2.3.2 Comparison of mass concentrations of indoor PM_{10} and $PM_{2.5}$ of the campus public places in daytime and nighttime …… (38)

2.3.3 Relationships between mass concentrations of indoor PM_{10} and meteorological conditions of campus public places …… (40)

2.4 Summary and suggestions …… (45)

2.4.1 Summary …… (45)

2.4.2 Suggestions for control of indoor PM_{10} pollution …… (45)

3 Microscopic morphology and source analysis of the indoor PM_{10} in residential and campus public places of Beijing …… (47)

3.1 Principles of the Scanning Electronic Microscopy (SEM) and its use in the characterization of inhalable particles …… (47)

3.1.1 Structure and principles of the Scanning Electronic Microscopy (SEM) and energy dispersive X-ray spectrometer …… (47)
3.1.2 Application of the Scanning Electronic Microscopy in the characterization of inhalable particles …… (50)
3.2 Microscopic morphology of the indoor PM_{10} in residential and campus public places … (50)
3.2.1 Sample preparation for SEM analysis …… (50)
3.2.2 Microscopic morphological types of the individual particles of indoor PM_{10} in residential and campus public places …… (52)
3.3 Comparisons of the microscopic morphology of the indoor and outdoor PM_{10} collected in residential rooms in different functional areas of Beijing during different seasons …… (63)
3.3.1 Comparisons of the microscopic morphology of the indoor and outdoor PM_{10} collected in residential rooms with and without smoking in suburban area of Beijing …… (63)
3.3.2 Comparisons of the microscopic morphology of the indoor and outdoor PM_{10} collected in residential rooms with and without smoking in urban area of Beijing …… (64)
3.3.3 Comparisons of the microscopic morphology of the indoor PM_{10} collected in kitchen and living rooms in the same home …… (65)
3.3.4 Comparisons of the microscopic morphology of the indoor PM_{10} collected with different fuel burnings …… (66)
3.4 Temporal and spatial variation of microscopic morphology and source analysis of the indoor PM_{10} in the campus public places …… (66)
3.4.1 Seasonal variation of microscopic morphology and source analysis of the indoor PM_{10} in library …… (67)
3.4.2 Seasonal variation of microscopic morphology and source analysis of the indoor PM_{10} in dining-hall on campus …… (68)
3.4.3 Principal microscopic morphological types and variation of the day and night indoor PM_{10} in the campus public places …… (70)
3.5 Micro-component analysis of typical individual particles of indoor PM_{10} …… (71)
3.5.1 Selection of experimental instrument and sample preparation for micro-component analysis …… (71)
3.5.2 Micro-component analysis of soot aggregates …… (72)
3.5.3 Micro-component analysis of spherical particles …… (73)
3.5.4 Micro-component analysis of mineral particles …… (73)
3.5.5 Micro-component analysis of biomass particles …… (75)
3.5.6 Micro-component analysis of unidentified particles …… (75)
3.6 Summary …… (75)

4 Size distribution of the indoor PM_{10} collected in residential and campus public places …… (77)

4.1 Size distribution analysis system used in airborne particle analysis …… (78)

4.1.1 Samples information …… (78)

4.1.2 Basics procedures of the image analysis system used in airborne particle analysis … …… (79)

4.2 Size distribution of the indoor PM_{10} collected with different fuel burning …… (81)

4.2.1 Number-size distribution of the indoor PM_{10} collected with burning of firewood coal, and natural gas …… (81)

4.2.2 Volume-size distribution of the indoor PM_{10} collected with burning of firewood, coal and natural gas …… (83)

4.3 Size distribution of the indoor PM_{10} collected in residential rooms …… (85)

4.3.1 Number-size distribution of the indoor and outdoor PM_{10} collected in the urban residential rooms in Beijing in winter and summer …… (85)

4.3.2 Volume-size distribution of the indoor and outdoor PM_{10} collected in the urban residential rooms in Beijing in winter and summer …… (89)

4.3.3 Number-size distribution and volume-size distribution of the indoor and outdoor PM_{10} collected in suburban residential rooms in Beijing …… (90)

4.3.4 Comparisons of number-size distribution and volume-size distribution of the indoor and outdoor PM_{10} collected in urban and suburban residential room in Beijing … (93)

4.4 Size distribution of the indoor PM_{10} collected in the campus public places …… (94)

4.4.1 Size distribution of the indoor PM_{10} collected in the campus public places in winter …… (94)

4.4.2 Size distribution of the indoor PM_{10} collected in the campus public places in spring …… (97)

4.4.3 Size distribution of the indoor PM_{10} collected in the campus public places in summer …… (99)

4.4.4 Size distribution of the indoor PM_{10} collected in campus public places in autumn …… (100)

4.4.5 Comparisons of size distribution of the indoor PM_{10} collected in the campus public places in different seasons …… (102)

4.4.6 Comparisons of size distribution of the indoor PM_{10} collected in the campus public places in daytime and nighttime …… (102)

4.5 Summary …… (104)

5 Elemental compositions of the indoor PM_{10} collected in the residential and campus public places …… (105)

5.1 Principle of chemical compositions analysis …… (106)

5.1.1 Basic principles and application of proton-induced X-ray emission (PIXE) … (106)

5.1.2 Basic principles and instrument of Inductively Coupled Plasma Mass Spectroscopy(ICP-MS) …… (107)
5.2 Sample preparation and analysis …… (108)
5.2.1 Sample preparation for PIXE analysis …… (108)
5.2.2 Sample preparation for ICP-MS analysis …… (109)
5.2.3 Source analysis of particles by enrichment factor method …… (112)
5.2.4 Application of factor analysis in atmospheric environment …… (112)
5.3 Elemental compositions analysis of the indoor PM_{10} collected in the residential indoors in Beijing …… (114)
5.3.1 Elemental compositions and enrichment factor analysis of the indoor PM_{10} collected with different fuel burnings …… (114)
5.3.2 Elemental compositions analysis of the residential indoor PM_{10} collected with and without smoking in urban area in Beijing …… (116)
5.3.3 Elemental compositions analysis of the residential indoor PM_{10} collected with and without smoking in suburban area in Beijing …… (118)
5.3.4 Comparisons of elemental compositions of the residential indoor and outdoor PM_{10} in Beijing …… (120)
5.3.5 Elemental compositions characteristic of the residential indoor PM_{10} and $PM_{2.5}$ in Beijing …… (121)
5.3.6 Factor analysis of the indoor PM_{10} collected in residential rooms in Beijing …… (122)
5.4 Trace element analysis of the indoor PM_{10} collected in the campus public places … (123)
5.4.1 Source analysis of trace element of the indoor PM_{10} collected in campus public places …… (123)
5.4.2 Enrichment factor analysis of the indoor PM_{10} collected in library and dining-hall on campus in winter and spring …… (125)
5.4.3 Factor analysis of trace elements of the indoor PM_{10} collected in library and dining-hall on campus …… (127)
5.5 Summary …… (129)

6 A toxicological assessment of the indoor PM_{10} collected in residential and campus public places: results from plasmid DNA assay …… (130)

6.1 Plasmid DNA assay for toxicology of airborne particles …… (130)
6.1.1 Basic principle of the plasmid DNA assay …… (130)
6.1.2 Experiment of the plasmid DNA assay …… (131)
6.1.3 Common issues in experiment of the plasmid DNA assay …… (133)
6.2 Oxidative stress on plasmid DNA induced by the indoor PM_{10} collected in residential rooms in Beijing …… (141)
6.2.1 Oxidative stress on plasmid DNA induced by the different indoor PM_{10} …… (141)
6.2.2 Causes of oxidative stress on plasmid DNA induced by the indoor PM_{10}

collected in residential rooms in Beijing ····· (145)
6.3 Oxidative stress on plasmid DNA induced by the indoor PM_{10} collected in the campus public places ····· (151)
6.3.1 Comparisons of oxidative stress of the indoor PM_{10} collected in campus public places in different seasons ····· (152)
6.3.2 Comparisons of oxidative stress of the indoor PM_{10} collected in the campus public places in daytime and nighttime ····· (158)
6.3.3 Comparisons of oxidative stress of the indoor PM_{10} and $PM_{2.5}$ collected in campus public places ····· (159)
6.3.4 Source analysis of oxidative stress of the indoor PM_{10} collected in campus public places ····· (160)
6.3.5 Correlation analysis of oxidative stress and mass concentration of the indoor PM_{10} collected in campus public places ····· (178)
6.4 Summary ····· (178)
7 The fractal characterization of physical properties of particles and its application ····· (180)
7.1 Outline of the fractal theory ····· (180)
7.1.1 Basic concepts of the fractal theory ····· (181)
7.1.2 Quantitative description of fractal dimensions ····· (182)
7.2 The application of fractal geometry in environmental science ····· (182)
7.2.1 The application of fractal geometry in ecology ····· (182)
7.2.2 The application of fractal geometry in coagulation process ····· (183)
7.2.3 The application of fractal geometry in atmospheric environment ····· (183)
7.3 The application and progress of fractal theory in airborne particulate ····· (183)
7.3.1 Fractal study on condensed state of airborne particulate ····· (183)
7.3.2 Fractal study on morphology of airborne particulate ····· (188)
7.3.3 Fractal study on size distribution of airborne particulate ····· (191)
7.4 Fractal dimension analysis on size distribution of airborne particles ····· (194)
7.4.1 Step of fractal dimension analysis on size distribution of airborne particles ····· (194)
7.4.2 Analysis on fractal dimension of size distribution of airborne particles ····· (196)
7.4.3 The relationships between fractal dimensions of size distribution and elemental compositions of indoor airborne particles ····· (197)
7.4.4 The relationships between fractal dimension of size distribution and oxidative stress on plasmid DNA induced by indoor airborne particles ····· (201)
7.5 Summary ····· (202)
References ····· (204)