RGC Ref.: N-HKU718/15 NSFC Ref. : 51561165015 *(please insert ref. above)*

The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Mechanistic study of the degradation of multiple indoor air pollutants through Vacuum UV photocatalysis

真空紫外光催化淨化室內複合空氣污染物機理研究

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Dennis Y.C. Leung	Prof. Haibao Huang
Post	Head of Department	Professor
Unit / Department / Institution	Department of Mechanical Engineering	School of Environmental Science and Engineering
Contact Information	ycleung@hku.hk	huanghb6@sysu.edu.cn
Co-investigator(s) *(with title and institution)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1-1-2016	-	
Project Completion date	31-12-2019	-	
Duration *(in month)*	48	-	
Deadline for Submission of Completion Report	31-12-2020	-	

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. *Study the characteristics of an efficient VUV photocatalysis process for simultaneous degradation of multiple indoor air pollutants;*
2. *Develop a multi-functional mesoporous TiO_2 photocatalyst with strong photocatalytic oxidation activity, high capability of ozone depletion and utilization;*
3. *Investigate the mechanism and kinetic of the degradation of indoor air pollutants under VUV photocatalysis.*
4. *To study the effects of varying environmental and operational factors on the performance for system optimization.*

5.2 Revised Objectives

Date of approval from the RGC: N.A.

Reasons for the change: √

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

In this project, series of catalysts with multiple functions such as photocatalytic oxidation, ozone catalytic oxidation, and ozone decomposition has been successfully developed to be applied in VUV-photocatalytic oxidation (PCO) by regulating the catalyst carriers, preparation method and active components. Efficient purification of complex pollutants, complete elimination of ozone and excellent disinfection performance are achieved. Establishing the structure-activity relationship of catalysts in VUV-PCO has an important guiding role in the synthesis, modification and optimization of catalysts. By tracing intermediate products, the synergistic purification mechanism of multiple pollutants in VUV-PCO were clarified: the degradation products and pathways of different components of VOCs are closely related to the molecular structure of VOCs. The degradation pathways of multiple pollutants mainly include OH^- addition and H extraction and isomerization. The intermediates mainly include benzaldehyde, benzoic acid and the oxygen-containing VOCs such as ethyl acetate, acetone, and ethanol, which are further oxidized to acetic acid, acetaldehyde, formic acid, and formaldehyde by the VUV-PCO system. We further examined the process parameters and stability of the vacuum ultraviolet photocatalytic purification system. Based on the research results of the VUV-PCO mechanism, we also successfully developed a new type of composite air pollution purification system, which has a good purification effect on particulate matter, gaseous molecules and microorganisms.

This project provides theoretical basis and technical guidance for solving the key scientific problems of vacuum ultraviolet photocatalytic purification of indoor composite air pollution and realizing its application, which can greatly improve indoor air quality and safeguard the health of occupants.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

In this study, various catalysts were developed with multiple functions. In order to better apply the catalysts in real application, further studies on the synthesis and immobilization methods of the catalysts need to be carried out to obtain more economic synthetic methods that can suit for mass production of catalysts.

A new purification system for multiple indoor air pollutants has also been developed in this study which can efficiently eliminate multiple indoor air gaseous pollutants as well as the ozone generated by the VUV lamps. However, it is only a preliminary prototype of air cleaner. The selection and arrangement of different modules as well as the appearance design of the air purifier need to be further improved for wider application and commercialization. Furthermore, the lifetime of the filter and catalysts as well as the energy consumption of the purifier also need to be considered.

In this project, the performance of the developed air purifier was evaluated in the testing chamber. Before the purifier can be commercialized and popularized, more tests in real cases need to be carried out. Possible testing places include traffic stations, hospitals, shopping malls and so on. The performance of particles removal, gaseous air pollutants degradation and disinfection of the air purifier will be test simultaneously. Arup Co. Ltd., an international consultant firm expressed interest to be partner of the testing in their selected offices.

7. The Layman's Summary

(describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

Among all the environmental pollution, air pollution is particularly serious, which is the biggest environmental threat to public health. Air pollution is rather cumulative and complex in the closed building environment, including various gaseous pollutants, particles and microorganisms. VOCs and viral microorganisms are the difficulties and hot spots of air pollution control. People spend more than 80% of their time in indoor living rooms and public places. Therefore, air quality is very important for people's physical and mental health.

In view of the typical indoor air pollution, the project proposes a new method of VUV-PCO. The purification system includes photolysis, photocatalysis, ozone oxidation and other processes,

which can greatly enhance air pollutant elimination and sterilization. This study makes full use of the synergism of photocatalytic oxidation, photolysis, ozone oxidation, etc. in the system, through adjusting and controlling the preparation of catalysts with various functions, aiming to realize the transformation of ozone from a harm gaseous to a useful species that strengthen the purification of pollutants to achieve an efficient elimination of indoor multiple pollutants at the same time. This research provides theoretical basis and technical guidance for solving the key scientific problems of the process and realizing its application, which is helpful to improve indoor air quality and people's health level.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) ***(bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/ Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
2020				**Wai Szeto**, W.C. Yam, **Haibao Huang, Dennis Y.C. Leung***	The efficacy of vacuum-ultraviolet light disinfection of some common environmental pathogens" BMC Infectious Diseases 2020; 20: 127 (https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-020-4847-9)	No	Yes	Yes	Yes
2019				Chi Him Tsang; Kai Li; Yuxuan Zeng; Wei Zhao; Tao Zhang*; Yujie Zhan; Ruijie Xie; **Dennis Y.C. Leung*; Haibao Huang***	Titanium oxide based photocatalytic materials development and their role in air pollutants degradation: Overview and forecast, Environment International, 2019, 125：200-228	No	Yes	Yes	Yes
2019				**Yajie Shu; Miao He; Jian Ji; Haibao Huang***; Shengwei Liu; **Dennis Y. C. Leung**	Synergetic degradation of VOCs by vacuum ultraviolet photolysis and catalytic ozonation over Mn-xCe/ZSM-5, Journal of Hazardous Materials, 2019 , 364：770-779.	No	Yes	Yes	Yes
2019				Ruimei Fang; Wenjun Huang; **Haibao Huang *;** Qiuyu Feng; **Miao He; Jian Ji; Biyuan Liu; Dennis Y C Leung**	Efficient MnOx/SiO_2@AC catalyst for ozone-catalytic oxidation of gaseous benzene at ambient temperature, Applied Surface Science, 2019 , 470：439-447	No	Yes	Yes	Yes

2019				**Muyan Wu; Yingguang Zhang; Wai Szeto**; Wending Pan; **Haibao Huang*; Leung, Dennis Y C***	Vacuum ultraviolet (VUV)-based photocatalytic oxidation for toluene degradation over pure CeO_2, Chemical Engineering Science, 2019 , 200：203-213	No	Yes	Yes	Yes
2019				**Muyan Wu; Dennis Y.C.Leung*; Yingguang Zhang; Haibao Huang***; Ruijie Xie; **Wai Szeto**; Fang Li	Toluene degradation over Mn-TiO_2/CeO_2 composite catalyst under vacuum ultraviolet (VUV) irradiation, Chemical Engineering Science, 2019 , 195：985-994	No	Yes	Yes	Yes
2019				Ruijie Xie; Dongxue Lei; Yujie Zhan; **Biyuan Liu;** Chi Him A. Tsang; Yuxuan Zeng; Kai Li; **Dennis Y.C. Leung; Haibao Huang***	Efficient photocatalytic oxidation of gaseous toluene over F-doped TiO_2 in a wet scrubbing process, Chemical Engineering J (On-line 15 Feb 2019) https://doi.org/10.1016/j.cej.2019.02.112	No	Yes	Yes	Yes
2019				Ruimei Fang; Qiuyu Feng; **Haibao Huang*; Jian Ji; Miao He**; Yujie Zhan; **Biyuan Liu; Dennis Y.C. Leung**	Effect of K+ ions on efficient room-temperature degradation of formaldehyde over MnO2 catalysts, Catalysis Today, 2019, 327：154-160.	No	Yes	Yes	Yes
2019				**Yingguang Zhang; Muyan Wu**; Y H Kwok; Yifei Wang; Wei Zhao; Xiaolong Zhao; **Haibao Huang***; **Dennis Y. C. Leung ***	In-situ synthesis of heterojunction TiO_2/MnO_2 nanostructure with excellent performance in vacuum ultraviolet photocatalytic oxidation of toluene, Applied Catalysis B: Environmental, 2019 , 259： 118034	No	Yes	Yes	Yes
2019				Chi Him A Tsang; John Tobin; Jin Xuan; Filipe Vilela; **Haibao Huang*; Dennis Y.C. Leung***	BTZ-copolymer loaded graphene aerogel as new type Green and metal-free visible light photocatalyst, Applied Catalysis B: Environmental, 2019 , 240：50-63.	No	Yes	Yes	Yes
2018				**Yajie Shu; Jian Ji; Ying Xu**; Jiguang Deng; **Haibao Huang*; Miao He; Dennis Y. C. Leung; Muyan Wu;** Shengwei Liu*; Shuilian Liu; Gaoyuan Liu; Ruijie Xie; Qiuyu Feng; Yujie Zhan; Ruimei Fang; Xinguo Ye	Promotional role of Mn doping on catalytic oxidation of VOCs over mesoporous TiO_2 under vacuum ultraviolet (VUV) irradiation, Applied Catalysis B: Environmental, 2018 , 220：78-87	2018	Yes	Yes	Yes
2018				Ruimei Fang; **Haibao Huang*; Jian Ji**; **Miao He**; Qiuyu Feng; Yujie Zhan; **Dennis Y C Leung**	Efficient MnOx supported on coconut shell activated carbon for catalytic oxidation of indoor formaldehyde at room temperature, Chemical Engineering Journal, 2018 , 334：2050-2057	2018	Yes	Yes	Yes

2018				Ruimei Fang; **Miao He; Haibao Huang***; Qiuyu Feng; **Jian Ji**; Yujie Zhan,; **Dennis Y. C. Leung; Wei Zhao**	Effect of redox state of Ag on indoor formaldehyde degradation over Ag/TiO_2 catalyst at room temperature, Chemosphere , 2018 , 213：235-243	No	Yes	Yes	Yes
2018				**Yajie Shu**; Yin Xu; **Haibao* Huang; Jian Ji**; Shimin Liang; **Muyan Wu; Dennis Y C Leung**	Catalytic oxidation of VOCs over Mn/TiO_2/activated carbon under 185 nm VUV irradiation, Chemosphere, 2018 , 208：550-558	No	Yes	Yes	Yes
2017				**Jian Ji,; Ying Xu; Haibao Huang*; Miao He;** Shuilian Liu; Gaoyuan Liu; Ruijie Xie; Qiuyu Feng; **Yajie Shu**; Yujie Zhan; Ruimei Fang; Xinguo Ye; **Dennis Y. C. Leung**	Mesoporous TiO_2 under VUV irradiation: Enhanced photocatalytic oxidation for VOCs degradation at room temperature, Chemical Engineering Journal, 2017 , 327：490-499.	2018	Yes	Yes	Yes
2017				**Haibao Huang*; Huiling Huang;** Qiuyu Feng; Gaoyuan Liu; Yujie Zhan; **Muyan Wu;** Haoxian Lu; **Yejie Shu; Dennis YC Leung**	Catalytic oxidation of benzene over Mn modified TiO_2/ZSM-5 under vacuum UV irradiation, Applied Catalysis B: Environmental, 2017 , 203：870-878.	2018	Yes	Yes	Yes
2016				**Huiling Huang; Haibao Huang***; Yujie Zhan; Gaoyuan Liu; Xuemei Wang; Haoxian Lu; Liang Xiao; Qiuyu Feng ; **Dennis Y.C. Leung***	Efficient degradation of gaseous benzene by VUV photolysis combined with ozone-assisted catalytic oxidation: Performance and mechanism, Applied Catalysis B: Environmental, 2016 , 186：62-68.	2018	Yes	Yes	Yes
2016				**Haibao Huang*;** Haoxian Lu; **Huiling Huang**; Lei Wang; Jieni Zhang; **Dennis Y. C. Leung***	Recent Development of VUV-Based Processes for Air Pollutant Degradation, Frontiers in Environmental Science, 2016, 4：17.	2018	Yes	Yes	Yes

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*

19-21 October 2017, Las Vegas, USA.	Photocatalysis for degradation of environmental pollutants under VUV irradiation	Global Conference on Catalysis and Reaction Engineering.	2018	Yes (Abstract)	Yes	
10-13 July 2018, Porto, Portugal.	Efficient degradation of water pollutants and air disinfection by VUV assisted photocatalysis	The 4th International Conference on photocatalytic and advance oxidation technologies for the treatment of water, air, soil and surfaces (PAOT4)	No	Yes (Abstract)	Yes	
16-20 June 2019, Thessaloniki, Greece	VOC degradation over Nano CeO2 photocatalysts under VUV irradiation	17th International Conference on Chemistry and the Environment (ICCE)	No	Yes (Abstract)	Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Muyan Wu	PhD	1-9-2016	30-8-2020 (expected)
Yingguang Zhang	PhD	1-6-2018	31-5-2022

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

Patents:

(1) 黄海保；曾宇翾；梁耀彰；刘璧源；何苗, 一种去除涂料涂层表面VOCs的方法和室内空气中VOCs的去除方法，2018-12-29，中国,CN201811642585.1. (authorized).

(2) 黄海保；曾宇翾；梁耀彰；刘璧源；何苗，一种去除涂料表面VOCs的方法和室内空气中VOCs的去除方法，2018-12-30, 中国，201811642585.1.

(3) 黄海保；曾宇翾；梁耀彰；刘璧源；何苗，一种空气中VOCs的去除系统，2018-12-30, 中国，201822256706.0.

(4) 吴沐彦；梁耀彰；张颖光；黄海保，一种真空紫外光催化净化材料及其制备方法和应用，中国，201810995872.4

12. Statistics on Research Outputs *(Please ensure the summary statistics below are consistent with the information presented in other parts of this report.)*

	Peer-reviewed journal publications	Conference papers	Scholarly books, monographs and chapters	Patents awarded	Other research outputs (Please specify)
No. of outputs arising directly from this research project [or conference]	18	3		4	