行政院國家科學委員會專題研究計畫成果報告

生物氣膠控制技術之評估

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Evaluation of Bioaerosol Control Techniques

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一、中文摘要

近年來生物氣膠與呼吸道相關症狀被發現具高度相關性；此外，因生物氣膠造成的傳染性疾病也是一大威脅。因此，如何有效的控制生物氣膠乃是降低生物氣膠健康危害的重要課題。

本研究的目的為進行實驗室定性、定量評估紫外線（UV-C，254nm）對細菌生物氣膠控制效率。使用卡里遜噴霧器在測試腔內產生生物氣膠，使其通過紫外燈的照射。測試結果發現，達到 99% 的殺菌效率而言，大腸桿菌所需的劑量為 1017 到 2356 μWsec/cm^2，枯草桿菌所需的劑量則為 15949 至 19345 μWsec/ cm^2；酵母菌所需的劑量為 12917 至 17497 μWsec/ cm^2；青黴菌所需的劑量則為 47984 至 89419 μWsec/ cm^2。

關鍵詞：紫外線殺菌、敏感性、大腸桿菌、枯草桿菌、酵母菌、青黴菌、生物氣膠

Abstract

Because of increasing incidence of microorganism infections, there are concerns in engineering control of indoor microorganism for reducing airborne infectious diseases. Ultraviolet germicidal irradiation (UVGI) was considered to be promising to inactivate microorganisms. In this investigation, the influences of UV dosage, microorganism species, and relative humidity on UVGI effectiveness were evaluated in a laboratory test chamber. A Collison nebulizer generated aerosols containing Escherichia coli, Bacillus subtilis spores, cells of Candida famata var. flareri, and spores of *Penicillium citrinum*. The UVGI control effectiveness was determined as the ratio, N_S /N_0, where N_S and N_0 were the colony concentrations collected by Andersen one-stage samplers at UVGI dosage of D and zero, respectively. In regard to 99% microorganism inactivation, the UVGI dosage ranges were of 1017 to 2356 μW sec/cm^2, 15949 to 19345 μW sec/cm^2, 12917 to 17497 μW sec/cm^2, 47984 to 89419 μW sec/cm^2 for *E. coli*, *B. subtilis*, yeast, and *P. citrinum*, respectively. Significantly, the microorganism susceptibilities of *E. coli* were the highest, and of *P. citrinum* were the lowest. In regard to relative humidity effects, it was observed that the microorganism susceptibilities at 80% relative humidity were lower than those found at 50% relative humidity for all four types of the evaluated microorganisms.

Keywords: UVGI, susceptibility, *E. coli*, *B. subtilis*, yeast, *P. citrinum*, bioaerosol

二、緣由與目的

Recently, health evaluation of bioaerosols has become an important issue. Airborne bioaerosols in indoor and outdoor environments, from either nature or industrial sources, may produce ill effects ranging from mild irritation to diseases. Therefore, it is important to reduce the concentrations of airborne bioaerosols in contaminated environments to ensure the health of the workers and the public.

Currently, the use of ultraviolet germicidal

irradiation (UVGI) for microorganism inactivation has been widely used. Microorganisms are uniquely vulnerable to light at wavelengths at or near 2537 Angstroms, because the maximum absorption wavelength of DNA molecule is 253.7 nm. The pyrimidine of DNA base could strongly absorb UV light. After irradiation, the DNA sequence where pyrimidine and pyrimidine link could form pyrimidine dimers. This would change the DNA double helix structure and interference DNA duplicate, as well as lead to cell mutation or lethality. Up to now, a significant increase in the incidence of certain airborne diseases, most notably the one caused by *Mycobacterium tuberculosis* (TB) was observed in different areas. To protect patients and health care workers who often interact with individuals in high-risk groups, UVGI fixtures are currently widely installed in the hospitals (Dumyahn and First, 1999).

In regard to UVGI effectiveness, it was found that irradiation level, duration of irradiation, room configuration, lamp placement, lamp age, air movement patterns, and moisture in the air could significantly influence the UVGI effectiveness (CDC, 1994). In general, UVGI levels were found to decrease as the inverse of the square of the distance from a point source (the inverse square law), and as the inverse of the distance from a line source (Summer, 1962; NIOSH, 1972). In addition, it was indicated that surfaces could reflect UVGI to varying degrees. The finish on walls, ceilings, and other items may influence the irradiance throughout a room. Furthermore, it was found that the degree of room air mixing was related to UVGI efficiency (Nicas, 1996; Nicas and Miller, 1999). In regard to the effects of relative humidity (RH), it was reported that a declined inactivation of airborne organisms by UV at RH in excess of 60 to 70%. However, there were data to indicate no significant RH effects on UVGI effectiveness (Riley and Kaufman, 1972). This controversy needs furthermore evaluation, especially for subtropical and tropical regions with high RH all year round.

In the field of UVGI operation, it was found that half of viable bacteria could be reduced with the ceiling-mounted lamps in the two operating rooms (Goldner et al., 1960). Moreover, it was reported that a twelve-fold bacterial colony reduction in an operating room with a high level of UVGI at 290 W / cm^2 (Lidwell, 1994). In a well-ventilated hospital waiting room equipped with wall-mounted lamps, it was demonstrated that there was a 14%-19% reduction in culturable bacterial concentrations (Macher et al., 1992, 1994). Therefore, UVGI should be a very promising technique for indoor microorganism control. In this current evaluation, the influences of microorganism species, UV exposure dosage, and relative humidity on UVGI effectiveness were assessed in a well-controlled chamber.

三、結果與討論

The culturability reductions for *E. coli*, *B. subtilis*, yeast, and *P. citrinum* at three relative humidity conditions are summarized in Figs 1, 2, 3, and 4, respectively. It was found that *E.coli*, was the most sensitive organism to ionizing radiations in this study, only required a very low UVGI dosage of 525 to 711 μW sec/cm^2 to obtain a 90 % inactivation. In addition, *B. subtilis* was more resistant than *E. coli*, as well as required a UVGI dose of 4585 to 5912 μW sec/cm^2 to obtain a 90 % inactivation. Spores of *P. citrinum* were observed to be the most resistant organism evaluated in this study and required a UVGI dose of 15197 to 24903 μW sec/cm^2 for 90 % inactivation. Yeast was less resistant than *P. citrinum* and required a UVGI dose of 4653 to 6324 μW sec/cm^2 for 90 % inactivation. It was clearly indicated that the UVGI dosage difference for 90% microorganism inactivation could be as high as 58 times between *P. citrinum* and *E.coli*. In regard to 99% microorganism inactivation, the UVGI dosage ranges were of 1017 to 2356 μW sec/cm^2, 15949 to 19345 μW sec/cm^2, 12917 to 17497 μW sec/cm^2,

47984 to 89419 μW sec/cm^2 for *E. coli*, *B. subtilis*, yeast, and *P. citrinum*, respectively. Moreover, the UVGI dosage difference for 99% inactivation could be as high as 80 times between *P. citrinum* and *E.coli*. Previous investigations indicated that UVGI dosage for 99% inactivation ranged from 37.5 to 7675 μW sec/cm^2, from 50 to 92000 μW sec/cm^2, and from 15350 to 230000 μW sec/cm^2 for gram positive bacteria, gram negative bacteria, and fungi, respectively (Wells, 1955; Kundsin, 1968; David, 1973; Keller, 1982; Mongold, 1992). It could be summarized that UVGI dosages for different microorganism species varied in a wide range. From our current results, it was clearly demonstrated that UVGI is very promising in microorganism inactivation and reduction, as well as could be used in ventilation system or indoor air cleaner.

Data revealed that for all four types of the evaluated microorganisms, survival fraction declined exponentially with UVGI dosage increase. Using the simple exponential regression analyses, the K values (microorganism susceptibility factor, cm^2/μWs), commonly used as the indicator of sensitivity of the test microorganism, were demonstrated to vary through a wide range, depending on microorganism species. Significantly, the microorganism susceptibilities of *E. coli* were the highest (3239-5380), and of *P. citrinum* were the lowest (92-152). In comparison with some previous data (Wells, 1955; Kundsin, 1968; David, 1973; Keller, 1982; Mongold, 1992), it was also clearly indicated that microorganism susceptibility factor strongly depended on microorganism species, and vary in a wide range.

In regard to relative humidity effects on UVGI effectiveness, it was observed that the microorganism susceptibilities at 80% RH were lower than those found at 50% RH for all four types of the evaluated microorganisms. Therefore, it was clearly demonstrated that it is more difficult to inactivate microorganism at higher relative humidity condition. Our observation agreed with the findings by the two previous reports at RH higher than 80% (Riley et al.,1972; Rentschler and Nagy, 1942). Further investigation on the mechanism of water vapor on UVGI effectiveness is needed. In addition, epifluorescent microscopy and standard culturing techniques are widely used for evaluating quantity of microorganisms (Moschandreas et al., 1996; Terzieva et al., 1996; Hernandez et al., 1999). In this current investigation, standard culturing technique was used for assessing UVGI effectiveness in microorganism reduction. Further evaluation of UVGI effectiveness should be performed to compare the effectiveness differences by these two methods.

The evaluation of the influences of UV dosage, microorganism species, and relative humidity on UVGI effectiveness was performed in a laboratory test chamber. It was demonstrated that UVGI effectiveness strongly depend on microorganism species. For 99% inactivation, the UVGI dosage difference could be as high as 80 times between fungal spore and bacterial cell. Regarding microorganism susceptibility factor, the highest value was observed for bacterial cell, as well as the lowest one was found for the UV resistant fungal spore. In addition, there were significant differences in the microorganism susceptibilities for bacterial and fungal bioaerosols between 50% RH and 80% RH. Further evaluation regarding on mechanism of the influence of relative humidity on UVGI effectiveness is needed.

四、計畫成果自評

本計畫已在實驗室中建立生物氣膠控制技術的評估系統，並運用此系統評估二種細菌及二種真菌紫外線之殺菌效能評估，此成果可運用於一般室內環境生物氣膠控制技術之參考。

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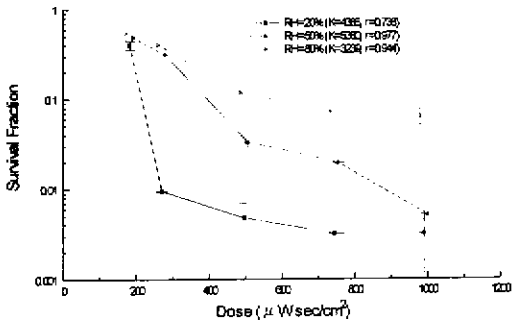

Figure 1. Survival fraction of *E. coli* exposed to UVGI at three relative humidity conditions. Each error bar represents one standard deviation on the mean of at least three trials.

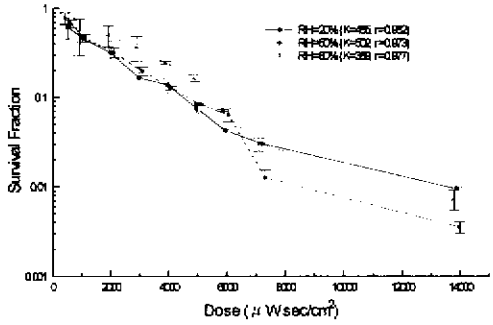

Figure 2. Survival fraction of *B. subtilis* spores exposed to UVGI at three relative humidity conditions. Each error bar represents one standard deviation on the mean of at least three trials.

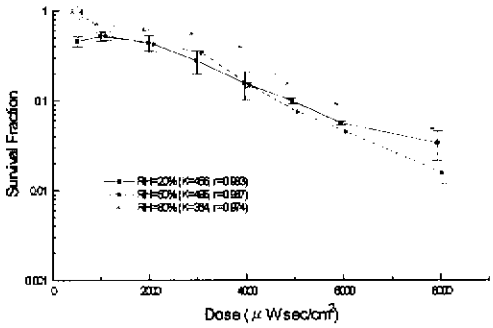

Figure 3. Survival fraction of yeast exposed to UVGI at three relative humidity conditions. Each error bar represents one standard deviation on the mean of at least three trials.

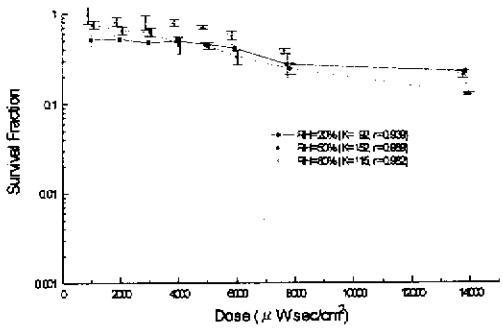

Figure 4. Survival fraction of *P. citrinum* exposed to UVGI at three relative humidity conditions. Each error bar represents one standard deviation on the mean of at least three trials.