American Journal of Environmental Science and Engineering
2023; 7(1): 1-4
http://www.sciencepublishinggroup.com/j/ajese
doi: 10.11648/j.ajese.20230701.11
ISSN: 2578-7985 (Print); ISSN: 2578-7993 (Online)

Performance of Cold Atmospheric Plasma in Reducing Airborne Particles and Carbon Dioxide Concentrations in Sports Facilities

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To cite this article:
Namwon Paik, Younghyo Park, Namkyung Kim, Yonghee Kim, Doyeon Kim, Hyunyoung Hong. Performance of Cold Atmospheric Plasma in Reducing Airborne Particles and Carbon Dioxide Concentrations in Sports Facilities. *American Journal of Environmental Science and Engineering*. Vol. 7, No. 1, 2022, pp. 1-4. doi: 10.11648/j.ajese.20230701.11

Received: December 21, 2022; **Accepted**: January 10, 2023; **Published**: January 17, 2023

Abstract: According to a few reports recently published, cold atmospheric pressure plasma (CAP) is a state-of-the-art technique in the field of environmental science. Studies reported the performance of CAP in the removal of particulate matter (PM) and microorganisms, including fungi, bacteria, and viruses. The CAP also effectively removed the odor, volatile organic compounds (VOCs), and numerous chemicals, including formaldehyde. However, studies on the control of PM and carbon dioxide (CO_2) in sports facilities are limited. This study was conducted in two parts. In Part 1, the levels of indoor PM10, PM2.5, PM1.0, and CO_2 were measured in two sports facilities, including a table tennis center and a fitness center, to determine the occupants' exposure levels to the pollutants. In part 2, the performance of the CAP technique in the reduction of airborne concentrations of PM10 and CO_2 was investigated. The PM10 concentrations were significantly higher in the fitness center than in the table tennis center. The concentration ratios of PM10, PM2.5, and PM1.0 to PM10 concentrations were 1.00, 0.95, and 0.81, respectively. The CO_2 concentrations were significantly higher in table tennis centers where aerobic exercise was predominant. The performance of CAP on the removal of PM10 and CO_2 was highly promising. The average reduction rates against PM10 and CO_2 concentrations were 69% and 35%, respectively. Further studies on the performance of CAP against other pollutants, such as total volatile organic compounds and microorganisms in sports facilities are needed.

Keywords: Particulates, Carbon Dioxide, Sports Facility, Cold Atmospheric Plasma

1. Introduction

Small particles less than 10 μm in diameter pose the greatest problems to public health because they can get deep into human lungs, and some may even get into the bloodstream. [1] Recent research has indicated that aerosol particles carry pathogens, such as coronaviruses and bacteria. [2] In sports facilities, such as fitness centers, users are often breathing more heavily, which causes an increased release of CO_2, aerosol particulates, and airborne microorganisms. Generally, the ventilation in the sports facilities is very poor or depends on natural ventilation through windows and doors.

There is mounting evidence that SARS-CoV-2 can be transmitted by inhalation of infected saliva aerosol particles. These particles are generated when breathing, talking, laughing, coughing, or sneezing. To minimize the potential risk of airborne virus transmission, aerosol particle concentrations should be kept as low as possible. [3] A study reported that deep exhalation resulted in a 4-6-fold increase in aerosol particles, and rapid inhalation produced a further 2-3-fold increase in particles. [4]

Viruses can be transmitted via contaminated intermediates, such as aerosols and surfaces. Transmission via contaminated aerosols has been demonstrated to be critical in the COVID-19 pandemic. Recently, CAP has been called a new hope in the field of virus inactivation. [5] Recent developments in the application of CAP have led to applications for chemical and biological decontamination in indoor air environments. The removal of very fine particulates is also enhanced by CAP. The process of CAP involves the electronically induced formation of small air ions, including reactive oxygen species, such as superoxide, which react rapidly with airborne VOC and PM. [6] Coronavirus 2 (SARS-CoV-2) is viable on various surfaces (e.g., plastic, metal, and cardboard) for several hours. A study was performed by employing CAP to inactivate SARS-CoV-2 on various surfaces, including plastic, metal, cardboard, and baseball leather.

The results demonstrate the great potential of CAP as a safe and effective means to prevent virus transmission and infections on a wide range of surfaces that experience frequent human contact. Since this is the first-ever demonstration of cold plasma inactivation of SARS-CoV-2, it is a significant milestone in the prevention and treatment of coronavirus disease 2019 (COVID-19) and presents a new opportunity for the scientific, engineering, and medical communities. [7] The aims of this study are: first, to evaluate the airborne concentrations of PM10, PM2.5, PM1.0, and CO_2 in two sports facilities, and two, to apply a new state-of-the-art technique, CAP, to reduce particulates and CO_2.

2. Materials and Methods

Two facilities, including Fitness Center A and Table Tennis Center B, were selected for this study. Both facilities are located near Seoul, South Korea. The dimensions of Fitness Center A were 14 m long, 10 m wide, and 6.5 m high. There was only natural ventilation with one door and two windows. The dimensions of Table Tennis Center B were 25 m long, 11.5 m wide, and 4.5 m high. There was only one door without a window. Although there was a central ventilation system in Table Tennis Center B, the owner did not operate it. The registered number of users at each of the two facilities was 99-105.

In both facilities, airborne concentrations of carbon dioxide (CO_2) and particulate matter, including PM10, PM2.5, and PM1.0 were measured from 10 am to 10 pm from Monday to Saturday for two weeks. Temperature and humidity were also measured simultaneously.

According to the World Health Organization, PM10 refers to particulate matter, which has an aerodynamic diameter equal to or less than 10 µm. Similarly, PM2.5 and PM1.0 refer to particulate matter, which has an aerodynamic diameter equal to or less than 2.5 µm and 1.0 µm, respectively. [8] The measurement was conducted using a PRIO A100, an indoor air central management system, made by WISECONN in South Korea. This equipment was calibrated in 2022 by Korea Conformity Laboratories, Korea's leading testing, and certification organization. The distribution of the data was statistically analyzed using the Industrial Hygiene Statistics tool developed by the American Industrial Hygiene Association (AIHA). [9] The two-way ANOVA test was performed in Excel. [10]

3. Results and Discussion

3.1. CO_2 Concentration

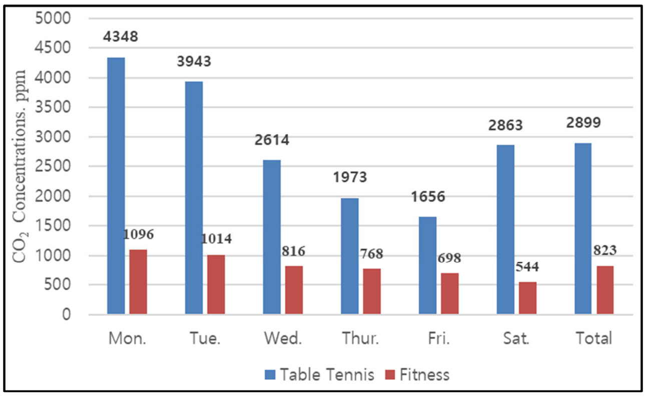

Figure 1. *Airborne CO_2 Concentrations by Type of Sports Centers and Day of the Week.*

Table 1 and Figure 1 present the indoor airborne CO_2 concentrations in two facilities by day of the week. Since there are two factors, such as the day of the week and the type of sports facilities, we performed the two-way ANOVA test. As shown in Table 2, the CO_2 concentration was significantly affected by the type of facility ($p<0.01$). However, the day of the week did not affect the CO_2 concentration significantly. ($p>0.01$). The average CO_2 concentrations in the table tennis center and fitness center were 2,899 (ranging from 1,656 ppm to 4,348 ppm) and 823 ppm (ranging from 544 ppm to 1,096 ppm). Thus, the CO_2 concentration in the table tennis center exceeded 1,000 ppm, the guideline recommended by ASHRAE. [11, 12]

Generally, there are two types of respiration exercises. One is aerobic oxidative respiration, which increases the breathing rate to compensate for the increased need for oxygen required by muscles and produces CO_2 and H_2O as end products. [13] According to researchers, the majority of energy contribution in table tennis is aerobic (approximately 96%), with anaerobic accounting for the remaining 4%. [14] The other type of exercise is anaerobic respiration, which means "without oxygen." In the fitness center of this study, there were 16 machines and a few treadmills and cycles. Therefore, anaerobic exercises might predominate in the fitness center. In Brazil, three fitness centers (A, B, and C) were investigated. The average CO_2 concentrations in the fitness centers A, B, and C were 3,752 ppm, 1,000 ppm, and 1,361 ppm, respectively. [15]

Table 1. *Airborne CO_2 Concentrations by Type of Sports Centers and Day of the Week.*

	Table Tennis		Fitness	
Day	N	CO_2 ppm	N	CO_2 ppm
Mon.	12	4,348	12	1,096
Tue.	12	3,943	12	1,014
Wed.	12	2,614	12	816
Thu.	12	1,973	12	768
Fri.	12	1,656	12	698
Sat.	12	2,863	12	544
Total	72	2,899	72	823

Table 2. *Two-Way ANOVA Summary of CO_2 Data.*

Factors	SS	DF	MS	P-Value
Day of the Week	3754391.417	5	750878.283	p>0.01
Type of Facility	12939710.08	1	12939710.1	P<0.01
Residuals	2127739.417	5	425547.883	
Total	18821840.92	11		

3.2. PM Concentrations

Table 3 and Figure 2 present the PM10 concentrations by sports facility and day of the week. The particle concentrations were significantly different depending on the type of sports facility. (p<0.01). The average concentration in the fitness center was 5.13 μg/m^3 (ranging from 1.6 μg/m^3 to 7.7 μg/m^3), and the concentration in the table tennis center was 2.35 μg/m^3 (ranging from 1.0 μg/m^3 to 4.0 μg/m^3). Although the concentrations in fitness centers were twice as high as those in table tennis centers, they were still below the WHO guidelines. The WHO AQGs for 2021 recommend annual mean concentrations of PM10 not exceeding 15μg/m^3 and eight-hour mean concentrations not exceeding 45μg/m^3. The WHO also recommends annual mean concentrations of PM2.5 not exceeding 5μg/m^3 and eight-hour mean concentrations not exceeding 15μg/m^3. [8] One of the sources of particulates in the fitness centers was the powder being used on people's hands. Table 4 and Figure 3 present PM concentrations by particle size. The ratios of PM10, PM2.5, and PM1.0 concentrations to PM10 concentration were 1.00, 0.95, and 0.81, respectively.

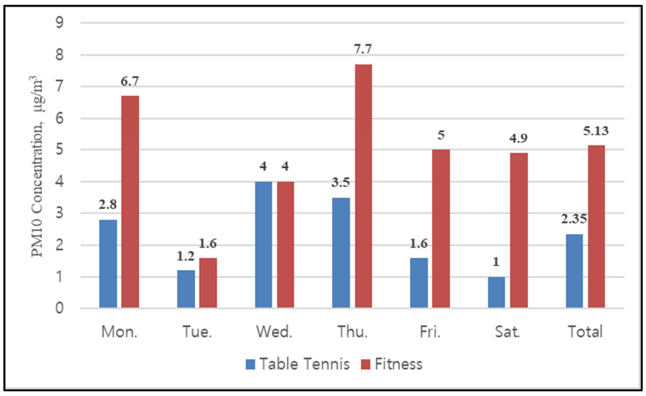

Figure 2. *Airborne PM10 Concentrations by Type of Sports Facility and Day of the Week.*

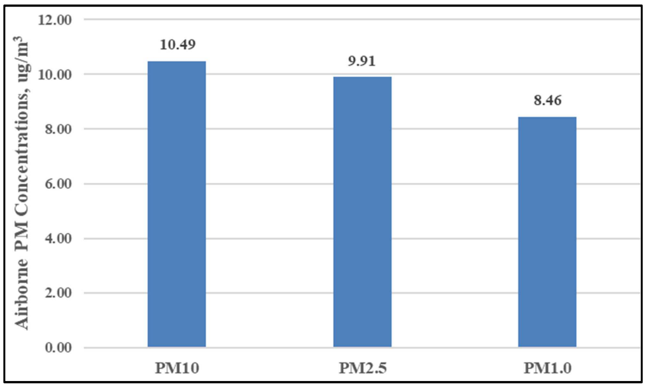

Figure 3. *Airborne PM Concentrations by Size of Particles.*

Table 3. *Airborne PM10 Concentrations by Type of Sports Facility and Day of the Week.*

Day	Table Tennis		Fitness	
	N	PM10, μg/m^3	N	PM10, μg/m^3
Mon.	12	2.8	12	6.7
Tue.	12	1.2	12	1.6
Wed.	12	4.0	12	4.0
Thu.	12	3.5	12	7.7
Fri.	12	1.6	12	5.0
Sat.	12	1.0	12	4.9
Total	72	2.35	72	5.13

Table 4. *Airborne Particle Concentrations by Size of Particles.*

	Particle Concentration, μg/m^3		
	PM10	PM2.5	PM1.0
Number of Measurements	50	50	50
Mean	9.57	9.06	7.75
SD	3.02	3.01	2.47

3.3. Performance of Cold Atmospheric Plasma (CAP) Against PM10

Another set of airborne PM10 concentrations was measured during a period of August 26-September 8 before and after applying the CAP generator. As presented in Table 5 and Figure 4, there was a significant difference between PM10 concentrations before and after applying the CAP generator. (p<0.01) The average PM10 concentration before applying the CAP generator was 15.59 μg/m^3 (ranging from 12.69 μg/m^3 to 18.99 μg/m^3). And the average PM10 concentration after applying the CAP generator was 4.90 μg/m^3 (ranging from 2.47 μg/m^3 to 8.00 μg/m^3). Thus, the average reduction rate was 68.6% (ranging from 50.9% to 83.5%). One of a few studies on the performance of negative air ion (or CAP) generators estimated that nearly 71.47% of PM10, 79.86% of PM2.5, and 61.25% of PM1.0 in indoor residential buildings can be removed by negative air ions. [16]

Table 5. *Performance of CAP for Reducing Airborne Particulates.*

Hour	PM10 Concentration, μg/m^3		Reduction Rate, %
	Plasma Off	Plasma On	
1000~1200	18.99	4.12	78.0
1200~1400	12.69	4.72	62.8
1400~1600	16.00	4.55	71.6
1600~1800	14.95	2.47	83.5
1800~2000	14.61	5.55	62.0
2000~2200	16.29	8.00	50.9
Average	15.59	4.90	68.6

3.4. Performance of CAP Against Carbon Dioxide

A set of tests was conducted to evaluate the performance of the CAP against carbon dioxide during a period of September 16-September 29 before and after applying the CAP generator. As presented in Figure 5, there was a significant difference between CO_2 concentrations before and after applying the CAP generator. (p<0.01) The average CO_2 concentrations before and after applying the CAP generator were 2,428 ppm (ranging from 504 ppm to 5,000 ppm) and 1,578 ppm (ranging from 498 ppm to 3,687 ppm), respectively. The number of tests before and after applying the CAP generator was 78 measurements, respectively. The average reduction rate was 35%.

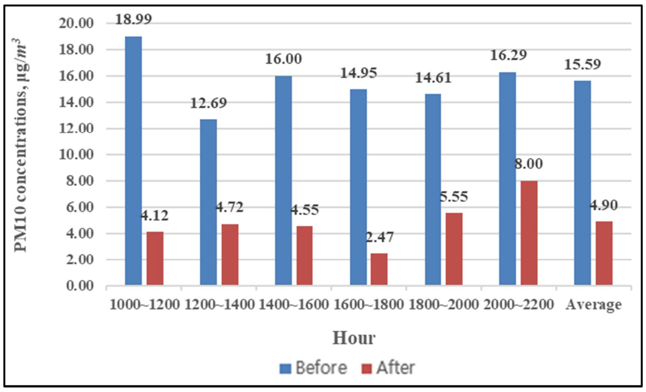

Figure 4. *PM10 concentrations before and after applying CAP generator.*

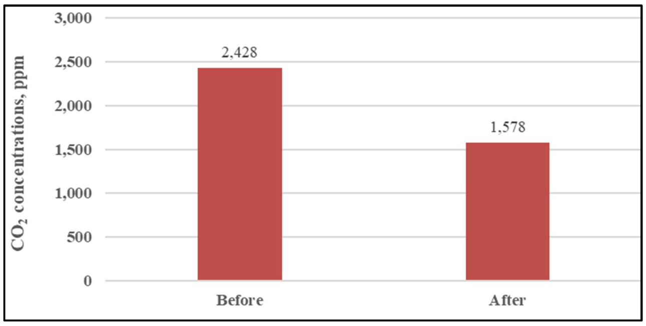

Figure 5. *Airborne CO_2 Concentrations before and after Applying CAP Generator.*

4. Conclusions

The most important two pollutants in sports facilities are fine particles and carbon dioxide. It has been reported that COVID-19 is mainly spread from person to person through aerosols exhaled by an infected person. Therefore, the concentrations of fine particles or aerosols should be as low as possible. In this study, we determined fine particles and CO_2 concentrations in two sports facilities, including a fitness center and a table tennis center. The PM10 concentrations were higher in the fitness center than in the table tennis center. The CO_2 concentrations were higher in the table tennis center, where aerobic exercises are predominant. The performance of cold atmospheric plasma in reducing concentrations of particles and CO_2 was determined. The average reduction rates against PM10 and CO_2 concentrations were 69% and 35%, respectively. It is concluded that the performance of CAP in reducing air pollutants is excellent. Further studies on the performance of CAP against other pollutants, such as total volatile organic compounds and microorganisms in sports facilities are needed.

Acknowledgements

This work was supported by the Ministry of Culture, Sports and Tourism (MCST) of the Republic of Korea (No. s202101-07-04-03, Development of safety technology for preventing infectious diseases in sports facilities).

References

[1] U.S. EPA; Health Effects, Health and Environmental Effects of Particulate Matter (PM). U.S. Environmental Protection Agency (2022).

[2] Gralton, J.; Tovey, E.; McLaws, M.; Rawlinson, W.: (2011). The role of particle size in aerosolised pathogen transmission: A review J Infect. 62 (1): 1–13.

[3] Blocken, B.; van Druenen, T.; Ricci, A.; Kang, L.; van Hooff, T.; Qin, P.; et al (2021). Ventilation and air cleaning to limit aerosol particle concentrations in a gym during the COVID-19 pandemic: Building and Environment 193 (15): 107659.

[4] Johnson, G.; Morawska, L (2009). The mechanism of breath aerosol formation: J. Aerosol Med. Pulm. Drug Deliv. 22 (3): 229-237.

[5] FilipićIon, A.; Gutierrez-Aguirre, I.; Gregor Primc, G.; Mozetič, M.; Dobnik, D (2020). Cold plasma, a new hope in the field of virus inactivation: Trends in Biotechnology 38 (11): 1278-1288.

[6] Daniels, S (2002). On the ionization of air for removal of noxious effluvia" (Air ionization of indoor environments for control of volatile and particulate contaminants with nonthermal plasmas generated by dielectric-barrier discharge): EEE Transactions on plasma science 30 (4): 1471-1481.

[7] Chen, Z.; Garcia, G.; Arumugaswami, V.; Wirz, R (2020). Cold atmospheric plasma for SARS-CoV-2 inactivation: Phys. Fluids 32: 111702.

[8] World Health Organization (WHO). WHO global air quality guidelines - Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. 2021.

[9] American Industrial Hygiene Association (AIHA). Industrial hygiene statistics. EXPASSVG-IHSTATmacrofree. 2020. https://www.aiha.org/public-resources/consumerresources/topics-of-interest/ih-apps-tools

[10] Microsoft Corporation. *Microsoft Excel*. Retrieved from https://office.microsoft.com/excel. 2018.

[11] Stumm, R (2022). Revisiting the 1,000 ppm CO_2 limit: Technical feature ASHRAE Journal, June 2022.

[12] ANSI/ASHRAE (2022). ANSI/ASHRAE Standard 62-1989, ANSI/ASHRAE ventilation of acceptable indoor air quality: ASHRAE Journal. ashrae.org

[13] Chaffin, D.; Andersson, G., Martin, B.; 3rd Ed. Occupational Biomechanics, 3rd Ed. New York: John Wiley & Sons; 1999.

[14] Zagatto, A.; de Mello Leite, J.; Papoti, M.; Beneke, R (2016). Energetics of table tennis and table tennis-specific exercise testing: Int J Sports Physiol Perform, 11 (8): 1012-1017.

[15] Andrade, A.; Dominski, F.; Pereira, M.; Liz, C (2018). Fitness centers demonstrate CO_2 concentration levels above recommended standards: Acta Scientiarum. Health Sciences, 40: e35768.

[16] Nada, A.; Mohammadmahdi, F (2020). Indoor and outdoor concentration of PM_{10}, $PM_{2.5}$ and PM_1 in residential building and evaluation of negative air ions (NAIs) in indoor PM removal: Environmental Pollutants and Bioavailability, 32 (1): 47-55.