Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: https://www.tandfonline.com/loi/uoeh20

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To cite this article: Aaron Cox, Darrah Sleeth, Rodney Handy & Victor Alaves (2019) Characterization of CO and NO_2 exposures of ice skating rink maintenance workers, Journal of Occupational and Environmental Hygiene, 16:2, 101-108, DOI: 10.1080/15459624.2018.1540875

To link to this article: https://doi.org/10.1080/15459624.2018.1540875

Accepted author version posted online: 14 Nov 2018.
Published online: 27 Feb 2019.

JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE
2019, VOL. 16, NO. 2, 101–108
https://doi.org/10.1080/15459624.2018.1540875

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REPORT

Characterization of CO and NO_2 exposures of ice skating rink maintenance workers

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ABSTRACT

Air quality is a common concern among indoor ice rink facilities due to the use of gasoline/propane ice resurfacing equipment. Although previous studies have investigated spectator, guest, and skater exposures, a review of the literature revealed little published research regarding ice maintenance employees' exposures. Ice maintenance includes edging and resurfacing. The resurfacer is commonly referred to as a Zamboni®. Edging is almost always followed by resurfacing, but resurfacing frequently happens independently of edging. The purpose of this study was to characterize ice rink maintenance employees' exposures to CO and NO_2. Employees from four ice rinks in Salt Lake County, Utah were sampled using direct reading instruments during routine ice maintenance activities. Maintenance was divided into four activities: 1) Edging only, 2) Resurfacing after edging (not including edging), 3) Edging and resurfacing (Activities 1 and 2 combined), and 4) Resurfacing only (independent of edging). Activities 1, 2 and 3 were sampled twenty-four ($n = 24$) times. Activity 4 was sampled eight times. Sampling results were graphed and summarized using descriptive statistics. The highest measured CO concentration was 202 ppm, which occurred during edging. Average CO concentrations for all activities ranged from 0 ppm to 60.4 ppm. Minimal CO exposure was observed when resurfacing occurred without edging, which implies that elevated CO exposure measured while using the resurfacer may be residual CO from prior edging activities. NO_2 concentrations were negligible for all rinks and all activities. Results confirmed that gasoline edgers significantly contribute to indoor CO levels, with peak levels exceeding some recommended exposure levels. Indoor ice rink facilities should monitor employees' CO exposures and implement procedures to limit exposures. This may be achieved by limiting the number of laps taken with the edger or replacing gasoline powered edgers with electric edgers.

KEYWORDS
Indoor air quality; occupational exposure; ice resurfacing; edger; combustion equipment

Introduction

Air quality is a common concern for indoor ice rink facilities.[1–4] The primary source of poor air quality is ice resurfacing equipment that runs on fossil fuels, which produces pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), volatile organic compounds (VOCs) and particulates.[5–10] Frequency of resurfacing[6,7] and resurfacer maintenance[7,11] are significant factors in indoor CO and NO_2 levels. The type of fuel used by resurfacers (commonly referred to by the brand Zamboni®) also influences contaminant levels.[5] Correlations exist between propane-fueled resurfacers and high NO_2 levels and gasoline-fueled resurfacers and high CO levels.[5] In addition, many facilities also use specialized equipment called edgers to maintain the ice around the edges of the rink where the resurfacer cannot reach. Unlike resurfacers, edgers are typically used only once per day or every other day.[8,10,11] Despite less frequent use, fossil-fuel edgers are a known contributor to both CO and NO_2 levels.[12]

Contaminants produced by resurfacers and edgers are associated with a range of negative health outcomes, although the severity of impact on health is determined by the duration and level of exposure.[13,14] Symptoms of CO exposure include headache, nausea, vomiting, and even death.[15] Excess exposure to NO_2 can cause coughing, throat irritation, hemoptysis (coughing up blood), chest pain, and dyspnea (difficulty breathing).[14,15] There is also evidence of longer term effects as well, including possible chronic airways inflammation and increased susceptibility to respiratory infection.[16]

Each year in the United States, CO exposure results in approximately 20,000 visits to the emergency room,

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Table 1. Summary of OELs for CO and NO_2 used for comparison.

	Analyte	
Exposure Limit	CO (ppm)	NO_2 (ppm)
OSHA 8-hr PEL	50	—
OSHA Ceiling	—	5
ACGIH 8-hr TLV	25	0.2
ACGIH Excursion 1	75	0.6
ACGIH Excursion 2	125	1
NIOSH 8-hr REL	35	—
NIOSH Ceiling	200	—
NIOSH STEL	—	1
NIOSH IDLH	1200	20

"-" indicates that no OEL currently exists

4,000 hospitalizations, and 400 deaths.[17] The negative effects that CO and NO_2 have on facility guests, spectators, coaches, cheerleaders, and especially hockey players, are well-documented.[9,14,18–22] Previous studies have focused almost exclusively on exposures to facility guests and rink users such as hockey players, figure skaters, or other skaters. A literature review found only one case report that included employees.[14]

In one study, peak CO concentrations up to 110 ppm were measured during resurfacing and up to 90 ppm immediately following resurfacing.[6] In several studies where CO concentrations were measured during a hockey game, where resurfacing occurs for approximately 15 minutes every 45 to 60 minutes, and found to be above the Permissible Exposure Level (PEL) of 50 ppm.[15,23] Spengler et al.[24] reported that CO levels were measured between 25 and 100 ppm in rinks throughout Massachusetts, and a case report from 1991 indicated a CO concentration of 47 ppm in a rink after a poisoning event with 40 cases.[19] Another case report from 2014 describes CO concentration levels between 45 and 165 ppm after a hockey player lost consciousness at a tournament in Wisconsin.[26]

Two case reports, one in 2012 and one in 1989, examined 31 cases and 116 cases of NO_2 poisoning, respectively. Concentrations of NO_2 in the former were measured at 0.5ppm[14] and at 4 ppm(14) in the latter. However, it is important to note that the case with the higher NO_2 concentrations had samples taken after operating the resurfacer for 30 minutes, which is twice as long as the normal operation time. In these instances of acute CO or NO_2 poisoning, toxicant levels measured after the exposures indicate that Occupational Exposure Limits (OELs) were likely exceeded at the ice rink during the incidents.[8] Relevant OELs are provided in Table 1.

Although OELs may have been exceeded, the populations of interest in previous studies were primarily ice rink users (i.e., the general population)[8,25,26] and not employees, therefore OELs are not necessarily applicable as a benchmark. Additionally, OELs may not be applicable to ice rink users such as hockey players or skaters, as their respiratory rates are much higher than the working population, especially when those users are children.[25] Connecticut, Massachusetts, Minnesota, Pennsylvania, and Rhode Island are the only states that currently have air quality standards for ice rinks with the intent of protecting hockey players and other skaters.[26]

Despite the known presence of these contaminants in the air of indoor ice rinks worldwide, a review of the literature revealed limited research regarding the exposures of rink maintenance personnel. In 2017, the International Ice Hockey Federation listed the number of indoor ice rinks in the United States as 1,535.[27] Many of these facilities have multiple indoor rinks, as well as multiple ice resurfacers, and even in facilities with only one rink or resurfacer, it is recommended industry practice to have more than one resurfacer operator.[28]

Of the studies previously mentioned for both CO and NO_2, only one included ice rink employees.[14] Therefore, the purpose of this study was to characterize short-term CO and NO_2 exposures among ice rink-maintenance personnel, including identification of activities with the highest exposures. Previous studies have focused on exposures to ice rink users while neglecting the employees who are exposed to the same contaminants and are much closer to the source, i.e., the resurfacing equipment. Therefore, it is unknown how much CO or NO_2 exposure these workers are receiving. This study aims to determine if employees involved in ice resurfacing and maintenance are at risk of exposure to CO or NO_2 while conducting routine duties involved in ice rink maintenance.

Methods

Recruitment

Access to four ice rinks was granted through the Salt Lake County Health Department. The University of Utah Institutional Review Board (IRB #00101482) determined that this research was exempt from additional human subjects research regulatory requirements, as researchers would merely be observing and taking personal air measurements as workers performed their routine duties. Informed consent was obtained from all workers who participated.

Sampling methods

Ice rink maintenance operations were divided into four activities: 1) Edging only, 2) Resurfacing after edging (not including edging), 3) Edging and resurfacing (Activities 1 and 2 combined), and 4) Resurfacing only (independent of edging). Activities were divided this way because resurfacing did not always include edging first; however, when edging occurred, resurfacing immediately followed. Dividing activities this way allowed for separate analysis of each portion of the work (Activities 1 and 2), as well as for the entire work period (Activity 3 or 4).

Associated start and end times for each activity during the sampling event were recorded by hand; there was no time gap between the end of Activity 1 and the beginning of Activity 2. Activity 2 began and Activity 1 ended when the employee turned the resurfacer on after having put the edger away. Additionally, observations were recorded about operating procedures (e.g., timing, number of laps). All sampling and observation was conducted by the same researcher.

Samples were gathered from four (4) ice rinks in Salt Lake County, Utah from October 2017 through December 2017. Activities 1, 2 and 3 were sampled twenty-four (24) times. Activity 4 was sampled eight times. Two rinks did not complete the intended number of samples (7) for activities 1, 2, and 3, as during the study period they purchased electric edgers and discontinued use of the gasoline edgers.

As samples representative of a normal workday were desired, maintenance personnel were instructed to work normally. Sampling events lasted the duration of the ice maintenance, which was approximately 15 minutes when only resurfacing occurred, and 30 minutes for both edging and resurfacing. Samples were taken during the regularly scheduled time for edging or resurfacing. Edging typically occurred between 6 AM and 1 PM depending on each rink's normal ice maintenance schedule. Resurfacing occurred at various times throughout the day as needed.

Qualitative information was also obtained regarding the facility age and any major remodels or additions; the number and sizes of ice sheets in the facility; the presence, type, and frequency of use of ventilation systems, and if the rink air supply was isolated from the rest of the facility; the number of resurfacers and their age, fuel type, frequency of use, and approximate date of last servicing; edger use in the facility, and if used, age, fuel type, frequency of use, and approximate date of last servicing.

The same employee operated both pieces of equipment during a sampling event. A total of six people participated. The employee operating the equipment wore one CO monitor on one lapel or side of the collar and one NO_2 monitor on the other, using the built-in clip on the monitor. The shoulder on which each monitor was placed was chosen arbitrarily. Monitors were attached immediately prior to the employee entering the maintenance area and removed once all maintenance activities were completed. For samples where both edging and resurfacing occurred, the start time of resurfacing and the end time for edging was determined to be when the operator turned the resurfacer on.

Samplers

Four (4) Dräger PAC® 7000 (Drägerwerk AG & Co., Lübeck, Germany) single gas monitors were used to collect real-time personal CO and NO_2 samples. Two (2) were equipped to measure CO and two (2) were equipped to measure NO_2. These are real-time data logging monitors designed for personal sampling use. The monitors were configured to record current concentrations every 10 seconds. The CO monitors had a resolution of 1 ppm, and the NO_2 monitors had a resolution of 0.1 ppm.

PAC® 7000 monitors are equipped with two alarm levels that were set using Dräger CC-Vision Basic software (Drägerwerk AG & Co., Lübeck, Germany). CO alarms were set at 125 ppm and 175 ppm; NO_2 alarms were set at 5 ppm and 10 ppm. These alarm levels were selected because the alarm must be set at a lower concentration than the calibration standard, otherwise the monitors' software would indicate a failed calibration check and require re-calibration. Additionally, alarm levels were chosen that were below concentrations that would have been Immediately Dangerous to Life or Health (IDLH).

Each monitor was calibrated and zeroed in the laboratory at the beginning of the study using calibration standards (Norlab, Boise, ID) of 200 ppm for CO and 25 ppm for NO_2. Prior to each sampling event, each monitor was still reading a zero value and therefore was not zeroed again. Calibration checks were performed immediately (less than 15 minutes) prior to each sampling event. If a monitor gave a reading outside of ±5% for CO or ±8% for NO_2 during the calibration check with the calibration standard gas, it was re-calibrated before being used to collect additional samples. Calibration checks and re-calibrations (as needed) were conducted in outdoor settings near the ice rinks. All calibrations and checks were conducted

Table 2. Qualitative results comparing the characteristics of the different ice rinks.

Rink	1	2	3 & 4
Age of Facility (years)	18	19	17
Major Remodels to ice?	no	no	no
Major Remodels to ventilation?	no	no	new heaters
Number of International ice sheets	1	1	1
Number of NHL ice sheets	0	0	0
Is the ventilation system used every time the resurfacer is used?	yes	yes	yes
Is the ventilation system used every time the edger is used?	yes	yes	yes
How many days per week is the ventilation system used?	7	7	7
Are there other areas of the facility that circulate the same air as the rink?	no	yes	no
Number of resurfacers	2	2	1
Age of primary resurfacer (years)	4	2	3
Fuel type	Gasoline	Gasoline	Gasoline
Uses per hour	1	1	0.5
Uses per day	6	10	8
Date of last servicing (approximate)	9/1/2017	12/1/2017	7/1/2017
Age of secondary resurfacer (years)	5	11	3
Fuel type	Gasoline	Gasoline	Gasoline
Uses per hour	1	0	0.5
Uses per day	Used for a week once a month	0	8
Date of last servicing (approximate)	8/1/2017	12/1/2017	7/1/2017
Number of edgers	1	1	1
Age of primary edger (years)	5	6	17
Fuel type	Gasoline	Gasoline	Gasoline
Laps per use	1	1	3
Uses per day	n/a	0.5	1
Uses per week	2	3	5
Date of last servicing (approximate)	9/1/2017	11/17/2017	7/1/2017

using the Dräger Bump Test Station (Drägerwerk AG & Co., Lübeck, Germany).

Data analysis

Sampling data were downloaded as a text file and exported to Excel 2016 (Microsoft Corporation, Redmond, WA) using Dräger Gas Vision software (Drägerwerk AG & Co., Lübeck, Germany). The data logger on each monitor was cleared after each download.

Using the 10-second interval measurements, mean, standard deviation, maximum and minimum concentrations were calculated for each activity that took place during a sampling event. These same descriptive statistics were also calculated for each activity category by rink. Data points from sampling events at each rink were graphed and then overlaid with the resurfacing (Activity 2 or 4) start time as 0 minutes. This start time was selected so that the transition between Activity 1 (edging only) and Activity 2 (resurfacing after edging) would be shown at a uniform point on the graph, indicative of the transition between activities. This was especially useful because the duration of activities varied from day to day and from rink to rink.

Table 3. Summary of CO concentration data by ice rink and by activity.

	All Locations	Rink1	Rink2	Rink3	Rink4
Activity 1 (Edging only)					
n	24	7	7	6	4
Mean (ppm)	27.2	2.1	7.4	57.5	60.4
Max. (ppm)	202	25	40	197	202
Min. (ppm)	0	0	0	0	0
Std. Dev. (ppm)	28.0	1.29	3.70	26.28	23.77
Activity 2 (Resurfacing after edging)					
n	24	7	7	6	4
Mean (ppm)	11.0	15.0	11.5	6.1	10.6
Max. (ppm)	63	63	62	53	60
Min. (ppm)	0	0	0	0	0
Std. Dev. (ppm)	5.0	7.38	5.56	3.14	4.81
Activity 3 (Edging and resurfacing, Activities 1 and 2 combined)					
n	24	7	7	6	4
Mean (ppm)	17.0	10.6	9.9	24.2	30.0
Max. (ppm)	202	63	62	197	202
Min. (ppm)	0	0	0	0	0
Std. Dev. (ppm)	10.2	5.19	4.73	11.49	12.39
Activity 4 (Resurfacing only, independent of edging)					
n	8	2	2	2	2
Mean (ppm)	0.1	0.0	0.3	0.1	0.0
Max. (ppm)	16	0	16	9	0
Min. (ppm)	0	0	0	0	0
Std. Dev. (ppm)	0.2	0.00	0.13	0.05	0.00

Results

A summary of qualitative results is given in Table 2, which indicates that there were minimal differences between rinks. All four rinks used gasoline powered resurfacers and gasoline powered edgers. However, there was variation in procedures from rink to rink. Normal procedure at Rink 1 was one lap with the mechanical edger, then resurfacing (without emptying the snow from the resurfacer's snow tank until completion of resurfacing). The resurfacing procedure did not change whether or not edging occurred. Workers in Rink 2 completed one lap with the mechanical edger, then one lap with the hand edger (a rectangular blade on a shovel handle), then resurfacing took place (dumping the snow about 1/3 of the way through resurfacing). When only resurfacing, the operator did not dump the snow until resurfacing was completed. The procedure for Rinks 3 and 4 was the same: three laps with the mechanical edger, then resurfacing (without emptying snow until completion).

Tables 3 and 4 summarize the air sampling results. Average CO concentrations during edging (Activity 1) ranged from 2.1 to 60.4 ppm at the different rinks (mean across all rinks = 27.2 ppm). Average CO concentrations during resurfacing after edging (Activity 2) ranged from 6.1 to 15.0 ppm (mean = 11.0 ppm). Average CO concentrations for the entire process, including edging and resurfacing (Activity 3) ranged from 9.9 to 30.0 ppm (mean = 17.0 ppm). For resurfacing only without edging beforehand (Activity 4), average CO concentrations were between 0.0 and 0.3 ppm (mean = 0.1 ppm). Across all activities, the 10-second peak reached a maximum of approximately 200 ppm. These peaks occurred during edging (Activity 1) at Rinks 3 and 4. For NO_2, nearly all samples showed concentrations of 0 ppm.

Graphs of the real-time CO concentrations from each sampling event are shown in Figure 1, separated out for each rink. Graphs of real-time NO_2 concentrations were not included because all but three (3) samples indicated concentrations of 0 ppm for the duration of the sampling event.

Table 4. Summary of NO_2 concentration data by ice rinks and by activity.

	All Locations	Rink1	Rink2	Rink3	Rink4
Activity 1 (Edging only)					
n:	24	7	7	6	4
Mean (ppm)	0.00	0.00	0.00	0.01	0.00
Max. (ppm)	0.3	0.0	0.0	0.3	0.1
Min. (ppm)	0.0	0.0	0.0	0.0	0.0
Std. Dev. (ppm)	0.01	0.00	0.00	0.01	0.00
Activity 2 (Resurfacing after edging)					
n	24	7	7	6	4
Mean (ppm)	0.02	0.00	0.00	0.04	0.07
Max. (ppm)	0.4	0.0	0.0	0.3	0.4
Min. (ppm)	0.0	0.0	0.0	0.0	0.0
Std. Dev. (ppm)	0.08	0.00	0.00	0.06	0.06
Activity 3 (Edging and resurfacing, Activities 1 and 2 combined)					
n	24	7	7	6	4
Mean (ppm)	0.02	0.00	0.00	0.03	0.05
Max. (ppm)	0.4	0.0	0.0	0.3	0.4
Min. (ppm)	0.0	0.0	0.0	0.0	0.0
Std. Dev. (ppm)	0.05	0.00	0.00	0.04	0.04
Activity 4 (Resurfacing only, independent of edging)					
n	8	2	2	2	2
Mean (ppm)	0.00	0.00	0.02	0.00	0.00
Max. (ppm)	0.3	0.0	0.3	0	0
Min. (ppm)	0.0	0.0	0.0	0	0
Std. Dev. (ppm)	0.01	0.00	0.01	0.00	0.00

Discussion

The results of this study indicate that using gasoline-powered edgers is a significant contributor to CO exposure in ice rinks. Not only did maximum CO exposures occur during edging, but when resurfacing happened without edging, the CO exposure was minimal. This study only included gasoline powered equipment and found only CO exposure was of concern in the sampled rinks, which is consistent with prior research.[5]

Variations in rinks' operating protocol may explain the differences between rinks. The number of laps taken with the edger was the most varied procedure. CO from the edger could accumulate and remain in the air for a short time after use and may subsequently be present when resurfacing takes place immediately afterward. This could explain why in rinks where the mechanical edger is only used for one lap (Rinks 1 and 2) there were lower CO concentrations than at rinks where it was used for multiple laps (Rinks 3 and 4). A slight increase from Rink 1 to Rink 2 was observed in the CO exposure during edging, where the worker used a manual edging tool for one lap after having used the mechanical edger, but still prior to resurfacing. In Rinks 3 and 4, the worker used the mechanical edger for three laps, therefore potentially being exposed to residual CO during the second and third laps. For those rinks (3 and 4), the average CO concentrations for edging were 57.5 and 60.5 ppm, respectively, compared to 2.1 ppm (Rink 1) and 7.4 ppm (Rink 2). This trend can be seen in Figure 1, where at Rink 1, CO levels are highest just after Activity 1 (edging only) has finished and Activity 2 (resurfacing after edging) has just begun (0 to 5 minutes). Conversely, at Rink 2 where the worker used a hand tool for 1 lap after using the mechanical edger, the highest CO levels are observed before Activity 1 (edging only) is over (i.e., 5 minutes before the "0" time in Figure 1). Similarly, Rinks 3 and 4 show the majority of high CO levels only during Activity 1 (edging only, 15 minutes before "0").

This potential relationship between the number of laps taken with the edger and CO concentrations may be an area for further research. This also suggests that a simple administrative control limiting the number of laps taken while edging could be implemented to reduce CO exposures for ice maintenance workers. Additionally, a longer term control would be for rinks to purchase electric edgers to replace gasoline edgers, effectively eliminating the source of CO emissions.

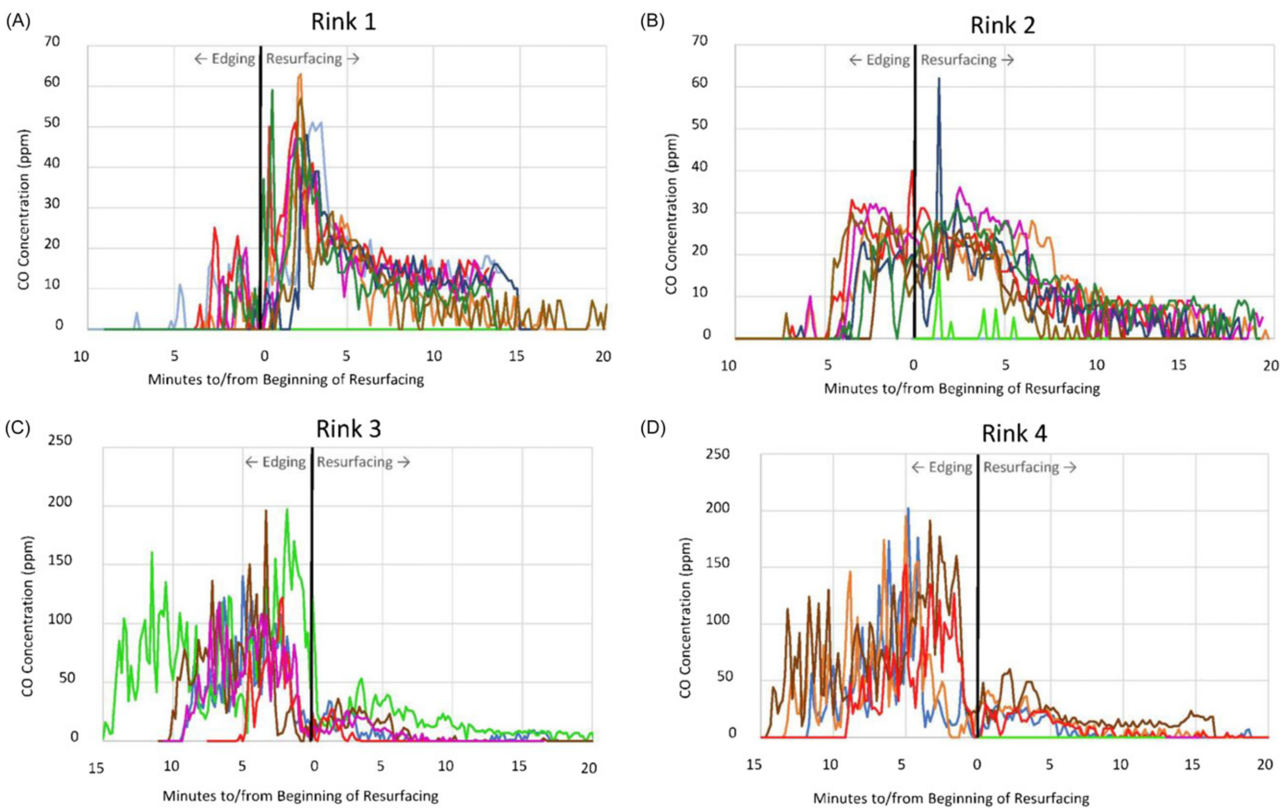

Figure 1. Real-time CO concentrations for sampling events for (a) Rink 1, (b) Rink 2, (c) Rink 3, and (d) Rink 4. Each color line represents a unique sampling event. Specific colors do not correlate to a specific activity. Please note the different scales used for each rink.

Figure 1 also shows an interesting difference in dissipation of CO concentrations between rinks. CO levels in Rinks 1 and 2 appear to diminish slowly, in contrast to Rinks 3 and 4 where CO levels drop sharply. Ventilation likely plays a significant role in the dissipation of CO, however, this was not formally evaluated. Future studies should include ventilation rates as a possible predictor variable.

In comparison to OELs, the peak exposures for Rinks 3 and 4 are of most concern. Ice rink maintenance workers are unlikely to be operating this equipment for 8 hours per day, but for short term exposures, the peak CO concentrations that were observed during edging (202 ppm) exceed some recommended levels (i.e., TLV Excursion = 125ppm and NIOSH Ceiling = 200 ppm). Identifying ways in which to reduce these exposure levels should therefore be investigated.

For NO_2, the peak concentration level (0.4 ppm) was nearly one-half the short-term REL, indicating that exposures to NO_2 are still possible in these rinks despite the use of gasoline-powered equipment. However, this level was only reached once and was maintained for less than 30 seconds, and the highest average at any rink was 0.05 ppm. Overall, NO_2 levels were of lesser concern in these rinks, primarily due to exclusive use of gasoline-powered equipment.

Strengths

One strength of this study was that the participating rinks were similar. All four were international sized rinks in small-scale buildings (no large arenas) and were of a comparable age. In addition to the physical characteristics of the rinks being alike, they all had the same equipment: Resurfacers and edgers were all serviced within the last year and were approximately the same age, although this does not preclude the possibility that equipment might have required additional maintenance at the time of sampling. Ventilation systems ran frequently or all the time in all rinks. Such similarities among the rinks that were sampled allowed for isolation of procedural differences between rinks, as well as allowing for combining the samples from different rinks in order to compare activities.

Another strength was the use of real-time sampling equipment, which enabled a more detailed investigation of trends in contaminant concentrations than integrated sampling. This benefit was especially noticeable in the ability to detect trends and patterns within a sampling event or activity. Additionally, the monitors used were small enough that sampling for CO and NO_2 simultaneously was possible.

Limitations

The samples collected for this study came from a relatively small population (four rinks over approximately two weeks each). In addition, two of the rinks chose to terminate sampling early, as they purchased electric edgers and would no longer be using the gasoline edger on a regular basis.

The NO_2 monitors seemed to be affected by temperature more than the CO monitors. Both types of monitors were calibrated, used, configured, and kept together for the duration of the study, as were the NO_2 and CO calibration gas standards. NO_2 readings for calibration checks appeared to be lower when the outdoor air temperature was lower, while lower temperatures did not appear to have any effect on CO readings. The operating manual for the samplers indicated that the range of operating temperatures was from -30°C (-22°F) to 50°C (122°F). The cause of this operational anomaly was not investigated further but may be related to the calibration standard used. Two NO_2 sampling events on the same day at Rinks 3 and 4 had to be re-calibrated outside immediately prior to sampling, possibly due to this temperature phenomenon.

Ventilation rates and information beyond a simple description of the ventilation systems were not collected. Ventilation is a known factor in indoor ice rink air quality, and differences in ventilation between days and/or rinks likely has an effect on employee exposure as well as on general contaminant levels. Differences in ventilation rates across seasons, e.g., increased use in the hotter summer months, is also a variable that should be considered in the future.

No outdoor air samples were taken at the rinks to use as a baseline for comparison. Outdoor CO or NO_2 levels may impact levels inside as it enters via doors, windows, and ventilation systems. An outdoor baseline sample would allow for comparison of levels inside the rinks to levels outside.

Conclusion

The results from this study confirm that edgers are a main source of CO in indoor ice rinks. Edger use protocol varies greatly from rink to rink, and, with it, CO levels. Ice resurfacers did not significantly contribute to CO or NO_2 levels at these facilities, but maintenance workers may be exposed to residual CO during resurfacing that was generated during edging. Areas for future research could include monitoring employee's exposures throughout the entire workday, monitoring employee exposure during simultaneous use of multiple pieces of ice maintenance equipment, and investigating the relationship between equipment's date of last servicing and emission levels.

Recommendations to ice rink managers or owners include monitoring of indoor CO levels, ensuring that resurfacing equipment is properly maintained, and instituting procedures that minimize workers' exposures. Possible control strategies for reducing workers' exposures while edging are to minimize the number of laps taken with a gasoline powered edger or to replace gasoline powered edgers with electric edgers.

Acknowledgments

The authors would like to thank the ice rink maintenance workers for their participation in this study, and the Salt Lake County Health Department for providing access to these facilities. Research reported in this publication was supported, in part, by the National Institute of Occupational Safety and Health (NIOSH) under award number T42OH008414. The authors also wish to thank Tracy M. Rees for technical writing support.

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