Exposure assessment of non-electric ice resurfacer operators in indoor ice rinks: a pilot study

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ABSTRACT

Exposure of ice resurfacer operators to indoor air contaminants was measured in six indoor ice arenas. A standardized questionnaire on technical and operational features was employed and indoor airborne concentrations of carbon monoxide (CO), carbon dioxide (CO₂), nitric oxide (NO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and total volatile organic compounds (VOCs) were measured. Air samples were collected using a range of direct reading instruments attached to the driver's seat of the resurfacer. The range of mean exposure concentrations via positional sampling (i.e. as close as able to the operator's breathing zone) were 5.7–7.4 ppm, 694–2171 ppm, <0.5 to 0.5 ppm, and < 0.1 to 0.2 ppm, for CO, CO₂, NO, and NO₂, respectively. Exposure levels for SO₂ and VOC were below detection. Overall, each of the measured indoor air contaminants was found to be below its respective occupational exposure limits (OEL), suggesting that the risk of hazardous exposure is low. The use of natural gas as a fuel source is believed to contribute to low contaminant concentrations.

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Introduction

The use of resurfacers to clean an ice rink surface has long been known to affect the air quality of the indoor arena. Past studies have shown that exhaust emissions associated with fuel combustion-powered resurfacers led to elevated concentrations of indoor air contaminants [1–11]. The main pollutants associated with these emissions are carbon monoxide (CO) and nitrogen dioxide (NO₂). General health effects associated with acute exposure to elevated levels of these two chemicals include, but are not limited to, eye irritation, shortness of breath, lung damage, and death [9,12–14].

There have been several reports of CO poisoning in Canadian ice rinks in the last 10 years – most recently an incident occurring in Dufferin County, Ontario in March 2017 [15]. This incident resulted in 11 people being sent to hospital with symptoms related to CO poisoning; however, the cause of this incident is yet to be determined. In February 2017, two separate incidents of CO poisoning occurred – one in Wetaskiwin County, Alberta [16] and another in Sault Ste. Marie, Ontario [17], with both incidents resulting in several hockey players seeking immediate medical attention. Emergency service personnel recorded peak CO levels of 258 ppm at the Sault Ste. Marie site. In November 2014, 20 hockey players were sent to hospital with symptoms of CO poisoning at an arena in Ottawa, Ontario

[18]. This incident was the result of the ice resurfacer operator failing to turn on the ventilation system while cleaning the ice. Fortunately, none of the above incidents resulted in long-term effects and/or fatalities, but they serve to illustrate the potential hazards that airborne contaminants can pose in indoor ice arenas. Although less commonly reported, NO₂ poisonings in indoor ice rinks have also occurred. An incident in November 2010 in the Czech Republic resulted in the hospitalization of 15 amateur ice hockey players with varying symptoms related to NO₂ poisoning [19].

Previous studies have characterized the airborne concentration levels with respect to potential exposure to the public such as visitors, spectators, and athletes using the rink facility [2–11]. However, little research has been done to examine the exposure levels of the ice resurfacer operator within these facilities to the same airborne contaminants. As the operator is closest to the source of the contaminants, i.e. the resurfacer, one would assume that the concentration of the airborne contaminants would be greater than that for the public and, therefore, pose a greater risk.

To our knowledge, the lone study which examined possible occupational exposure in ice rinks reported mean levels of 9.6 ppm of CO and 0.291 ppm of NO₂ while the ventilation system was in full operation [1]. These values are below the corresponding 8-h occupational exposure limits of 25 and 3 ppm, respectively, for

the province of Ontario [20]. However, this study was limited by the fact that CO and NO₂ levels were examined using passive samplers and badges. Passive samplers are known to be more affected by environmental conditions such as temperature, which in an ice rink would be lower than typical room temperatures [21,22]. In addition, passive samplers are limited when sampling short durations, particularly with NO₂ samplers [21].

Furthermore, many resurfacers are now fueled with natural gas, whereas past studies have examined the airborne contaminant levels in indoor rinks with gasoline, propane, and electric fuel-powered resurfacers. Therefore, this pilot study aimed to assess the personal exposure levels of operators of natural gas-fueled ice resurfacers to CO, carbon dioxide (CO₂), nitric oxide (NO), NO₂, sulfur dioxide (SO₂), and total volatile organic compounds (VOCs) in indoor ice arenas. Combustion of natural gas fuel is known to produce CO₂, nitrogen oxides, and CO as byproducts [23]. In addition, SO₂ and VOCs were included in this study as indicators of gasoline fuel sources such as ice edgers, which are used on occasion to facilitate the cleaning and maintenance of the ice surface. These two contaminants are known products of gasoline combustion as per previous studies [4].

Methods

Selection of ice arenas

Ethics approval was obtained prior to the start of the study. There are approximately 50 public indoor ice rinks in the City of Toronto, 6 of which were selected as sites for evaluation. Based on data obtained by Toronto Public Health via the Toronto Parks and Recreation department, the largest, smallest, oldest, and newest ice arenas in the City of Toronto were selected for inclusion in the study. The remaining two sites were chosen at random from the remaining pool of indoor ice arenas. Visits to each site were coordinated via Toronto Public Health officials who contacted arena operators through email and a mutually convenient site visit date was arranged. Operating hours for the six rinks were at least 7 h a day with various programs including open family skate, youth hockey, figure skating, and adult hockey scheduled.

Questionnaire development

The questionnaire used in this study was adapted from Brauer et al. [3] and modified for the purposes of this study to focus on operator exposure rather than public exposure. As such, this resulted in the inclusion of questions regarding the age of the resurfacer, number of resurfacings per day, average duration of a resurfacing event, and maintenance practices on the resurfacers. The questionnaire also included questions about the facility and its operational characteristics such as volume of the

arena, age of the arena, testing methods for indoor air quality monitoring, and the ventilation system used.

During site visits, resurfacer operators were asked to complete the self-administered questionnaire to the best of their ability/knowledge. The results from the questionnaire were summarized for each site and compared to the corresponding air sampling results to identify any possible correlations.

Air sampling and analysis

As mentioned previously, the air contaminants evaluated were CO, CO₂, NO, NO₂, SO₂, and VOCs as they are all possible combustion byproducts. Temperature and relative humidity (RH) for each site were also recorded. Q-Trak monitors were used to measure the indoor airborne concentrations of CO and CO₂, and to determine RH and temperature (Model Number 7575-X, TSI Inc. Probe Number 982, St. Paul, MN, U.S.A.). The reported resolutions for CO and CO₂ were 0.1 and 1 ppm, respectively. The accuracy of the Q-Trak's sensors was ± 50 ppm and ± 3 ppm for CO₂ and CO, respectively. Q-Trak's were set up to collect and log measurements at 5-s intervals. Two portable Multi-RAE gas monitors (Model Number PGM-6228, RAE Systems, San Jose, CA, U.S.A.) were used to measure the indoor airborne concentrations of NO, NO₂, SO₂, and VOCs. The reported resolutions for NO₂, SO₂, and VOCs were 0.1 ppm and for NO it was 0.5 ppm. The Multi-RAEs were also set up to collect and record measurements at 5-s intervals during the sampling duration. Measurement of NO employed the use of Multi-RAE Plus models (Model Number PGM50-5P, San Jose, CA, U.S.A.) at the first three sites while the portable Multi-RAE was used for the last three arenas. This was due to technical issues with obtaining the NO sensor for the Multi-RAE units. The Multi-RAE Plus units were set up to record measurements at 60-s intervals, as this was the manufacturer's default setting.

Levels of all contaminants were measured during a one-day site visit at each of the six arenas, under normal operating conditions. Two sets of sampling equipment were used at each site. The first was securely placed on the resurfacer (Figure 1) to monitor the exposure levels of the operator during resurfacing. For the purpose of this study, these samples represented potential personal exposure of the operator via positional sampling. Although not in the worker's breathing zone *per se* (due to the cumbersome nature of the instruments), the instruments were mounted as close as able to the operator. The second set of instruments was set up rink side as an area sample to monitor dissipation of airborne contaminants to the surrounding area. Since resurfacing was conducted at least four times a day, we aimed to record the data for at least two resurfacing events *per site*. This resulted in a range of measurements spanning anywhere between two and three hours consecutively.

Figure 1. Direct reading instrument setup on the resurfacer, measuring personal exposure.

Table 1. Characteristic and technical information for participating ice arenas and their respective resurfacers.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Age of resurfacer (years)	2–4	0–2	4–7	*	2–4	>8
Resurfacings per day	7–9	>10	7–9	>10	7–9	4–6
Resurfacing duration (minutes)	6–10	6–10	6–10	6–10	6–10	6–10
Number of rink users	150–249	>250	>250	*	150–249	50–149
User hours/day (hours)	7–9	>9	>9	*	>9	7–9
Age of the rink (years)	6–10	>15	>15	*	>15	>15
Size of rink (ft ²)	>20,000	>20,000	>20,000	12,000–20,000	12,000–20,000	*
Ventilation System	Mechanical	Air dehumidifier	Mechanical & Air dehumidifier	Mechanical	Mechanical & Air dehumidifier	Air dehumidifier
IAQ** currently tested	Yes	Yes	Yes	Yes	Yes	Yes

*The ice resurfacer operator was unable to answer this question in the questionnaire;

**IAQ = indoor air quality, these parameters include CO, CO₂, temperature, and relative humidity.

All instruments were calibrated following the manufacturers' recommended procedures prior to air sampling. Equipment was powered on to take measurements at least five minutes before the first resurfacing event and kept running until approximately five minutes following the last ice resurfacing. This sample duration was adopted to coincide with the exposure of the resurfacer operator.

After completion of sampling, data were downloaded from the instruments using the associated software (ProRAE Studio II, ProRAE Suite and TrakPro). The average concentration and range of each chemical were determined and compared between sites.

Results

The characteristics of the six indoor ice arenas can be found in Table 1. Note that for all sites, natural gas was used as the fuel source for the resurfacer. It bears

mentioning that at site 3, the ice resurfacer operator was new to the facility and only partially completed the questionnaire. Additional information regarding this arena's characteristics was obtained from the Parks and Recreation Department Permit Officers at a later time.

Table 2 reports the airborne concentration levels that were obtained for both the personal and area samples. At four of the six arenas, data were collected for three ice resurfacing events. The results for personal exposure (conducted by positional sampling) to the indoor air quality (IAQ) parameters illustrate that CO was highest at sites 5 and 6, with average values of 6.1 and 7.4 ppm, respectively. The peak values for CO obtained at these sites were 23.2 and 10.8 ppm. CO₂ levels were highest at sites 2 and 3, with average values of 1208 and 2171 ppm, respectively. The peak values obtained for CO₂ at these sites were 1479 and 3021 ppm. The highest values obtained for NO and NO₂ were 0.5 ppm at site 6 and 0.2 ppm at site 1, respectively.

Table 2. Personal and area CO, CO₂, NO, NO₂, SO₂, and VOC (in ppm) airborne concentrations in all ice arenas during testing.

Chemical	Site	Personal (ppm)		Area (ppm)		Ontario 8-h OEL-TWA (ppm)
		Average	Max	Average	Max	
CO	1	5.7	7.5	2.5	2.7	25
	2	5.7	7.8	1.6	2.0	
	3	5.8	7.9	2	2.5	
	4	6.0	10	0.1	37.5	
	5	6.1	23.2	6.2	7.1	
	6	7.4	10.8	8.3	10.5	
CO ₂	1	951	1482	1002	1288	5000
	2	1208	1479	845	1163	
	3	2171	3021	1803	2061	
	4	694	1288	790	4415	
	5	1131	1529	1447	1556	
	6	700	1041	811	1013	
NO	1	LOD*	LOD	LOD	LOD	25
	2	LOD	LOD	LOD	LOD	
	3	LOD	LOD	LOD	LOD	
	4	LOD	0.5	LOD	LOD	
	5	LOD	LOD	0.5	0.5	
	6	0.5	4.0	1.5	4.0	
NO ₂	1	0.2	0.4	0.1	0.2	3
	2	LOD	0.1	0.1	0.2	
	3	LOD	0.3	0.3	0.5	
	4	LOD	LOD	0.1	0.2	
	5	LOD	LOD	LOD	0.1	
	6	LOD	LOD	0.1	0.4	
SO ₂	1	LOD	LOD	LOD	LOD	2
	2	LOD	0.3	LOD	LOD	
	3	LOD	LOD	LOD	LOD	
	4	LOD	0.1	LOD	0.1	
	5	LOD	0.5	LOD	LOD	
	6	LOD	LOD	LOD	0.1	
VOCs	1	LOD	LOD	LOD	LOD	Varies**
	2	LOD	LOD	LOD	0.1	
	3	LOD	LOD	LOD	LOD	
	4	LOD	LOD	LOD	LOD	
	5	LOD	4.1	LOD	LOD	
	6	LOD	LOD	LOD	LOD	

Note: During monitoring at arena site 5, a gasoline-powered snow blower was used to remove ice shavings and snow from the resurfacer storage area. This spiked the results of CO, SO₂, and VOCs.

*See Methods – Air Sampling and Analysis (page 5) for instrument resolutions.; **VOC OEL in Ontario, Canada is dependent on characterization of the specific volatile organic compound.

All chemical contaminants were below their corresponding 8-h occupational exposure limit as per the Ontario Occupational Health and Safety Regulation. There did not appear to be any correlations with the characteristic of the arena and the corresponding airborne contaminant concentrations. For CO, personal concentration measurements were generally greater than area measurements, except for two sites which reported slightly higher area measurements. For all other contaminants, there was no discernible pattern between the set of personal and area measurements.

Discussion

The purpose of this pilot study was to assess the personal exposure levels of ice resurfacer operators to indoor air contaminants produced by resurfacers fueled by natural gas. The concentration levels of all the measured airborne contaminants (CO, CO₂, NO, NO₂, SO₂, and VOCs) were below their respective occupational exposure limit. This

indicates that, during sample collection, the existing ventilation system reduced airborne concentrations to levels deemed safe.

Results for CO showed site 5 had a peak personal exposure value of 23.2 ppm, which corresponded with the brief usage of a snow blower to remove snow from the resurfacer bay. However, the average CO concentration at this site was 6.1 ppm which is below the occupational exposure limit. The highest average personal CO exposure was reported at site 6 and was measured to be 7.4 ppm. Our results are slightly lower than the results obtained by Brauer et al. [1] which reported average CO concentrations at the resurfacer as 9.3 ppm during normal operation.

Results for average personal exposure levels of CO₂ were found to be the highest at site 3, measuring 2171 ppm and peaking at 3021 ppm. Overall, average measurements of CO₂ ranged from 694 to 2171 ppm across all arenas. This result is similar to that of a previous study which reported average area CO₂ concentrations ranging from 851 to 1329 ppm [4]. The higher CO₂ levels obtained at site 3 are believed to be an outlier and could possibly be linked to the age of the arena (site 3 is the oldest public arena in Toronto) as suggested by Pennanen et al. [11]. Higher measured CO₂ concentration levels at site 3 may have also been influenced by expired CO₂ from arena occupants which may have been less efficiently removed from the arena due to the older ventilation system.

Results for NO average values were 0.5 ppm at site 6, whilst they were below the instrument's resolution (0.5 ppm) at all other sites. This suggests that, regardless of the number of resurfacing events, there was no significant increase in NO concentrations as sampling duration increased. Compared to previous results reported by Guo et al. of 0.04–0.82 ppm across three ice arenas, our highest recorded values were within the range of results reported [4].

Average values for NO₂ personal exposure were 0.20 ppm in this study at site 1, but less than the instrument's resolution (0.1 ppm) at all other sites. These findings are lower than the results by Brauer et al. who reported average NO₂ concentrations at the resurfacer during usual operating conditions of 0.65 ppm [1].

Average values obtained for SO₂ and VOCs were below the instrument's resolution (0.1 ppm) across all 6 sites with peak measurements of 0.5 ppm for SO₂ and 4.1 ppm for VOCs. Both peak values were measured at site 5, and corresponded to the time in which the gasoline-powered snow blower was in use. The mean SO₂ results are comparable to those obtained from Guo et al. who reported average SO₂ levels of 0.01 ppm [4]. Mean TVOC concentrations reported by Guo et al. ranged from 0.12 to 0.22 ppm while the current study had average levels below the resolution level, but peaks at site 5 that far exceeded the results reported by Guo [4].

Our study was limited by the duration of time spent at sites recording data. It would have been ideal to collect data over 8 h which is the accepted duration for occupational exposure assessments as it is more representative of the operator's exposure profile over a full work shift. Another limitation is that we were unable to record data when the ice edger was in use. Ice edgers are only used for a total of 1–2 h of weekly ice surface maintenance and did not coincide with any of our site visits. As the fuel source for the ice edger is gasoline, we might have seen results similar to those in previous studies which examined gasoline-powered resurfacers.

The results of this pilot study suggest a switch in fuel from gasoline to natural gas may reduce airborne concentration of NO₂ and CO in indoor ice rinks; this, in turn, can result in less instances of CO and NO₂ poisoning (for both the operator and the public). As the airborne contaminant concentrations were low and not likely to be harmful, no future similar studies are warranted. However, because ice edgers may still be a source for contaminants as they are fueled by gasoline, it is recommended that a study be conducted to sample during ice maintenance days when an ice edger is in use. This would allow for a more comprehensive assessment of the ice resurfacer operators' exposure to the contaminants of interest. Lastly, it is recommended that future exposure assessments consider other hazards such as noise and vibration as the resurfacer operator can be exposed to these hazards while operating the resurfacer. A noise exposure assessment would be important to conduct due to the known ototoxic effects of carbon monoxide exposure which leads to increased severity of hearing loss from environmental noise exposure [24].

Conclusion

Overall, the exposure of the operator to known contaminants generated by the ice resurfacer (CO, CO₂, NO, NO₂, SO₂, and VOCs) was below the corresponding occupational exposure limits. It is believed that lower results reported in this study are due to the difference in resurfacer fuel utilized in previous studies (gasoline, propane, and electricity). The present study examined six sites that all used natural gas as the resurfacer fuel source. The byproducts of natural gas are limited to carbon dioxide, carbon monoxide, water vapour, and reduced amounts of nitrogen oxides when compared to gasoline and propane fuel sources as they burn cleaner than other fossil fuels [23]. It was important to test for the remaining contaminants due to the potential use of a gasoline-powered ice edger at the sites. Thus, it is believed that the lower results obtained in this study are mostly attributed to the fuel used by the resurfacers in this study. Also, because the gasoline-powered ice edger was not employed during sampling periods, it likely resulted in lower airborne concentrations overall.

Based on the findings of this study, there is no recommendation for an additional larger study.

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Disclosure statements

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