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Carbon Monoxide Poisoning Related to the Indoor Use of Propane-Fueled Forklifts in Colorado Workplaces

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The Colorado Department of Public Health and Environment (CDPHE) measured area carbon monoxide concentrations at three separate workplaces where workers had experienced acute carbon monoxide poisoning related to the indoor use of propane-fueled forklifts. Follow-up investigations were conducted at two of these workplaces where full-shift carbon monoxide exposure and end-exhaled carbon monoxide concentrations were measured to estimate carboxyhemoglobin concentrations. Draeger dataloggers equipped with carbon monoxide sensors were used to measure full-shift personal exposure and area airborne carbon monoxide concentrations. The dataloggers were also used to measure preshift and postshift end-exhaled carbon monoxide concentrations, which were then used to calculate carboxyhemoglobin concentrations. At the first workplace, a beverage distributing warehouse using two propane-fueled Nissan forklifts, carbon monoxide exposures ranged from 25 to 68 ppm (mean = 44 ppm) as work shift time-weighted averages (TWAs), with peaks ranging from 43 to 639 ppm. The range of increase in end-exhaled carbon monoxide concentrations of the tested nonsmoking employees was 17 to 65 ppm (average increase was 42 ppm) through the work shift. Following forklift maintenance and a reduction in the use of forklifts, employee exposures were reduced (range of TWAs was 16 to 33 ppm; mean = 25 ppm), but were still in excess of recommended limits. The range of increase in end-exhaled carbon monoxide concentrations for nonsmokers after maintenance was 13 to 40 ppm (average increase was 26 ppm), again indicating that maintenance was not adequate. At the second workplace, a sugar packaging company also using two propane-fueled Nissan forklifts, carbon monoxide exposures measured after forklift repairs and related reduction in carbon monoxide emissions were low (1 to 10 ppm over a 7-hour work shift). The increases in end-exhaled carbon monoxide concentrations for the two nonsmokers at this workplace were 2 and 3 ppm. Area concentrations of carbon monoxide measured at the third workplace were as high as 300 ppm. The data from these workplaces combined with data related to 57 other propane-fueled forklift-related carbon monoxide poisoning cases found through CDPHE record reviews and literature searches demonstrate that the use of propane forklifts indoors without diligent monitoring of carbon monoxide emissions, and without subsequent maintenance aimed at reducing these emissions, can result in carbon monoxide poisoning.
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Unintended exposure to carbon monoxide caused more than 800 deaths annually in the United States between 1979 and 1988, during which Colorado's unintentional carbon monoxide-related death rate was the tenth highest (0.83 per 100,000 per year) among all states.[1] To describe the epidemiology of unintentional fatal and nonfatal carbon monoxide poisoning in Colorado, and to help develop prevention strategies, surveillance for carbon monoxide-related poisonings was initiated by the Colorado Department of Public Health and Environment (CDPHE) in February 1985. This surveillance is conducted through required laboratory reporting of carbon monoxide poisonings (carboxyhemoglobin concentrations greater than 12% must be reported within 30 days of the analysis) and voluntary reporting of carbon monoxide poisonings by hyperbaric medicine departments and others throughout Colorado. CDPHE recently received funding from the National Institute for Occupational Safety and Health (NIOSH) Sentinel Event Notification System for Occupational Risk program to conduct investigations of occupational poisonings. The purpose of these investigations is to determine if additional employees were overexposed to carbon monoxide, to ensure that the employer adequately controlled the hazard, and to collect data for development of larger prevention efforts.

In this article we describe investigations of carbon monoxide poisonings related to propane-powered forklifts which were reported to CDPHE. In late January, early February, and mid-April 1995, CDPHE received reports of five cases of carbon monoxide poisoning related to the use of propane-powered forklifts at three separate workplaces. Results of initial short-duration area monitoring of airborne carbon monoxide conducted at all three workplaces are presented, as are results of further full-shift monitoring of employee carbon monoxide exposures and related estimated carboxyhemoglobin concentrations measured at two of the three workplaces.

Background

Carbon monoxide is a colorless, odorless, tasteless, nonirritating gas that is produced as a by-product of incomplete combustion of fuels such as propane. Carbon monoxide combines with hemoglobin in the blood to form carboxyhemoglobin. Carbon monoxide displaces oxygen in the blood because hemoglobin has as much as 200 times greater affinity for carbon monoxide than oxygen.[2] Carboxyhemoglobin concentrations in the general nonsmoking urban population range from 1 to 2 percent.[3] The mean carboxyhemoglobin concentration

among one-pack-per-day cigarette smokers is 5 to 6 percent (range of 4 to 20%).[4]

Depending on the concentration of exposure, symptoms of carbon monoxide poisoning include headache, nausea, dizziness, fatigue, weakness, lack of muscle coordination, visual disturbances, chest pain, and loss of consciousness. Neurologic signs and symptoms (e.g., disorientation, gait disturbances, hallucinations, and difficulties in speaking or understanding speech) experienced during the initial poisoning may disappear when carbon monoxide exposure stops, or may continue or recur for weeks or months even in the absence of reexposure.[5,6] Carbon monoxide exposure can cause chest pain, electrocardiographic abnormalities, irregular heartbeat, or insufficient supply of blood to the heart. Exposure to high concentrations of carbon monoxide [4000 parts per million (ppm) or above, or exposure sufficient to result in carboxyhemoglobin concentrations of 50 to 70%] can result in coma and death.

Exposure Monitoring Methods

CDPHE measured airborne carbon monoxide using Draeger 190 dataloggers equipped with carbon monoxide sensors. The dataloggers were calibrated before and after the shift with 0, 50, and 300 parts of carbon monoxide per million parts of carbon monoxide per million parts of air. These dataloggers are accurate to within ±3 percent of the measured concentration, according to the manufacturer. Employees were asked to wear the carbon monoxide dataloggers (also referred to in this report as carbon monoxide monitors) through the work shift. Additional carbon monoxide monitors were placed in areas where employees were working. Hand-held dataloggers were used to isolate sources of exposure and verify individual carbon monoxide monitor results. In addition, hand-held dataloggers were used to measure background outdoor carbon monoxide concentrations.

Preshift and postshift carboxyhemoglobin estimates were calculated for each employee using the method described in the documentation of the American Conference of Governmental Industrial Hygienists (ACGIH) biological exposure index (BEI).[3] Each worker was asked to:

1. exhale completely,
2. inhale rapidly until lungs are filled,
3. hold breath for 20 seconds,
4. exhale a small amount of breath into the ambient air, and
5. exhale the remainder of the breath into a tube leading to a 5-L Mylar sample bag.

The concentration of carbon monoxide in the exhaled air was then immediately measured using a Draeger datalogger. The percentage of carboxyhemoglobin in the blood was calculated using the formula

$$-0.5 + (\text{expired carbon monoxide in ppm}/5)$$

Evaluation Criteria

The Occupational Safety and Health Administration (OSHA) permissible exposure limit for carbon monoxide at the time of this investigation was 50 ppm as a time-weighted average (TWA) over an 8-hour work shift,[7] 40 ppm for a 10-hour work shift, and 33 ppm for a 12-hour work shift.[8]

ACGIH recommends that employee exposures to carbon monoxide not exceed 25 ppm as a TWA over an 8-hour work shift, 18 ppm over a 10-hour work shift, or 13 ppm over a 12-hour work shift.[9] The ACGIH BEI relevant to carbon monoxide exposure is an end-of-shift carboxyhemoglobin concentration of 3.5 percent, or 20 ppm carbon monoxide measured in end-of-shift end-exhaled air.[9]

NIOSH recommends that carbon monoxide exposures be limited to 35 ppm over an 8-hour work shift, and that carbon monoxide exposure not exceed 200 ppm during the shift.[10]

Walk-Through Investigations and Short-Term Carbon Monoxide Monitoring

Case Report and Workplace Descriptions

WORKPLACE 1. On January 24, 1995, a hospital laboratory reported a case of carbon monoxide poisoning to CDPHE based on a measured carboxyhemoglobin concentration of 17.7 percent. On that day, a 52-year-old employee of a wholesale beverage distributer (elevation 6000 feet) in Colorado was transported to a local hospital because of chest pain. The employee had been working in the warehouse of this company for approximately 9.5 hours, during which two propane forklifts and several natural gas space heaters were in operation. CDPHE responded to this report of carbon monoxide poisoning by conducting a walk-through investigation on February 1.

At this company, palletized cases of beverages are delivered to the warehouse in semi-tractor trailer trucks. These trucks are backed up to a loading dock and beverages are unloaded by propane-powered forklifts that are driven into the trailer. Palletized beverages are stored in a large holding area, where individualized pallets are prepared according to customer orders. Propane forklifts and manual or electric hydraulic hand-operated pallet movers are used in the preparation of orders. The orders are then moved to another part of the warehouse and loaded onto delivery trucks that are parked within an enclosed bay. The warehouse and office areas are heated by natural gas-powered, ceiling-mounted space heaters.

At the time of the CDPHE walk-through investigation, 15 people worked at the warehouse (7 people preparing and moving pallets, 2 office workers, and 6 supervisors of warehouse and field personnel). Employees were not trained about the hazards of exposure to carbon monoxide. The company did not conduct employee exposure monitoring. Tailpipe carbon monoxide emissions were not monitored by the company or their maintenance contractor.

WORKPLACE 2. On February 7, 1995, a 24-year-old propane forklift driver working in a sugar packaging company (elevation 5400 feet) was treated for carbon monoxide poisoning in the emergency room of a hospital in Colorado. The forklift driver reported experiencing headache, nausea, and dizziness, with onset sometime during an 8.5-hour period of exposure to forklift emissions. Her measured carboxyhemoglobin was 24 percent. Because the case's symptoms persisted, she was transferred to the hyperbaric medicine department of another Colorado hospital for further treatment. CDPHE was notified of this incident by telephone on February 9 by the hyperbaric medicine department treating the patient. CDPHE visited the

workplace on February 13 to discuss the incident with the employer and conduct a walk-through inspection.

The employer of the forklift driver was a contractor for a company that packaged sugar. The contracted company was hired to unload bags of sugar, each weighing 2200 pounds (1 metric ton), from railroad cars and transfer the bags to a large warehouse. The railroad cars were positioned near the warehouse for unloading. The forklifts were driven into the railcar, where a bag of sugar was hung on the forklift forks. The bags were then taken to the warehouse for stacking and storage. The warehouse had no heating or ventilation system.

At the time of the CDPHE investigation, four people from the contracted company were unloading the sugar. Employees were not trained about the hazards of exposure to carbon monoxide. The company did not conduct employee exposure monitoring. Tailpipe carbon monoxide emissions were not monitored by the employer.

WORKPLACE 3. On April 19, 1995, three additional cases of carbon monoxide poisoning occurred and were reported by a hospital hyperbaric medicine department to CDPHE by telephone (measured carboxyhemoglobin concentrations were 21.1, 17.0, and 16.8%). These poisonings occurred at a Colorado workplace (elevation 5280 feet) that distributed metal to artists and also manufactured metal flashing. A propane forklift and gas-powered heaters were in use when the poisonings occurred. The local fire department and utility company responded to initial requests for emergency assistance at the company, where building occupants were evacuated and operations shut down. The heaters were red-tagged and orders were issued for heater repair. CDPHE visited the company on April 25 after the heaters had been repaired and the hazard was assumed to have been corrected. Employees were back at work and operations within the workplace were back to normal. One forklift was in use, and heaters were not operating because it was a warm day. The forklift moved throughout the low ceilinged (10 ft), 68,000-ft^3 workplace, where approximately ten people were working.

Results of Short-Term Sampling of Area Carbon Monoxide Concentrations During Walk-Through Investigations

WORKPLACE 1. CDPHE measured carbon monoxide concentrations as high as 140 ppm inside the beverage distributing company. Generally, airborne concentrations of carbon monoxide were between 95 and 100 ppm everywhere within the main warehouse and in the offices. Outdoor carbon monoxide concentrations were 0 to 5 ppm. A follow-up investigation was immediately scheduled. Forklift tailpipe carbon monoxide emissions measured before forklift maintenance the following week (and thus related to the airborne carbon monoxide concentrations here) were 9.5 percent (95,000 ppm).

WORKPLACE 2. Indoor carbon monoxide concentrations as high as 70 ppm were measured at the sugar packaging company. Outdoor carbon monoxide concentrations were 0 to 5 ppm. Carbon monoxide concentrations diminished rapidly when the warehouse doors were opened, but product storage requirements made this an unacceptable method to reduce carbon monoxide exposures. CDPHE discussed reduction of forklift emissions with the company and scheduled a follow-up investigation. Forklift tailpipe carbon monoxide emissions of 9.5 percent were measured by the company before forklift maintenance on the following day.

WORKPLACE 3. Airborne carbon monoxide concentrations greater than 300 ppm were measured at the metal distributing company in the areas where the propane forklift was in operation. Outdoor carbon monoxide concentrations were between 0 and 10 ppm. CDPHE discussed reduction of tailpipe carbon monoxide emissions with the company and scheduled a follow-up investigation. Tailpipe carbon monoxide emissions of 9.5 percent were measured by the company before forklift maintenance on the following day.

Full-Shift Investigations: Exposure and Biological Monitoring

Workplace 1

CDPHE returned to workplace 1 five days after the walk-through investigation to measure employee full-shift carbon monoxide exposures, estimate employee carboxyhemoglobin concentrations through exhaled breath carbon monoxide measurements, and investigate possible sources of carbon monoxide. Results of personal exposure monitoring and related estimated employee carboxyhemoglobin concentrations using end-exhaled carbon monoxide measurements are summarized in Table 1. Measured carbon monoxide exposures ranged from 25 to 68 ppm (mean = 44 ppm) as work shift TWAs, with peaks ranging from 43 to 639 ppm. The range of increase in end-exhaled carbon monoxide concentrations of the tested nonsmoking employees was 17 to 65 ppm (average increase was 42 ppm) through the work shift.

Airborne carbon monoxide was measured in the main warehouse, delivery truck bay, semi-tractor trailer truck dock, business office, and operations office before forklifts were in use, and before delivery trucks were being moved in the bay to determine if the natural gas-fueled warehouse heaters were contributing carbon monoxide to the atmosphere. All of these measurements were similar to outdoor concentrations (0 to 8 ppm), and were very low compared with measurements taken when forklifts were in use. The area carbon monoxide monitor placed in the delivery truck bay, and measurements taken with hand-held dataloggers, indicated that delivery truck emissions were a minor contributing factor to overall employee exposures.

Air sampling results from the hand-held dataloggers and area monitors placed in the warehouse, truck bay, and business office indicated that carbon monoxide concentrations rose dramatically when one of the two forklifts was in use. Employee monitor alarms sounded when the forklift was in the truck trailer (637 ppm) and when the forklift passed them in the aisles (310 ppm). When the second forklift was operated, carbon monoxide concentrations everywhere in the facility again rose dramatically.

Since hand-held and area dataloggers indicated that carbon monoxide concentrations in the business office consistently coincided with or exceeded carbon monoxide concentrations in the main warehouse, CDPHE investigated the air supply for the business office. Heated air was supplied to the offices by a heater that appeared to be inadequately supplied with outside air and inadequately ducted. In addition, emissions from the burner portion of the heater appeared to be inadequately

TABLE 1. Carbon Monoxide Air and Biological Sampling Results: Beverage Distributing Company

	Airborne Carbon Monoxide Concentrations				Biological Concentrations					
					Preshift		Postshift		Change	
	TWA (ppm)	Sample Time (hours)	Peak (ppm)	STEV[A] (ppm)	Exhaled Carbon Monoxide (ppm)	COHb[B] % Estimate	Exhaled Carbon Monoxide (ppm)	COHb % Estimate	Exhaled Carbon Monoxide (ppm)	COHb % Estimate
February 6–7 (before CDPHE recommendations)										
Day shift										
Nonsmokers										
Worker 1	39	8	95	83	23	4.1	40	7.5	+17	+3.4
Worker 2	25	8	43	40	8	1.1	34	6.3	+26	+5.2
Area samples										
Truck bay	25	8	128	68	N/A	N/A	N/A	N/A	N/A	N/A
Warehouse	29	8	114	47	N/A	N/A	N/A	N/A	N/A	N/A
Office	48	8	95	92	N/A	N/A	N/A	N/A	N/A	N/A
Night shift										
Nonsmokers										
Worker 3	40	12	310	91	7	0.9	69	13.3	+62	+12.4
Worker 4	47	11.5	170	110	1	0	66	12.7	+65	+12.7
Smokers										
Worker 5	46	11	199	161	34	6.3	71	13.7	+37	+7.4
Worker 6	46	12	525	113	58	11.1	86	16.7	+28	+5.6
Worker 7	68	11.5	639	—	38	7.1	96	18.7	+58	+11.6
Area samples										
Truck bay	60	11.5	171	126	N/A	N/A	N/A	N/A	N/A	N/A
Warehouse	48	11.5	126	106	N/A	N/A	N/A	N/A	N/A	N/A
February 16–17 (after CDPHE recommendations)										
Day shift										
Nonsmoker										
Worker 1	16	8.5	56	43	9	1.3	22	3.9	+13	+2.6
Smoker										
Worker 8	20	8.5	84	42	45	8.5	50	9.5	+5	+1
Area samples										
Warehouse	17	11.5	49	34	N/A	N/A	N/A	N/A	N/A	N/A
Warehouse	24	8.25	72	51	N/A	N/A	N/A	N/A	N/A	N/A
Office 1	19	9.5	28	27	N/A	N/A	N/A	N/A	N/A	N/A
Office 2	17	11.5	28	25	N/A	N/A	N/A	N/A	N/A	N/A
Night shift										
Nonsmokers										
Worker 4	26	10	63	51	15	2.5	39	7.3	+24	+4.8
Worker 5	27	10.3	78	60	20	3.5	60	11.5	+40	+8
Smokers										
Worker 6	33	10.3	101	67	35	4.5	62	11.9	+27	+7.4
Worker 7	31	10.5	109	88	58	11.1	71	13.7	+13	+2.6
Area samples										
Truck bay	33	10.3	147	104	N/A	N/A	N/A	N/A	N/A	N/A
Warehouse	30	10	75	62	N/A	N/A	N/A	N/A	N/A	N/A
Warehouse	35	10.3	86	70	N/A	N/A	N/A	N/A	N/A	N/A
Warehouse	23	10	71	45	N/A	N/A	N/A	N/A	N/A	N/A
Office 2	24	10.5	51	49	N/A	N/A	N/A	N/A	N/A	N/A

[A]STEV = short-term exposure value (20 minutes).
[B]COHb = carboxyhemoglobin.

vented to the outside of the building. Carbon monoxide measurements near the heater and in the office below indicated that these design problems were causing the heater to draw contaminated air from the warehouse into the office.

All but two of the seven employees who wore a datalogger were exposed to carbon monoxide concentrations in excess of OSHA limits for occupational exposure. All employees were exposed to carbon monoxide concentrations equal to or in excess of ACGIH and NIOSH recommended limits for exposure.

Estimated carboxyhemoglobin concentrations calculated from preshift and postshift exhaled air carbon monoxide concentrations indicated a substantial rise over the work shift for every employee, and all but two employees monitored had an end-of-shift carboxyhemoglobin estimate that was above the CDPHE reporting requirement for carboxyhemoglobin levels. All end-of-shift exhaled carbon monoxide concentrations rose in excess of the ACGIH BEI.

The data presented above strongly indicated that propane-powered forklifts represented the most significant source of carbon monoxide exposure in this facility. Employee carbon monoxide exposure concentrations, combined with the initial carbon monoxide poisoning incident and data regarding exhaled-air carbon monoxide and related carboxyhemoglobin estimates, indicated the need for immediate correction of the carbon monoxide hazard in this workplace. CDPHE recommended that the company take steps to reduce tailpipe carbon monoxide emissions either through repair of the forklift's propane fuel system, addition of catalytic converters to the forklift's exhaust system, or substitution of electric-powered forklifts. The company was advised to document initial and continued reductions in tailpipe carbon monoxide emissions (if substitution of electric forklifts was not chosen) through regular measurement of carbon monoxide in the exhaust. CDPHE also recommended that employee carbon monoxide exposures be measured after forklift emissions were reduced or eliminated to ensure that carbon monoxide tailpipe emission control sufficiently reduced exposures, and that the heater above the offices was not emitting hazardous quantities of carbon monoxide into the office air.

On February 16–17, CDPHE returned to workplace 1 to repeat measurements of employee carbon monoxide exposure and estimated carboxyhemoglobin concentrations. Workplace conditions differed from the previous visit. Two forklifts were operating during the previous sampling periods; during the subsequent CDPHE investigation, only one forklift was in use because the second forklift was not operable. Employees stated that, with that exception, the work load was very similar to that during the previous CDPHE visit. In addition, the company had hired a new forklift maintenance contractor who was able to monitor forklift carbon monoxide tailpipe emissions, and the contractor had performed maintenance activities aimed at reducing these emissions from as high as 9.5 percent to as low as 0.2 percent. Further, the company had initiated a new policy requiring that hand-operated forklifts be used to unload pallets from the trailer trucks at the loading dock. This policy was initiated prior to CDPHE's departure the previous week in response to the peak exposure of 639 ppm experienced by one of the propane forklift drivers while he was in the truck trailer.

Results of employee carbon monoxide exposure and area monitoring conducted during this second full-shift investigation and related estimated carboxyhemoglobin concentrations are listed in Table 1. Measurements of airborne carbon monoxide in office areas again indicated that the source of carbon monoxide in the offices was carbon monoxide in the warehouse rather than the office heater. The range of work shift TWAs was lower than those measured previously (16 to 33 ppm; mean = 25 ppm), but was still in excess of ACGIH recommended limits. The range of increase in end-exhaled carbon monoxide concentrations for nonsmokers after forklift maintenance was 13 to 40 ppm (average increase was 26 ppm).

Although employee exposures were lower than exposures measured during the previous week, it is important to note that only one forklift was operating during this phase of the investigation. No employee wearing a datalogger was exposed to carbon monoxide concentrations in excess of the OSHA or NIOSH limits for occupational exposure. All evening shift employees, however, were exposed to carbon monoxide concentrations in excess of the ACGIH limit.

Estimated carboxyhemoglobin concentrations calculated from preshift and postshift exhaled air carbon monoxide concentrations indicated a rise over the work shift for every employee, and three employees monitored had an end-of-shift carboxyhemoglobin estimate that was above the CDPHE reporting requirement for carboxyhemoglobin levels. End-exhaled carbon monoxide concentrations of three employees (one smoker and two nonsmokers) rose in excess of the ACGIH BEI.

Workplace 2

CDPHE returned to workplace 2 on February 14 to measure employee exposures over a work shift and evaluate the performance of the forklifts after they were repaired. Results of exposure monitoring are presented in Table 2. Work shift 7-hour TWA exposures during and after forklift maintenance ranged from 8 to 17 ppm (mean = 13 ppm). Exposures measured during this day were not an accurate indication of a normal work day because forklift repairs were taking place during the shift. A second day of sampling was scheduled to evaluate the effects of simultaneous operation of both properly tuned forklifts.

On February 21, CDPHE measured carbon monoxide exposures while both repaired forklifts were in use. Results of personal exposure monitoring and related estimated carboxyhemoglobin concentrations measured at this workplace are summarized in Table 2. Work shift carbon monoxide exposures ranged from 1 to 10 ppm over a 7-hour work shift (mean = 4 ppm). End-exhaled carbon monoxide concentrations of the two nonsmoking employees were 8 ppm, and rose 2 and 3 ppm over the shift.

No employees wearing a datalogger were exposed to carbon monoxide concentrations in excess of required or recommended limits for occupational exposure. Estimated carboxyhemoglobin concentrations calculated from preshift and postshift exhaled-air carbon monoxide concentrations indicated a minimal rise over the work shift for most employees.

Workplace 3

Characterization of full-shift employee exposures and estimated employee carboxyhemoglobin concentrations at workplace 3 are pending.

TABLE 2. Carbon Monoxide Air and Biological Sampling Results: Sugar Packaging Company

	Airborne Carbon Monoxide Concentrations				Biological Concentrations					
					Preshift		Postshift		Change	
	TWA (ppm)	Sample Time (hours)	Peak (ppm)	STEV[A] (ppm)	Exhaled Carbon Monoxide (ppm)	COHb[B] % Estimate	Exhaled Carbon Monoxide (ppm)	COHb % Estimate	Exhaled Carbon Monoxide (ppm)	COHb % Estimate
February 14										
Worker 1	15	7	147	34	—	—	—	—	—	—
Worker 2	17	7	121	40	—	—	—	—	—	—
Worker 3	8	7	146	31	—	—	—	—	—	—
Area samples										
Warehouse	23	7	122	45	N/A	N/A	N/A	N/A	N/A	N/A
February 21										
Nonsmokers										
Worker 4	3	7	15	8	5	0.5	8	1.1	+2	+0.4
Worker 5	10	7	34	28	6	0.7	8	1.1	+3	+0.6
Smokers										
Worker 1	1	7	10	5	31	5.7	32	5.9	+1	+0.2
Worker 2	2	7	18	9	29	5.3	25	4.5	−4	−0.8
Area samples										
Warehouse	0	7	10	4	N/A	N/A	N/A	N/A	N/A	N/A

[A]STEV = short-term exposure value (20 minutes).
[B]COHb = Carboxyhemoglobin.

Conclusions/Recommendations

A comparison of employee exposures before and after forklift maintenance at workplace 1 indicated that maintenance and reduced use of the forklifts resulted in carbon monoxide exposures that were below OSHA and NIOSH limits, but in excess of ACGIH limits. Use of a second forklift, as is common on the evening shift, would probably result in exposure near or in excess of OSHA and NIOSH limits.

CDPHE recommended that the employer further reduce propane forklift tailpipe carbon monoxide emissions. The employer indicated that emissions on the operable Nissan forklift were lowered from 9.5 percent (95,000 ppm) carbon monoxide to approximately 1.5 percent (15,000 ppm). A forklift maintenance company with which CDPHE had been working at another work site (see case 2 below) indicated that it was possible to reduce tailpipe carbon monoxide emissions to 0.2 percent (2000 ppm) on Nissan propane forklifts without catalytic converters through fuel system repairs. CDPHE recommended that the beverage distributing company consider the addition of a catalytic converter on the operable forklift if tailpipe emissions could not be further reduced.

Employee carbon monoxide exposure concentrations combined with end-exhaled air carbon monoxide and related carboxyhemoglobin estimates (compared with the carboxyhemoglobin measurement of 24% for the carbon monoxide poisoning case) indicated that the repairs made on the forklifts at workplace 2 were successful in reducing the carbon monoxide hazard in this workplace.

CDPHE recommended that the employer measure forklift tailpipe carbon monoxide emissions every 4 to 6 months to ensure that regular engine maintenance continues to result in reduced tailpipe emissions, and that written information about carbon monoxide hazards be added to the company's hazard communication program.

Discussion

In an attempt to better define the extent of carbon monoxide poisonings related to the use of propane forklifts in Colorado workplaces, CDPHE reviewed past carbon monoxide poisoning surveillance records subsequent to receipt and investigation of carbon monoxide poisonings reported in this article. Twenty-five earlier reports of carbon monoxide poisoning related to forklifts were found in these records, 11 of which were specified as related to propane-fueled forklifts (bringing the total number of CDPHE propane-fueled forklift-related cases to 16; the earlier case reports occurred between 1986 and 1995). The remaining 14 of 25 forklift-related cases were listed as forklifts of unspecified fuel source. The range of carboxyhemoglobin concentrations for the 11 cases specified as related to propane-fueled forklifts was 15.0 to 27.3 percent, with a mean concentration of 20 percent. Ten of the eleven cases were related to indoor use of the propane-fueled forklift; no such information was available for the eleventh case. Two of the eleven cases were rendered unconscious as a result of carbon monoxide exposure.

A literature search revealed that other investigators have identified carbon monoxide poisonings related to propane forklifts. Fawcett *et al.*[11] examined medical records for 17 patients who were poisoned in eight separate episodes by indoor use of propane-fueled forklifts. The average time of carbon monoxide exposure in these 17 cases was 4.4 hours on the day of the poisoning, and the average carboxyhemoglobin level at the time of medical evaluation was 21.5 percent (range 4.2 to 28.2%). These authors measured exhaust emissions

from 12 propane-fueled forklifts used in five separate workplaces and found average carbon monoxide emissions of 36,000 ppm (3.6%, range of 200 to 88,700 ppm) when the engines were at idle, and 30,000 ppm (3.0%, range of 900 to 72,800 ppm) when the engines operated at working speed. Worker exposures and related carboxyhemoglobin concentrations related to the forklift emission data were not characterized in this study.

Ely *et al.*[12] reported on the emergency evaluation and management of 30 employees who were exposed to exhaust from a propane-fueled forklift. Workplace carbon monoxide concentrations of 386 and 370 ppm were measured by the fire department responding to the incident.

CDPHE and others have identified at least 63 cases of carbon monoxide poisoning known to be related to the use of propane-fueled forklifts. In addition, CDPHE has documented that other, undetected poisoning may exist at workplaces where workers succumb to the effects of poisoning. Experience and data presented here indicate that these are not isolated incidents, but may, in fact, be common in industrial settings where forklift maintenance often becomes a priority only when the forklift will not operate. The number of identified cases indicates a significant potential for carbon monoxide poisoning when equipment maintenance with specific attention to carbon monoxide emissions from propane-fueled forklifts is not carried out on a routine basis.

The use of propane-fueled equipment as a substitute for equipment fueled by gasoline does not solve the problem of carbon monoxide emissions. Although burning propane typically results in lower carbon monoxide emission concentrations than burning gasoline, use of propane equipment indoors must be accompanied by diligent equipment maintenance and testing of carbon monoxide emissions and resulting employee exposures. If carbon monoxide emissions cannot be sufficiently reduced through routine maintenance, careful adjustment of the fuel-to-air ratio, and regular monitoring of carbon monoxide emissions, then the use of catalytic converters or an alternative power supply should be considered. If carbon monoxide emissions are reduced sufficiently to control the hazard, tailpipe emissions should be regularly tested to ensure that carbon monoxide emissions remain low.

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