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Portable Emission Measurements of Yellowstone Park Snowcoaches and Snowmobiles

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ABSTRACT

As part of the National Park Service's Temporary Winter Use Plans Environmental Assessment, the University of Denver has been collecting in-use tailpipe emissions data from snowcoaches and snowmobiles in Yellowstone National Park. During the winter of 2006, using a portable emissions monitoring system, tailpipe data were collected from 10 snowcoaches and 2 four-stroke snowmobiles. These vehicles were operated over a standard route within the park, and the snowcoaches all carried identical passenger loads. These snowcoaches were newer in age with more advanced fuel management technology than those studied earlier, and average emissions were lower as a result (120, 1.7, and 11 g/mi for carbon monoxide [CO], hydrocarbons [HC], and oxides of nitrogen [NO_x]). Large emissions variability was still observed despite using a standardized route and equal passenger loading. A comparison between five nearly identically equipped snowcoaches that had CO emissions ranging between 12 and 310 g/mi suggests that snow and road conditions are the most important factors behind the large emissions variability observed between modern snowcoaches. The first comprehensive emission measurements, using a portable emissions measurement system, on two snowmobiles showed that computer-controlled fuel management systems have increased fuel economy (>25 mpg) and are a major reason that emissions from these winter vehicles have dropped so dramatically. Using all of the tailpipe emissions data collected to date shows that the two primary winter vehicles in Yellowstone National Park are now very similar in their per-passenger emissions.

IMPLICATIONS

Portable emission measurements have been made of the snowmobiles and snowcoaches operating in Yellowstone National Park. The replacement of two-stroke snowmobiles with four-stroke versions along with the migration to port fuel-injection techniques in both have led to large emission reductions. Even on a per-passenger basis, emissions are now similar between snowmobiles and snowcoaches. However, poor road and snow conditions can still cause modern snowcoaches to spend large amounts of time in power enrichment, resulting in higher levels of CO and HC emissions. The data suggest that continued modernization via fleet turnover will work to reduce even these emissions.

INTRODUCTION

Wintertime visitors to Yellowstone National Park have traditionally relied upon snowcoaches and snowmobiles for access to the interior of the park because the only road open to wheeled vehicles is in the north between Gardiner and Cook City, MT. Large growth in wintertime snowmobile visits to Yellowstone National Park in the 1990s led to a series of lawsuits and environmental impact statements, resulting in the adoption of a Temporary Winter Use Plans Environmental Assessment (EA).[1–5] The EA has been in effect for the last four winter seasons beginning in 2003. It allows motorized winter visits on snowcoaches and a limited number (up to 720/day in Yellowstone and an additional 140/day in Grand Teton) of guided snowmobiles that meet a best available technology (BAT) standard.[6] As part of the EA, the University of Denver has been involved with helping the National Park Service (NPS) better understand the emission distributions produced by winter vehicles operating in the park and the factors that are important contributors in their production.

During the winter season of 2004–2005, in-use emission measurements were made in Yellowstone National Park of 9 snowcoaches using a portable emissions monitoring system (PEMS) and 965 measurements of BAT-approved snowmobiles using a remote sensing device.[7,8] These were the first reported in-use emission measurements for snowcoaches, whereas the snowmobile measurements, when compared with the previous measurements, showed large carbon monoxide (CO) and hydrocarbon (HC) emission improvements.[9,10] The nine snowcoach measurements were characterized by large emission ranges in CO (5–630 g/mi), HC (1–50 g/mi), and oxides of nitrogen (NO_x; 1–49 g/mi; nitric oxide [NO] measured but reported as mass of nitrogen dioxide [NO_2]) emissions. All of these measurements were collected during actual operational runs and as such many of the coach's loads and routes were different.

Additional PEMS (Clean Air Technologies International, Inc.) measurements on snowcoaches and snowmobiles were conducted in January 2006 in Yellowstone National Park with the goal of eliminating route and load differences to test the extent to which these impacted over the snow emission rates. The town of West Yellowstone, MT, has the largest concentration of privately operated snowcoaches, with more than 40 for rent. All of

these trips into the park enter through the west entrance, with most trips being roundtrip excursions to Old Faithful. By expanding the number of snowcoaches tested, other important factors such as vehicle age, fuel management type, and snow conditions could also be further explored while improving emission operating range estimates for the NPS. The authors were also interested in trying to duplicate the PEMS measurements on a snowmobile driven over the same route as the snowcoaches for further comparisons between these two types of vehicles.

EXPERIMENTAL APPROACH

PEMS measurements were carried out on 10 commercial snowcoaches (9 gasoline and 1 diesel) and 2 snowmobiles operating out of West Yellowstone, MT, from January 25 to February 3, 2006 and are listed in Table 1. Each vehicle was rented for the measurements and all were tested over the same route with the same passenger load. The route driven was from the west entrance of the park, up the Madison River Valley to Madison Junction and then toward Old Faithful, stopping at the Cascades of the Firehole River turnout and returning via the same route (32.5 mi roundtrip). If any data collection problems were encountered, the drive would be stopped until those issues were resolved, ensuring that emissions were collected from the entire drive with no gaps. Each snowcoach was loaded with the equivalent of 8 passengers utilizing the researchers and 160 lb of sand per additional passenger. Data collected included CO, carbon dioxide (CO_2), HC (HC from gasoline-powered coaches only corrected for the known discrepancy between nondispersive infrared and flame-ionization detector HC readings), oxygen, NO (thermal conductivity), particulate matter (PM; diesel-powered coach only by light scattering), engine-intake mass airflow (reported directly by the engine computer or calculated from engine displacement, compression ratio, engine revolutions per minute (RPM), intake air temperature, and intake manifold pressure using a speed-density method), latitude, and longitude. Mass emissions are determined by multiplying the instantaneous concentrations by the calculated exhaust flow rate.[11,12] In addition, the analyzer also calculates fuel consumption on a gram-per-second basis that is used in determining the vehicles fuel economy. The analyzer was calibrated with a certified gas cylinder containing 12.93% CO_2, 3.17% CO, 1515 parts per million (ppm) propane, and 1515-ppm NO (Scott Specialty Gases) before each measurement, and the reported emission results have a precision (including any instrument drift) of approximately $\pm 10\%$.[11,12]

The exhaust tail pipes of the snowcoaches were typically located behind the rear track and an L-shaped extension was used when needed to extend the tailpipe distance from the track to protect the extraction sampling probe. Fiberglass, aluminum insulating tape, and aluminum dryer vent tubing were used at the probe-hose interface for extra insulation and protection. The sample line was insulated with oversized foam pipe insulation and routed the shortest distance possible through a window into the cabin. The extra space in the opened window was plugged with foam rubber. A plastic tee was installed into both ends of the foam insulation, allowing air to flow through the insulation. Because of power limitations, the sampling line was not electrically heated. Instead, the combination of exhaust heat, which is considerable for a snowcoach, and a 12-V rechargeable motorcycle battery-powered fan to continuously draw warm air out of the cabin and pass it through the oversized pipe insulation were relied on to heat the sample and exhaust lines. This combination proved effective, and no water condensation was observed collecting in the analyzer's condensate bowl during any of the tests. However, because the sampling line is not electrically heated, the authors do not report any of the HC measurements from the diesel snowcoach, and the HC measurements on the gasoline-powered vehicles may be subject to HC losses because of condensation on the walls of the sampling line. Figure 1 shows a rear view of a coach with the tailpipe extension, insulated sample line, and the side window sealed with the foam rubber.

The analyzer was placed in the seat behind the driver, and power was taken either from the 12-V power outlet or from a power cable connected to the battery in the engine

Table 1. Sampling dates, vehicle information and mean emission measurements

Identifier Date Sampled Year and Make	Engine Fuel and Drive Track Type	Fuel Use (mpg)[a]	Emissions (g/mi)			
			CO	HC[b]	NO_x	PM[b]
AG Kitty, February 1, 2006, 1956 Bombardier	Carbureted 5-L, V-8 gasoline/2WD twin tracks with skis	4.4	310	3.7	36	NA
YEXP R250, January 27, 2006, 1994 Dodge 250	PFI 5.2-L, V-8 gasoline/2WD Snowbuster	2.4	84	1.9	22	NA
YEXP R350, January 27, 2006, 1994 Dodge 350	PFI 5.2-L, V-8 gasoline/ 2WD Snowbuster	2.3	45	2.8	15	NA
3BL Van2, January 30, 2006, 2000 Ford E350	PFI 6.8-L, V-10 gasoline/2WD Mattracks with Skis	2.4	260	2.4	1.5	NA
YSCT van, January 30, 2006, 2000 Ford E350	PFI 6.8-L, V-10 gasoline/4WD Mattracks	2.7	310	1.5	1.7	NA
3BL Van5, January 31, 2006, 2001 Ford E350	PFI 6.8-L, V-10 gasoline/4WD Mattracks	3.0	12	0.30	1.4	NA
AG Cygnet, January 29, 2006, 1952 Bombardier	2002 PFI 5.3-L, V-8 gasoline/2WD twin tracks with Skis	5.7	5.0	0.40	2.8	NA
BBC van, January 26, 2006, 2003 Ford E350	PFI 6.8-L, V-10 gasoline/4WD Mattracks	3.2	65	1.4	0.32	NA
BBC Vanterra, January 26, 2006, 2004 Ford E350	PFI 6.8-L, V-10 gasoline/4WD Mattracks	3.4	46	0.86	0.12	NA
NPS bus, January 25, 2006, 2006 International	DI 6-L, V-6 turbo diesel/2WD cleated Mattracks	1.9	6.6	NA	31	0.33
Arctic Cat, February 2, 2006, 2006 T660 Touring	PFI 0.66-L, 3-cylinder gasoline snowmobile	25.1	15	1.6	7.7	NA
Ski Doo, February 3, 2006, 2004 Legend GT	PFI 1-L, 2-cylinder gasoline snowmobile	28.3	22	0.6	1.4	NA

Notes: [a]Fuel densities were assumed to be 2800 g/gal for gasoline and 3200 g/gal for diesel; [b]HC data are not considered valid for the diesel vehicle (NPS bus) and PM data were only collected from this vehicle. 2WD = two-wheel drive, 4WD = four-wheel drive, NA = not applicable.

Figure 1. Rear view of coach 3BL Van2, showing the tailpipe extension, insulated sample line with cabin air pass through tee, and the foam insulation installed to seal the side window. The upstanding pipe to the rear carries the warm cabin air exit flow.

compartment. All of the externally mounted sampling lines and wires were held in place by right-angle brackets held to the vehicle by magnets. For the modern vehicles, the on-board diagnostic (OBD) equipment data line was duct-taped along the floor to the dash area and connected to the data port. In the vintage rear engine Bombardier, the lines were routed via a rear roof hatch.

The integrated global positioning system (GPS) receiver was magnetically mounted to the roof of the vehicle and was relied upon for recording all of the vehicle speeds and distances covered. Because the drive wheels used in the track systems are all smaller than the wheels they replace, the speed/odometer readings obtained via the OBD connector are not correct. The only caveat when summing the GPS distances is recognizing that the GPS receiver the authors used had a stationary variation of approximately 0.5 m. In calculating distance traveled, any change in location that is less than or equal to 0.5 m was summed as 0 m.

For the two snowmobiles, the analyzer was encapsulated inside of a specially constructed clam-shell foam chest, and heavier insulation was used to protect the unheated sample line. The bottom of the chest was lined with two side-by-side 115-V heating pads that overlapped the rear input and exit lines. The heating pads provided a warm enough external environment to allow the analyzers' internal heaters to maintain their regulated sampling temperature set points. Prior attempts to instrument snowmobiles had revealed that the 12-V power from the snowmobile was insufficient for powering the analyzer. Instead, a 1-kW gasoline-powered generator (Honda EU-1000) was used to power the heating pads, and an ac/dc converter to provide the 12-V power for the analyzer.[7] The generator was arranged on the snowmobile so that its exhaust was directed to the opposite side of the snowmobile from the analyzer's zero-air input line. This provided sufficient isolation and was confirmed by the zero points for the CO_2 analyzer being at or near-background levels during testing. With no engine diagnostic port the snowmobile exhaust flow rate was calculated using a speed-density method that relies upon the engine design parameters (displacement and compression ratio) and three specially mounted sensors to measure engine RPM, intake manifold air pressure, and intake air temperature.[11,12]

RESULTS AND DISCUSSION

Ten days of sampling vehicles in Yellowstone National Park resulted in the collection of 24 hr of second-by-second data with 22.7 hr of valid gram-per-second data for CO_2, CO, HC, and NO_x, and an additional 1.8 hr of valid PM data from the NPS diesel-powered bus. The analyzer only measures NO and reports those measurements as mass of NO_2 (NO_x) for all of the gram-per-mile emission values. Not measuring diesel NO_2 emissions will likely lead to underreporting total NO_x emissions of between 5 and 10%.[13] The entire valid gram-per-second data include at least engine RPM, intake air temperature, and absolute intake manifold pressure. Speed, acceleration, percent throttle, torque, coolant temperature, and fuel economy were also reported from some of the engines' diagnostic ports. The GPS receiver reported its fix status, number of satellites visible, time, longitude, latitude, and altitude. Table 1 gives the mean values for the valid data collected for each of the 12 vehicles instrumented during this study and driven over the test route. The entire database is available for download from the Web site at http://www.feat.biochem.du.edu.

This snowcoach fleet is almost 5 yr newer than the previously reported measurements, and overall emissions are lower (see Table 1). Mean emissions were 120, 1.7, and 11 g/mi for CO, HC, and NO_x, respectively, for the 10 snowcoaches measured in 2006 compared with 300, 10, and 24 g/mi, respectively, for the 2005 fleet.[7,8] Additional fleet differences contributing to lower emissions are that 9 of 10 of the current snowcoaches in the fleet were port fuel injected compared with only 4 of 9 of the previous snowcoaches. Route and operating conditions were also changed, which contributed smaller reductions. The decision to standardize the route and passenger loading necessitated private operation of the snowcoaches, reducing coach idling times by almost 70%. This is due to the frequent stops that are required when serving real tourists on vacation.

A complete discussion of snowcoach emissions patterns in Yellowstone National Park is best accomplished with all of the available data. Figure 2 compares the mean snowcoach trip emissions collected for both years of measurements arranged by fuel and fuel management technology. The model years are only denoted when the model year of the vehicle changes, so bars lacking a model year designation are the same model year as the previous bar. Starting from the left of the figure, the first 2 vehicles are vintage Bombardiers with carbureted engines, followed by 4 throttle-body-injected 1991 and 1992 vans, followed by 11 port fuel-injected vehicles from 1994 to 2004, and ending with the 2 diesel vehicles. Because of the small number of snowcoaches measured and the many variables involved, there are no smooth trends. However, the emissions generally decline for the gasoline vehicles from the older to the newer vehicles. This is less

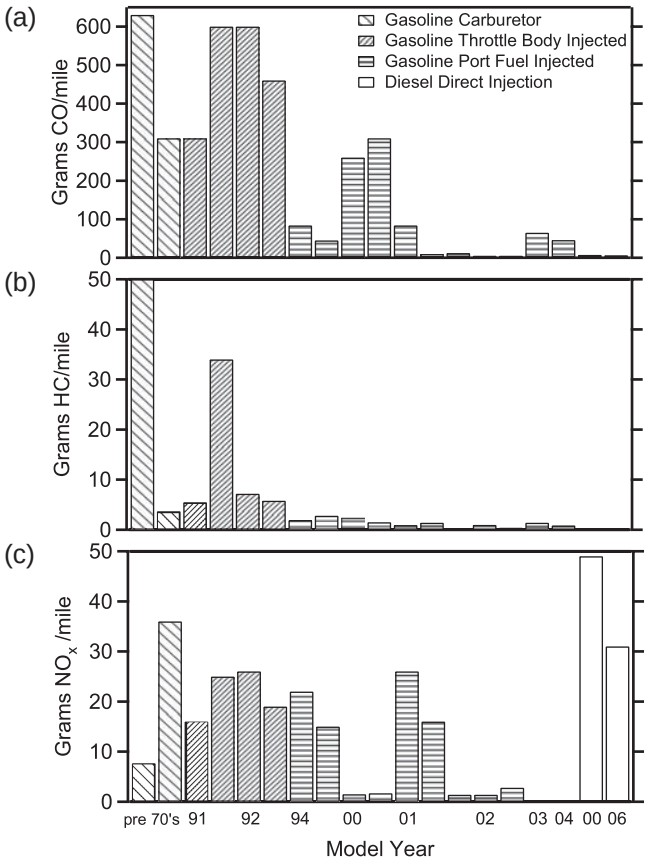

Figure 2. Combined 2005 and 2006 snowcoach emissions comparison arranged by fuel and fuel management technology for (a) CO, (b) HC, and (c) NO_x emissions. Within each technology class, the vehicles are ordered left to right by model year. HC emissions were not collected on the diesel snowcoaches.

a dependence on model year than it is on the changes in fuel management technology from carburetors through throttle-body injection (a computerized carburetor) to port fuel injection. All modern technology vehicles are port fuel injected, and the fuel metering control that technology provides clearly improves the emissions performance of the vehicles. The two diesel vehicles in the group are typically distinguished by low CO and high NO_x emissions characteristic of lean-burn compression ignition engines.

The large variability in emissions seen among the newer coaches in Figure 2 is unlike what one would generally find in the wheeled vehicle world, except for cases of poorly maintained vehicles.[14] However, maintenance is not the issue for the snowcoaches; engine load is the more important issue. Previous work had revealed this important relationship, and one of the criticisms of that work was that the authors had not determined the extent to which passenger loading was a contributing factor. With the route and passenger loadings fixed, Figure 3 compares the percent CO emissions for five similarly equipped 2000- to 2004-model-year Ford vans (refer to Table 1) with a 6.8-L, V-10 port fuel-injected engine.[15] All used Mattracks conversions; however, one of the five was a two-wheel drive conversion with front steering skis (see Figure 1). The graphs are ordered from oldest snowcoach (Figure 3b) to newest (Figure 3f). The elevation profile was recorded by snowcoach 3BL Van2 and has been adjusted to approximately match the U.S. Geological Survey maps' altitude at the highest point. These five coaches averaged 140, 1.3, and 1 g/mi for CO, HC, and NO_x, respectively; however, there was a factor of 25 differences in CO emissions between the lowest and highest. Each spike of CO emissions in Figure 3 corresponds to a power enrichment excursion in which the engine load has increased considerably, requiring more fuel for power than can be provided under stoichiometric combustion conditions. The two newest snowcoaches (the BBC vans) do a better job of capping these excursions, with maximum CO emissions staying at approximately 4% compared with the slightly older snowcoaches, in which the CO excursions approach 6%. Previous measurements from the early 1990s throttle-body-injected engines found these levels approached 12% CO.[7,8] These decreases are most likely improvements to predictive fuel management that have been added to the newer engines, slowly lowering the extent of these emissions. These new fuel management techniques should continue to lower overall emissions by further reducing the peak levels of these emissions during power enrichment excursions.

The two 2000 model year snowcoaches (the top two emission graphs in Figure 3) had overall CO emissions of 260 and 310 g/mi, respectively, and were both driven on

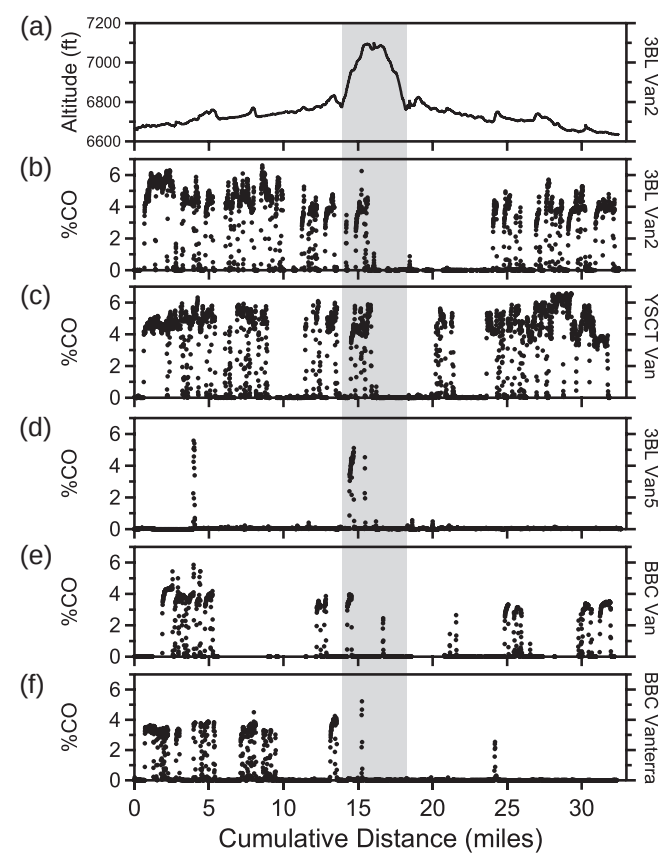

Figure 3. CO emissions comparison for five nearly identically equipped snowcoaches. These five snowcoaches each have a Ford chassis with a 6.8-L, V-10 gasoline engine from model years (b) 2000, (c) 2000, (d) 2001, (e) 2003, and (f) 2004. (a) The altitude profile was collected during the 3BL Van2 drive, and the shading marks enclose the largest grades encountered during the drive.

January 30. The major observable differences between January 30 and the days the other vans were driven were the snow and road conditions. January 30 was marked by a wet overnight snowfall that continued during the day and left the roads noticeably softer. This allowed the tracks to sink deeper in the snow, greatly increasing engine loads and resulting in large amounts of time spent in a power enrichment mode. These observations strongly suggest that vehicle loads caused by road conditions are a more determining factor of power enrichment excursions when compared with other factors such as passenger loading.

The two vintage Bombardiers in the current measurement fleet were at opposite ends of the vehicle emissions technology spectrum, with one carbureted and with no emissions control equipment (AG Kitty) and the second upgraded with a 2002 model year computer-controlled fuel-injected engine and three-way catalytic converter (AG Cygnet). In the authors' previous measurements, similarly equipped vehicles were the emission bookends, with the carbureted vehicle being the highest CO and HC emitter and the upgraded Bombardier being the lowest emitting vehicle for all three pollutants.[7,8] To test how representative these previous measurements were led to the selection of these two Bombardiers because these coaches make up a significant percentage of the Yellowstone snowcoach fleet. Although the carbureted Bombardier measured this year had lower CO and HC (310 and 3.7 g/mi vs. 630 and 50 g/mi) emissions than last year's vintage Bombardier, the end result was that the carbureted vehicle was still at the high end of the emission range observed. The extremely high HC emissions from the previous year's measurement were the result of a pronounced and obvious misfire in that coach. Conversely, the upgraded Bombardier was again one of the lowest emitting coaches measured. Anecdotal observations of the operational performance of the Bombardiers suggest that they have an unmatched power-to-weight ratio advantage over the van conversions. This is based on the observation of their ability to comfortably manage the roundtrip drive while operating in overdrive much of the trip and their higher fuel economy results (see Table 1). No other type of snowcoach was noted as being able to operate in this high of a gear for as large of a fraction of time as the upgraded Bombardiers. Although old, this vehicle was designed from the ground up to be a snowcoach and has a lighter cabin (one penalty paid here is their interior noise is much higher when underway) and larger surface area twin tracks, which also help its performance. Even the carbureted Bombardier benefits from these features, with better fuel economy than any of the other gasoline-fueled snowcoaches.

The authors successfully instrumented and obtained emissions data from two snowmobiles (a 2006 Arctic Cat T660 Touring and a 2004 Ski Doo Legend GT). Previous remote sensing measurements of snowmobiles collected at the west entrance had shown a large difference in CO emissions between these two models.[7,8] The remote sensor and the PEMS measurements found the Arctic Cat snowmobiles were lower for CO and higher for NO emissions when compared with the Ski Doo models. However, the Ski Doo's entrance CO measurements observed with the remote sensor were much higher than those measured during cruise mode by the PEMS instrument. With the second-by-second PEMS data one can observe that the operational fuel management of these two snowmobile engines is quite different. Figure 4, a and b, compares the observed CO emission for these two snowmobiles operating in the entrance gate area. The Arctic Cat engine (three cylinders and 0.66l; Figure 4a) seems to have two operational ranges for CO emissions: idle with percent CO values of approximately 4% that rapidly decreases in all other driving modes to percent CO values of less than 1%. Difficulties inserting the sampling probe far enough into the Ski Doo's exhaust pipe because of restrictions resulted in higher measured oxygen concentrations that necessitated the application of a dilution correction to compare the second-by-second concentration data. The Ski Doo engine (two cylinders and 1 L; Figure 4b) idles at lower CO emissions of between 2 and 3%; however, whenever the throttle is applied, its CO emissions rapidly increase to between 4 and 6% and at steady operation these emissions begin to exponentially decrease. This means that the more transient the operation of the Ski Doo snowmobile, as observed by the remote sensor at the entrance gate, the higher the average CO emissions will be because it will spend more time at these higher levels. This also helps to explain how these two engines are able to meet similar NPS BAT emissions levels because the certification test is a steady-state test.

The snowmobile fuel economy values measured this year are 19% better (27 mpg compared with 22 mpg) than the short drive measured on a 2004 Arctic Cat snowmobile in 2005.[7,8] These fuel economies are a major reason

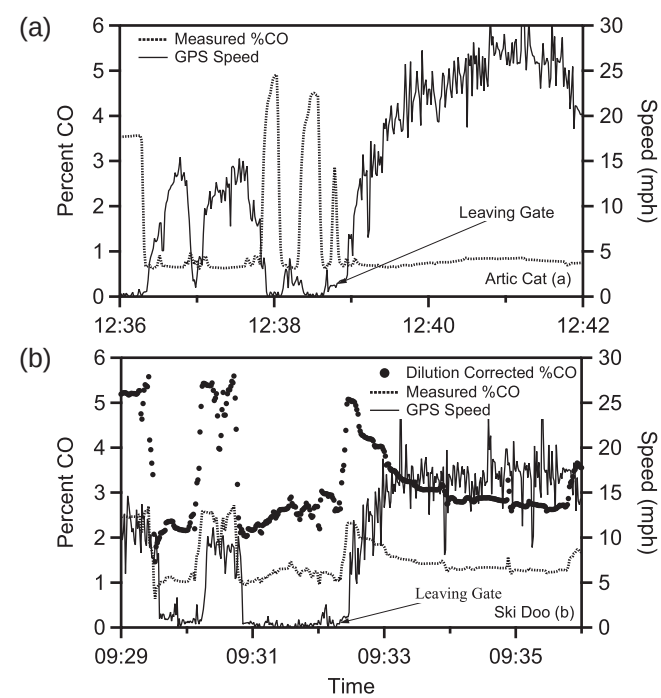

Figure 4. CO emissions and GPS-measured speed for the (a) 2006 Arctic Cat snowmobile and (b) the 2004 Ski Doo snowmobile entering and leaving the west entrance gate area. The dilution-corrected CO values for the Ski Doo (b) are a result of problems inserting the sample probe into the tailpipe, which led to higher oxygen values and artificial dilution of the concentration data.

for the large reduction in CO and HC emissions in the park.[16] This is a result of the combination of the four-stroke electronic fuel-injected engines and a large track/ski surface that gives the snowmobiles a much lighter footprint when compared with the snowcoaches enabling the small engines to easily handle the loads encountered.

Table 2 compiles all of the emissions measurement data collected to date in Yellowstone National Park and combines them with winter visitor statistics to make several comparisons possible among the two types of winter vehicles. The snowmobile values are averages of the entrance and exit remote sensing measurements collected in 1999 and 2005.[8,9] To convert the remote sensing snowmobile gram-per-gallon measurements to gram-per-mile estimates, the authors have used a two-stroke fuel economy of 13 mpg (this was the average gas mileage for two two-stroke snowmobiles used during a week of work transporting researchers and equipment during the 1999 measurements), and for four strokes the authors used 25 mpg, which is the average of the three snowmobiles instrumented with the PEMS unit.[7,8,17] The PEMS emission means for snowmobiles and snowcoaches are time-weighted averages of all of the data collected. Snowmobile entries for 1999 were 62,878 with 76,271 passengers for a 1.2 persons/snowmobile average.[18] Snowmobile entries for 2006 were 21,916 with 28,833 passengers for an average of 1.3 persons/snowmobile. Snowcoach entries for 2006 were 2463 with 19,856 passengers for an average of 8.1 persons/coach.[18]

The 2006 snowcoach emissions measurements are significantly lower than last year's measurements but because the route this year was shorter, the combined average is still dominated by the measurements collected in 2005. The snowmobile data are most likely more robust and representative of that fleet's average emissions because of the many remote sensing measurements that have been collected. The mean snowcoach emission factors are likely more suspect to bias, because the 19 snowcoaches measured to date are still a minority of the fleet operating in the park. In particular, this fleet probably underrepresents the number of passengers transported in vintage carbureted Bombardiers and overrepresents the number of passengers transported in diesel coaches. The combined data result in the per-person emissions for either the four-stroke snowmobiles or the snowcoaches being significantly reduced from the two-stroke snowmobile era. In general, the replacement of the two-stroke snowmobile fleet has resulted in the new snowmobile fleet having tailpipe emissions that are comparable or better than the fleet of snowcoaches that have been measured to date.

CONCLUSIONS AND RECOMMENDATIONS

The University of Denver successfully carried out 10 days of in-use emission measurements on 10 commercial snowcoaches and 2 snowmobiles operating in Yellowstone National Park. The 12 vehicles combined in producing approximately 22 hr of CO, HC, and NO_x emissions and vehicle activity data and the first detailed PEMS measurements on an in-use snowmobile.

When these snowcoach emission measurements are combined with previous data, a picture emerges with emission trends generally decreasing with decreasing age that the authors believe is largely related to the vehicles fuel-injection technology. Carbureted engines produce more excess emissions than throttle-body-injected engines, which produce more emissions than port fuel injected engines. Emissions continue to decrease with age among the port fuel injected engines as the newest models continue to lower the peak emissions experienced during power enrichment excursions. As such, the NPS should work to upgrade the snowcoach fleet by eliminating carbureted and throttle-body-injected snowcoaches. Despite the use of a standardized route and passenger loading, road and snow conditions can contribute to large increases in CO and HC emissions when comparing similarly equipped snowcoaches. Only the Bombardiers' that have been upgraded with a modern fuel-injected engine have proven to have the power-to-weight ratio needed to avoid extensive power enrichment excursions during poor road conditions. This means that even an upgraded snowcoach fleet operating in Yellowstone National Park will have days for which emission levels might exceed desired limits.

For the first time snowmobiles were successfully instrumented with the PEMS unit, allowing the collection of a complete trip to compare against the snowcoaches

Table 2. Estimated gram-per-mile-per-person emissions for Yellowstone winter transportation options.

		Mean g/gal[ab]			Mean g/mi (estimated g/mi)[c]			Estimated g/mi/person[d]		
Data	Instrument	CO	HC	NO_x	CO	HC	NO_x	CO	HC	NO_x
1999 mean two-stroke snowmobile	Remote sensor	1100	1400	NA	(85)	(110)	NA	71	92	NA
2005 mean four-stroke snowmobiles	Remote sensor	670	80	80	(27)	(3.2)	(3.2)	21	2.5	2.5
2006 mean four-stroke snowmobiles	PEMS				19	1.0	4.0	15	0.8	3.1
2005 mean snowcoach	PEMS				300	10	24	37	1.2	3.0
2006 mean snowcoach	PEMS				120	1.7	11	15	0.2	1.4
2005 and 2006 mean snowcoach	PEMS				230	6.7	19	28	0.8	2.3

Notes: [a]Gram-per-gallon calculations for the snowmobiles assume a fuel density of 726 g/L; [b]Snowmobile NO emissions have been converted to NO_2; [c]Snowmobile gram-per-mile estimates use 13 mpg for two-stroke engines and 25 mpg for four-strokes engines; [d]1999 and 2006 data obtained from the NPS Public Use Statistics Office.

measured. The two makes and models studied have similar cruise-mode emissions, but transient emissions were found to be much larger for the Ski Doo snowmobile. Because of the computer-controlled fuel-injected engines, both of the snowmobiles were found to have better fuel economy (>25 mpg) than previously estimated, and they are one of the reasons that high-traffic areas in the park have seen decreases in ambient emission levels.

The complex issue of how winter visitors should travel in the park during their visits cannot be answered by simply comparing vehicle emission levels. However, snowmobile emission levels were one of the issues publicly highlighted when the first lawsuits were filed against the NPS seeking to change the winter access rules. This and previous works have sought to provide a more complete picture of vehicle emissions and activity data that were not previously available to the NPS. The good news is that technological improvements in both snowmobiles and snowcoaches have contributed to lower the emissions from both types of vehicles to the point that per-passenger emissions are now similar.

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