An In-Use Snowmobile Emission Survey in Yellowstone National Park

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Snowmobiles (sleds) have become a very popular way for visitors to explore Yellowstone National Park during its winter season with more than 60 000 visits during the 1997–1998 season. In-use emissions data are very limited, and only a small number of sleds tested under controlled conditions have had their measurements reported. Snowmobiles are currently manufactured and marketed in the U.S. by four companies: Arctic Cat, Bombardier (Ski-Doo), Polaris, and Yamaha. Using the University of Denver's nondispersive infrared remote sensing equipment carbon monoxide (CO) and hydrocarbon (HC) emission measurements were collected on 1210 sleds at the West Yellowstone, MT park entrance during 4 days in February 1998. Mean emissions for the measurements were 5.56 $\pm$ 0.07% CO and 2.58 $\pm$ 0.02% HC (as propane). Using a carbon to hydrogen molar ratio of 1:2 for the fuel, the emissions are 460 $\pm$ 6 g CO and 331 $\pm$ 2 g HC per kilogram of fuel consumed. This is in large part because snowmobiles utilize conventional two-stroke engine designs which cannot avoid extensive blowby (the exhaust port and intake port being open at the same time) of the unburned fuel, oil, and air mixture which is also poorly regulated by simple carburetors.

Introduction

During Yellowstone's winter season, which runs from mid-December through the first few weeks of March, the interior areas of the parks are accessible to the public only by foot (snowshoes/skis), snow coaches, and snowmobiles (sleds). Snowmobiles have become a very popular choice for exploring the park. Large numbers of visitors rent sleds to visit the park. Snowmobile visits peaked during the 1992–1993 season at 77 000 visits and fell to 60 000 for the 1997–1998 season (*1*). In-use emissions data on snowmobiles are very limited, and only a small number of sleds have been tested under controlled conditions using engine dynamometers (*2–4*). Largely due to health concerns for park employees at the entrance stations the University of Denver was invited by the National Park Service to conduct the first emission survey of in-use snowmobiles at the West Yellowstone entrance to Yellowstone National Park during February 1998.

Snowmobiles are currently manufactured and marketed in the U.S. by four companies: Arctic Cat, Bombardier (Ski-Doo), Polaris, and Yamaha. All current production sleds utilize two-stroke liquid or fan-cooled engines which range in size from a twin cylinder 340 cm^3 engine to 1 L triple cylinder engine. All of the sleds utilize direct oil injection systems which do not require premixing of lubricant with fuel. The transmission consists of a centrifugal clutch and a belt driven track. The centrifugal clutch provides distinct bimodal engine operation modes of high loads and no loads.

Utilizing the University of Denver's nondispersive infrared remote sensor (FEAT, fuel efficiency automobile test) originally designed to measure the ratios of carbon monoxide (CO) and hydrocarbon (HC) emissions to carbon dioxide (CO_2) of light-duty motor vehicles (*5*), measurements were carried out between February 26 and March 1, 1998 at the West Yellowstone park entrance. The majority of the sleds measured at this location were the latest 1998 models rented in the town of West Yellowstone.

Experimental Section

Measurements were attempted in two locations at the west entrance (elevation 6666 ft). In the mornings, the FEAT was set up approximately 20 ft beyond the park service attendant booths with the sleds accelerating (6000–7000 rpm but speeds less than 10 mph) up a slight incline. In the afternoons the FEAT was set up at the park exit. This site was flat with the sleds cruising at constant speeds of 10–30 mph.

The FEAT source and detector were placed on insulating pads on top of the snow. Snowmobile exhaust exits at the front of the sleds toward the ground, so the beam height was lowered to approximately 6 in. above the snow. A 1 s sample of exhaust was made after each sled using the standard FEAT software used for automobiles. The video camera photographed the front cowling of each sled as it was measured. The support equipment was housed inside the heated attendant booth. The instrument was calibrated before each measurement period using a sealed multigas cell (*6*). Temperatures during the 4 days ranged between 0 and 20 F.

Results and Discussion

During the 4 days of sampling, we attempted 1861 measurements (1121 in the morning and 740 in the afternoon) on snowmobiles of which 1210 measurements (886 morning and 324 afternoon) had valid CO and HC readings. Two additional morning measurements were made on snow coaches. The afternoon location proved to be a difficult sampling site due to the large amount of snow spray that many sleds produced at the higher speeds. The videotapes were transcribed for make, model, engine size, and engine cooling type. Engine displacement was determined from make and model information obtained from the manufacturers for their 1998 models. No sleds appearing to be an older model year were included in the comparison. Fuel status of the sleds was unknown, although some rental companies and the National Park Service were experimenting with ethanol blended fuels.

Table 1 details the measured CO/CO_2 and HC/CO_2 ratios along with quantities derived through the combustion equation (*5*). All of the hydrocarbon quantities are reported in units of propane, and the g/kg values are reported using

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TABLE 1. Summary of Emission Measurements with Valid CO and HC[a]

period/make (samples)	mean CO/CO_2 mean g CO/kg[b]	mean HC/CO_2 mean g HC/kg[b,c]	mean % CO (median)	mean % HC[b] (median)
mornings	0.53 ± 0.01	0.26 ± 0.003	5.17% ± 0.08	2.75% ± 0.03
(886)	419 ± 6	348 ± 2	(5.10%)	(2.70%)
afternoons	0.73 ± 0.02	0.23 ± 0.006	6.6% ± 0.1	2.14% ± 0.05
(324)	571 ± 10	283 ± 5	(6.61%)	(2.06%)
totals	0.58 ± 0.01	0.25 ± 0.003	5.56% ± 0.07	2.58% ± 0.02
(1210)	460 ± 6	331 ± 2	(5.59%)	(2.56%)
Arctic Cat fan cooled	0.38 ± 0.02	0.206 ± 0.007	4.1% ± 0.2	2.38% ± 0.08
(120)	359 ± 16	316 ± 8	(3.9)	(2.44%)
Polaris fan cooled	0.64 ± 0.02	0.253 ± 0.005	6.0% ± 0.1	2.49% ± 0.03
(547)	494 ± 9	322 ± 3	(6.1%)	(2.44%)
Ski-Doo fan cooled	0.43 ± 0.04	0.198 ± 0.007	4.5% ± 0.3	2.25% ± 0.07
(61)	396 ± 26	308 ± 8	(4.3%)	(2.29%)
Yamaha fan cooled	0.77 ± 0.07	0.29 ± 0.02	6.8% ± 0.5	2.8% ± 0.1
(30)	545 ± 37	346 ± 10	(6.8%)	(2.8%)
Arctic Cat liquid cooled	0.45 ± 0.04	0.26 ± 0.01	4.6% ± 0.3	2.93% ± 0.09
(66)	377 ± 23	368 ± 8	(4.6%)	(2.9%)
Polaris liquid cooled	0.61 ± 0.03	0.294 ± 0.008	5.9% ± 0.2	2.97% ± 0.07
(106)	470 ± 14	366 ± 5	(5.9%)	(2.96%)
Ski-Doo liquid cooled	0.52 ± 0.05	0.29 ± 0.01	5.1% ± 0.3	3.0% ± 0.1
(60)	403 ± 26	369 ± 10	(4.8%)	(3.1%)
Yamaha liquid cooled	0.54 ± 0.03	0.31 ± 0.1	6.8% ± 0.3	2.8% ± 0.1
(60)	422 ± 19	387 ± 9	(5.4%)	(3.2%)

[a] All errors are reported as the SE of the mean. [b] Uses a carbon to hydrogen molar ratio of 1:2. [c] All hydrocarbon values are reported in units of propane.

a carbon to hydrogen molar ratio for the fuel of 1:2. All errors are reported as the SE of the mean.

The large HC emissions are due to conventional two-stroke engine design which cannot avoid extensive blowby (the exhaust port and intake port being open at the same time) of the unburned fuel air mixture (*7*). The fraction of the charge lost due to blowby scales proportionately with power at a fixed rpm (*7*). The observed afternoon decrease in HC emissions could be due to lower power demand from a fully warmed engine, drive train, and the cruise operation mode.

The observed differences in HC emissions between the fan cooled and liquid cooled sleds may be an artifact. The 3.4μ HC detector can be positively interfered with by the broad band absorption of liquid water (steam) and appear as HC emissions. While the liquid cooled sleds were not observed to emit steam at the exhaust pipe, we did note appreciable amounts of steam emitted from the running boards at colder temperatures. The running boards serve as the cooling system heat exchanger on the liquid cooled sleds and snow which is kicked up on the underneath side of the running board often produces a small "steam" cloud which could be entrained with the exhaust as the sled moves forward. There are other differences between the fan cooled and liquid cooled sleds, for example, liquid cooled sleds engines are larger and performance oriented, which could also account for the difference observed.

For comparison, two fully warmed U.S. vehicle fleets measured in Denver, CO in the winter of 1995/1996 and Chicago, IL in September of 1997 averaged 62 g CO/kg, 4.3 g HC/kg, 55 g CO/kg, and 4 g HC/kg, respectively (*9*, *10*). These averages may increase by as much as a factor of 2 or 3 if measured at the cold temperatures under which snowmobiles operate (*11*).

Table 1 and Figure 1 illustrate that the measurements are normally distributed (means and median are approximately equal) for both CO and HC. This is an important and unusual finding and is in sharp contrast to automobile emissions distributions (even pre-1974 vehicles without emissions control equipment), which are γ distributed (*8, 9*). Even though the means for CO and HC are similar, the standard deviations of the distributions are very different. We believe

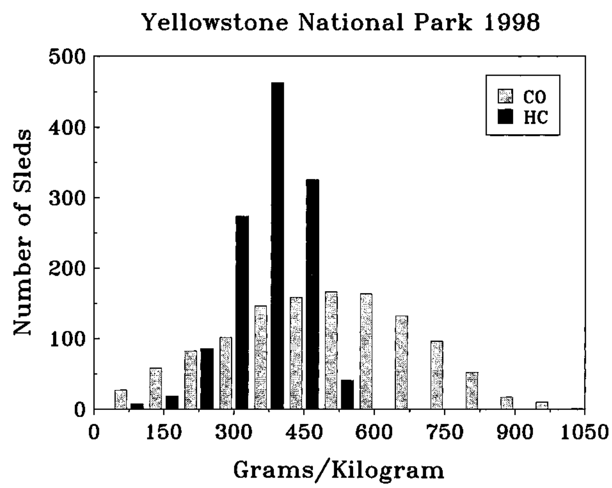

FIGURE 1. CO (mean of 460 g/kg) and HC g/kg (mean of 331 g/kg) emissions data distribution for 1210 snowmobiles measured at the West Yellowstone MT entrance to Yellowstone National Park. Each bin on the *x*-axis is labeled with its upper terminus. The g/kg calculations use a carbon to hydrogen molar ratio for the fuel of 1:2. One CO data point for a 1964 four-stroke Arctic Cat sled (1367 gCO/kg) is not plotted.

the broad distribution for CO to be the result of simple carburetors, which, while properly jetted, do a poor job of controlling air-to-fuel ratios. Since the HC emissions are dominated by blowby, which is a function of power demand, we would expect a narrower range of values which track power demand. One very low HC measurement was made from a 1964 Arctic Cat sled powered by a 10 hp four-stroke engine (12.95% CO (1367 g CO/kg) and 0.083% HC (13.8 g HC/kg)).

Due to blowby and large amounts of friction associated with the drive train snowmobiles are very fuel inefficient vehicles (*3*). These results and our experience point to the fleet measured having a fuel economy range of 8−15 mpg, scaling with engine size. For comparison, the average fuel economy for the two snowmobiles (1998 Polaris Indy Trail, 488 cm^3 fan-cooled and a 1996 Polaris Indy Wide Track LX, 488 cm^3 liquid cooled) used to transport the equipment and personnel through the park during the week of work (300+ miles) was 13 mpg. The 488 cm^3 engine displacement was the most frequently identified engine size (263 out of 782) for sleds entering the park during the 4 days of measurements.

Engine dynamometer work carried out by Southwest Research on two snowmobile engines (a 1997 488 cm^3 fan cooled engine from Polaris and a 1995 440 cm^3 liquid cooled engine from Arctic Cat) are the only measurements to provide fuel consumption and emissions data to directly compare with this work (*3*). A five-mode steady-state test was run using various fuels (gasoline, gasohol, and aliphatic) and lubes at room temperature (intake air temperatures of ∼70 F). Emission ranges of 824−882 g CO/kg and 259−384 g HC/kg were reported for the Polaris engine and 665−732 g CO/kg and 298−329 g HC/kg for the Arctic Cat engine. The CO emissions reported by Southwest Research are about a factor of 2 higher than we observed at the park entrance, while our HC measurements are similar. The fuel composition for West Yellowstone is unknown, but one can expect the NDIR method we used to underreport the aromatic portion of the fuel when compared with the flame ionization method used by Southwest Research resulting in a difference which could increase our HC values by as much as a factor of 2 (*12*). It is uncertain the extent to which the differences in intake air temperature and altitude account for these differences. Rental sleds in West Yellowstone have relatively simple carburetors jetted for their altitude by the manufacturers. The increases in air densities caused by the low temperatures and the resulting increase in oxygen is the most likely reason for the lower CO emissions observed in the park. Confirmation of this will require additional measurements with a concurrent temperature record. The combination of higher densities and colder temperatures could also combine to increase the amount of blowby in the engine.

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