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1998 Preliminary Snowmobile Emission Survey in Yellowstone National Park

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Final Report

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Introduction

During Yellowstone's winter season, which runs from mid-December to the first of March, the interior areas of the parks are only accessible to the public by foot (snowshoes/skis), snow coaches and snowmobiles. Snowmobiles are a very popular choice for exploring the park and as such large numbers of visitors rent snowmobiles to visit the park during this time. The University of Denver was invited by the National Park Service to conduct an emission survey of in-use snowmobiles (sleds) at the West Yellowstone entrance to Yellowstone National Park during February 1998.

Utilizing an infra-red remote sensor (FEAT, Fuel Efficiency Automobile Test), originally designed to measure carbon monoxide (CO) and hydrocarbon (HC) emissions of light-duty motor vehicles, measurements were carried out between February 26 - March 1, 1998 at the West Yellowstone park entrance (1). The majority of the sleds measured at this location were rented in the West Yellowstone area.

Experimental

The entrance to the park from the town of West Yellowstone, MT. is divided into three single lane entrances with attendant booths located on the left side of each lane. The FEAT was setup in the mornings approximately 20 ft. beyond the entrance booth on a slight uphill incline to measure the sleds as they were entering the park. This location was chosen to minimize the amount of snow spray that the sleds would entrail. Two changes were made to the standard operating procedure, the source and detector were placed atop the snow on insulating pads and the infra-red sensing beam was lowered to about 6 inches above the snow. The beam height was lowered to better sample the nearly snow level exhaust plumes which snowmobiles leave behind. Lane 3 (numbered from south to north) is the primary entrance lane from W. Yellowstone (the express lane for prepurchased passes which are predominately rental sleds) and was used for data collection on the mornings of 2/26 - 2/28. Lane 2 was used on the final morning (3/1/98) to attempt measurements on the small number of snow coaches which enter the park. Data were collected in the morning between the hours of 7:30 and 12:00 am.

The afternoon measurements were all attempted on the single exit lane located at the far north end of entrance gate. The morning measurements were made at speeds between 5 - 15 mph with operating rpm levels of 4000 - 7000 rpm's. The afternoon measurements were attempted over a much larger range of speeds but with similar operating rpm's. It should be noted that successful afternoon measurements were only accomplished on the slow moving (5 - 15 mph) sleds due to interferences caused by snow spray at the higher speeds. Afternoon measurements were collected between 2:00 and 5:00 pm.

Results / Discussion

Tables 1 and 2 summarizes all of the measurements. Table 2 reviews a subset of the data where both the carbon monoxide (CO) and hydrocarbon (HC) measurement had valid data flags. Gram per gallon values have been calculated assuming a fuel density of 0.726 g/ml

Table I. Summary of Measurement Activity.

Date	NPS Snowmobile Entrance Count[1]	Measurement Attempts (Entrance/Exit)	Valid CO Measurements	Valid CO & HC Measurements
2/26/98	530	451 (219/232)	347 (208/139)	308 (194/114)
2/27/98	633	373 (313/60)	332 (283/49)	308 (264/44)
2/28/98	712	946 (498/448)	662 (469/193)	538 (372/166)
3/1/98		93 (93/0)	75 (75/0)	58 (58/0)
Totals	1875+	1863 (1123/740)	1416 (1035/381)	1212 (888/324)

[1] West Yellowstone entrances only.

and these values have been converted to gram/mile values for the range of gas mileage of 9 to 15 mpg. These ranges were chosen to span the fuel consumption range between the larger 3-cylinder performance sleds (600 - 700 cc displacements) and the much smaller sport models (340 - 440 cc displacements). The average fuel economy for the two snowmobiles (1998 Polaris Indy Trail, 488cc fan-cooled and a 1996 Polaris Indy Wide Track LX, 488cc liquid cooled) used to transport the equipment and personnel through the park during the week of work was 13 mpg.

Previous emissions measurements of snowmobiles is limited. Dynamometer work carried out by Southwest Research on two snowmobile engines (a 1997 488cc Fan cooled engine from Polaris and a 1995 440cc liquid cooled Artic Cat engine) provide the only measurements which can be directly compare with this work (2). Using an engine dynamometer a 5-mode steady-state test was run on these engines using various fuels (gasoline, gasohol and Aliphatic) and lubes at room temperature (~70° F). Emissions ranges of 2299 - 2557 gCO/gal and 723 - 1028 gHC/gal were reported for the Polaris engine. Emissions ranges of 1856 - 2040 gCO/gal and 833 - 918 gHC/gal for the Artic Cat engine. The CO emissions reported by Southwest Research are a factor of two higher than we observed at the park entrance while the HC emissions are similar. The tests conducted by Southwest Research were made with intake air temperature of 70°F compared with 0° - 15°F for the measurements at park entrance. The increased air density which accompanies the lower temperature alone can account for the decreases in CO emissions observed at the park entrance. HC emissions, since they are dominated by non-combustion sources should be largely unaffected by air density changes. Changes in air density may also contribute to the differences observed between the morning and afternoon measurements and indicates that future emissions measurements need to include temperature measurements.

Table II. Summary of Emissions Measurements with Valid CO & HC.

Measurement Period (# records)	Mean %CO (Median)	Mean %HC (Median)	gCO/gal[1] (gCO/mile)[2]	gHC/gal[1] (gHC/mile)[2]
Mornings (888)	5.16% (5.10%)	2.74% (2.70%)	1151 (128 - 77)	956 (106 - 64)
Afternoons (324)	6.62% (6.61%)	2.14% (2.06%)	1569 (174 - 105)	779 (87 - 52)
Totals (1212)	5.55% (5.59%)	2.58% (2.56%)	1262 (140 - 84)	909 (101 - 61)

[1] Assumes a fuel density of 0.726 g/ml.
[2] Assumes a gas mileage of range of 9 to 15 mpg.

The emissions data are normally distributed (means and median are approximately equal) for both CO and HC. Figure 1 shows this for CO. This is in sharp contrast to automobile emissions (even older models without emissions control equipment) where these emissions are gamma distributed (the median is much lower than the mean). The dramatic differences can be seen in the comparison between the decile plots shown in Figures 2 and 3. Figure 2 is for the normally distributed snowmobiles and Figure 3 for the gamma distributed on-road vehicle fleet measured in Denver in 1995/1996 (3,4). The normal distribution may likely be rooted in the fact that 2-stroke engines have a limited operational range which is not greatly impacted by maintenance habits which can dramatically affect emissions from automobiles.

For comparison purposes a few measurements were collected on winter transportation vehicles other than snowmobiles. One Ford Econoline conversion snow coach (0.42 %CO, 155 gCO/gal, -0.098 %HC) and one Bombardier snow coach (2.88 %CO, 972 gCO/gal, 0.15 %HC, 80 gHC/gal) were measured on 3/2/97. The negative value measured on the Ford Econoline van does not mean it is cleaning the air, but that a very low reading was recorded which was negatively impacted by instrument noise or perhaps the environmental conditions. The emission values obtained from the Bombardier snow coach are typical of a modern 4-stroke gasoline engine with no emissions control equipment.

A still frame video picture of each snowmobile measurement was recorded on video tape for later review. These tapes were transcribed for make, model and engine displacement where possible. Engine displacement was inferred from make and model information obtained from the manufacturers for their 1997 models. The West Yellowstone rental fleet is composed

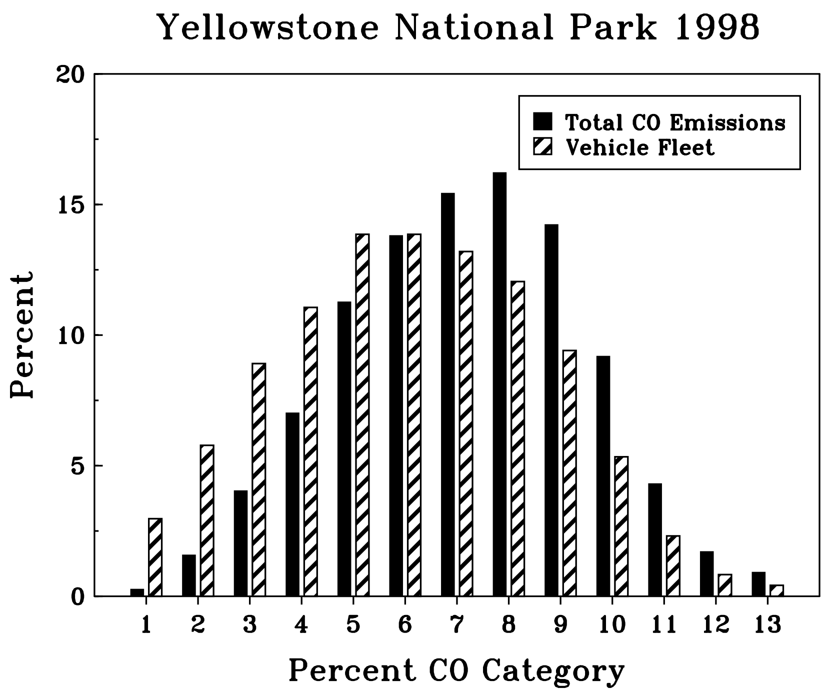

Figure 1. Percent of snowmobile fleet and the total CO emissions for all valid CO and HC measurements (1212 sleds). The upper boundary of each bin defined as <= %CO.

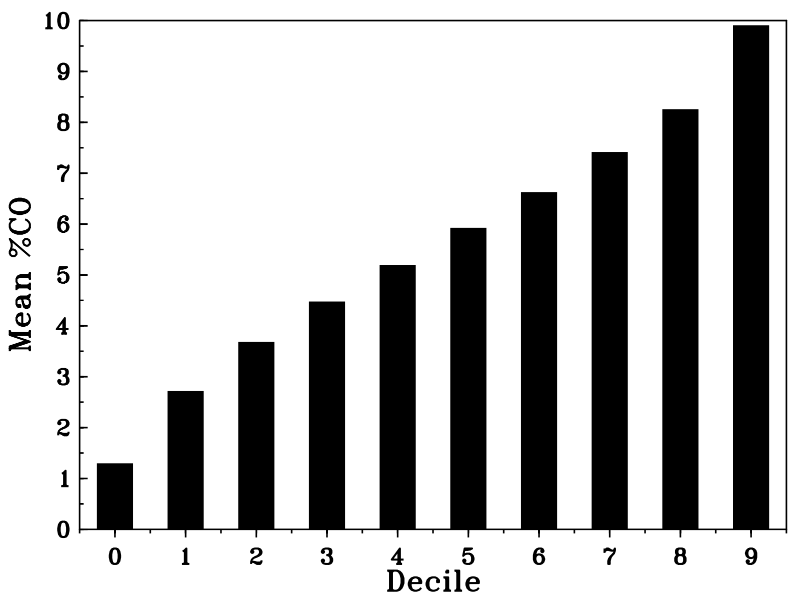

Figure 2. Mean %CO emissions by decile for all valid CO and HC measurements (1212 sleds) collected at the W. Yellowstone entrance to Yellowstone National Park.

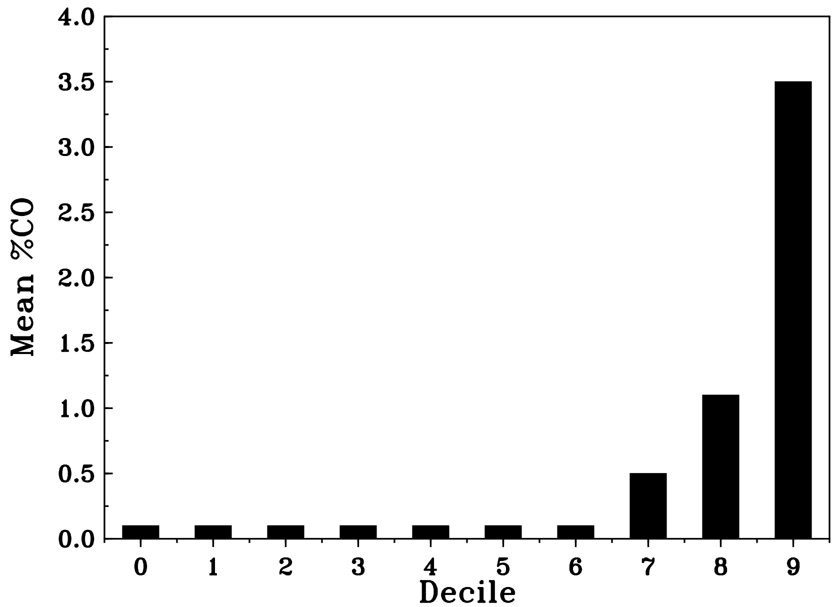

Figure 3. Mean %CO emissions by decile for 19,011 on-road vehicles measured in Denver, CO. in December, 1995 and January, 1996 (4).

mainly of the newer models each year, however, the engine displacement information will be subject to potential errors for older sled.

Figure 4 shows the distribution of makes for the morning data for the four manufacturers. Out of the 888 snowmobiles which entered the park during the morning 849 could be identified from the video tapes for make. Only 805 of the sleds could be identified for engine cooling type. Figure 5 shows the distribution by engine size (assuming that the identified sleds were all 1997 models). Figure 6 gives the mean CO and HC emissions by manufacturer and engine cooling type. The error bars are reported as the standard error of the mean.

System limitations of the standard on-road system were explored during all of the testing. One limitation is the inability of the system to tolerate snow spray which is kicked up behind the sleds. The software restricts the amount of noise which the data can contain and still report a valid measurement. This limits measurements to low speeds, such as at the entrance gates, or requires a means to reduce or eliminate loose snow. One additional measurement location might be in the thermal areas where the roadways are covered with wood chips.

A second limitation may account for the differences observed in the HC emissions between the fan cooled engines and the liquid cooled engines. The HC channel in the remote sensor can be positively interfered with by liquid water vapor (steam) and report this interference as HC emissions. While the liquid cooled sleds were not observed to emit steam at the exhaust pipe there is often a large amount of steam emitted off of the sleds running boards. The running boards serve as the cooling systems heat exchangers on the liquid cooled sleds and

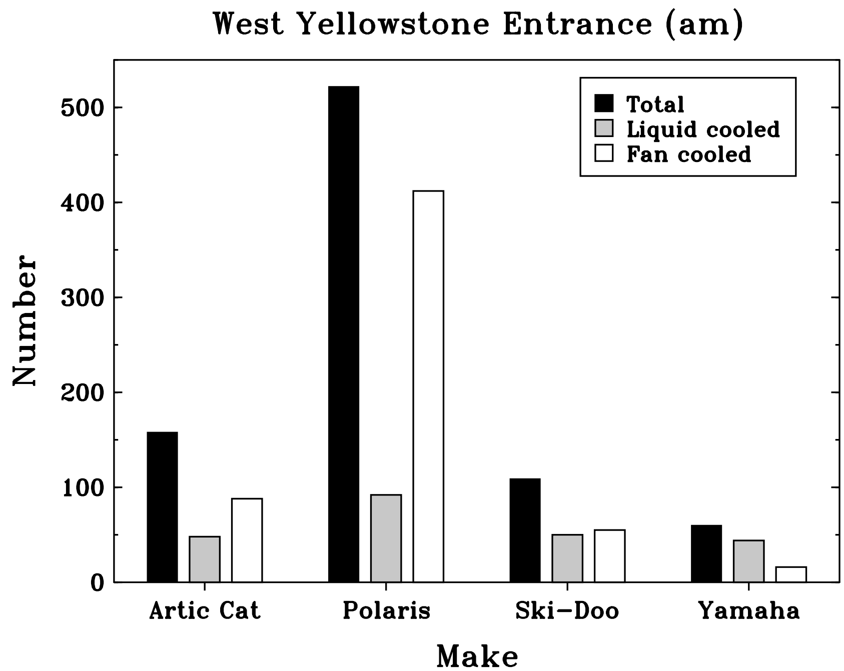

Figure 4. Frequency by make and cooling type among emission measured snowmobiles entering Yellowstone National Park at the West Yellowstone entrance.

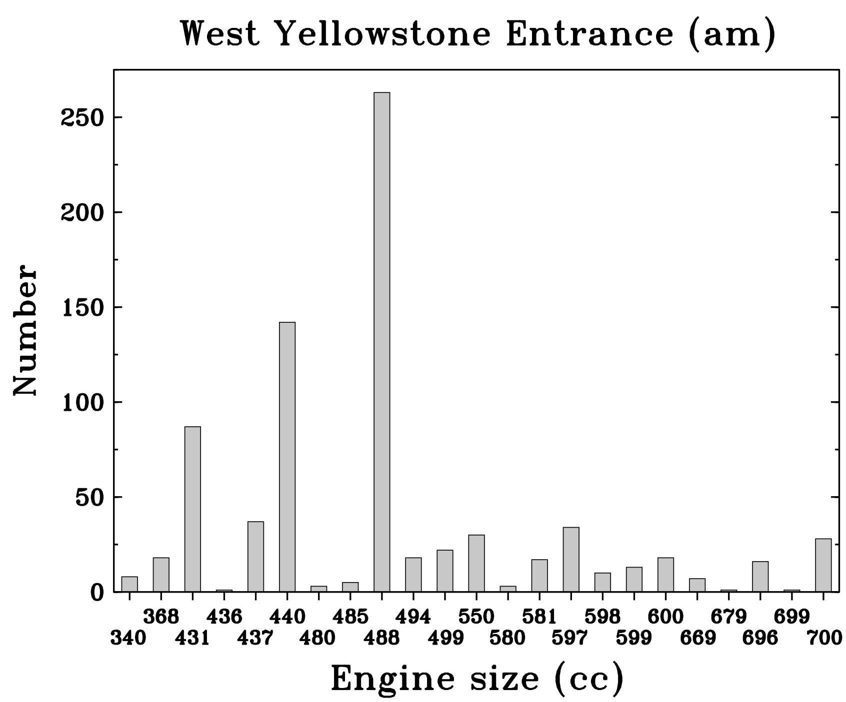

Figure 5. Frequency of snowmobile engine size (assuming 1997 model sleds) among emission measured snowmobiles entering Yellowstone National Park at the West Yellowstone entrance.

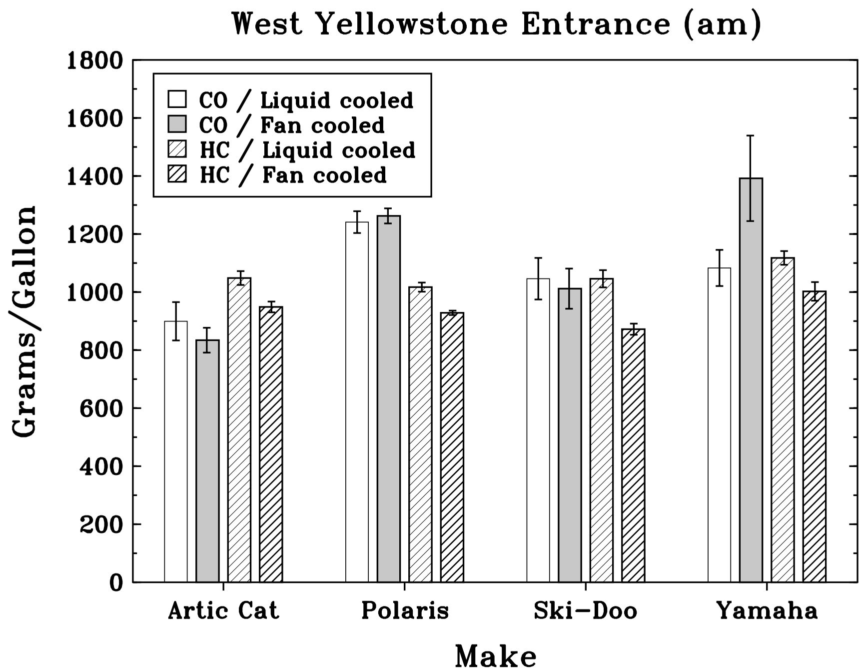

Figure 6. Measured CO and HC g/gal emissions by make and engine cooling type for morning snowmobile entrances to Yellowstone National Park at the West Yellowstone entrance.

snow which is kicked up on the underneath side of the running board often produces a "steam" cloud which is then entrained with the exhaust as the sled moves forward. It is therefore possible that the higher HC emissions observed from the liquid cooled sleds could be the result of a positive water interference during the measurement.

It was beyond the scope of this work to attempt to evaluate the impact on emissions that the use of oxygenated fuels may be having. While many of the rental companies in West Yellowstone are using the fuel in their rental sleds there are still many fuel sources inside and outside the park which are not selling the fuel. The observed difference in CO emissions in the morning and afternoon may be a result of fuel changes, but is just as likely to be a result of the sampling bias which was introduced by the software and its intolerance of snow spray. Air density changes caused by warmer afternoon temperatures could also be a contributing factor.

Acknowledgements

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