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EMISSIONS FROM SNOWMOBILE ENGINES USING BIO-BASED FUELS AND LUBRICANTS

By

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FINAL REPORT

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

APPENDICES

GLOSSARY

Alkylate	Brand name of aliphatic fuel provided by Aspen Petroleum
CO	Carbon monoxide
CO_2	Carbon dioxide
DEQ	Department of Environmental Quality (Montana)
EEE Clear	Certification-grade gasoline
EIS	Environmental Impact Statement
FID	Flame ionization detector
Gasohol	10% volume ethanol splash-blended in certification gasoline
GC	Gas chromatograph
GC/MS	Gas chromatograph/mass spectrograph
HC	Hydrocarbon
MIR	Maximum incremental reactivity
NO_x	Oxides of nitrogen
NPS	National Park Service
PAH	Polycyclic aromatic hydrocarbons
PIB	Polyisobutylene
PM	Particulate matter
PUF	Polyurethane foam
RRF	Relative response factor
SAE	Society of Automotive Engineers
SCFM	Standard cubic feet per minute
SCMM	Standard cubic meters per minute
SIR	Selected ion recording
SO_2	Sulfur dioxide
THC	Total hydrocarbons
WOT	Wide open throttle
YNP	Yellowstone National Park

EXECUTIVE SUMMARY

Snowmobile engine emissions are of concern in environmentally sensitive areas, such as Yellowstone National Park (YNP). A program was undertaken to determine potential emission benefits of use of bio-based fuels and lubricants in snowmobile engines. Candidate fuels and lubricants were evaluated using a fan-cooled 488-cc Polaris engine, and a liquid-cooled 440-cc Arctic Cat engine. Fuels tested include a reference gasoline, gasohol (10% ethanol), and an aliphatic gasoline. Carburetor jets were not changed between fuels. Lubricants evaluated include a bio-based lubricant, a fully synthetic lubricant, a high polyisobutylene (PIB) lubricant, as well as a conventional, mineral-based lubricant. Emissions and fuel consumption were measured using a five-mode test cycle that was developed from analysis of snowmobile field operating data. Emissions measured include total hydrocarbons (THC), carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2), particulate matter (PM), polycyclic aromatic hydrocarbons (PAH, both particulate bound and vapor-phase), individual hydrocarbon species (C_1-C_{12} and C_{13} - C_{22}), ammonia, and sulfur dioxide.

The following observations were made:

- Gasohol produced 16 percent less HC, 9 percent less CO, and 24 percent less PM emissions compared to gasoline with the fan-cooled engine. NO_x emissions were slightly increased, and engine power was about the same.

- The liquid-cooled engine was less sensitive to fuel differences than the fan-cooled engine. With gasohol, CO and PM were reduced 6 percent and 3 percent, respectively, compared to gasoline. Oxides of nitrogen emissions increased 6 percent, and HC emissions increased 5 percent. PM emissions were more than double those of the fan-cooled engine.

- Proper engine setup for temperature and elevation is important. HC, CO, and PM emissions were all significantly increased by richer operation resulting from incorrect setup.

- Lubricant formulation affects PM emission rates. The high PIB TORCO Smoke·less lubricant created significantly less PM than the three other lubricants tested.

- Particulate emission levels are influenced by lubrication rate, and may also be influenced by engine cooling system design. The fan-cooled engine had significantly higher spark plug seat temperatures (and, by inference, cylinder temperatures), and substantially lower PM emissions, than the liquid-cooled engine.

- The aliphatic fuel, while increasing total hydrocarbon emissions, yielded the lowest ozone formation potential of the three fuels tested. It also yielded the lowest benzene emissions.

- Toxic hydrocarbon species are present in snowmobile exhaust in proportions similar to those observed from other sources such as passenger cars fueled with gasoline.

Results show that moderate reductions in emissions can be achieved in the near term through the use of gasohol and low PM lubricants. Subsequent to this project, gasohol was used extensively in snowmobiles in the YNP area during the winter of 1997/8. Both National Park Service and rental sleds operated out of West Yellowstone, Montana were fueled with gasohol. The visible haze associated with snowmobile operation in congested areas was reportedly reduced compared to the previous winter. Operators reported excellent service with gasohol noting equivalent performance, and reduced engine maintenance. No fuel freeze ups were reported. Further studies of snowmobile particulate matter emissions and in-field emissions are planned for late 1998.

IV. CONCLUSIONS, RECOMMENDATIONS, AND FOLLOW-UP ACTIVITIES

A. Conclusions

Snowmobiles emit significant amounts of HC, CO, and PM due to the use of 2-stroke engines. Emissions of air toxics are proportionate to HC emission rates. Results show that both type of fuel and lubricant have effects on emissions from snowmobile engines.

- Gasohol reduced CO and PM emissions, and slightly increased NO_x emissions, while maintaining equivalent engine power, as compared to results with reference gasoline.

  Gasohol produced 16 percent less HC, 9 percent less CO, and 24 percent less PM emissions compared to gasoline with the fan-cooled engine. NO_x emissions were slightly increased, and engine power was about the same.

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- The aliphatic fuel, while increasing total hydrocarbon emissions, yielded the lowest ozone formation potential of the three fuels tested. It also yielded the lowest benzene emissions. While these data suggest some important benefits of aliphatic fuels, ozone formation potential is likely of less concern than CO (and HC) emissions in a winter-use scenario, because ozone is less likely to be formed at low winter temperatures.

- Toxic hydrocarbon species are present in snowmobile exhaust in proportions similar to those observed from other sources such as passenger cars fueled with gasoline.

Moderate emission reductions were observed using alternative fuels and lubricants. While reductions are significant, they are likely not as great as could be achieved with advanced engine technologies such as 4-stroke designs, or direct injected 2-stroke designs. Alternative fuels and lubricants have the advantage of being able to provide near term benefits, as they can be implemented now in the existing snowmobile fleet.

B. Recommendations

While this project generated much good information about snowmobile engine emissions and fuel and lubricant effects, many questions remain unanswered, and other issues have also been surfaced. The following areas are recommended for further study.

1. One mechanism by which alcohol-containing fuels reduce emissions is by enleanment due to the fuel's oxygen content. It may be of interest to compare emission reductions achieved with gasohol to those achieved by an "equivalent" amount of enleanment using conventional gasoline.

2. Emission results were found to be sensitive to engine operating conditions, including intake air temperature and humidity. Further studies should be performed to identify and reduce sources of variability in snowmobile engine emission results.

3. Lubricants evaluated showed large differences in PM emission rates. This suggests that opportunity exists to develop advanced, low PM lubricants for snowmobiles and other 2-stroke powered equipment.

4. During review of the draft report, several individuals questioned the impact of snowmobile operation on water quality. This issue was beyond the scope of this project, but is certainly worthy of investigation.

5. Advanced, low-emission engine designs are being developed for personal watercraft to meet EPA marine engine emission regulations. It may be of interest to evaluate the feasibility and potential emission benefits of utilizing these or other designs in snowmobile engines.

6. Snowmobile PM emissions, while high, are known to be quite different from particulate emitted by diesel engines. Diesel particulate is composed of carbonaceous soot with adsorbed heavy hydrocarbons. Two-stroke PM is primarily uncombusted lubricant. Snowmobile particulate matter should be further studied to quantify its character and any potential health impacts.

7. Speciation of heavier hydrocarbons in snowmobile exhaust was problematic. Sampling procedures and analytical techniques could be refined to provide better results from engines of this type.

8. The question of whether snowmobiles contribute to ammonia found in snowpack was unanswered in this study. Further research would be required to establish a link in this area, and determine whether there are any significant impacts.

C. Follow-Up Activities

Results show that moderate reductions in emissions can be achieved in the near term through the use of gasohol and low PM lubricants. Subsequent to this project, gasohol was used extensively in snowmobiles in the YNP area during the winter of 1997/8. Both National Park Service and rental sleds operated out of West Yellowstone, Montana were fueled with

gasohol. The visible haze associated with snowmobile operation in congested areas was reportedly reduced compared to the previous winter. Operators reported excellent service with gasohol, noting equivalent performance and reduced engine maintenance. No fuel freeze ups were reported. Further studies of snowmobile particulate matter emissions and in-field emissions are planned for late 1998.

As a result of this demonstration, the Park Service at Yellowstone requested its next fuel supply agreement to provide only gasohol in place of gasoline for year-round use (about 220,000 gallons). The contractor was selected through their normal solicitation process, and gasohol (E-10) became the only fuel available for gasoline-powered NPS vehicles in Yellowstone starting June 1, 1998. AmFac, Yellowstone's primary concessionaire, is also planning to use gasohol in its winter fleet. The Yellowstone Park Service Stations (YPSS) are investigating the feasibility of offering gasohol to the public for the 1998/99 winter season.

As noted above, the private sector actively promoted the use of these products through news releases and paid radio announcements. By January 4, 1998, all West Yellowstone snowmobile and snowcoach operators were voluntarily using gasohol and environmentally preferred lubes. All service stations in West Yellowstone carried gasohol. Gasohol also was provided at service stations in Jackson and Cody, Wyoming.

As a result of the laboratory and field work, the Montana DEQ drafted text for a brochure (in Appendix F) on how to make snow machines environmentally friendly. The text was distributed by area snowmobilers to visitors, and has been incorporated with other rules for snowmobiling on their World Wide Web page. The brochure is being printed by Conoco. Polar Bear Productions and Conoco have teamed up to develop a cost-shared program for television that summarizes this work. The program is aimed at snowmobilers visiting in the Yellowstone area, and is planned for airing in the 1998/9 season.

A series of eight scientific studies (totaling about $807,000) was developed to evaluate the questions remaining from these laboratory investigations and field demonstrations. By September 28, 1998, all but two studies had been fully funded as summarized below. This science program for the 1998/99 winter will develop more data on fuels, emissions, economics, and winter use (only $22,800 of it will be from the Western Regional

Bioenergy Program). These studies will be the basis for the Yellowstone winter use EIS, and the results will be applied over the next 20 or more years.

This project also helped fuel the Green Gateway Corridors Project which promotes safety and the availability of environmentally friendly products at service stations along the highways leading to and from the Park. Conoco stations (and later others) will use environmentally friendly products and practices in the Park gateway corridors (Yellowstone, Grand Teton, Glacier, etc). This project was developed during the Greening of Yellowstone Workshop in May 1998, along with two others that follow.

As a result of discussions at the Workshop, Planet Electric will work with Gote Snowmobile Technologies, Clyde Park MT, in developing an electric snowmobile for use in Yellowstone area fleets. Testing of these sleds will occur during the 1998/99 winter season.

Other meetings at the May Workshop resulted in development of a national student design competition for snowmobiles. The competition will be under the auspices of the Society of Automotive Engineers. The emissions competition will be involve two parts--in-motion (Dr. Don Stedman and Dr. Gary Bishop of the University of Denver), and at idle (Wyoming DEQ). Other competitions still seeking sponsors include a cold-start event, an endurance competition, and a noise competition.

The International Snowmobile Manufacturers Association is working with the SAE to review and update the noise test for snowmobiles. Each manufacturer has a sound engineer on the task force in addition to two sound engineers from SAE. The task force is looking at modifying the current SAE test so that it can be used easily under field conditions.