

# Measurement of Regulated and Unregulated Exhaust Emissions from Snowmobiles in the 2009 SAE Clean Snowmobile Challenge

2010-32-0126

20109126

Published

09/28/2010

Scott A. Miers, Christopher Green and Jay Meldrum  
Michigan Technological Univ

Matt Chmielewski  
AVL North America Inc

Copyright © 2010 SAE International and Copyright © 2010 SAE Japan

## ABSTRACT

Alternative and renewable fuels show tremendous promise for addressing concerns of energy security, energy supply, and CO<sub>2</sub> emissions. However, the new fuels have the potential to produce non-regulated exhaust components that may be as detrimental or worse, than currently regulated emissions components. For the 2009 SAE Clean Snowmobile Challenge (CSC), a commercially-available Fourier Transform Infrared (FTIR) spectrometer was used to sample raw exhaust from eight student teams' snowmobiles for comparative analysis with a conventional emissions bench. The levels of CO<sub>2</sub>, CO, NO<sub>x</sub>, O<sub>2</sub>, and THC were compared for the five operating modes, which included both gasoline and diesel powered snowmobiles. The fuel was either an ethanol blend for spark-ignition engines or a biodiesel for compression-ignition engines. Final emissions result scores varied by less than 2% between the conventional emissions bench and the FTIR. In addition, due to the ability of the FTIR to measure non-regulated exhaust species, significantly increased levels of formaldehyde and ammonia were detected for some of the engine and exhaust configurations that displayed significant reductions in regulated emissions.

## INTRODUCTION

The recent introduction of bio-fuels and the development of new exhaust after-treatment catalyst technologies for both on-road and off-road vehicles have resulted in additional challenges for engine and vehicle manufacturers when measuring vehicle exhaust. These new fuels and technologies

often carry with them the potential for producing previously non-regulated components that are no less toxic or hazardous to the environment. The current Environmental Protection Agency (EPA) emission requirement for snowmobiles only regulates THC and CO. Some of these non-regulated components include ammonia (NH<sub>3</sub>), nitrous oxide (N<sub>2</sub>O), isocyanic acid (HNCO), hydrogen cyanide (HCN), alcohols, and aldehydes such as acetaldehyde (CH<sub>3</sub>CHO) and formaldehyde (HCHO). The addition of an exhaust catalyst may significantly reduce regulated emissions, but adding a catalyst without making proper adjustments to engine control can result in the production of pollutants that may be just as bad, if not worse, than those that are being reduced. As a result, it has become increasingly necessary for manufacturers and regulatory agencies to have a way to measure not only the exhaust components currently regulated, but these other emissions components as well.

An emissions measurement system that integrates a Fourier transform infrared (FTIR) analyzer is one tool that provides manufacturers and regulatory agencies the capability to measure many of the non-regulated components of interest. The broad spectrum analysis of the FTIR analyzer provides several advantages in the research and development of new engine and exhaust after-treatment technologies. The wide range of species that can be quantitatively measured using an FTIR analyzer allows for a more complete understanding of combustion chemistry, exhaust catalysis chemistry, alternative fuel use, and the by-products of the introduction of these new technologies.

## CSC OVERVIEW

The SAE Clean Snowmobile Challenge was created in 2000 in response to increased concern over snowmobile operation in Yellowstone National Park, Grand Teton National Park, and the John D. Rockefeller Parkway. It was designed to challenge students with the mission of reducing snowmobile noise and emissions while maintaining current performance levels. In mid-March, student teams from around North America convene at one location to have their designs tested through a series of static and dynamic events. The on-snow events include a 100 mile endurance trail ride, a subjective and objective handling evaluation, an acceleration test event, and an in-service emissions event where the vehicles emissions are sampled while being operated on a pre-determined test course. The static events include a safety inspection, a design presentation, a public display of the teams design, and an evaluation of exhaust emissions during a stationary, five-mode emissions test. It is this five-mode emissions test where the FTIR was utilized to add unregulated emissions data to the scope of the competition.

The teams choosing to compete in the internal combustion engine division of the competition are shown in [Table 1](#) which includes general information about each of the student team's designs.

*Table 1. 2009 internal combustion engine teams [1]*

| <i>Team</i>      | <i>Engine Details</i>       | <i>Engine Size (cc)</i> | <i>Fuel System (a)</i> | <i>After-treatment</i>                    |
|------------------|-----------------------------|-------------------------|------------------------|-------------------------------------------|
| <b>Madison</b>   | Four-stroke, turbo          | 750                     | PFI                    | 3-way catalyst with O <sub>2</sub> sensor |
| <b>Clarkson</b>  | Four-stroke, turbo          | 750                     | PFI                    | 3-way catalyst with O <sub>2</sub> sensor |
| <b>Kettering</b> | Four-stroke                 | 499                     | PFI                    | 3-way catalyst with O <sub>2</sub> sensor |
| <b>Buffalo</b>   | Four-stroke, turbo (diesel) | 953                     | DI                     | Oxidation catalyst and PM filter          |
| <b>MTU</b>       | Four-stroke, turbo          | 750                     | PFI                    | 3-way catalyst with O <sub>2</sub> sensor |
| <b>Maine</b>     | Four-stroke                 | 499                     | PFI                    | 3-way catalyst with O <sub>2</sub> sensor |
| <b>Idaho</b>     | Two-stroke                  | 593                     | SDI                    | 3-way catalyst                            |
| <b>ETS</b>       | Two-stroke                  | 593                     | SDI                    | n/a                                       |

(a)PFI: port fuel injection, DI: direct injection, SDI: semi-direct injection

## EPA EMISSIONS REGULATIONS

Snowmobile emissions standards are set by the EPA and the first regulations of snowmobile emissions were enacted in 2006 [2]. [Table 2](#) shows the emissions regulations for snowmobiles starting in 2006 and continuing past 2012, along with the percentage of the vehicle fleet that must meet the emissions standards (Phase-In %).

**Table 2. Snowmobile emissions regulations**

| Phase | Model Year   | Phase-In [%] | Emissions Standards [g/kW-hr] |     |
|-------|--------------|--------------|-------------------------------|-----|
|       |              |              | THC                           | CO  |
| 1     | 2006         | 50           | 100                           | 275 |
| 1     | 2007 - 2009  | 100          | 100                           | 275 |
| 2     | 2010 - 2011  | 100          | 75                            | 275 |
| 3     | 2012 & later | 100          | (b)                           | (b) |

(b) The emissions for 2012 and later are defined by a functional relationship:

$$\left(1 - \frac{THC_{std}}{150}\right) \times 100 + \left(1 - \frac{CO_{std}}{400}\right) \times 100 \geq 100$$

and the corporate average HC cannot exceed 75 g/kW-hr  
CO and the corporate average CO cannot exceed 275 g/kW-hr

## EXPERIMENTAL SETUP

The conventional emissions bench for measuring raw exhaust from the snowmobiles was an AVL AMA-i60 which is considered an industry standard. The bench contained the traditional analyzers used for measuring internal combustion engine exhaust, which included a FID (flame ionization detector) analyzer for total hydrocarbons (THC), NDIR (non-dispersive infrared) analyzers for CO<sub>2</sub> and CO, a CLD (chemiluminescence detector) analyzer for NO<sub>x</sub>, and a PMD (paramagnetic detector) analyzer for O<sub>2</sub>. The conventional emissions bench was connected to a ¼" outer diameter stainless steel probe supplied by the participating teams. The final results of the emissions challenge were calculated using the emissions values as measured by the conventional emissions analyzer.

A FTIR emissions bench was provided as a secondary measurement tool of exhaust emissions. It should be noted that the emissions concentrations measured by the FTIR system were not used in the calculation of final results for the stationary emissions portion of the CSC. The FTIR emissions bench was setup with a 3/8" outer diameter stainless steel, open end tube sample probe. The probe was inserted into the snowmobile tail pipe as far as possible without interfering with any exhaust components installed on the snowmobile.



**Figure 1. Stationary snowmobile emissions testing at the 2009 SAE CSC**

## EMISSIONS TEST PROCEDURE

The exhaust emissions measured by the conventional analyzer were sampled through a 0.25" OD × 0.035" thick wall stainless steel tube inserted into the exhaust stream of the snowmobile, a minimum of 12" upstream of the exhaust pipe exit. Fuel was supplied and measured by the test facility's fuel system. The snowmobile cooling system was modified to allow quick-connection with an external cooling system for the duration of the emissions testing. The snowmobile was started and allowed to warm up for several minutes. When the students determined the engine had been sufficiently warmed up, a full throttle RPM sweep was performed to determine the peak power value and associated engine speed. This information set the "mode-1" point and the other 4 modes, as shown in Table 3. This five-mode operational regime was generated from actual snowmobile tests conducted in the mid-90's over a variety of driving conditions to provide a concise stationary test procedure for snowmobiles [3].

**Table 3. Five-mode test procedure for evaluating snowmobile emissions**

| Mode Number | Engine Speed [%] | Engine Torque [%] | Weighting Factor |
|-------------|------------------|-------------------|------------------|
| 1           | 100              | 100               | 0.12             |
| 2           | 85               | 51                | 0.27             |
| 3           | 75               | 33                | 0.25             |
| 4           | 65               | 19                | 0.31             |
| 5           | Idle             | 0                 | 0.05             |