Technical Report

Evaluation Of A Schatz Heat Battery
On A Flexible-Fueled Vehicle

by

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Ronald M. Schaefer

September 1991

NOTICE

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources
Emission Control Technology Division
Control Technology and Applications Branch
2565 Plymouth Road
Ann Arbor, MI 48105
MEMORANDUM

SUBJECT: Exemption From Peer and Administrative Review

FROM: Karl H. Hellman, Chief
       Control Technology and Applications Branch

TO: Charles L. Gray, Jr., Director
    Emission Control Technology Division

The attached report entitled "Evaluation Of a Schatz Heat Battery On a Flexible-Fueled Vehicle," (EPA/AA/CTAB/91-05) describes the evaluation of a Schatz Heat Battery as a means of reducing cold start emissions from a vehicle fueled with both gasoline and M85. This evaluation was conducted at both 20°F and 75°F ambient temperatures. The test vehicle was a flexible-fueled 1990 Audi 80 supplied by Volkswagen of America.

Since this report is concerned only with the presentation of data and its analysis and does not involve matters of policy or regulation, your concurrence is requested to waive administrative review according to the policy outlined in your directive of April 22, 1982.

Concurrence: [Signature] Date: 10-14-91
Charles L. Gray, Jr., Dir., ECTD

Nonconcurrence: [Signature] Date: 
Charles L. Gray, Jr., Dir., ECTD

cc: E. Burger, ECTD
Table of Contents

I. Summary ...................................................... 1
II. Introduction ............................................... 3
III. Description of Schatz Heat Battery ...................... 4
IV. Description of Test Vehicle and Heat Battery
    Integration .............................................. 6
V. Test Facilities and Analytical Methods .................. 7
VI. Test Procedures .......................................... 8
VII. Schatz Heat Battery Check ............................... 8
VIII. Discussion of Test Results .............................. 11
      A. Gasoline Fuel ................................. 11
      B. M85 Fuel .................................. 18
IX. Evaluation Highlights ................................... 25
X. Future Efforts ........................................... 26
XI. Acknowledgments ......................................... 26
XII. References ............................................. 26
APPENDIX A - Test Vehicle Specifications .................. A-1
I. Summary

A Schatz Heat Battery was acquired from Autotech Associates, Inc. and evaluated by EPA as a means of reducing unburned fuel and CO emission levels during the cold start segment (Bag 1) of the Federal Test Procedure. This unit was installed on a flexible-fueled vehicle provided by Volkswagen of America and evaluated at ambient temperatures of 20°F and 75°F while operating on both gasoline and M85 high methanol blend fuels.

The Schatz Heat Battery is able to store latent heat energy which is transferred from the engine's coolant, and it can store this energy for a substantial amount of time. Upon engine cold start, the Heat Battery transfers this stored heat by conduction to the circulating coolant which in turn releases heat to the cold engine. A pump was added to the coolant circuit to circulate coolant through the Heat Battery prior to starting the engine.

Table 1 is a summary of the gasoline-fueled engine emissions and fuel economy during the Bag 1 segment of the FTP. Presented are percent changes from stock levels of each pollutant and fuel economy resulting from two Heat Battery strategies at 20°F and 75°F ambient temperatures. Stock is defined here as the test vehicle not equipped with the Heat Battery.

<table>
<thead>
<tr>
<th>Category</th>
<th>HC</th>
<th>CO</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Preheat, 20°F</td>
<td>-35</td>
<td>-53</td>
<td>+9</td>
</tr>
<tr>
<td>Preheat, 20°F</td>
<td>-69</td>
<td>-76</td>
<td>+14</td>
</tr>
<tr>
<td>No Preheat, 75°F</td>
<td>-10</td>
<td>-2</td>
<td>+2</td>
</tr>
<tr>
<td>Preheat, 75°F</td>
<td>-12</td>
<td>-62</td>
<td>+4</td>
</tr>
</tbody>
</table>

The positive MPG figures indicate an increase by that percentage when compared to the stock configuration at that temperature. Similarly, a negative number indicates that percent reduction from the stock level. No preheat values were obtained with the Schatz Heat Battery present in the engine coolant system and operating once the FTP is started. Preheat indicates a 60 second preheat of the circulating coolant prior to engine ignition and the start of the FTP.

Levels of unburned HC and CO decreased 69 and 76 percent respectively when preheating for 60 seconds at 20°F; fuel economy also significantly improved by 14 percent. The influence of the
Heat Battery is more pronounced in testing at 20°F. Although not presented here, large increases in Bag 1 levels of NOx were also detected. However, these substantial increases in Bag 1 NOx do not greatly increase NOx overall FTP levels. For example, the large increase in Bag 1 NOx experienced when preheating only increased composite FTP levels from 0.1 to 0.2 grams per mile. This occurred because most of the NOx emissions are formed later in the FTP when the engine has completely warmed to near steady-state conditions. Also, a 29 percent increase in Bag 1 levels of formaldehyde increased composite FTP levels from 3 to 4 milligrams per mile. Even without a preheat period, levels of unburned hydrocarbons and CO were reduced 35 and 53 percent respectively from stock levels. A fuel economy improvement of 9 percent during Bag 1 was also noted. Again, a substantial increase in Bag 1 NOx emissions was detected, however composite FTP NOx levels were unaffected by this increase.

The changes in emission levels during the 75°F testing were not as great as those noted during 20°F testing. When a preheat period was utilized, unburned hydrocarbons and CO were reduced by 12 and 63 percent respectively from stock levels. A 4 percent improvement in Bag 1 fuel economy was also noted. A 23 percent increase in Bag 1 NOx was measured here. Without a preheat, only a 10 percent reduction in Bag 1 hydrocarbons was noted, while CO remained approximately unchanged. An 8 percent decrease in Bag 1 NOx was measured during this testing, an unexpected result. Also, fuel economy improved slightly by 2 percent.

M85 reductions in Bag 1 hydrocarbons and CO and improvements in fuel economy were even more pronounced than with gasoline testing when a preheat period was utilized at 20°F. Table 2 is a summary of the M85 results. NA denotes that these emission measurements were not made. Emission sampling capabilities for methanol and formaldehyde were not available for 20°F testing. Hydrocarbon values here are obtained by treating the exhaust as if the fuel were gasoline and measured with a propane calibrated FID.

<table>
<thead>
<tr>
<th>Category</th>
<th>*HC</th>
<th>CO</th>
<th>HCHO</th>
<th>CH₃OH</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Preheat, 20°F</td>
<td>-26</td>
<td>-57</td>
<td>NA</td>
<td>NA</td>
<td>+13</td>
</tr>
<tr>
<td>Preheat, 20°F</td>
<td>-85</td>
<td>-83</td>
<td>NA</td>
<td>NA</td>
<td>+18</td>
</tr>
<tr>
<td>No Preheat, 75°F</td>
<td>-6</td>
<td>+9</td>
<td>-16</td>
<td>-7</td>
<td>-1</td>
</tr>
<tr>
<td>Preheat, 75°F</td>
<td>-20</td>
<td>-41</td>
<td>-28</td>
<td>-22</td>
<td>+2</td>
</tr>
</tbody>
</table>

* Gasoline-fueled measurement procedure.
In cold temperature testing (20°F), both HC and CO emission levels were reduced over 80 percent when preheating for 60 seconds. A substantial 18 percent increase in Bag 1 fuel economy was noted here. Levels of Bag 1 NOx emissions increased by 9 percent with preheating, which did not affect composite FTP NOx levels. Although this is not quantitatively described here, startability and driveability at 20°F was noticeably improved for M85 fuel when preheating the engine.

Without a preheat period at 20°F, hydrocarbon levels were reduced approximately 26 percent, along with a 57 percent reduction in CO from stock levels. NOx levels without preheat actually decreased by 9 percent. A 13 percent improvement in fuel economy was also noted during this testing.

Emission level reductions obtained during 75°F testing with M85 fuel were also significant when a preheat period was utilized. Unburned methanol and hydrocarbons were both reduced by over 20 percent, while CO was reduced over 40 percent. Bag 1 formaldehyde levels were also reduced almost 30 percent when a preheat period was used. However, with the absence of preheating, CO levels actually increased during Bag 1. No engine problems, which may have contributed to excess CO, were noted during this testing.

Levels of unburned methanol were reduced 7 percent without preheating. Levels of methanol and hydrocarbon emissions were reduced proportionally; unburned methanol was reduced by 7 percent, comparable to the 6 percent reduction in unburned hydrocarbons. There was also a 16 percent reduction in formaldehyde emissions during this testing. Fuel economy was unchanged by the use of the Heat Battery here.

II. Introduction

The largest portion of unburned fuel (hydrocarbon emissions for gasoline fuel and methanol emissions for M100 fuel), carbon monoxide (CO), and formaldehyde exhaust emissions from a catalyst-equipped vehicle tested over the Federal Test Procedure (FTP) occur during the cold start or catalyst warm-up phase in Bag 1.[1,2,3] Emissions of nitrogen oxides (NOx) at cold start are generally not as significant as levels generated later in the FTP when the engine has warmed. Cold start is defined here as following a vehicle soak of 12-36 hours at 70-80°F for testing at 75°F and at 15-25°F for testing at 20°F.[4]

Cold start emissions of unburned fuel and CO are much higher when testing over the FTP at lower ambient temperatures such as 20°F.[5] These higher levels of unburned fuel and CO result partly from an increased period of fuel enrichment, a cold engine, and an extended period before catalyst "light-off" can occur. Recent enactment of new clean air legislation in the United States has refocused attention on regional problems of high levels of CO emissions from motor vehicles operated in low ambient temperatures.[6]
One possible way of reducing cold start emissions of unburned fuel and CO from either a gasoline- or M100-fueled vehicle is to reduce the catalyst "light-off" time. EPA has been interested in catalyst preheating for some time and has conducted several evaluations of resistively heated catalyst technologies with favorable results.[1,2,5,7,8,9,10] This catalyst heating reduces the time during which the catalyst remains ineffective because of insufficient warming by the cold exhaust gas. However, while improvements in emissions may result from the use of this technology, driveability may still suffer until the engine has warmed to near steady-state conditions.

Another way to reduce cold start emissions of unburned fuel and CO is to reduce the period of cold start enrichment. This period of enrichment may be a function of engine coolant temperature. If the engine is heated to operating temperature faster, the period of enrichment to ensure good driveability may be correspondingly reduced.

Schatz Thermo Engineering, Munich, Germany, has constructed a heat storage device that stores excess heat energy from the engine coolant for use in later applications. This device, referred to here as a Heat Battery, stores heat energy under vacuum in a molten salt. The salt releases heat energy to the cold engine coolant which is pumped through a canister containing the packaged molten salt. The coolant, warmed by contact with the salt containing packages, may be pumped to various locations within the vehicle. Although applications for this heat energy have included passenger compartment heating [11], the discussion in this paper is limited to the application of engine heating. This heating allows the engine to heat to near steady-state conditions faster, thereby reducing the time requirement for richer operating conditions at cold start.

An initial evaluation of this technology on a gasoline-fueled vehicle reduced cold start HC and CO emissions 30 and 50 percent respectively over the FTP at 20°F conditions. [12] The licensed representative of Schatz in the United States, Autotech Associates, Inc. supplied a Heat Battery to EPA for an independent evaluation on a flexible-fueled vehicle. The test vehicle was supplied by Volkswagen of America. This evaluation was conducted using both gasoline and M85 high methanol blend fuels; the results from this testing are presented in this paper.

III. Description Of Schatz Heat Battery

The Schatz Heat Battery is a latent heat storage device which can accumulate waste heat from the engine's coolant and can store this heat for a substantial amount of time. The efficiency of this heat accumulator is enhanced because this latent heat would normally be wasted. Upon engine cold start, the Heat Battery releases this stored heat to the coolant; the warmed coolant assists in heating the engine to operating temperature substantially faster.
Figure 1 below is a picture of the interior of a Heat Battery. This unit is cylindrical in shape with an overall length of approximately 370 mm, a 170 mm outside diameter, and a total weight of approximately 10 kg. The heat capacity is 600 Wh when cooled from 176°F to 122°F.

Figure 1
Schatz Heat Battery

The core of the Schatz Heat Battery consists of stacked flat-sheet metal elements that contain the heat storage mass. If the coolant temperature flowing in-between the stacked elements is higher than the heat storage mass melting point (167°F), latent heat is absorbed and stored. During the ensuing cold start, the stored heat is then delivered to the cooler engine coolant. Once the circulating coolant reaches 167°F, the heat storage mass begins storing latent heat again.

The heat storage mass inside the sealed metal elements is the molten salt Ba(OH)\(_2\)·8H\(_2\)O. The latent heat of the pure molten salt is 88.5 Wh/kg, and the heat conductivity in its solid state is 1.26 W/mK. The Heat Battery core is surrounded by a high-vacuum insulation which limits ambient heat losses to approximately 3 W at -4°F.
IV. Description Of Test Vehicle And Heat Battery Integration

The test vehicle was a flexible-fueled 1990 Audi 80 four-door sedan, equipped with a manual 5-speed transmission, air conditioning, and radial tires. The vehicle had approximately 5,000 miles when it was received by EPA. The 1.8-liter engine has a rated maximum power output of 75 kW at 5,500 rpm with gasoline fuel and 80 kW at 5,500 rpm with M85 fuel. The vehicle was tested at 1,304 kilograms (2,875 lbs) inertia weight and 6.4 actual dynamometer horsepower. This vehicle was loaned to the U.S. EPA by Volkswagen of America.

A detailed description of this test vehicle and special methanol-blend modifications is included as Appendix A.

The integration of the Schatz Heat Battery into the test vehicle's coolant system was performed by Volkswagen of America. Figure 2 is a schematic diagram of the vehicle's coolant system as it was tested by EPA.

Figure 2
Coolant System Configuration

1 Engine
2 Pump
3 Heat Battery
4 Heater Core
5 Oil Cooler/Heater
6 Radiator
7 Electric Valves
8 Thermostat
Two switches inside the passenger compartment dictated the Heat Battery configuration. The first switch enabled the circulation of coolant prior to the starting of the engine. This switch initiated a Bosch electric pump (2), which circulated the coolant through the Schatz Heat Battery (3). The Heat Battery in turn transferred stored heat to the cold coolant, and thus the engine (1) prior to start. At this point, the radiator thermostat is still closed so that all the heated coolant passes through the cold engine. This is referred to here as a "preheat" test.

The second switch allowed for the Schatz Heat Battery to be taken out or placed in the coolant system with the use of two electric valves (7). If stock (heat battery out of the coolant circuit) emission levels were required, a single switch would close electric valve 7a and open 7b. This would allow coolant to pass from the engine through the oil heater/coolant (5), the heater core (4), and then back to the engine, with the thermostat closed during a cold start. If the Heat Battery was to be included in the coolant system, the same switch would then open electric valve 7a and close 7b. Now the Heat Battery would be present before the heater core and after the oil heater/coolant. This is referred to here as a "no preheat" test. This same electric valve configuration would be utilized if a coolant preheat test was desired. The pump would operate until just prior to starting the engine. At that point, the pump switch would be manually switched off, and the Heat Battery would remain in the coolant system for the remainder of the FTP.

V. Test Facilities And Analytical Methods

Two separate sites were used for testing at the two different ambient temperatures. EPA emissions testing at 75°F was conducted on a Clayton Model ECE-50 double-roll chassis dynamometer using a direct-drive variable inertia flywheel unit and a road load power control unit. Emissions testing at 20°F was conducted on a Labeco Electric single-roll chassis dynamometer using a direct-drive variable inertia flywheel unit and a road load power control unit. Both sites utilized a Philco Ford constant volume sampler that has a nominal capacity of 350 cfm. Both test sites also used the same emission analyzers. Exhaust hydrocarbon (HC) emissions were measured with a Beckman Model 400 flame ionization detector (FID). CO was measured using a Bendix Model 8501-5CA infrared CO analyzer. NOx emissions were determined with a Beckman Model 951A chemiluminescent NOx analyzer.

Exhaust formaldehyde and methanol emission samples could only be measured at the 75°F test site. Exhaust formaldehyde was measured using a dinitrophenol-hydrazine (DNPH) technique.\[13,14\] Exhaust carbonyls including formaldehyde are reacted with DNPH solution forming hydrazine derivatives; these derivatives are separated from the DNPH solution by means of high performance liquid chromatography (HPLC), and quantization is accomplished by spectrophotometric analysis of the LC effluent stream.
The procedure developed for methanol sampling and presently in-use employs water-filled impingers through which are pumped a sample of the dilute exhaust or evaporative emissions. The methanol in the sample gas dissolves in water. After the sampling period is complete, the solution in the impingers is analyzed using gas chromatographic (GC) analysis.[15]

Some of the emission results in this report for M85 fuel are computed using the methods outlined in the "Final Rule For Methanol-Fueled Motor Vehicles And Motor Vehicle Engines," which was published in the Federal Register on Tuesday, April 11, 1989. Because our cold room test cell is not equipped to measure methanol and formaldehyde emissions, we have also included a hydrocarbon result for M85 fuel which is what would be obtained if the exhaust was treated as if the fuel were gasoline.

VI. Test Procedures

This program had as its goal the evaluation of a Schatz Heat Battery for the reduction of unburned fuel and CO emissions, and improvements in fuel economy during the cold start portion of the FTP (Bag 1), using either gasoline or M85 fuels.

The evaluation consisted of three phases which are discussed separately in the following two sections. The first phase was a Schatz Heat Battery heat release check. Before testing for emission levels, it was necessary to determine if the Heat Battery was functioning properly.

The second phase of this evaluation consisted of emissions testing with gasoline (indolene clear) fuel conducted over the FTP cycle. The vehicle, equipped with the Schatz Heat Battery, was tested first at an ambient temperature of 75°F and then at 20°F. Testing at each ambient temperature consisted of three different Heat Battery configurations. The first configuration had the Heat Battery out of the coolant system and hereafter is referred to as the stock configuration. The vehicle was then tested with the Heat Battery in the coolant system (no preheat), and the last configuration again had the Heat Battery in the coolant system but with a 60 second preheat prior to engine start (preheat).

The last phase consisted of the same ambient temperature and Heat Battery configuration testing as described in the previous paragraph, but M85 fuel was utilized in this phase of testing instead of gasoline.

VII. Schatz Heat Battery Check

This first phase of the evaluation ensured that the Heat Battery supplied by Autotech Associates, Inc. functioned properly, and that the unit was being sufficiently "charged" during each LA-4 prep cycle. A full Heat Battery charge occurred when the temperature of the coolant leaving the Heat Battery was the same as the coolant temperature entering it.
Two thermocouples were installed to monitor these temperatures. The thermocouple measuring coolant temperature into the Heat Battery was located approximately 25 mm from the entrance of the Heat Battery, whereas the thermocouple measuring coolant temperature out was located approximately 250 mm downstream of the unit.

At the conclusion of the LA-4 prep cycle, a coolant temperature trace revealed that the two temperatures leaving and entering the Heat Battery were approximately equal, denoting a fully charged Heat Battery. After about a 15-hour soak at 75°F, the same temperature data was taken with only the Bosch pump circulating coolant; the engine was not running during this test. Figure 3 is a summary of these results.

Figure 3
Pump Circulation Of Coolant
Heat Battery Coolant Temperatures

Engine Not Operating

The initial spike in battery-out (engine-in) coolant temperature is the result of the approximately one gallon of coolant that was trapped inside the Heat Battery during the vehicle soak. The maximum temperature of this peak was above the melting point of the molten salt, 167°F. After approximately 60 seconds of coolant circulation, the temperature entering the Heat Battery (engine-out coolant temperature) reaches approximately 122°F. Again, these results were acquired with the engine not operating and at an ambient temperature of 75°F.
A third thermocouple was needed to monitor coolant temperature when the Heat Battery was bypassed (stock configuration). This thermocouple was located approximately 125mm downstream of the engine. Data from this stock configuration was then compared with coolant temperature results obtained when the Heat Battery was utilized with and without a 60 second preheat when tested over the FTP. This data was gathered after an LA-4 prep cycle and an approximate 15-hour soak at 20°F. Zero seconds here denotes key-on of the engine during the Bag 1 portion of the FTP. This data was also obtained using M85 fuel. Figure 4 summarizes these results.

**Figure 4**

**Engine Out Coolant Temperatures**

**Audi 80 During FTP With M85 Fuel**

![Graph showing engine out coolant temperatures](image)

- Stock
- No Preheat
- Preheat

*Preheat Was 60 Seconds*

The "no preheat" trace represents engine-out coolant temperatures when the Heat Battery was utilized without any coolant circulation prior to engine start. The "preheat" trace utilized a 60 second coolant circulation prior to the start of the FTP.

The preheat trace begins at approximately 90°F instead of the 20°F ambient temperature. The first acceleration of the FTP does not occur until 20 seconds after key-on, and the second idle begins at 125 seconds. During this second idle, which lasts approximately 38 seconds, the coolant temperatures do not change significantly with all three configurations.

In the stock configuration, the coolant temperature increases at a steady rate until approximately 270 seconds into the FTP. The stock coolant temperature did not change until well into the first acceleration, however during the test of the Heat Battery with no preheat, coolant temperature rose much faster than the stock
configuration and resulted in about a 60°F difference after only 60 seconds into the FTP. With the 60 second preheat period, there is an additional difference of 25°F in coolant temperatures from no preheat levels after 60 seconds into the FTP. After approximately 130 seconds into the FTP, coolant temperatures with and without preheat reach the same level and the advantage of preheating ends. Stock coolant temperature reaches Heat Battery levels after about 280 seconds into the FTP.

VIII. Discussion Of Test Results

A. Gasoline Fuel

This evaluation consisted of three separate phases. The first phase, a familiarization with the operation of the Heat Battery has already been discussed. The results commented on in this section represent the second phase of this evaluation, results obtained from testing at ambient temperatures of 20°F and 75°F with indolene clear fuel. All test results referred to hereafter were acquired during the Federal Test Procedure. Bag 1 emission levels are given in grams (g) of emissions over the test segment (Bag 1) except for formaldehyde, which are presented in milligrams (mg) over Bag 1. Composite FTP emissions are given in grams per mile (g/mi) except for formaldehyde, which are presented in milligrams per mile (mg/mi).

During the 20°F and 75°F testing, results were obtained from three different Heat Battery configurations. "Stock" results were obtained by removing the Schatz Heat Battery from the engine coolant system via a switch located inside the passenger compartment that controls two electric valves described previously. "No Preheat" results were obtained by switching the Heat Battery into the engine coolant system. The coolant would circulate only after the engine was started. "Preheat" results were obtained by again leaving the Heat Battery in the engine coolant system but also switching on an auxiliary pump 60 seconds prior to engine start. This auxiliary pump was able to circulate the coolant through the Heat Battery and engine prior to engine start. The coolant would act as a heat transfer medium by taking stored heat from the Heat Battery and releasing heat to the cold engine block. A 60 second preheat prior to key-on may be impractical in order to accommodate a driver's desire for a quick start/drive sequence, however, this preheat period ensured a warmed engine prior to key-on for these laboratory experiments. The pump was shut off at the same instant the engine was started and emission samples taken.

Figure 5 presents Bag 1 hydrocarbon (HC) emission levels for gasoline fuel tested in an ambient temperature of 20°F, hereafter referred to as cold room testing. Presented along with Bag 1 results are Bag 3 levels for comparison. Generally, Bag 3 levels remained constant for each Heat Battery configuration evaluated. However, with the Heat Battery present in the coolant system at the start of Bag 3, some emission level changes can be noticed, particularly during 20°F testing. However, this report will only
examine cold start (Bag 1) improvements. HC emissions (unburned fuel) levels were reduced almost 35 percent, from 13.95 grams to 9.12 grams, from stock values by the use of the Heat Battery during Bag 1. By circulating the coolant 60 seconds prior to key-on (preheat), HC emission levels were reduced an additional 52 percent (to 4.35 grams) from no preheat levels. By preheating, HC emission levels were reduced almost 70 percent when compared to levels from the stock configuration.

Figure 5
Gasoline Fuel, 20 Deg. F Testing
Hydrocarbon Emissions, Bags 1 & 3

<table>
<thead>
<tr>
<th>Heat Battery Configuration</th>
<th>Exhaust Hydrocarbons (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock, Bag 1</td>
<td>13.95</td>
</tr>
<tr>
<td>Stock, Bag 3</td>
<td>0.39</td>
</tr>
<tr>
<td>No Preheat, Bag 1</td>
<td>9.12</td>
</tr>
<tr>
<td>No Preheat, Bag 3</td>
<td>0.33</td>
</tr>
<tr>
<td>Preheat, Bag 1</td>
<td>4.35</td>
</tr>
<tr>
<td>Preheat, Bag 3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The Heat Battery proved to be very efficient at reducing the causes of excess CO emissions during Bag 1 as seen in Figure 6. Cold room reductions of CO emission levels were even more substantial than HC reductions on a percentage basis. Incomplete combustion during cold start caused Bag 1 levels of CO to reach 202.9 grams. With the addition of the Heat Battery, CO levels were lowered approximately 54 percent to 94.3 grams. With the 60 second preheat, CO levels dropped an additional 23 percent to 47.8 grams during the Bag 1 segment. This results in an overall CO reduction of almost 77 percent when compared to stock results, a substantial reduction.

By allowing the engine to warm to operating temperature in less time after key-on (reducing the fuel enrichment period), fuel economy during the Bag 1 segment also increased. From Figure 7, with the Heat Battery present in the coolant system, fuel economy increased 9 percent from 21.1 miles per gallon to 23.0 miles per
Figure 6
Gasoline Fuel, 20 Deg. F Testing
Carbon Monoxide Emissions, Bags 1&3

Heat Battery Configuration
- Stock, Bag 1: 202.9 grams
- Stock, Bag 3: 3.9 grams
- No Preheat, Bag 1: 94.3 grams
- No Preheat, Bag 3: 3.4 grams
- Preheat, Bag 1: 47.8 grams
- Preheat, Bag 3: 3.9 grams

Figure 7
Gasoline Fuel, 20 Deg. F Testing
Fuel Economy, Bags 1&3

Heat Battery Configuration
- Stock, Bag 1: 21.1 miles per gallon
- Stock, Bag 3: 30.6 miles per gallon
- No Preheat, Bag 1: 23 miles per gallon
- No Preheat, Bag 3: 30.4 miles per gallon
- Preheat, Bag 1: 24 miles per gallon
- Preheat, Bag 3: 30.1 miles per gallon
gallon even without a preheat period. A 60 second preheat increased fuel economy an additional 4 percent from no preheat levels to 24.0 miles per gallon, an overall fuel economy improvement of approximately 14 percent during the cold start (Bag 1) portion of the FTP.

Generally, emission levels of NOx at cold start are not as high as levels of NOx generated when the engine has warmed. NOx emissions during the Bag 1 segment might be expected to increase with the use of the Heat Battery. This happened with gasoline testing as presented in Table 3. The use of the Heat Battery without preheat increased NOx emission levels 120 percent from 0.5 grams to 1.1 grams during Bag 1. The presence of a 60 second preheat caused NOx emission levels during the cold start segment to increase another 73 percent above no preheat levels. Overall, preheating increased Bag 1 NOx emissions to 1.9 grams, up from 0.5 grams without the Heat Battery.

Table 3
Schatz Heat Battery, 20°F Testing
Bag 1 Of FTP Cycle

<table>
<thead>
<tr>
<th>Gasoline Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>Stock</td>
</tr>
<tr>
<td>No Preheat</td>
</tr>
<tr>
<td>Preheat</td>
</tr>
</tbody>
</table>

This 1.4 gram increase in Bag 1 NOx only increased the FTP composite NOx level from 0.1 grams per mile to 0.2 grams per mile as seen in Table 4. Most NOx emissions occur later during the FTP cycle when the engine is warm and operated under load. Generally, the changes in Bag 1 emissions levels are reflected in the weighted FTP levels, especially for hydrocarbon and CO emissions, because most of these pollutants are generated during cold engine/catalyst operation. For example, the 70 percent reduction in Bag 1 hydrocarbon emissions with preheating resulted in a composite FTP emission rate reduction of approximately 66 percent. Similarly, the 77 percent reduction in Bag 1 CO levels with the same preheat period resulted in a 66 percent reduction for composite FTP CO emission rates. However, the magnitude of Bag 1 fuel economy improvements are not reflected in overall FTP fuel economy. The 14 percent increase in Bag 1 fuel economy with preheating only resulted in a 3 percent FTP fuel economy improvement.
Table 4
Schatz Heat Battery, 20°F Testing
Composite FTP Emission Levels

Gasoline Fuel

<table>
<thead>
<tr>
<th>Category</th>
<th>HC g/mi</th>
<th>CO g/mi</th>
<th>NOx g/mi</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>0.88</td>
<td>12.6</td>
<td>0.1</td>
<td>24.7</td>
</tr>
<tr>
<td>No Preheat</td>
<td>0.60</td>
<td>6.3</td>
<td>0.1</td>
<td>25.1</td>
</tr>
<tr>
<td>Preheat</td>
<td>0.30</td>
<td>3.6</td>
<td>0.2</td>
<td>25.3</td>
</tr>
</tbody>
</table>

The next testing with gasoline fuel was performed at a soak temperature of 75°F. The 20°F Heat Battery configurations were used here; stock, no preheat (Heat Battery only), and preheat (Heat Battery with a 60 second preheat prior to key-on). Exhaust methanol and formaldehyde emissions levels were also measured during this testing. This 75°F testing was conducted in a test cell different than that used for the 20°F testing.

Reductions in unburned fuel, CO, and fuel consumption during Bag 1 were again noted during this testing. These reductions were not as great as those from the 20°F testing. Figure 8 is a summary of hydrocarbon results from this testing. The use of the Heat Battery without preheat reduced Bag 1 levels almost 10 percent from 2.72 grams to 2.46 grams. Preheat levels of 2.39 grams were measured, which resulted in an overall hydrocarbon reduction of over 12 percent when compared to stock levels.

Similar reductions were also noted in Bag 1 CO emission levels, as can be seen in Figure 9. There was only a modest 2 percent reduction, from 33.0 grams to 32.2 grams, noted without utilizing a preheat period. This was an unexpected event, and no unusual driving conditions or engine/Heat Battery problems were noted during this testing that might have contributed to this unexpected result. However, when a 60 second preheat was used, Bag 1 CO levels were reduced to 12.6 grams, a 62 percent reduction from stock levels.

Table 5 presents the rest of the Bag 1 emission and fuel economy results. The 10 percent reduction of unburned hydrocarbons without preheat resulted in only a 2 percent improvement in Bag 1 fuel economy. Similarly, the 12 percent reduction in hydrocarbons experienced when preheating resulted in a 4 percent increase in fuel economy during this test segment.
Figure 8
Gasoline Fuel, 75 Deg. F Testing
Hydrocarbon Emissions, Bags 1&3

Heat Battery Configuration

- Stock, Bag 1: 2.72 grams
- Stock, Bag 3: 0.32 grams
- No Preheat, Bag 1: 2.46 grams
- No Preheat, Bag 3: 0.3 grams
- Preheat, Bag 1: 2.39 grams
- Preheat, Bag 3: 0.33 grams

Figure 9
Gasoline Fuel, 75 Deg. F Testing
Carbon Monoxide Emissions, Bags 1&3

Heat Battery Configuration

- Stock, Bag 1: 33 grams
- Stock, Bag 3: 4 grams
- No Preheat, Bag 1: 32.2 grams
- No Preheat, Bag 3: 3.6 grams
- Preheat, Bag 1: 12.6 grams
- Preheat, Bag 3: 3.4 grams
Table 5

Schatz Heat Battery, 75°F Testing
Bag 1 of FTP Cycle

Gasoline Fuel

<table>
<thead>
<tr>
<th>Category</th>
<th>NMHC g</th>
<th>HC g</th>
<th>HCHO mg</th>
<th>CO g</th>
<th>NOx g</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>2.43</td>
<td>2.72</td>
<td>34</td>
<td>33.0</td>
<td>1.3</td>
<td>25.2</td>
</tr>
<tr>
<td>No Preheat</td>
<td>2.19</td>
<td>2.46</td>
<td>33</td>
<td>32.2</td>
<td>1.2</td>
<td>25.6</td>
</tr>
<tr>
<td>Preheat</td>
<td>2.18</td>
<td>2.39</td>
<td>44</td>
<td>12.6</td>
<td>1.6</td>
<td>26.3</td>
</tr>
</tbody>
</table>

An unexpected result was also noted in Bag 1 NOx levels. With the absence of a preheat period, NOx levels decreased by 8 percent from 1.3 grams to 1.2 grams. However, when preheating was utilized, NOx levels increased to 1.6 grams, a 23 percent increase from stock levels. Without preheating, Bag 1 formaldehyde levels remain unaffected by the Heat Battery. However, when preheating was used, formaldehyde levels increased 29 percent, from 34 to 44 milligrams.

This 29 percent increase in Bag 1 formaldehyde only results in an FTP composite rate increase of 1 milligram per mile, as seen in Table 6. The only substantial decrease in FTP composite emission rates occurred with CO when preheating. The 62 percent reduction observed in Bag 1 resulted in a emission rate reduction of 48 percent, from 2.7 grams per mile to 1.4 grams per mile. Bag 1 changes in hydrocarbons and fuel economy do not materially affect composite FTP results.

Table 6

Schatz Heat Battery, 75°F Testing
Composite FTP Emission Levels

Gasoline Fuel

<table>
<thead>
<tr>
<th>Category</th>
<th>NMHC g/mi</th>
<th>HC g/mi</th>
<th>HCHO mg/mi</th>
<th>CO g/mi</th>
<th>NOx g/mi</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>0.17</td>
<td>0.21</td>
<td>3</td>
<td>2.7</td>
<td>0.2</td>
<td>25.2</td>
</tr>
<tr>
<td>No Preheat</td>
<td>0.16</td>
<td>0.20</td>
<td>3</td>
<td>2.6</td>
<td>0.1</td>
<td>25.2</td>
</tr>
<tr>
<td>Preheat</td>
<td>0.15</td>
<td>0.19</td>
<td>4</td>
<td>1.4</td>
<td>0.2</td>
<td>25.3</td>
</tr>
</tbody>
</table>
The use of a Schatz Heat Battery without preheat has little effect on reducing emission levels or fuel consumption when testing at 75°F conditions. This may be the result of the coolant system configuration. The routing of the coolant carrying hoses is being reconfigured to correct inefficient heat transfer between the Heat Battery and the engine.

Another problem may be present as the result of the electric valves. If the valves leaked slightly during stock testing, inaccurate emission levels and fuel economy values resulted. These effects may be difficult to detect during cold room testing. The reconfiguration of the coolant system will assist in quantifying the effectiveness of the Schatz Heat Battery as an emission reduction concept.

B. M85 Fuel

Once gasoline testing was complete, the fuel tank was drained and then filled with a blend of 85 percent methanol and 15 percent gasoline (M85), and the same test sequence used during gasoline testing was followed.

Hydrocarbon values presented here were levels that would be obtained if the exhaust was treated as if the fuel were gasoline. Exhaust methanol and formaldehyde sampling capabilities were not available during cold room testing.

Preheat hydrocarbon and CO reductions are even higher with M85 fuel during cold room testing than with gasoline fuel. Figure 10 presents Bag 1 hydrocarbon results from cold room testing with M85 fuel. Without preheat, HC levels were reduced approximately 26 percent, from 16.88 grams to 12.54. Preheating the engine for 60 seconds resulted in another 59 percent reduction to 2.53 grams HC for an overall reduction of 85 percent from stock levels. Engine start and run was also significantly improved with the use of a preheat. The longer 10 second crank period necessary during stock 20°F testing was eliminated at the beginning of the FTP during this testing. Cold start driveability was also improved although it is not quantitatively described here. The engine operated in a much smoother manner after cold start.

CO emission reductions at 20°F were also very substantial as can be seen in Figure 11. The use of the Heat Battery lowered CO emission levels from 169.6 grams to 73.5 grams, a reduction of 57 percent. Preheating reduced Bag 1 CO emission levels an additional 26 percent to 28.4 grams, an overall reduction of 83 percent from stock values.

Figure 12 presents changes in Bag 1 fuel economy at 20°F. Fuel economy, with no preheat configuration, improved from 11.9 to 13.4 miles per gallon, an increase of almost 13 percent. Preheating for 60 seconds improved fuel economy an additional 5 percent to 14.1 miles per gallon, an overall Bag 1 improvement of 2.2 miles per gallon or 18 percent from stock levels.
Figure 10
M85 Fuel, 20 Deg. F Testing
*Hydrocarbon Emissions, Bags 1&3

Heat Battery Configuration

- Stock, Bag 1: 16.88 grams
- Stock, Bag 3: 1.16 grams
- No Preheat, Bag 1: 12.54 grams
- No Preheat, Bag 3: 0.54 grams
- Preheat, Bag 1: 2.53 grams
- Preheat, Bag 3: 0.4 grams

* Gasoline-fueled vehicle measurement procedure with a propane calibrated FID

Figure 11
M85 Fuel, 20 Deg. F Testing
Carbon Monoxide Emissions, Bags 1&3

Heat Battery Configuration

- Stock, Bag 1: 169.6 grams
- Stock, Bag 3: 8.3 grams
- No Preheat, Bag 1: 73.5 grams
- No Preheat, Bag 3: 7.5 grams
- Preheat, Bag 1: 28.4 grams
- Preheat, Bag 3: 7.8 grams
Table 7 presents all the M85 20°F test results for the Bag 1 segment of the FTP. The substantial reductions of CO and HC emission levels with no preheating were also accompanied by lower NOx emission levels. During gasoline testing referred to previously, lower NOx levels were noted only when there were no substantial reductions in HC and CO during Bag 1. The use of the Heat Battery without preheat actually reduced NOx levels by 9 percent from 2.3 grams to 2.1 grams. However, when preheating the engine for 60 seconds, NOx levels increased 19 percent from no preheat levels, an overall increase of 9 percent from the stock value.

Table 7
Schatz Heat Battery, 20°F Testing
Bag 1 of FTP Cycle

<table>
<thead>
<tr>
<th>Category</th>
<th>*HC g</th>
<th>CO g</th>
<th>NOx g</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>16.88</td>
<td>169.6</td>
<td>2.3</td>
<td>11.9</td>
</tr>
<tr>
<td>No Preheat</td>
<td>12.54</td>
<td>73.5</td>
<td>2.1</td>
<td>13.4</td>
</tr>
<tr>
<td>Preheat</td>
<td>2.53</td>
<td>28.4</td>
<td>2.5</td>
<td>14.4</td>
</tr>
</tbody>
</table>

* Gasoline-fueled vehicle measurement procedure with a propane calibrated FID.
Table 8 presents composite FTP emission levels and fuel economy results for M85 testing at 20°F. Again, Bag 1 reductions of hydrocarbons and CO are consistent with FTP emission rate reductions. For instance, the 83 percent reduction in Bag 1 CO when preheating resulted in an FTP emission rate reduction of 73 percent. The changes in Bag 1 NOx levels during this testing did not affect composite FTP NOx rates. FTP fuel economy only increased by 4 percent from 14.0 to 14.6 miles per gallon with no preheat, then remained constant at 14.6 miles per gallon when a preheat period was utilized.

Table 8

Schatz Heat Battery, 20°F Testing
Composite FTP Emission Levels

<table>
<thead>
<tr>
<th>M85 Fuel</th>
<th>Category</th>
<th>*HC g/mi</th>
<th>CO g/mi</th>
<th>NOx g/mi</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>1.44</td>
<td>11.4</td>
<td>0.2</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>No Preheat</td>
<td>0.96</td>
<td>5.7</td>
<td>0.2</td>
<td>14.6</td>
<td></td>
</tr>
<tr>
<td>Preheat</td>
<td>0.24</td>
<td>3.1</td>
<td>0.2</td>
<td>14.6</td>
<td></td>
</tr>
</tbody>
</table>

* Gasoline-fueled vehicle measurement procedure with a propane calibrated FID.

After the cold room M85 testing was completed, the same Heat Battery configurations were tested at an ambient temperature of 75°F. Figure 13 presents Bag 1 exhaust methanol levels for each Heat Battery configuration evaluated at this temperature. Without preheat, exhaust methanol levels were reduced from 2.96 grams to 2.76 grams, a 7 percent reduction. When utilizing a preheat period, methanol emissions were reduced an additional 15 percent to 2.30 grams, an overall reduction of 22 percent from stock levels.

Bag 1 CO results are given in Figure 14. Without preheat, CO emission levels increased 9 percent, to 22.6 grams from 20.7. No reason for this unexpected occurrence is given here. Again, there were no unusual driving conditions, engine or Heat Battery problems noted during this testing. With a 60 second preheat, however, CO levels dropped to 12.3 grams, a 41 percent reduction from stock levels.
Figure 13
M85 Fuel, 75 Deg. F Testing
Methanol Emissions, Bags 1&3

Heat Battery Configuration

- Stock, Bag 1: 2.96 grams
- Stock, Bag 3: 0.29 grams
- No Preheat, Bag 1: 2.78 grams
- No Preheat, Bag 3: 0.3 grams
- Preheat, Bag 1: 2.3 grams
- Preheat, Bag 3: 0.33 grams

Figure 14
M85 Fuel, 75 Deg. F Testing
Carbon Monoxide Emissions, Bags 1&3

Heat Battery Configuration

- Stock, Bag 1: 20.7 grams
- Stock, Bag 3: 3.9 grams
- No Preheat, Bag 1: 22.6 grams
- No Preheat, Bag 3: 4.7 grams
- Preheat, Bag 1: 12.3 grams
- Preheat, Bag 3: 4.7 grams
Formaldehyde levels measured during this testing are presented here in Figure 15. Although there was only small amounts of exhaust formaldehyde noted with gasoline fuel during Bag 1, an increase was noted when a preheat period was used. However, with M85 fuel, formaldehyde levels decreased with the use of the Heat Battery. Without preheating, Bag 1 formaldehyde levels are reduced from 274 milligrams to 231 milligrams, a reduction of 16 percent. Preheating reduces formaldehyde an additional 12 percent to 197 milligrams. This results in a 28 percent reduction in Bag 1 formaldehyde levels.

Figure 15

M85 Fuel, 75 Deg. F Testing
Formaldehyde Emissions, Bags 1&3

Heat Battery Configuration

<table>
<thead>
<tr>
<th>Condition</th>
<th>Bag 1</th>
<th>Bag 3</th>
</tr>
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<tbody>
<tr>
<td>Stock, Bag 1</td>
<td>274</td>
<td></td>
</tr>
<tr>
<td>Stock, Bag 3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>No Preheat, Bag 1</td>
<td>231</td>
<td></td>
</tr>
<tr>
<td>No Preheat, Bag 3</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Preheat, Bag 1</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td>Preheat, Bag 3</td>
<td>5</td>
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</table>

Fuel economy values from this testing are given in Table 9. There was no significant change in fuel economy without preheating during Bag 1. With the use of a preheat period, Bag 1 fuel economy improved from 14.9 miles per gallon to 15.2 miles per gallon, a very small 2 percent improvement from stock levels. NOx levels remained approximately constant during each Heat Battery configuration at about 1.1 grams during this testing. It was observed that with M85 fuel, reductions in measured hydrocarbons and methanol exhaust levels were approximately equal in each Heat Battery configuration evaluated. For example, with a 60 second preheat at 75°F, measured hydrocarbons were reduced by 20 percent whereas exhaust methanol levels were reduced 22 percent during Bag 1.
Table 9
Schatz Heat Battery, 75°F Testing
Bag 1 of FTP Cycle

M85 Fuel

<table>
<thead>
<tr>
<th>Category</th>
<th>NMHC</th>
<th>HC</th>
<th>CH3OH</th>
<th>HCHO</th>
<th>CO</th>
<th>NOx</th>
<th>MPG</th>
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</thead>
<tbody>
<tr>
<td>Stock</td>
<td>0.67</td>
<td>1.75</td>
<td>2.96</td>
<td>274</td>
<td>20.7</td>
<td>1.1</td>
<td>14.9</td>
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<tr>
<td>No Preheat</td>
<td>0.63</td>
<td>1.65</td>
<td>2.76</td>
<td>231</td>
<td>22.6</td>
<td>1.0</td>
<td>14.8</td>
</tr>
<tr>
<td>Preheat</td>
<td>0.56</td>
<td>1.40</td>
<td>2.30</td>
<td>197</td>
<td>12.3</td>
<td>1.1</td>
<td>15.2</td>
</tr>
</tbody>
</table>

* Gasoline-fueled vehicle measurement procedure with a propane calibrated FID.

The composite FTP results are presented in Table 10 below. Again, FTP composite levels of methanol and CO follow the same trend as Bag 1 changes. Measured hydrocarbon changes were approximately equal to exhaust methanol changes during this testing also. For example, the 14 percent reduction in FTP composite levels of methanol seen when preheating resulted in an 8 percent reduction in measured hydrocarbons. Composite FTP NOx levels and fuel economy results remained unchanged. Formaldehyde FTP levels decreased by 21 percent when the engine was preheated for 60 seconds.

Table 10
Schatz Heat Battery, 75°F Testing
Composite FTP Emission Levels

M85 Fuel

<table>
<thead>
<tr>
<th>Category</th>
<th>NMHC</th>
<th>HC</th>
<th>CH3OH</th>
<th>HCHO</th>
<th>CO</th>
<th>NOx</th>
<th>MPG</th>
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</thead>
<tbody>
<tr>
<td>Stock</td>
<td>0.02</td>
<td>0.12</td>
<td>0.22</td>
<td>19</td>
<td>1.8</td>
<td>0.1</td>
<td>14.7</td>
</tr>
<tr>
<td>No Preheat</td>
<td>0.03</td>
<td>0.13</td>
<td>0.21</td>
<td>18</td>
<td>2.3</td>
<td>0.1</td>
<td>14.5</td>
</tr>
<tr>
<td>Preheat</td>
<td>0.02</td>
<td>0.11</td>
<td>0.19</td>
<td>15</td>
<td>1.5</td>
<td>0.1</td>
<td>14.8</td>
</tr>
</tbody>
</table>

* Gasoline-fueled vehicle measurement procedure with a propane calibrated FID.
IX. Evaluation Highlights

1. The addition of a Schatz Heat Battery, with a 60 second preheat period prior to the start of the FTP, reduced Bag 1 CO emission levels approximately 80 percent for both gasoline and M85 fuels when tested at an ambient temperature of 20°F. Substantial cold temperature CO reductions were also observed without a preheat period during the Bag 1 segment of the FTP. CO emissions were reduced over 50 percent for both fuels when tested at this ambient temperature without a preheat.

Significant reductions of CO, when tested in an ambient temperature of 75°F, were only observed when preheating the engine. With a preheat, the heat battery was able to reduce CO levels by 60 percent with gasoline fuel and 40 percent with M85 fuel at this temperature.

2. A substantial reduction in unburned fuel was also noted during testing at 20°F. With gasoline fuel, unburned hydrocarbons during Bag 1 were reduced 35 percent with the addition of the Heat Battery and almost 70 percent with the Heat Battery plus a preheat, when compared to stock levels. Reductions in unburned fuel emissions were noted during 75°F testing, however, these reductions were not as great as 20°F results. A 10 percent reduction was noted without a preheat at this temperature and a 12 percent reduction with a preheat for gasoline fuel.

Exhaust methanol measurement capabilities were not present during cold room testing. Thus, for M85 fuel tested at 20°F, measured hydrocarbon emission levels are presented. These values were obtained by treating the exhaust as if the fuel were gasoline. HC levels were reduced 26 percent without a preheat period and 85 percent with a preheat when compared to stock levels. There was also a reduction of exhaust methanol for testing at 75°F. Methanol exhaust levels were reduced 7 percent without preheating and 22 percent with a preheat period when compared to stock levels.

3. Fuel consumption is very high during the cold start Bag 1 portion of the FTP. By heating the engine to a steady-state operating condition faster, fuel economy was improved during the Bag 1 portion of the FTP with both gasoline and M85 fuels during testing at 20°F.

For gasoline fuel, fuel economy improved by 9 percent during Bag 1 without a preheat. A 14 percent improvement was noted when preheating at the same conditions. Greater fuel economy improvements with M85 fuel were noted during 20°F testing. Bag 1 fuel economy improved 13 percent without preheating and 18 percent with preheating. No significant improvements were noted in fuel economy when tested at 75°F for either fuel.
X. **Future Efforts**

Future efforts will be made to better quantify the relationship between coolant temperature, exhaust temperature, and catalyst efficiency. A Horiba modal analysis system has been installed at EPA Motor Vehicle Emission Laboratory, and this analyzer will be used to monitor second-by-second exhaust emission levels both before and after the catalytic converter. While it is not possible to obtain methanol or formaldehyde modal analysis, CO, NOx, and FID-measured hydrocarbon emission levels will be determined. It is also not possible to perform modal analysis at an ambient temperature of 20°F.

Future efforts will also include the reconfiguration of the coolant system to remove the electric valves. The coolant will also no longer pass through the oil cooler/heater. These results will better represent the use of the Schatz Heat Battery as an emissions control device. The Heat Battery will then be physically removed from the test vehicle to obtain true stock emission levels.

The work described above will first be carried out with gasoline fuel. Once capabilities are installed, M85 and M100 fuels will also be utilized for modal analysis.

XI. **Acknowledgments**

The Schatz Heat Battery evaluated in this test program was supplied by Autotech Associates, Inc., located in Farmington Hills, Michigan. Autotech is the United States representative for Schatz Thermo Engineering of Munich, Germany, the manufacturers of the Heat Battery. The flexible-fueled Audi test vehicle was supplied by Volkswagen of America.

The authors appreciate the efforts of James Garvey, Steven Halfyard, Robert Moss, Rodney Branhm, and Ray Ouillette of the Test and Evaluation Branch, ECTD, who conducted the driving cycle test and prepared the methanol and formaldehyde samples for analysis. The authors also appreciate the efforts of Jennifer Criss and Leslie Cribbins of CTAB, ECTD, for word processing and editing support.

XII. **References**


APPENDIX A

Test Vehicle Specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Vehicle Type</td>
<td>1990 Audi 80</td>
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<tr>
<td>Fuel</td>
<td>Indolene Clear, M85</td>
</tr>
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<td>Mileage When Received</td>
<td>5,000 miles 8,000 kilometers</td>
</tr>
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<td>Engine:</td>
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</tr>
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<td>Cylinders</td>
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<td>Displacement</td>
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<td>Bore</td>
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</tr>
<tr>
<td>Stroke</td>
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</tr>
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<td>Compression Ratio</td>
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</tr>
<tr>
<td>Maximum Output</td>
<td>75 kW at 5,500 rpm with gasoline</td>
</tr>
<tr>
<td></td>
<td>80 kW at 5,500 rpm with M85</td>
</tr>
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<td>Oxygen controlled closed loop system with a 3-way catalyst</td>
</tr>
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<td>Fuel System</td>
<td>Fuel Injection, Digifant II/I-System</td>
</tr>
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<td></td>
<td>Modified for Multi-Fuel Operation</td>
</tr>
<tr>
<td>Transmission Type</td>
<td>5-speed Manual</td>
</tr>
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<td>Equivalent Test Weight</td>
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