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Technical Report

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

Phase II

by

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OFFICE OF
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MEMORANDUM

SUBJECT: Exemption From Peer and Administrative Review

FROM: Karl H. Hellman, Chief
Technology Development Group

TO: Charles L. Gray, Jr., Director
Regulatory Programs and Technology Division

The attached report entitled "Evaluation Of A Schatz Heat Battery On A Flexible-Fueled Vehicle - Phase II" (EPA/AA/TDG/92-03) describes the evaluation of a Schatz Heat Battery as a means of reducing cold start emissions from a vehicle fueled alternately with indolene clear and M85 high methanol blend fuels. This evaluation was conducted at both 20 and 75°F ambient temperatures.

The Heat Battery was previously evaluated, and the results of this preliminary evaluation were presented in the technical report EPA/AA/CTAB/91-05. The coolant system was then reconfigured in an attempt to further reduce cold start emissions. This report presents the results obtained during this later evaluation.

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: ______________________ Date: ________
Charles L. Gray, Jr., Dir., RPT

cc: E. Burger, RPT

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I. Summary

The Schatz Heat Battery stores waste latent heat energy from engine exhaust. At cold start, this stored heat is returned by conduction to the engine coolant which in turn heats the cold engine; an auxiliary pump can circulate the coolant at cold start. A Schatz Heat Battery was evaluated by EPA to reduce emissions of unburned fuel and carbon monoxide (CO) during cold start (Bag 1) of the CVS-75 Federal Test Procedure (FTP). This evaluation was a continuation of testing previously reported on.[1]

The Heat Battery was installed on a flexible-fueled vehicle and emission tested at ambient temperatures of 20°F and 75°F while operating on either indolene or M85 methanol blend fuels. Through a valve system, the heater core could be removed from the coolant system. ("Core Out", below, refers to testing with the heater core taken out of the coolant system.) "Preheat" signifies engine warming for 60 seconds prior to cold start in the FTP.

Table 1 presents Bag 1 percent changes from stock for each pollutant and fuel economy variations resulting from several Heat Battery strategies at both 20°F and 75°F ambient temperatures with gasoline fuel. Stock emissions are from previous EPA testing.[1]

Table 1

Schatz Heat Battery Evaluation
Indolene Clear Fuel, Bag 1 of FTP

Percent Changes From Stock

Configuration	HC	CO	MPG
Testing at 20°F Ambient Conditions			
Core In/No Preheat/20°F	-46	-56	+ 7
Core In/Preheat/20°F	-63	-71	+ 8
Core Out/No Preheat/20°F	-50	-58	+ 8
Core Out/Preheat/20°F	-66	-73	+10
Core Out/20°F/ 2-Minute Preheat	-63	-73	+ 3
Testing at 75°F Ambient Conditions			
Core In/No Preheat/75°F	-22	-37	+ 2
Core In/Preheat/75°F	+ 3	-62	+ 2
Core Out/No Preheat/75°F	-19	-27	NC
Core Out/Preheat/75°F	+ 4	-58	+ 3

NC No change.

A negative number in Table 1 indicates a reduction from the stock emission level occurred. With the Core In the coolant system at a cold soak temperature of 20°F, Bag 1 levels of unburned HC and CO decreased 66 and 73 percent respectively when preheating for 60 seconds. Bag 1 fuel economy also slightly improved (10 percent) with this Heat Battery configuration at 20°F conditions. An extended preheat period (2 minutes) and Core Out had little effect on further lowering cold start emission levels of HC and CO but did result in a slight fuel economy reduction from the levels obtained with the 60-second preheat period.

Bag 1 emission level reductions at 75°F were much lower than those obtained during 20°F testing. The largest reduction of unburned HC occurred with Core In the coolant circuit and no preheat, 22 percent from stock. Bag 1 fuel economy also increased slightly with this configuration. The largest reduction in Bag 1 CO (62 percent from stock) was obtained with Core In and preheat. The vehicle was also soaked at 20°F for 11 days to test the heat storage duration capability of the Heat Battery. The vehicle was tested over the FTP cycle on indolene fuel; the Heat Battery configuration used was Core Out with a 60-second preheat period. This test resulted in 50 percent reductions from stock for both Bag 1 hydrocarbons and CO, and a slight increase in Bag 1 fuel economy.

Testing continued over the same schedule with M85 methanol blend fuel. Table 2 presents emission changes from stock with M85.

Table 2

Schatz Heat Battery Evaluation
M85 Fuel, Bag 1 of FTP

Percent Changes From Stock

Configuration	HC	CO	MPG
Testing at 20°F Ambient Conditions			
Core In/No Preheat/20°F	+14	+ 1	+ 3
Core In/Preheat/20°F	-58	-72	+13
Core Out/No Preheat/20°F	- 8	-23	+ 7
Core Out/Preheat/20°F	-60	-54	+19
Testing at 75°F Ambient Conditions			
Core In/No Preheat/75°F	+13	-19	+ 1
Core In/Preheat/75°F	-25	-54	+ 2
Core Out/No Preheat/75°F	+15	- 6	+ 1
Core Out/Preheat/75°F	- 7	-55	+ 3

Significant reductions were noted in Bag 1 levels of emissions measured as hydrocarbons and CO when M85 fuel was used during 20°F testing. The greatest reductions in Bag 1 emissions at 20°F (60 percent for HC and 72 percent for CO) occurred with a 60-second preheat period. Bag 1 fuel economy at this temperature also increased by 19 percent with Core Out of the coolant system and preheating. However, with Core In and no preheat, Bag 1 levels of emissions measured as hydrocarbons and CO increased above stock configuration levels.

The maximum reduction in Bag 1 hydrocarbons at 75°F occurred with Core In and preheat, a 25 percent reduction from stock. The maximum reduction in Bag 1 CO resulted with Core Out of the coolant system and preheat, 55 percent from stock emission levels.

In the absence of a preheat period during testing at 75°F, Bag 1 hydrocarbons increased above stock configuration levels. However, even though hydrocarbons increased, Bag 1 CO levels decreased for both configurations without preheat. Increases in Bag 1 fuel economy were also noted for each Heat Battery configuration tested at 75°F.

Several engine modifications and repairs were performed by Volkswagen of America (VW) at the conclusion of this testing. The engine repairs included replacement of the fuel injectors, the oxygen sensor, and the fuel composition sensor. The engine coolant temperature sensor was also relocated from the radiator loop to the outlet of the engine. The vehicle was then returned to EPA for additional testing at 75°F at the request of VW and Schatz Thermo Engineering.

During the testing that followed, the test vehicle stalled during Bag 1 on many tests that included a preheat period. One test conducted on M85 fuel that utilized a preheat period did not experience a stall in Bag 1, however. During this single test, Bag 1 hydrocarbons and CO were reduced 52 and 65 percent from stock. This same configuration also resulted in a 3 percent fuel economy increase over Bag 1. When gasoline fuel was used without preheat, Bag 1 hydrocarbon and CO reductions from stock levels were 16 and 42 percent respectively.

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.[2,3,4] Emissions of oxides of nitrogen (NOx) at cold start are generally much lower than 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.[5]

Cold start emissions of unburned fuel (UBF) and CO from late model vehicles are much higher when testing over the FTP at lower ambient temperatures such as 20°F.[6] These higher levels of unburned fuel and CO result partly from an increased period of fuel enrichment, cold cylinder/intake manifold walls, and an extended period before catalyst light-off occurs. 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 at low ambient temperatures.[7]

One way to reduce cold start UBF and CO emissions from either gasoline or M100-fueled vehicles is to reduce the catalyst light-off time. EPA is interested in catalyst preheating and has evaluated electrically heated catalyst (EHC) technologies with favorable results.[2,3,6,8,9,10,11] This resistive heating reduces the time during which the catalyst remains ineffective because of insufficient warming by the cold exhaust gas.

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 is generally a function of engine temperature. If the engine is heated to operating temperature faster, the period of enrichment to ensure good driveability might be correspondingly reduced.

Schatz Thermo Engineering, Munich, Germany, has developed 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 the heat energy have included passenger compartment heating [12], the discussion in this report will be 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 at the EPA National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan [1], was conducted using both gasoline and M85 high methanol blend fuels. This evaluation was conducted at both 75°F and 20°F ambient temperatures. At 20°F, Bag 1 levels of HC and CO were reduced 69 and 76 percent respectively from stock levels when gasoline fuel was used (a 60-second preheat period was used to obtain these results). Bag 1 HC and CO were reduced 85 and 83 percent respectively from stock with a similar preheat period at 20°F with M85 fuel. A substantial improvement in Bag 1 fuel economy was also noted during this testing with both fuels.

The manufacturer of the Heat Battery stated that significant improvements in emissions could be obtained with minor adjustments to the coolant circuit. The circuit was rerouted to transfer more stored heat to the cold engine block. The placement of the Heat Battery in the coolant system is detailed below in Section IV., Description of Test Vehicle and Coolant Configuration. The vehicle was then retested on both gasoline and M85 fuels at 20°F and 75°F ambient temperatures; the results from this latest testing are presented in this report.

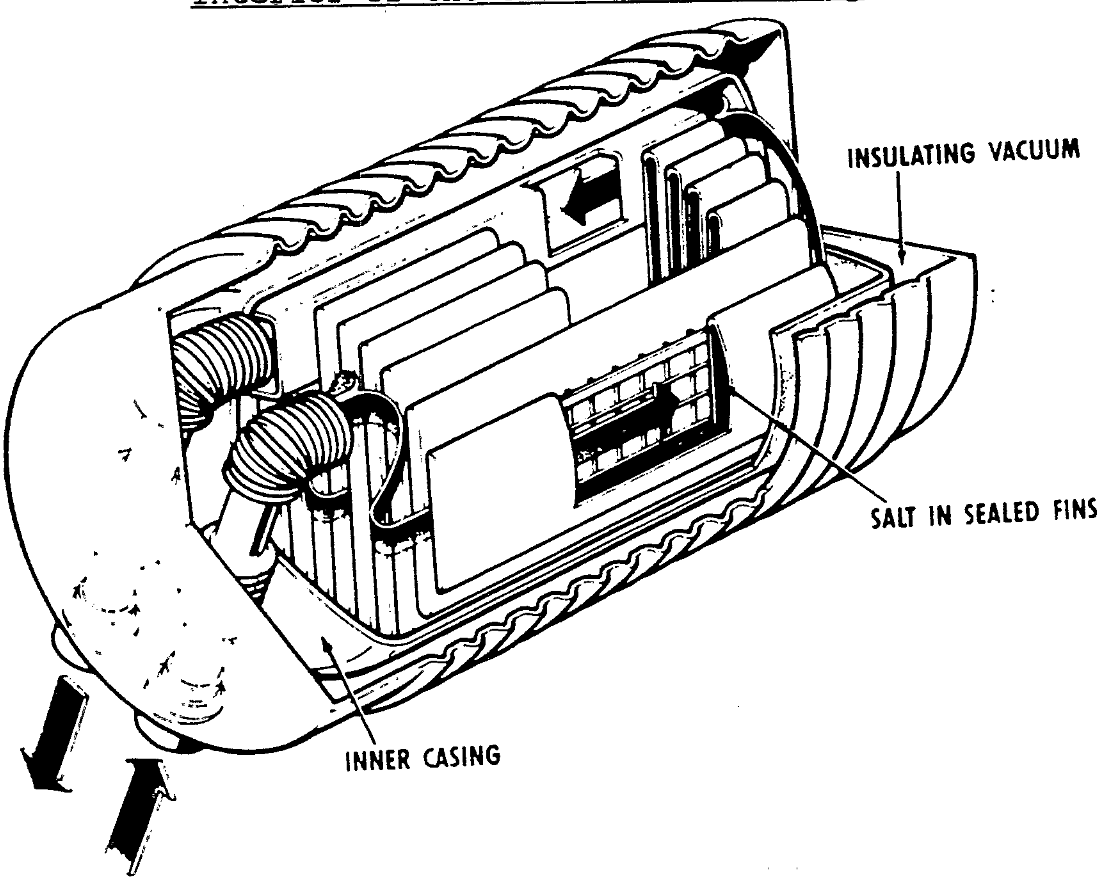
III. Description of Schatz Heat Battery

The Schatz Heat Battery is a latent heat storage device which accumulates waste heat from the engine's coolant and can store this heat for an extended period of time. Upon or before engine cold start, the Heat Battery releases this stored energy to the coolant; the warmed coolant heats the engine to operating temperature faster.

Figure 1 below is a picture of the interior of a Heat Battery. This unit is cylindrical in shape with dimensions of 370 mm length, 170 mm outside diameter, and a total weight of approximately 10 kg. The heat release capacity is 600 Wh when cooled from 176°F to 122°F.

Figure 1

Interior of the Schatz Heat Battery



The core of the Heat Battery consists of stacked, flat-sheet metal elements that contain the heat storage salts. If the coolant temperature flowing between the stacked elements exceeds the heat storage mass melting point (167°F), latent heat is absorbed and stored. During cold start, the stored heat is then transferred to the cold engine head through coolant circulated by an auxiliary pump. Once the circulating coolant temperature exceeds the temperature of the salt, the Heat Battery begins to recharge.

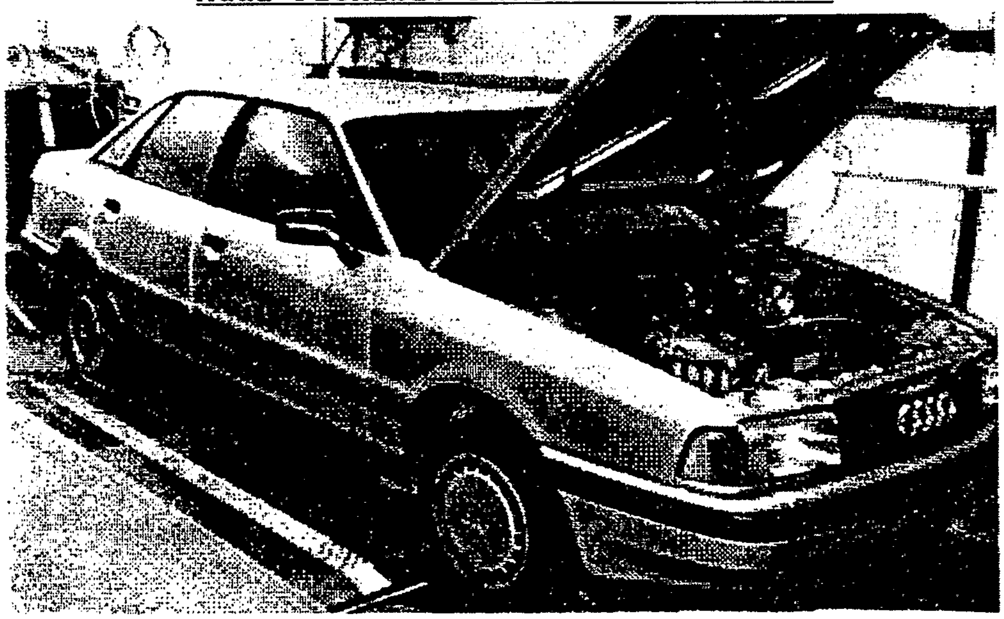
The heat storage mass inside the sealed metal elements is the molten salt $Ba(OH)_2{*}8H_2O$. The latent heat of the pure molten salt is 88.5 Wh/kg, and the heat conductivity in its solid state is 1.26 W/mK. The Heat Battery core is surrounded by high-vacuum insulation which limits ambient heat losses to approximately 3 W at -4°F, according to Schatz Thermo Engineering.

IV. Description of Test Vehicle and Coolant Configuration

The test vehicle was a flexible-fueled (M0 through M85) 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 accumulated 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 pounds) ETW and 6.4 actual dynamometer horsepower. This vehicle was loaned to the U.S. EPA by Volkswagen of America. A picture of this vehicle is presented as Figure 2.

Figure 2

Audi Flexible-Fueled Test Vehicle

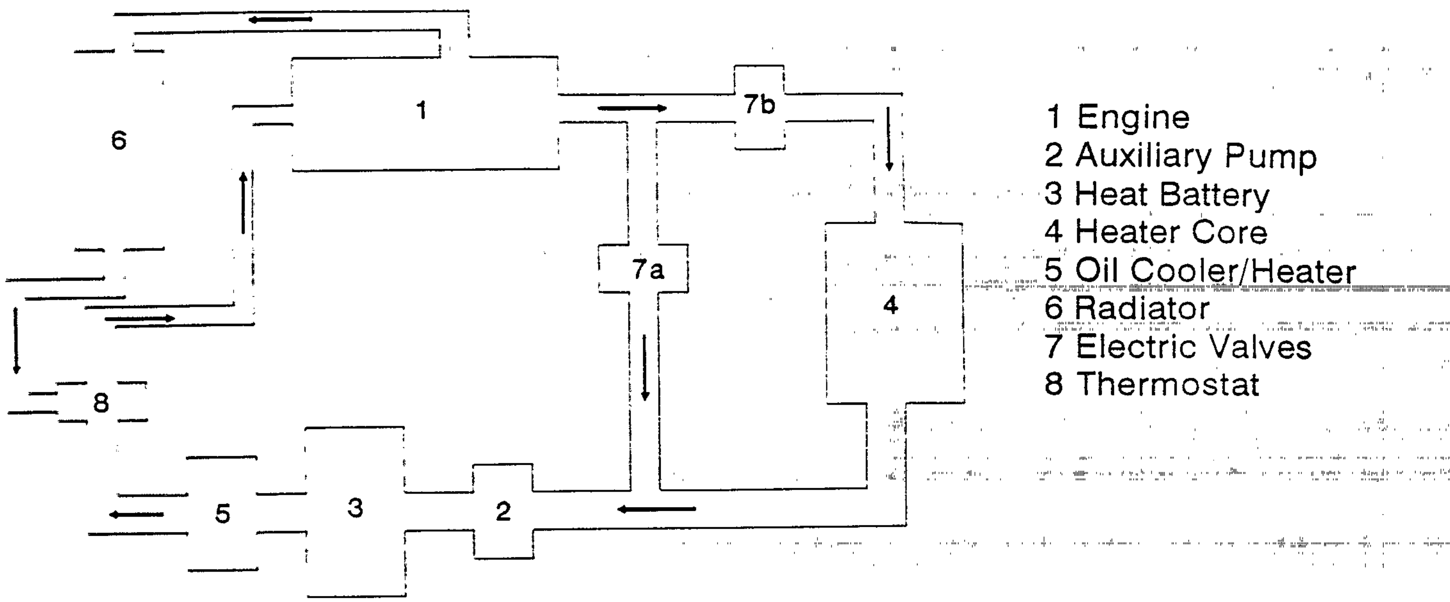


A detailed description of the test vehicle and special methanol-blend modifications is included as Appendix A.

A schematic diagram of the new coolant configuration was provided to EPA by Schatz Thermo Engineering. Figure 3 below is a schematic diagram of the reconfigured coolant system as it was tested here by EPA.

Figure 3

Coolant System Configuration



Two switches inside the passenger compartment dictated the Heat Battery configuration. One 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 Heat Battery (3) prior to key-on of the FTP. The Heat Battery was then able to transfer the stored heat to the cold coolant, and thus to the engine (1) prior to start of the FTP. At this point, the thermostat (8) is still closed so that none of the coolant passes through the radiator (6). This engine warming prior to key on cold start is referred to here as a "preheat" test. If a "no preheat" test was desired, the auxiliary pump remained off until the start of the FTP.

The auxiliary pump operated during the entire FTP to supply the maximum amount of stored heat to the engine during idle. With the pump operating, the coolant flow approximately doubled during the first acceleration of the FTP cycle.

The second switch inside the passenger compartment removed the heater core from the coolant system. If a test was desired with the heater core out (Core Out) of the coolant system, this switch would close valve 7b and open 7a. During cold start, this action allowed coolant to pass from the engine (1), through valve 7a, the auxiliary pump (2), the Heat Battery (3), the oil cooler/heater (5), and back to the engine.

The Heat Battery was present in the coolant system for each test conducted in this evaluation. Baseline levels presented in this report were obtained during the Phase I evaluation and were published in an earlier report.[1] No heat was supplied to the passenger compartment during any test conducted in this evaluation.

V. Test Facilities And Analytical Methods

Two dynamometer sites were used for this testing. 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. The 75°F site utilized a Philco Ford constant volume sampler that has a nominal capacity of 600 cfm, and the 20°F site used a similar model with a nominal capacity of 350 cfm. Both test sites used similar emission analyzers. Exhaust hydrocarbon 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. Methane emissions were quantified with a Model 8205 Bendix methane analyzer.

Exhaust formaldehyde and methanol emission samples were only 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 hydrazone 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 used by EPA 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 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 the EPA cold room test cell was not equipped to measure methanol and formaldehyde emissions, measurements using gasoline fuel procedures are included here.

VI. Test Procedures

This program had as its goal the evaluation of a Schatz Heat Battery for the reduction of cold start unburned fuel and CO emission levels with both gasoline and M85 fuels. This Phase II evaluation was performed with a reconfigured coolant system to further reduce cold start emissions below those noted during the initial Phase I evaluation.[1]

This evaluation consisted of five phases, discussed separately in the Discussion of Test Results section below. The first phase determined the effect of auxiliary pump on cold start emissions of unburned fuel and CO when the pump operated during the entire FTP. The auxiliary pump was used to provide the maximum amount of heat to the engine during a cold start by circulating more coolant than a standard water pump. This testing was conducted at a soak temperature of 75°F with gasoline fuel. All tests here were conducted over the FTP cycle.

The second phase of this evaluation was conducted at ambient temperatures of 75°F and 20°F with gasoline fuel. Five Heat Battery configurations were evaluated at 20°F and four at 75°F. Table 3 below presents a summary of these configurations.

Table 3

Heat Battery Configurations Evaluated
Indolene Clear Fuel, FTP Cycle

20°F Testing		
Configuration	Heater Core In/Out	Preheat (?)
1	In	No
2	In	Yes (60 Seconds)
3	Out	No
4	Out	Yes (60 Seconds)
5	Out	Yes (2 Minutes)
75°F Testing		
1	In	No
2	In	Yes (60 Seconds)
3	Out	No
4	Out	Yes (60 Seconds)

The third phase of this evaluation consisted of the same ambient temperature and Heat Battery configuration testing discussed above, except that M85 fuel was utilized. No 2-minute preheat tests were conducted with M85 fuel, however.

The fourth phase consisted of a single test after the vehicle had soaked at an ambient temperature of 20°F for an 11-day period. The Heat Battery configuration for this test utilized the Core Out of the coolant system with a 60-second preheat period. This test was conducted to determine the Heat Battery's heat storage capability over extended soak periods. The final phase consisted of retests done at the request of the manufacturer of the Heat Battery.

VII. Heat Battery Effect

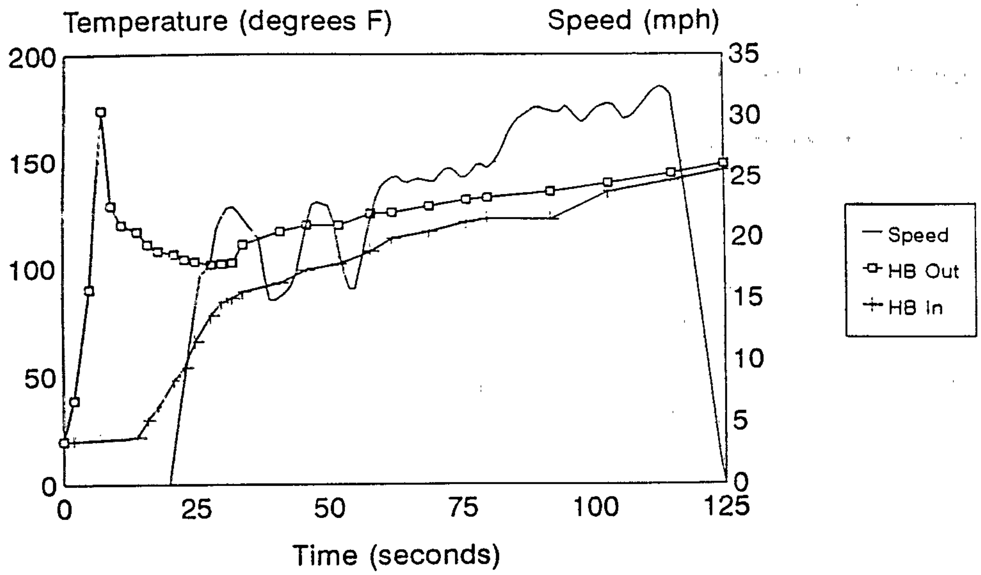
During each FTP cycle test conducted during this evaluation, coolant temperature was monitored in several locations. Coolant flowrates were also measured over the entire FTP cycle with and without the auxiliary pump running.

Thermocouples were installed to monitor coolant temperature at three different locations. The first thermocouple was located approximately 25 mm from the entrance of the Heat Battery, denoted here as Heat Battery In temperature. The second thermocouple was located approximately 250 mm from the exit of the Heat Battery, denoted here as Heat Battery Out temperature. The last thermocouple was located approximately 240 mm from the exit of the oil cooler/heater, referred to as oil cooler/heater out temperature.

A flowmeter was installed to measure flow in the coolant system. With the auxiliary pump, the flow remained relatively constant throughout the FTP at about 2.2 gallons/minute. The coolant flow and temperature data enable a rough estimate of the heat supplied to the cold engine during a test with the Core Out of the coolant system. The Heat Battery was considered "fully-charged" when the Heat Battery In/Out temperatures were equal.

Figure 4 below presents coolant temperature into and out of the Heat Battery and vehicle speed/time data for the first 125 seconds of the FTP cycle. Oil cooler/heater In and Heat Battery Out temperatures are denoted here as equal, because it was assumed that a negligible amount of heat was lost from the coolant during travel from the Heat Battery to the oil cooler/heater. Oil Cooler/Heater Out coolant temperatures were approximately equal to Heat Battery Out temperatures and were not included in Figure 4. The data presented in Figure 4 was obtained with the Core Out of the coolant system, with indolene fuel, and at an ambient temperature of 20°F.

Figure 4
Heat Battery Effect On Coolant Temperature Bag 1 Cold Start, 20 Deg. F Conditions



The trace labeled "HB Out" represents the temperature of the coolant leaving the Heat Battery and entering the oil cooler/heater. The path labeled "HB In" represents the temperature of the coolant leaving the engine and entering the Heat Battery. The "HB Out" path was similar to the "Oil Cooler/Heater Out" trace and therefore is representative of the coolant temperature entering the engine. The heater core was not present in the coolant system (Core Out) when these tests were conducted.

The initial spike in "HB Out" 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 spike was above the melting point of the molten salt, 167°F, an indication of a "charged" Heat Battery.

The maximum temperature difference between "HB Out" and the temperature of the engine at cold start (20°F) is approximately 155°F. The coolant flow remained relatively constant at approximately 2.2 gallons per minute for the duration of the FTP with the auxiliary pump operating. This information may be used to estimate a maximum heat transfer rate at cold start, approximately 43.5 kW. This maximum rate decreases sharply with time, however. (Figure 4)

VIII. Discussion of Test Results

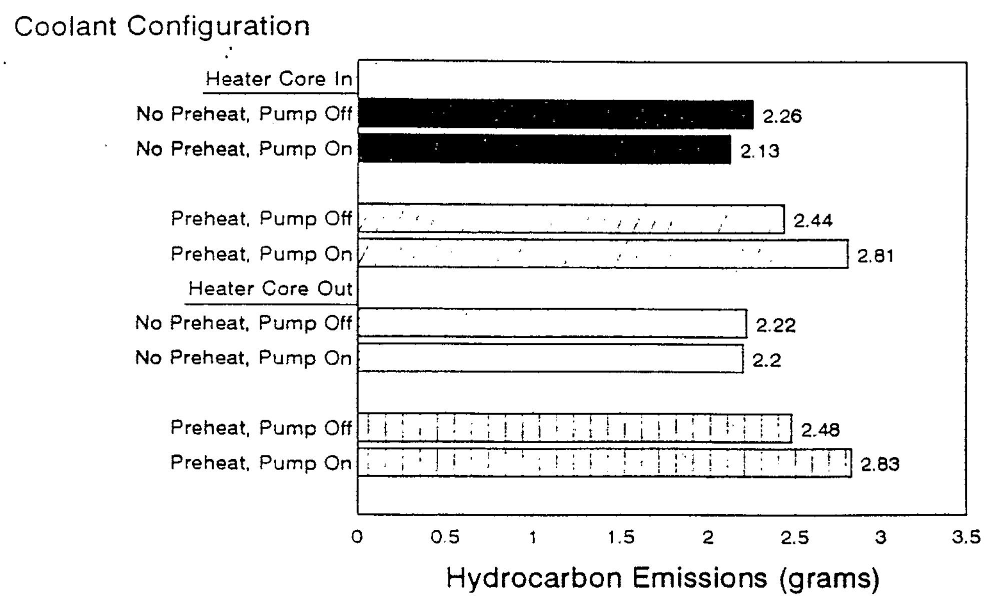
A. Auxiliary Pump Effect

This evaluation consisted of five separate phases. The first phase investigated the effect of operating the auxiliary coolant pump during the entire FTP cycle (except for the 10-minute soak period before the Bag 3 segment). All testing during this phase was conducted over the FTP at an ambient temperature of 75°F with indolene fuel. Bag 1 emission levels are given in grams (g) over the test segment (Bag 1) except for formaldehyde, which is presented in milligrams (mg) over Bag 1. Composite FTP emissions are given in grams per mile (g/mi) except formaldehyde, given in milligrams per mile (mg/mi).

Four separate Heat Battery configurations were evaluated here. The first had the heater core present in the coolant system (Core In) and no preheat period (preheat signifies circulation of the coolant by the auxiliary pump for 60 seconds prior to key-on). The second configuration had the Core In the coolant circuit with a 60-second preheat. The final two configurations had the heater core out of the coolant system (Core Out) with/without a 60-second preheat period. The vehicle was first tested over each of these configurations with the auxiliary pump inoperative during the FTP, then tested again over the same four configurations with the pump running during the entire FTP cycle. The results from this testing are presented below.

Figure 5 below presents Bag 1 hydrocarbon levels noted during this testing at 75°F conditions. Preheating occurred when the auxiliary pump operated for 60 seconds prior to key-on in Bag 1.

Figure 5
Auxiliary Pump Effect, 75 Deg. F Testing
Indolene Fuel, Bag 1 HC Levels



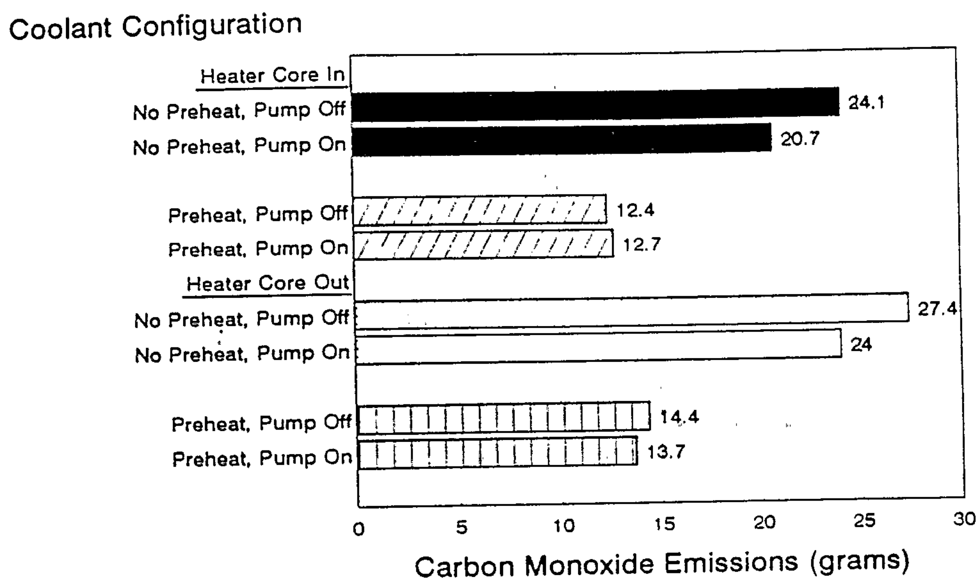
The top bar presented in Figure 5 denotes the Bag 1 hydrocarbon level measured with Core In the coolant system, the auxiliary pump off during the FTP cycle (Pump Off), and no preheat utilized (No Preheat). The remaining bars represent variations of heater core position, preheat, and pump operating strategy.

Operating the auxiliary pump during the entire FTP had a small effect on Bag 1 hydrocarbons. With the Core In the coolant system and no preheat, Bag 1 hydrocarbons decreased approximately 6 percent by operating the pump during the FTP. With the Core Out of the coolant system and no preheat, Bag 1 hydrocarbons were approximately equal for testing with and without the pump operating during the FTP cycle.

Using a 60-second preheating period for the Heat Battery unexpectedly resulted in higher Bag 1 hydrocarbon emissions, however. With both the Core In/Out configurations, hydrocarbon emissions were also higher when the auxiliary pump continued to operate during the entire FTP.

Figure 6 below presents Bag 1 CO levels for the same testing configurations referred to in Figure 5.

Figure 6
Auxiliary Pump Effect, 75 Deg. F Testing
Indolene Fuel, Bag 1 CO Levels



With the Core In the coolant system and no preheat, Bag 1 CO levels decreased approximately 14 percent by running the auxiliary pump during the FTP cycle. When a 60-second preheat period was utilized with this Heat Battery configuration, Bag 1 levels of CO remained the same regardless of the pump operating strategy.

With the Core Out of the coolant system, Bag 1 CO levels slightly decreased with the operation of the pump during the FTP. Without preheat and the Core Out, Bag 1 levels of CO decreased 12 percent when the pump continued to operate during the FTP. Operating the pump over the FTP with a 60-second preheat period reduced Bag 1 levels of CO about 5 percent.

Table 4 below presents all Bag 1 emission levels noted during this testing. "PH" represents a 60-second preheating period.

Table 4

Auxiliary Pump Effect, 75°F Testing
Bag 1 Emission Levels

Indolene Clear Fuel

Configuration	NMHC g	HC g	HCHO mg	CO g	NOx g	MPG
Core In/Pump Off/No PH*	2.06	2.26	32	24.1	1.6	25.9
Core In/Pump On/No PH	1.93	2.13	36	20.7	2.1	25.6
Core In/Pump Off/PH**	2.29	2.44	44	12.4	1.8	25.9
Core In/Pump On/PH	2.64	2.81	47	12.7	1.8	25.7
Core Out/Pump Off/No PH	2.00	2.22	32	27.4	1.4	26.0
Core Out/Pump On/No PH	1.99	2.20	34	24.0	1.7	25.3
Core Out/Pump Off/PH	2.28	2.48	44	14.4	1.8	25.9
Core Out/Pump On/PH	2.64	2.83	43	13.7	2.0	26.0

* Denotes no preheat period.
** 60-second preheat period.

Bag 1 NOx appeared to increase when the pump operated during the entire FTP and the Heat Battery was not preheated. For example, with the Core In the coolant system, Bag 1 levels of NOx increased from 1.6 grams to 2.1 grams, a 31 percent increase. Bag 1 formaldehyde (HCHO) levels generally increased only slightly when the auxiliary pump operated during the entire test.

Bag 1 fuel economy decreased very slightly for each Heat Battery configuration, except Core Out and a preheat period, when the pump was operated during the entire FTP cycle. In this configuration, a slight increase, from 25.9 mpg to 26.0 mpg, was recorded; this change was essentially negligible.

Table 5 below presents the composite FTP emission rates for this phase of testing.

Table 5

Auxiliary Pump Effect, 75°F Testing
Composite FTP Emission Levels

Indolene Clear Fuel

Configuration	NMHC g/mi	HC g/mi	HCHO mg/mi	CO g/mi	NOx g/mi	MPG
Core In/Pump Off/No PH*	0.15	0.18	3	1.8	0.4	25.6
Core In/Pump On/No PH	0.14	0.17	3	1.8	0.3	25.1
Core In/Pump Off/PH**	0.16	0.18	4	1.3	0.3	25.4
Core In/Pump On/PH	0.18	0.21	4	1.3	0.4	25.2
Core Out/Pump Off/No PH	0.15	0.18	2	2.2	0.3	25.7
Core Out/Pump On/No PH	0.15	0.18	2	2.0	0.3	25.1
Core Out/Pump Off/PH	0.16	0.19	4	1.4	0.3	25.3
Core Out/Pump On/PH	0.19	0.22	4	1.6	0.4	25.2

* Denotes no preheat period.
** Denotes 60-second preheat period.

Operating the auxiliary pump during the entire FTP had little effect on composite emission levels of hydrocarbons and CO and fuel economy. FTP composite hydrocarbons, however, even increased with the pump running during preheat configuration testing. FTP composite NOx levels also increased during preheat testing with the pump on during the FTP. For each of the four Heat Battery configurations tested, FTP fuel economy decreased very slightly when the pump operated during the entire FTP cycle.

At the suggestion of the manufacturers of the Heat Battery, the auxiliary pump was operated during the entire FTP cycle for the remainder of the tests conducted during this evaluation. All test results discussed in the next three sections were obtained with the pump operating during the entire FTP.

B. Gasoline Fuel Results

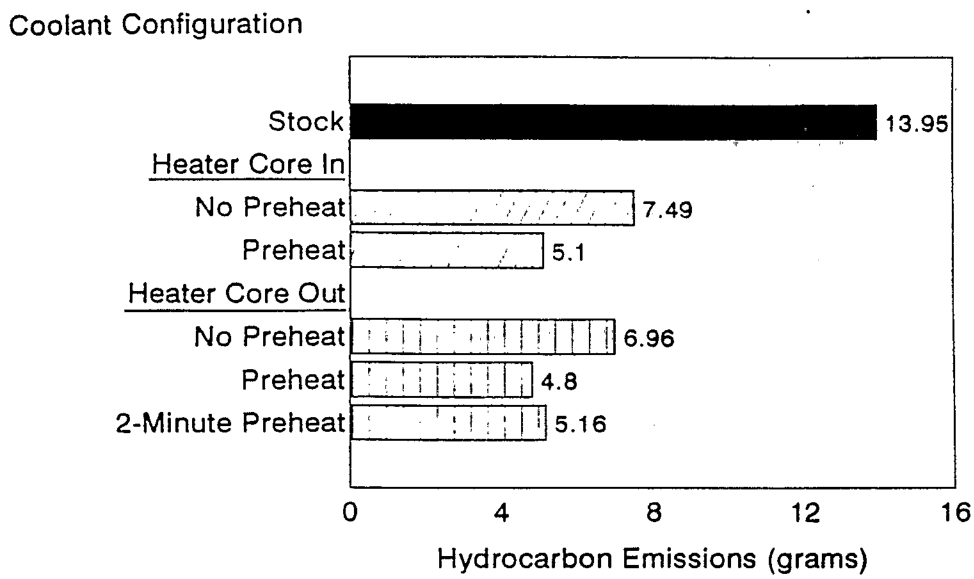
The vehicle was next tested at an ambient temperature of 20°F using indolene fuel. In this section, emissions data presented for 75°F testing are the same data presented in the previous section (A). However, the focus of this discussion will be changes in emission levels and fuel economy resulting from the use of the Heat Battery, not the effect of operating the auxiliary pump.

All results presented here were obtained with the auxiliary pump running during the entire FTP cycle. In this section, the emission levels with gasoline fuel will be compared to stock levels to determine the effect of the Heat Battery as an emissions control device. Stock levels presented here were the levels obtained during the Phase I evaluation and presented in the EPA technical report EPA/AA/CTAB/91-05. These stock levels were obtained with the Heat Battery out and the heater core in (Core In) the coolant system.

The same conventions used to describe the Heat Battery configurations in the previous section are used here also. Preheat (PH) levels were obtained by running the auxiliary pump 60 seconds prior to cold start in the FTP cycle. 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; this preheat period, however, ensured a warmed engine prior to key-on for these laboratory experiments. During 20°F testing, some tests were also conducted while using an extended 2-minute preheat period and the Core Out.

Figure 7 below presents Bag 1 hydrocarbon emission levels for gasoline fuel testing at 20°F. Stock levels presented here were obtained with the Heat Battery out of the coolant system.

Figure 7
Indolene Fuel, 20 Deg. F Testing
Bag 1 Hydrocarbon Levels

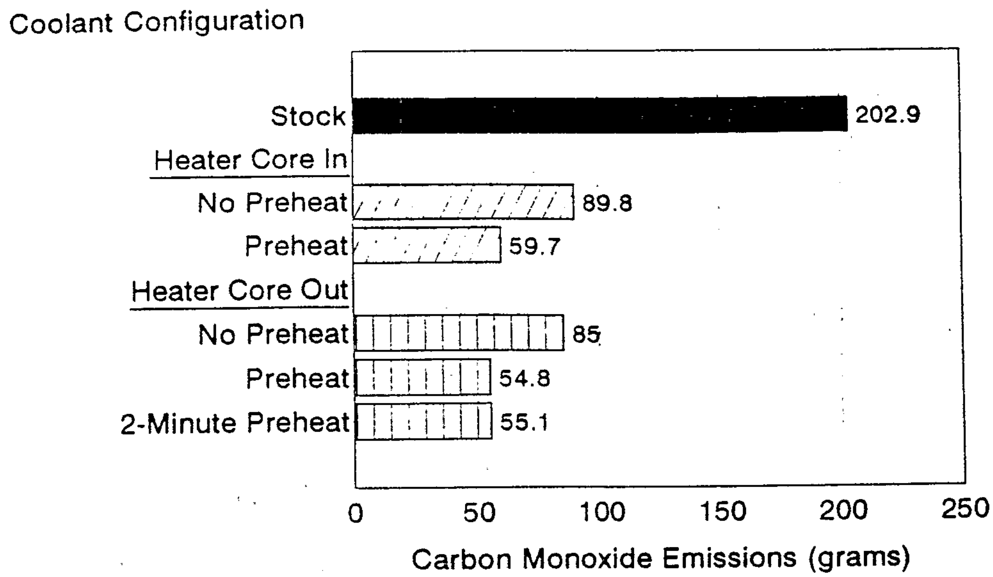


With the Core In the coolant system with no preheat, Bag 1 hydrocarbons were reduced 46 percent, to 7.49 grams from the stock level of 13.95 grams. With the Core In and 60 seconds of preheat, Bag 1 hydrocarbon levels decreased an additional 17 percent, to 5.10 grams. This represents a Bag 1 hydrocarbon reduction of 63 percent from stock levels.

Bag 1 hydrocarbons were reduced to even lower levels with the Core Out configuration. With the Core Out and no preheat, Bag 1 hydrocarbons were 7 percent lower than with Core In and no preheat. When a 60-second preheat period was used, Bag 1 hydrocarbons with Core Out were 6 percent lower than with Core In and preheat. The 4.80 grams of hydrocarbons in Bag 1 with this Heat Battery configuration represented a 66 percent reduction from stock. Using an extended 2-minute preheat period did not further affect Bag 1 unburned hydrocarbon levels.

Figure 8 below presents Bag 1 CO levels for the same Heat Battery configurations described in Figure 7.

Figure 8
Indolene Fuel, 20 Deg. F Testing
Bag 1 Carbon Monoxide Levels



With the Core In and no preheat, Bag 1 levels of CO were reduced approximately 56 percent from stock, from 202.9 grams to 89.8 grams. When a 60-second preheat period was used with Core In, Bag 1 levels of CO decreased an additional 15 percent, to 59.7 grams. This represents a 71 percent reduction in levels of Bag 1 CO from stock. With the Core Out, Bag 1 CO levels were slightly lower than Core In levels. With Core Out and no preheat, Bag 1 CO was reduced to 85.0 grams, approximately 5 percent lower than levels with HC In. With the Core Out and a 60-second preheat period, Bag 1 CO levels were reduced to 54.8 grams, approximately 8 percent lower than with the Core In. A longer 2-minute preheat period did not further reduce Bag 1 CO levels.

Table 6 below presents Bag 1 emission and fuel economy data for testing with indolene fuel at a 20°F ambient temperature.

Table 6

Indolene Fuel, 20°F Testing
Schatz Heat Battery Evaluation

Bag 1 Emission Levels

Configuration	NMHC g	HC g	CO g	NOx g	MPG
Stock	NA	13.95	202.9	0.5	21.1
Core In, No Preheat	6.99	7.49	89.8	2.6	22.5
Core In, Preheat	4.67	5.10	59.7	3.2	22.8
Core Out, No Preheat	6.41	6.96	85.0	3.2	22.8
Core Out, Preheat	4.40	4.80	54.8	3.6	23.2
Core Out, 2-Minute Preheat	NA	5.16	55.1	4.4	21.7

NA Not available.

A small improvement in Bag 1 fuel economy was also noted during this testing. With Core In, Bag 1 fuel economy increased to 22.5 mpg with no preheat and to 22.8 mpg with a 60-second preheat period. These represent 7 and 8 percent increases, respectively, from stock levels. Bag 1 fuel economy also increased above stock levels with the Core Out. When a 60-second preheat period was used, Bag 1 fuel economy levels reached 23.2 miles per gallon, a 10 percent increase from stock levels. The extended 2-minute preheat period resulted in Bag 1 fuel economy only slightly higher than stock, at 21.7 mpg.

A significant increase in Bag 1 NOx was also noted during this testing for all four Heat Battery configurations. The lowest Bag 1 NOx with the Heat Battery was with Core In and no preheat, 2.6 grams. This represents a 420 percent increase from stock levels. The largest increase in Bag 1 NOx from stock was with the Core Out and a 2-minute preheat, at 4.4 grams.

Table 7 below presents composite FTP emissions and fuel economy results from this testing at 20°F.

Table 7

Indolene Fuel, 20°F Testing
Schatz Heat Battery Evaluation

FTP Composite Emission Levels

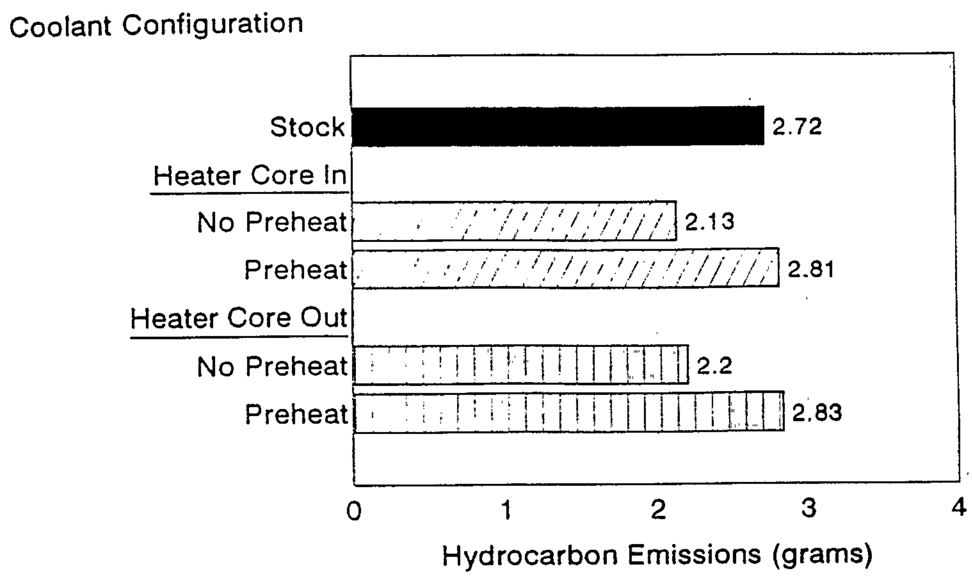
Configuration	NMHC g/mi	HC g/mi	CO g/mi	NOx g/mi	MPG
Stock	NA	0.88	12.6	0.1	24.7
Core In, No Preheat	0.43	0.48	5.8	0.4	24.5
Core In, Preheat	0.30	0.34	4.1	0.5	24.6
Core Out, No Preheat	0.40	0.45	5.6	0.5	24.8
Core Out, Preheat	0.29	0.33	3.9	0.5	24.7
Core Out, 2-Minute Preheat	NA	0.36	3.8	0.6	23.0

NA Not available.

Generally, changes in Bag 1 emissions of unburned fuel and CO are reflected in the weighted FTP levels. For example, the 73 percent reduction in Bag 1 CO with the Core Out and 60 seconds of preheat resulted in a 69 percent reduction in the FTP composite emission rate, from 12.6 grams/mile to 3.9 grams/mile. The same trend was also noted in FTP composite levels of NOx. For the five Heat Battery configurations tested here, FTP composite levels of NOx increased substantially from the stock level of 0.1 grams/mile. The slight increases in Bag 1 fuel economy for the Heat Battery configurations did not materially affect overall city fuel economy. For example, the 10 percent increase in Bag 1 fuel economy with the Core Out and 60 seconds of preheat resulted in no change in FTP fuel economy. In fact, testing with the Core In resulted in FTP fuel economy values less than stock. This also occurred when an extended 2-minute preheat period was used.

Figure 9 below presents Bag 1 hydrocarbon levels at 75°F for the same Heat Battery configurations used during 20°F testing except for 2-minute preheat testing.

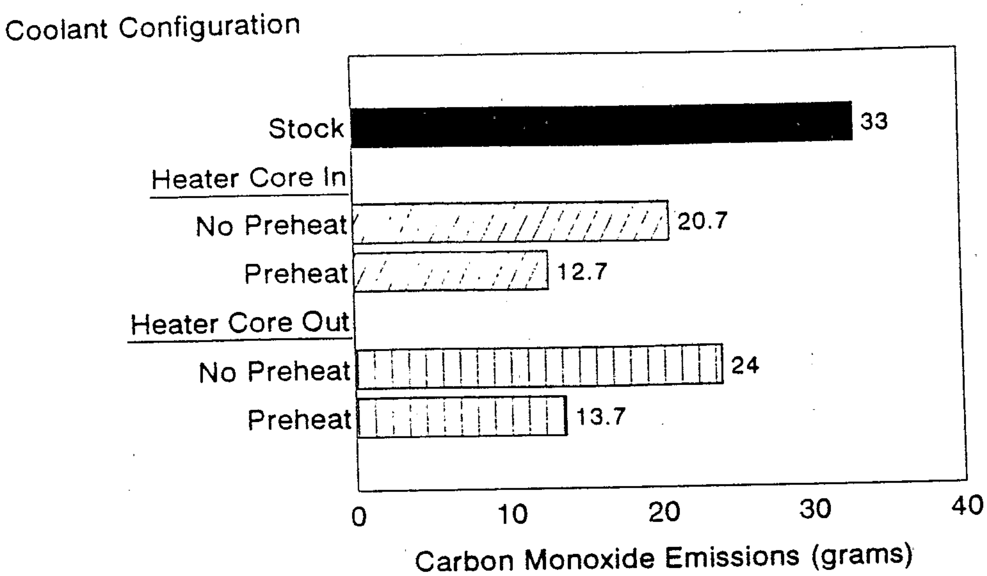
Figure 9
Indolene Fuel, 75 Deg. F Testing
Bag 1 Hydrocarbon Levels



With the Core In the coolant system and no preheat, Bag 1 levels of hydrocarbons decreased from 2.72 grams to 2.13 grams, a reduction of 22 percent from stock. Similarly, when the heater core was removed from the coolant system (Core Out) and with no preheat, the Bag 1 hydrocarbons reduction from stock was 19 percent, at 2.20 grams. Unexpectedly, when a 60-second preheat period was used, Bag 1 hydrocarbons increased above levels noted during stock configuration testing. No unusual driving conditions or engine problems were noted during this testing that might have contributed to this unexpected result. Because modal analysis or catalyst temperature monitoring was not used during this testing, it is very difficult to determine the effect that preheating may have on the catalyst activity or light-off time.

Figure 10 below presents Bag 1 CO levels for this testing.

Figure 10
Indolene Fuel, 75 Deg. F Testing
Bag 1 Carbon Monoxide Levels



The Heat Battery substantially reduced Bag 1 CO emission levels when tested at an ambient temperature of 75°F. Without preheating and with the Core In, Bag 1 CO levels decreased from the 33.0 grams stock level to 20.7 grams, a reduction of 37 percent. When a preheat period was used with the Core In, Bag 1 CO decreased to 12.7 grams, a reduction from stock of approximately 62 percent.

However, when the heater core was removed from the coolant system, reductions in Bag 1 CO levels were not as great as those noted with the heater core in. For example, in the absence of a preheat period, Bag 1 CO was 24.0 grams, a 27 percent reduction from stock levels. With the heater core out and a 60-second preheat period, Bag 1 levels of CO were 13.7 grams, a 58 percent reduction from stock.

Table 8 below presents Bag 1 emission and fuel economy results for testing with gasoline fuel at an ambient temperature of 75°F.

Table 8

Indolene Fuel, 75°F Testing
Schatz Heat Battery Evaluation

Bag 1 Emission Levels

Configuration	NMHC g	HC g	HCHO mg	CO g	NOx g	MPG
Stock	2.43	2.72	34	33.0	1.3	25.2
Core In, No Preheat	1.93	2.13	36	20.7	2.1	25.6
Core In, Preheat	2.64	2.81	47	12.7	1.8	25.7
Core Out, No Preheat	1.99	2.20	34	24.0	1.7	25.3
Core Out, Preheat	2.64	2.83	43	13.7	2.0	26.0

Bag 1 fuel economy increased only slightly over stock levels for each Heat Battery configuration tested here. The highest fuel economy value noted was obtained with the Core Out of the coolant system and a 60-second preheat, 26.0 mpg. This represents a 3 percent increase over stock levels. With the Core Out of the coolant system and no preheat, Bag 1 fuel economy was essentially unchanged from stock.

Bag 1 NOx increased over stock levels for each Heat Battery configuration tested here. The highest level of Bag 1 NOx noted was with the Core In and no preheat, at 2.1 grams. This represents a 62 percent increase from stock levels. The lowest level of Bag 1 NOx was obtained with the Core Out of the coolant system and no preheat. At 1.7 grams, this represents a 31 percent increase in Bag 1 NOx from stock.

Levels of Bag 1 formaldehyde also significantly increased above stock levels when a preheat period was used. With the Core In and preheat, Bag 1 formaldehyde increased to 47 milligrams from the 34 milligrams stock value. This represents an increase of 38 percent. When no preheat was utilized, Bag 1 formaldehyde levels remained basically unchanged from stock levels.

Table 9 below presents FTP composite emissions and fuel economy results for this testing.

Table 9

Indolene Fuel, 75°F Testing
Schatz Heat Battery Evaluation

Composite FTP Emission Levels

Configuration	NMHC g/mi	HC g/mi	HCHO mg/mi	CO g/mi	NOx g/mi	MPG
Stock	0.17	0.21	3	2.7	0.2	25.2
Core In, No Preheat	0.14	0.17	3	1.8	0.3	25.1
Core In, Preheat	0.18	0.21	4	1.3	0.4	25.2
Core Out, No Preheat	0.15	0.18	2	2.0	0.3	25.1
Core Out, Preheat	0.19	0.22	4	1.6	0.4	25.2

Similar to 20°F results, Bag 1 emission changes in unburned fuel and CO are reflected in changes in FTP composite emission rates. For example, the 62 percent reduction in Bag 1 CO levels noted with the Core In and preheat correlates with the 52 percent reduction in FTP composite CO obtained with this configuration. Also, the increases noted in Bag 1 NOx are reflected in increases in FTP composite levels of NOx. The increase in Bag 1 fuel economy values, however, is not reflected in overall FTP fuel economy. Though increases were noted in Bag 1 fuel economy for both no preheat configurations, reductions in city fuel economy from stock levels also occurred.

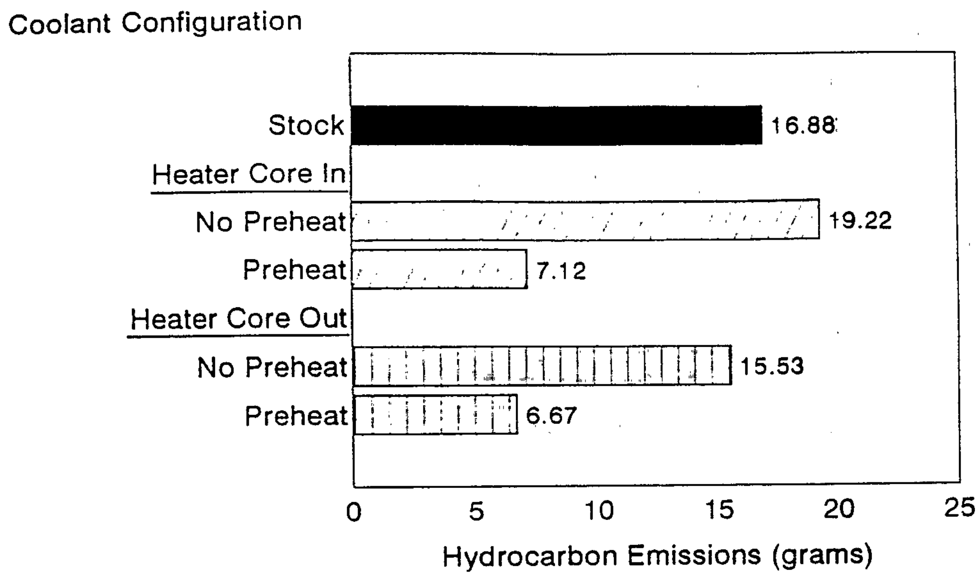
C. M85 Fuel Results

Once gasoline testing was complete, the fuel tank was drained and filled with a blend of 85 percent methanol and 15 percent gasoline (M85). The same test sequence described for gasoline testing in subsection B was repeated, except that no 2-minute preheat tests were conducted. 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 were sampled only during 75°F testing.

Figure 11 below presents Bag 1 hydrocarbon levels from cold room testing with M85 fuel. Substantial emission reductions were again noted here when a 60-second preheat period was used. With the Core In, Bag 1 hydrocarbons decreased 58 percent from stock levels, from 16.88 grams to 7.12 grams, when a 60-second preheat was used. An even greater reduction of 60 percent was noted when the heater core was removed from the coolant circuit. Emission levels without a preheat period varied considerably. With the heater core present in the coolant system (Core In), Bag 1 hydrocarbons increased above stock levels by 14 percent, to 19.22

grams. With the Core Out of the coolant circuit, Bag 1 hydrocarbons decreased to 15.53 grams, a 19 percent reduction from Core In/no preheat levels and an 8 percent reduction from stock levels.

Figure 11
M85 Fuel, 20 Deg. F Testing
Bag 1 Hydrocarbon Levels



Similar trends were also noted with Bag 1 CO. Bag 1 CO levels, depicted in Figure 12, were unchanged from stock levels with the Core In and no preheat. However, when the heater core was removed from the coolant system again with no preheat, Bag 1 levels of CO decreased to 130.0 grams, a 23 percent reduction from stock. When a 60-second preheat period was used with the Core Out, Bag 1 CO decreased to 77.7 grams, a reduction of 54 percent from stock levels. The largest reduction in Bag 1 CO, however, was obtained with the Core In the coolant system and a 60-second preheat. Bag 1 CO was measured then at 46.8 grams, a 72 percent reduction from stock.

Figure 12
M85 Fuel, 20 Deg. F Testing
Bag 1 Carbon Monoxide Levels

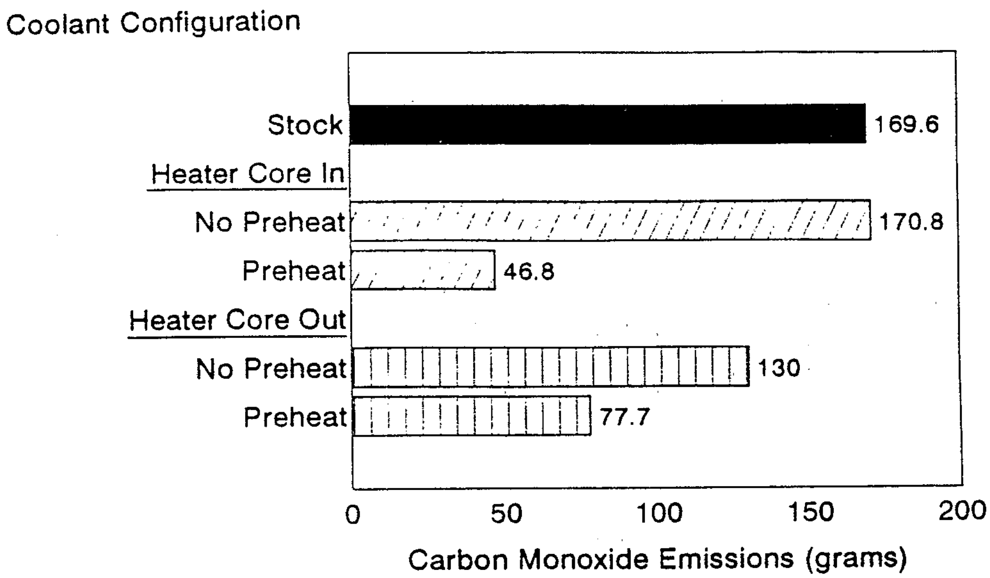


Table 10 below presents Bag 1 emissions and fuel economy results from testing at 20°F with M85 fuel. Using the Heat Battery without preheat, Bag 1 fuel economy increased by 3 percent with the Core In the coolant circuit and by 7 percent with the Core Out. When a preheat period was used, Bag 1 fuel economy increased substantially above stock levels. With the heater core in and 60 seconds of preheat, Bag 1 fuel economy reached 13.4 miles per gallon, a 13 percent increase from the stock value of 11.9 miles per gallon. With Core Out/60 seconds preheat, Bag 1 fuel economy was 14.2 mpg, 19 percent higher than stock.

Table 10

M85 Fuel, 20°F Testing
Schatz Heat Battery Evaluation

Bag 1 Emission Levels

Configuration	NMHC g	*HC g	CO g	NOx g	MPG
Stock	NA	16.88	169.6	2.3	11.9
Core In, No Preheat	18.50	19.22	170.8	0.4	12.3
Core In, Preheat	6.80	7.12	46.8	0.8	13.4
Core Out, No Preheat	14.92	15.53	130.0	0.4	12.7
Core Out, Preheat	6.35	6.67	77.7	0.7	14.2

NA Not available.
* Gasoline-fueled vehicle measurement with a propane calibrated FID.

Each of the four configurations evaluated here had lower than stock levels of Bag 1 NOx. Also, preheating tended to increase Bag 1 NOx from no preheat levels. For example, with the Core In the coolant circuit and preheat, Bag 1 NOx doubled from no preheat levels (0.4 grams to 0.8 grams).

FTP composite emission levels are given below in Table 11.

Table 11

M85 Fuel, 20°F Testing
Schatz Heat Battery Evaluation

FTP Composite Test Levels

Configuration	NMHC g/mi	*HC g/mi	CO g/mi	NOx g/mi	MPG
Stock	NA	1.44	11.4	0.2	14.0
Core In, No Preheat	1.16	1.21	10.4	0.1	14.2
Core In, Preheat	0.44	0.48	5.4	0.2	14.5
Core Out, No Preheat	0.96	1.02	8.4	0.1	14.3
Core Out, Preheat	0.47	0.51	5.4	0.1	14.6

NA Not available.
* Gasoline-fueled vehicle measurement with a propane calibrated FID.

FTP NOx levels decreased slightly below above the 0.2 grams/mile noted with the stock configuration for most Heat Battery configurations tested here. Although Bag 1 hydrocarbons increased above stock levels with the Core In and no preheat, a small reduction was noted in FTP composite levels. In spite of the 14 percent increase in Bag 1 hydrocarbons, a 16 percent reduction in FTP composite hydrocarbons, from 1.44 grams/mile to 1.21 grams/mile, was noted. Emissions measured with this Heat Battery configuration during the Bag 2 and Bag 3 portions of the FTP were substantially lower than stock levels.

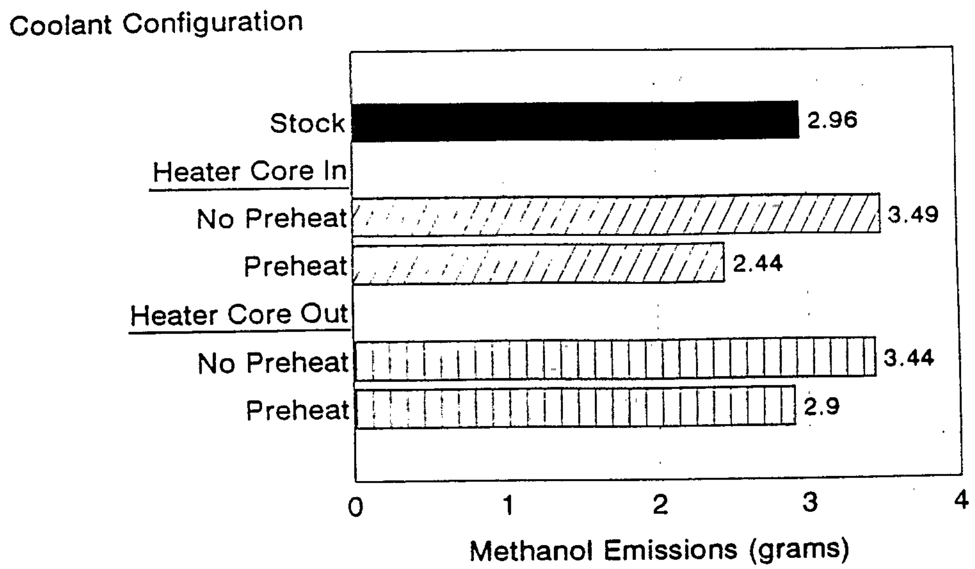
Changes in Bag 2/3 emissions may have resulted from running the auxiliary pump during the entire FTP cycle. For example, although Bag 1 CO was unchanged from stock levels with the Core In and no preheat configuration, FTP composite CO was lower than stock levels, from 11.4 grams/mile to 10.4 grams/mile. Here also, Bag 2 and Bag 3 levels were substantially lower than stock levels with this Heat Battery configuration.

FTP emissions were reduced in every case with the Core Out/no preheat configuration. An 8 percent reduction in Bag 1 hydrocarbons as well as a 29 percent reduction in FTP composite hydrocarbon levels was noted with this configuration. Here also, Bag 2 and Bag 3 levels of hydrocarbons were substantially lower than stock levels with this Heat Battery configuration. The CO reduction noted in FTP composite levels remained consistent with Bag 1 reductions for this configuration, however.

When a preheat period was used, reductions in Bag 1 hydrocarbons and CO were similar to those in FTP composite levels. For example, the 54 percent reduction from stock levels noted in Bag 1 CO with the Core Out and 60 seconds of preheat resulted in a 52 percent reduction in FTP composite CO levels. Bag 1 fuel economy improvements were also reflected in overall FTP fuel economy results, however, the FTP increases were much smaller. For example, the 19 percent improvement in Bag 1 fuel economy calculated with the Core Out and preheat was much larger than the 4 percent increase in FTP fuel economy when compared to stock levels.

Upon completion of the cold room testing, these Heat Battery configurations were evaluated again after overnight cold soaks in an ambient temperature of 75°F. Figure 13 presents Bag 1 exhaust methanol levels for each Heat Battery configuration evaluated at this temperature.

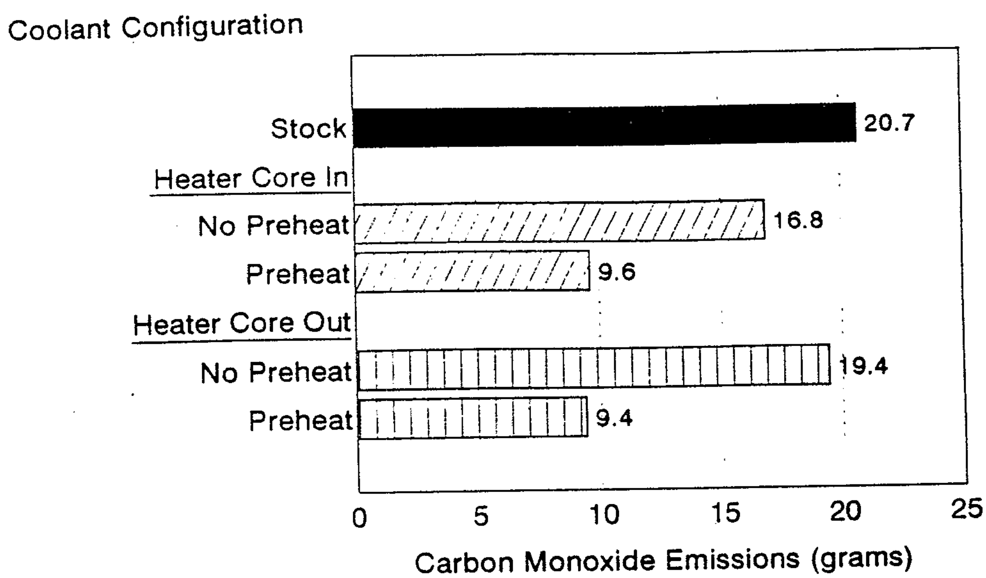
Figure 13
M85 Fuel, 75 Deg. F Testing
Bag 1 Methanol Levels



Without preheating, Bag 1 levels of methanol increased above stock levels. This was an unexpected result. However, when a 60-second preheat period was utilized, Bag 1 methanol decreased 18 percent from stock levels with the Core In, to 2.44 grams. When the heater core was removed from the coolant system and preheating was used, methanol emissions were approximately unchanged from stock levels.

Figure 14 presents Bag 1 CO measured during testing at 75°F.

Figure 14
M85 Fuel, 75 Deg. F Testing
Bag 1 Carbon Monoxide Levels



Without preheat, lower levels of Bag 1 CO were noted with the heater core in the coolant circuit. With the Core In and no preheat, Bag 1 CO decreased from the stock level of 20.7 grams to 16.8 grams, a 19 percent reduction. When the Core Out configuration was tested, Bag 1 CO levels were essentially unchanged from stock levels. When a preheat period was used, Bag 1 CO decreased substantially from stock levels, regardless of heater core presence. Both configurations utilizing a preheat period had Bag 1 CO emissions approximately 54 percent lower than stock levels.

Table 12 below presents Bag 1 emissions and fuel economy levels measured during testing with M85 fuel at 75°F.

Table 12

M85 Fuel, 75°F Testing
Schatz Heat Battery Evaluation

Bag 1 Emission Levels

Configuration	*HC g	NOx g	CO g	CH_3OH g	HCHO mg	OMHCE g	MPG
Stock	1.75	1.1	20.7	2.96	274	2.20	14.9
Core In, No PH	1.98	1.4	16.8	3.49	218	2.46	15.1
Core In, PH**	1.32	2.0	9.6	2.44	187	1.67	15.2
Core Out, No PH	2.02	1.2	19.4	3.44	234	2.50	15.0
Core Out, PH	1.63	1.8	9.4	2.90	181	2.03	15.4

* Gasoline-fueled vehicle measurement with a propane calibrated FID.
** PH indicates 60-second preheat period.

Bag 1 fuel economy increased only very slightly when the Heat Battery was used. Cold start aldehydes also decreased from stock levels when the Heat Battery was used. In the absence of a preheat period with the Core In, Bag 1 formaldehyde decreased over 20 percent from stock levels, from 274 milligrams to 218 milligrams. The largest reduction in formaldehyde noted was with Core Out and 60 seconds of preheat. Bag 1 NOx increased above stock levels for each Heat Battery configuration tested here. The largest increase in Bag 1 NOx was with the Core In and 60 seconds of preheat, from 1.1 grams to 2.0 grams.

Table 13 below presents composite emissions from this testing.

Table 13

M85 Fuel, 75°F Testing
Schatz Heat Battery Evaluation

FTP Composite Emission Levels

Configuration	*HC g/mi	NOx g/mi	CO g/mi	CH_3OH g/mi	HCHO mg/mi	OMHCE g/mi	MPG
Stock	0.12	0.1	1.8	0.22	19	0.15	14.7
Core In, No PH	0.14	0.2	1.4	0.26	16	0.17	14.7
Core In, PH**	0.10	0.4	0.8	0.20	12	0.12	14.8
Core Out, No PH	0.14	0.3	1.6	0.26	18	0.18	14.6
Core Out, PH	0.12	0.4	1.0	0.22	14	0.15	14.9

* Gasoline-fueled vehicle measurement with a propane calibrated FID.
** PH indicates 60-second preheat period.

The changes noted in Bag 1 emission levels of methanol and CO were generally reflected in FTP emission levels. The 54 percent reduction noted in Bag 1 CO levels with the Core In and 60 seconds of preheat resulted in a 56 percent reduction in FTP composite CO, from 1.8 grams/mile to 0.8 grams/mile. Increases in methanol emissions above stock levels noted when no preheat was used resulted in greater than stock levels of FTP composite methanol emissions (up from 0.22 grams/mile to 0.26 grams/mile). Weighted FTP NOx levels substantially increased above stock levels for each Heat Battery configuration tested even though the increases noted in Bag 1 NOx were not as proportionally large. The greatest increase occurred when a preheat period was used, from 0.1 grams/mile to 0.4 grams/mile. FTP fuel economy was affected slightly by the use of the Heat Battery. However, with Core Out and no preheat, FTP fuel economy decreased below stock levels.

D. 11-Day Cold Soak Results

The test vehicle was soaked for an 11-day period at a 20°F ambient temperature in an attempt to determine the heat storage duration capability of the Heat Battery. This single test was run on gasoline with the heater core out of the coolant system and with a 60-second preheat period. The initial spike in coolant temperature leaving the Heat Battery was typically around 175°F for a 1-day cold soak test at 20°F (Figure 4). The initial spike approached 125°F for this test. The emission results from this test are presented below in Table 14, along with the stock and 1-

day soak emission levels with same Heat Battery configuration. Both Bag 1 and composite FTP emission and fuel economy results are presented in Table 14.

Table 14

Gasoline Fuel, 20°F Testing
Schatz Heat Battery Evaluation

11-Day Cold Soak Emission Levels

Configuration	HC	CO	NOx	MPG
Bag 1 (grams):				
Stock	13.95	202.9	0.5	21.1
1-Day Soak*	4.80	54.8	3.6	23.2
11-Day Soak*	7.35	101.6	5.3	22.0
FTP (grams/mile):				
Stock	0.88	12.6	0.1	24.7
1-Day Soak*	0.33	3.9	0.5	24.7
11-Day Soak*	0.49	6.5	0.6	23.7

* Core Out, 60-second preheat period.

After soaking for 11 days at a constant ambient temperature of 20°F, the use of the Heat Battery with a 60-second preheat period resulted in a 47 percent reduction from stock in Bag 1 hydrocarbons and a 50 percent reduction in Bag 1 CO levels. Bag 1 CO decreased from the stock level of 202.9 grams to 101.6 after the 11-day cold soak; the 1-day cold soak level was 54.8 grams. Bag 1 fuel economy after an 11-day cold soak increased from 21.1 miles per gallon to 22.0 miles per gallon, lower than the 1-day cold soak Bag 1 fuel economy of 23.2 miles per gallon. Bag 1 NOx was surprisingly highest after the 11-day cold soak test (5.3 grams, compared to the stock level of 0.5 grams).

This increase in Bag 1 NOx levels also affected composite FTP NOx levels. After an 11-day cold soak, FTP composite NOx levels increased to 0.6 grams/mile from the stock level of 0.1 grams/mile. This is also larger than the 0.5 grams/mile composite NOx level noted during the 1-day cold soak test. The reductions noted during the Bag 1 portion for hydrocarbons and CO was again reflected in FTP composite levels. The 50 percent reduction from stock levels in Bag 1 CO after the 11-day soak resulted in a 48 percent reduction in FTP composite CO levels, from 12.6 grams/mile to 6.5 grams/mile. However, the increase noted in Bag 1 fuel economy with the extended cold soak was not reflected in overall FTP fuel economy results. After soaking for 11 days, the FTP fuel economy (23.7 miles per gallon) fell below the stock configuration fuel economy of 24.7 miles per gallon. FTP fuel economy after a 1-day cold soak remained unchanged from stock levels.

E. Retests At Manufacturer's Request

Once the testing discussed in Sections A-D above was completed, the test vehicle was returned to Volkswagen of America (VW). VW detected a misfire resulting from a malfunctioning fuel injector during idle operation. This condition was also noted by EPA personnel, but did not develop, however, until the very end of the test program (75°F testing with M85 fuel). All test data was obtained during testing conducted within valid driving limits according to the EPA vehicle testing procedure in spite of the misfire.

VW made several repairs and modifications to the test vehicle. The fuel injectors, oxygen sensor, and the fuel composition sensor were all replaced. The coolant system was again rerouted by placing the ECU coolant temperature sensor at the outlet of the engine. For all the previous testing, this sensor was located behind the thermostat in the radiator loop. Therefore, the sensor did not detect warm coolant until the thermostat began to open. The sensor location now allowed for detection of warm coolant immediately upon circulation. VW and Autotech then requested that certain tests previously conducted at 75°F be repeated in order to determine the effect of the repairs on vehicle emissions.

Figure 15 is a schematic diagram of the coolant configuration utilized for the retests presented in this section. In this configuration, it was possible to run stock configuration tests (Heat Battery out of the coolant system) by using the electric valves (7). The ECU coolant temperature sensor (2) is present at the outlet of the engine and not in the radiator loop as before. Stock tests were performed with the auxiliary pump not running during any portion of the FTP cycle. For testing with the Heat Battery in the coolant system, the auxiliary pump was operating during the entire FTP.

Figure 15

Coolant System Configuration
<u>Manufacturer Requested Retests</u>

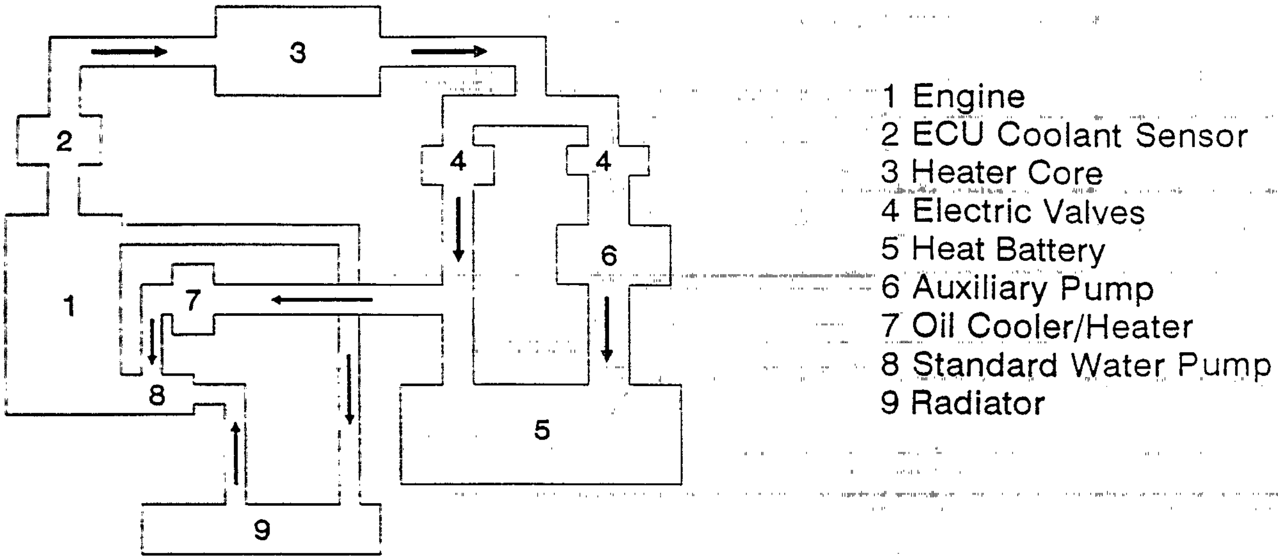
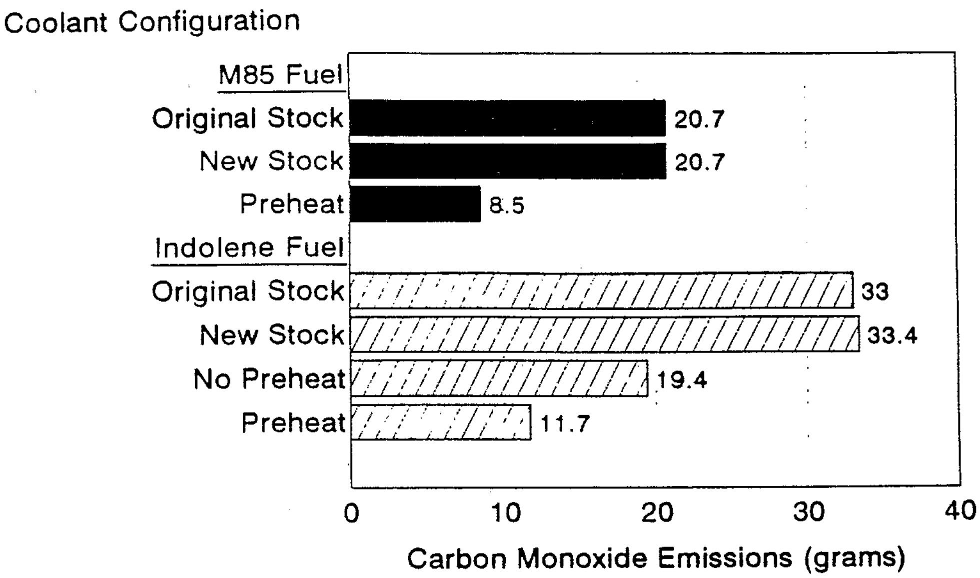


Figure 16 presents Bag 1 emission results of CO obtained during this testing for both fuels at an ambient temperature of 75°F. Also presented in this figure are the stock values that were obtained previously and presented in Sections A-D of this report. When M85 fuel was used, tests with the Heat Battery were conducted only with a 60-second preheat period. When gasoline fuel was used, tests were conducted with both preheat and no preheat.

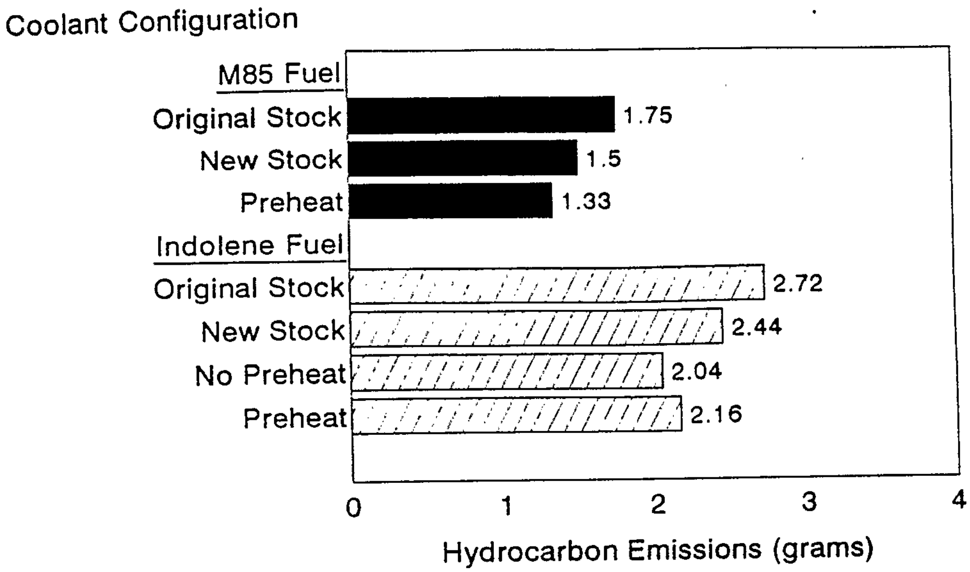
Figure 16
75 Deg. F Testing
Bag 1 Carbon Monoxide Levels



For both fuels, the engine modifications and coolant system reconfiguration did not significantly change levels of CO emissions over the Bag 1 portion of the FTP. With M85 fuel, a 59 percent reduction in Bag 1 CO from stock levels resulted when a 60-second preheat period was used. Similarly, with gasoline fuel, a 65 percent reduction in Bag 1 CO occurred with a similar preheat period. In the absence of preheat with gasoline fuel, a 42 percent reduction in Bag 1 CO occurred.

Figure 17 presents Bag 1 hydrocarbon levels for the same Heat Battery configurations discussed in the previous figure.

Figure 17
75 Deg. F Testing
Bag 1 Hydrocarbon Levels



With both fuels, the stock level of Bag 1 hydrocarbons obtained during this testing was slightly lower than the stock level obtained previously. With M85 Fuel, an 11 percent reduction in Bag 1 hydrocarbon levels occurred when a 60-second preheat period was used. However, when a preheat period was used, engine stalls were noted in three of the four tests conducted. Each of these stalls occurred during the first 15 seconds following cold start, while the vehicle was still idling. These stalls were the only driveability problems that occurred during these three tests.

During the single test conducted without stalling, a substantial reduction in Bag 1 hydrocarbons of 52 percent from stock was noted. During the tests where engine stall did occur, Bag 1 levels of hydrocarbons remained unchanged from stock levels.

When gasoline fuel was used, a 60-second preheat also resulted in engine stall following cold start. Two tests were then conducted utilizing no preheat, and no engine stalls occurred. Bag 1 hydrocarbon levels were reduced 11 percent from stock levels with a preheat and 16 percent without preheat.

Fuel economy slightly increased from stock levels over the Bag 1 portion with both fuels when the Heat Battery was utilized. With M85 fuel, a 60-second preheat period resulted in a Bag 1 fuel economy improvement from 15.2 to 15.6 mpg. With gasoline fuel, the use of the Heat Battery, with and without preheat, resulted in a Bag 1 fuel economy gain from 25.7 to 26.3 mpg. The fuel economy increase over the entire FTP was limited to 0.1 mpg for M85 fuel and 0.2 mpg with gasoline.

Appendix B contains the individual test results for all testing conducted at manufacturer's request. Both Bag 1 and composite FTP results are presented for each fuel. Appendix C contains comments provided by Schatz Thermo Engineering regarding the results from this testing.

IX. Acknowledgements

The Schatz Heat Battery evaluated in this test program was supplied by Autotech Associates, Inc., located in Southfield, 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.

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APPENDIX A

Test Vehicle Specifications

Vehicle Type	1990 Audi 80
Fuel(s)	Indolene clear unleaded gasoline, M85 high methanol blend fuels
Mileage When Received	8,000 kilometers
Engine:	
Cylinders	4 in-line
Displacement	1.8 liter
Bore	81.0 mm
Stroke	86.4 mm
Compression Ratio	
Maximum Output	75 kw at 5,500 rpm with gasoline 80 kw at 5,500 rpm with M85
Exhaust Catalyst System	Oxygen sensor controlled closed-loop system with a 3-way catalyst
Fuel System	Fuel Injection, Digifant II/I-System Modified for multi-fuel operation
Transmission Type	5-speed manual
Equivalent Test Weight	1304 kilograms (2,875 lbs.)
Actual Dynamometer Horsepower	6.4

APPENDIX B

Schatz Heat Battery Evaluation
M85 Fuel, 75°F Testing

Bag 1 Emission Levels

Config.	HC g	NOx g	CO g	CH_3OH g	HCHO mg	OMHCE g	MPG
Stock #1	1.62	0.4	22.1	2.69	141	1.97	15.1
Stock #2	1.52	0.6	18.4	2.73	134	1.88	15.2
Stock #3	1.53	0.6	18.6	2.72	155	1.90	15.2
Stock #4	1.42	0.5	23.5	2.39	163	1.75	15.1
Stock #5	1.42	0.7	20.8	2.32	176	1.75	15.2
Ave. Stock	1.50	0.6	20.7	2.57	154	1.85	15.2
Preheat#1	0.72	0.8	7.2	0.89	67	0.84	15.7
Preheat#2*	1.66	0.7	8.3	2.69	117	2.01	15.7
Preheat#3*	1.43	0.7	7.9	2.19	131	1.72	15.7
Preheat#4*	1.52	0.7	10.5	2.54	132	1.85	15.5
Average Preheat	1.33	0.7	8.5	2.08	112	1.60	15.6

* Engine stall occurred during test.

APPENDIX B (CONT'D)

Schatz Heat Battery Evaluation
M85 Fuel, 75°F Testing

FTP Composite Emission Levels

Config.	HC g/mi	NOx g/mi	CO g/mi	CH_3OH g/mi	HCHO mg/mi	OMHCE g/mi	MPG
Stock #1	0.11	0.1	1.5	0.20	11	0.14	15.1
Stock #2	0.10	0.1	1.3	0.19	10	0.13	15.2
Stock #3	0.11	0.1	1.4	0.20	11	0.13	15.1
Stock #4	0.10	**	1.7	0.18	12	0.13	15.1
Stock #5	0.10	0.1	1.6	0.18	13	0.12	15.2
Ave. Stock	0.10	0.1	1.5	0.19	11	0.13	15.2
Preheat#1	0.06	0.1	0.8	0.09	5	0.07	15.3
Preheat#2*	0.12	0.1	0.9	0.21	8	0.14	15.3
Preheat#3*	0.10	**	0.8	0.17	10	0.13	15.3
Preheat#4*	0.10	0.1	1.0	0.18	10	0.13	15.2
Average Preheat	0.10	0.1	0.9	0.16	8	0.12	15.3

* Engine stall occurred during test.
** Less than 0.05 g/mi measured.

APPENDIX B (CONT'D)

Schatz Heat Battery Evaluation
Indolene Fuel, 75°F Testing

Bag 1 Emission Levels

Config.	HC g	NOx g	CO g	NMHC g	HCHO mg	MPG
Stock #1	2.61	0.8	33.3	2.36	21	25.8
Stock #2	2.46	0.8	34.2	2.21	21	26.1
Stock #3	2.61	1.0	32.2	2.36	20	25.6
Stock #4	2.18	0.9	32.0	1.94	25	25.5
Stock #5	2.32	0.9	35.2	2.07	25	25.5
Ave. Stock	2.44	0.9	33.4	2.19	22	25.7
Preheat*	2.16	1.1	11.7	1.97	34	26.3
No Preheat #1	2.07	1.0	18.2	1.86	23	26.6
No Preheat #2	2.02	1.0	20.6	1.80	25	26.0
Average No Preheat	2.04	1.0	19.4	1.83	24	26.3

* Engine stall occurred during test.

APPENDIX B (CONT'D)

Schatz Heat Battery Evaluation
Indolene Fuel, 75°F Testing

FTP Composite Emission Levels

Config.	HC g/mi	NOx g/mi	CO g/mi	NMHC g/mi	HCHO mg/mi	MPG
Stock #1	0.19	0.1	2.3	0.16	3	26.1
Stock #2	0.20	0.1	2.5	0.16	2	26.0
Stock #3	0.21	0.1	2.3	0.18	2	25.8
Stock #4	0.17	0.1	2.3	0.14	3	25.7
Stock #5	0.17	0.1	2.4	0.14	3	25.6
Ave. Stock	0.19	0.1	2.4	0.16	3	25.8
Preheat*	0.17	0.1	1.1	0.14	3	26.0
No Preheat #1	0.16	0.1	1.4	0.13	3	26.3
No Preheat #2	0.16	0.1	1.6	0.13	3	25.7
Average No Preheat	0.16	0.1	1.5	0.13	3	26.0

* Engine stall occurred during test.

APPENDIX C

Comments Provided by Schatz Thermo Engineering

M85 Testing

1. M85 baseline tests are O.K. There is a tendency of increase in CO over the test series. Therefore, it is reasonable to average all 5 tests for a baseline value. This baseline value is somewhat smaller than in the first test series with M85 at EPA.

2. M85 preheat tests with engine stalls cannot be accepted to be representative for possible hydrocarbon reduction. In the EPA technical report, at least the emission reductions of the Preheat #1 test without any stall need to be acknowledged. This test showed that HC dropped below the LEV level (-42%) and in CO a 48% reduction was achieved when the Heat Battery is applied.

The fuel enrichment in the engine map so far never was optimized for Heat Battery operation. By doing this in small steps, it is expected that stalls will be eliminated and no significant changes in HC and CO emissions will result compared to the test Preheat#1. The test Preheat#1 showed already that only a little more enrichment would be necessary.

3. The NOx increase is significant (+38%) but still the NOx emissions is within the ULEV limit.

4. The 1.6% improvement in M85 fuel consumption in the test Preheat#1 occurred mainly in the first bag (+3.7%).

5. Compared to the first test series, in test Preheat#1 a significant reduction in HC and CO with the Heat Battery and preheat was achieved at 75°F.

Gasoline Testing Without Preheat

1. The gasoline baseline tests are pretty much O.K. There is a tendency of HC decrease comparing the values before and after the Heat Battery tests. Again, it is reasonable to average all 5 baseline tests. The baseline value is a bit lower than in the first test series at EPA with gasoline.

2. The Heat Battery tests with no preheat are O.K. A 14% improvement in HC and a 37% improvement in CO was achieved. The CO level dropped below the ULEV level.

3. NOx decreased by 3.1%.

4. The 0.8% improvement in gasoline fuel consumption resulted mainly from the first bag (1.9%).

5. Compared to the first test series, a significant further reduction in HC and CO with the Heat Battery and no preheating was achieved at 75°F.

Gasoline Testing With Preheat

1. The test with preheat and engine stall cannot be accepted to be representative for possible HC reduction.

2. With an optimized engine map, the engine stalls would be avoided when preheat is applied. Then further emission improvement is expected.