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DISSOCIATED METHANOL VEHICLE TEST RESULTS

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ABSTRACT

This paper presents the results of chassis dynamometer testing of a 1980 Chevrolet Citation modified to run on dissociated methanol. Data are presented on the composition of the dissociated methanol gas during steady-state operation, vehicle fuel consumption during steady-state and transient operation, and exhaust emissions during transient operation.

During low speed, low load operation there are significant amounts of unconverted methanol and side products to the desired dissociation reaction. Despite this, fuel economy improvements over baseline gasoline operation are high. Fuel economies of 13.3 km/L (31.3 mpg) and 11.4 km/L (26.8 mpg) were obtained at steady speed road load conditions of 65 km/h and 90 km/h respectively. Methanol fuel economy over the EPA '74 CVS hot start city driving cycle was 7.74 km/L (18.2 mpg). Methanol fuel economy over the EPA highway fuel economy test was 10.2 km/L (24.0 mpg). No work has yet been done to try to calibrate the vehicle for low exhaust emissions, but test data presented are encouraging.

These results have been obtained in a first-of-a-kind vehicle that was operated with crude control systems that did not permit accurate calibration of spark advance or, to a lesser degree, air/fuel ratio. Spark advance and air/fuel control were obtained with relatively simple mechanical systems.

1. INTRODUCTION

Dissociation of methanol on board a vehicle uses waste heat to increase the chemical energy of the fuel, thereby providing a gaseous fuel with a high hydrogen concentration which can be burned at very low equivalence ratios (large amounts of excess air). Operating at low equivalence ratios improves engine efficiency by reducing

pumping work, reducing combustion temperatures (heat transfer losses), and improving the specific heat ratio of the expanding gases. Figure 1-1 shows the energy flow in a reformed alcohol system. Engine improvements increase the thermal efficiency over that possible with conventional fuels. Waste heat is recycled from the coolant and exhaust to drive vaporization and reformation of the fuel, respectively. This increases the total chemical energy input to the engine, and thus increases the shaft power fraction of the original liquid fuel energy correspondingly.

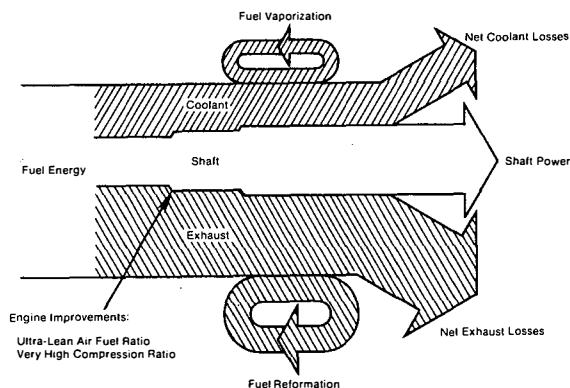


FIGURE 1-1. ENERGY FLOW IN A REFORMED METHANOL SYSTEM

2. PREDICTED FUEL ECONOMY IMPROVEMENT

Table 2-1 shows the improvement in lower heating value obtained by the dissociation and steam reformation of methanol. The first reaction, dissociation, is of greater interest for the automotive application since it results in greater waste heat utilization and does not require on-board storage of water. It is accomplished in two steps: (1) vaporization of the methanol and (2) gas-phase dissociation. Since vaporization of methanol requires an energy input equal to 6% of the

TABLE 2-1. METHANOL REFORMING REACTIONS

			Increase In Lower Heating Value (%)
Dissociation:			
Methanol (liquid)	+ heat	Methanol (vapor)	6
Methanol (vapor)	+ heat	Hydrogen + Carbon Monoxide	14
Methanol (liquid)	+ heat	Hydrogen + Carbon Monoxide	20
Steam Reforming:			
Methanol (liquid)	+ heat	Methanol (vapor)	6
Methanol (vapor)	+ steam + heat	Hydrogen + Carbon Dioxide	9
Methanol (liquid) + steam	+ heat	Hydrogen + Carbon Dioxide	15

fuel's lower heating value, it has a 6% higher lower heating value than liquid methanol. Table 2-2 presents lower heating values for some fuels of interest (liquid methanol, gasoline, and indolene data from Reference 1). The gas-phase dissociation of vaporized methanol into hydrogen and carbon monoxide requires an energy input equal to 14% of the lower heating value of liquid methanol, and increases its lower heating value correspondingly. Combining the two effects shows that dissociated methanol has a 20% higher lower heating value than liquid methanol. Thus the fuel processing efficiency (the lower heating value of the products at room temperature divided by the lower heating value of the reactants at room temperature) is 120%.

TABLE 2-2. LOWER HEATING VALUES^a

Fuel	kJ/g	Btu/lb	MJ/L	Btu/gal
Liquid methanol	20.0	8,580	15.8	56,800
Vaporized methanol	21.1	9,050	N/A	N/A
Dissociated methanol (2H ₂ + CO)	23.9	10,290	N/A	N/A
Gasoline (Amoco 91)	43.9	18,900	32.5	117,000
Indolene Clear	43.8	18,800	32.9	118,000
Fuel Methanol (M90) (90 volume % methanol, 10 volume % unleaded gasoline)	22.2	9,560	17.5	62,900

^aBased in part on Reference 1.

The conclusion is that if engines burning dissociated methanol and liquid methanol have identical brake thermal efficiencies (shaft output power divided by the product of fuel mass flow into the engine and the lower heating value of the fuel), the dissociated methanol system would have a 20% higher thermal efficiency. In actual practice, complete dissociation of all the methanol is not

achieved and, therefore, the full 20% gain is not obtained. Reference 2 presents a second law analysis of this process.

In the moderate engine speed and torque regime encountered in normal driving, engine exhaust temperatures are relatively cool. It is therefore important to preserve exhaust heat and to use a low-temperature catalyst. The importance of exhaust temperature and catalyst activity temperature is shown by the following equation for usable exhaust heat:

$$Q_{\text{usable}} = \dot{m}_{\text{ex}} \times c_p \times (T_{\text{ex}} - T_{\text{cat}}),$$

where

$$\begin{aligned} Q_{\text{usable}} &= \text{usable exhaust heat} \\ \dot{m}_{\text{ex}} &= \text{exhaust mass flow rate} \\ c_p &= \text{exhaust heat capacity} \\ T_{\text{ex}} &= \text{engine exhaust temperature} \\ T_{\text{cat}} &= \text{minimum catalyst operation temperature.} \end{aligned}$$

Based on existing data, it is impossible to calculate the overall reaction conversion achievable over a driving cycle in a fully developed dissociated methanol system.

Several side reactions are possible along with the desired dissociation reaction (see Table 2-3). The extent of side reactions depends on the catalyst selected and the operating temperatures and space velocities. Catalysts have been developed that are over 95% selective for the desired dissociation reaction (Reference 3).

TABLE 2-3. METHANOL DISSOCIATION AND SIDE REACTIONS

CH ₃ OH	→	CO + 2H ₂
2CH ₃ OH	→	CH ₃ OCH ₃ + H ₂ O
CH ₃ OH + H ₂	→	CH ₄ + H ₂ O
CO + H ₂ O	→	CO ₂ + H ₂
2CO	→	C + CO ₂
CH ₃ OH	→	CH ₂ O + H ₂
CH ₃ OH + CO	→	HCO ₂ CH ₃

In practice, dissociated methanol engines have higher brake thermal efficiency than

liquid methanol engines at light loads. This is attributed to the ability of engines burning a hydrogen-rich fuel to operate at lower equivalence ratios than can engines burning any other fuel. This improves engine efficiency by (1) enabling operation at higher intake manifold pressures (required to admit the extra air) which reduce pumping work, (2) lowering combustion temperatures which reduce heat transfer losses and losses resulting from dissociation of water and carbon dioxide in the combustion and expansion processes, and (3) increasing the specific heat ratio of the expanding gases which allows a closer approach to air cycle efficiency. Figure 2-1 (Reference 4) presents data showing the effect of various amounts of hydrogen on the lean combustion limit and the indicated thermal efficiency that results. Note that the effect of hydrogen addition is very nonlinear. Twenty-five percent hydrogen yielded essentially the same thermal efficiency as 100% hydrogen. Equivalence ratio (ϕ) is defined as the actual fuel/air ratio divided by the stoichiometric fuel/air ratio. The dramatic improvement in thermal efficiency achieved is a much stronger function of equivalence ratio than of the choice of fuels per se. The use of hydrogen actually tends to cause a slight decrease in thermal efficiency if the equivalence ratio is not leaned out. (This data was taken on a CFR single cylinder research engine that permits much leaner operation than conventional multicylinder engines.) Inagaki et al. (Reference 5) confirmed these benefits on simulated dissociated methanol (67% hydrogen, 33% carbon monoxide).

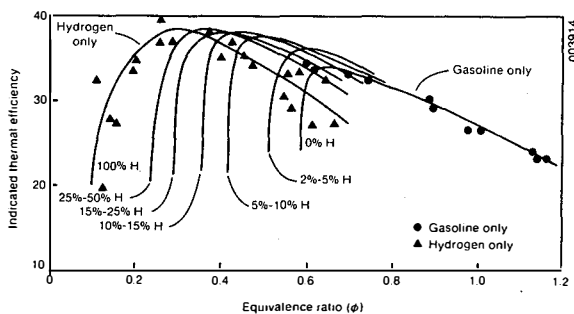
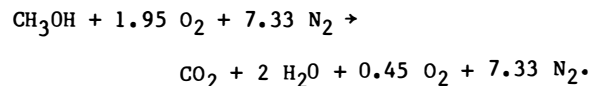


FIGURE 2-1. EFFECT OF HYDROGEN ON LEAN COMBUSTION LIMIT (Reference 4)

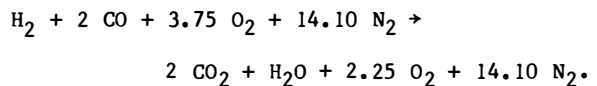
In addition to the above advantages, there are two debits to dissociated methanol engine thermal efficiency that must be included: (1) molar contraction upon combustion and

(2) unavailability of liquid methanol to reduce compression work or recover waste heat inside the engine.

A relative increase in the number of moles, **everything else being equal**, will have a net effect of decreasing the compression work somewhat. Combustion of liquid methanol at an equivalence ratio of 0.77 results in a 5% increase in the number of moles:



Combustion of dissociated methanol at an equivalence ratio of 0.4 results in a 7% decrease in the number of moles:



In a liquid methanol engine, methanol evaporates in three different places: (1) the intake system, (2) in contact with the cylinder walls and piston crown, and (3) in the bulk air/fuel mixture. Vaporization of methanol in either of the first two places increase the efficiency of a liquid methanol system by waste heat utilization to drive the vaporization process. That portion of the methanol vaporized in the bulk air/fuel mixture during the compression process reduces the work required to compress the air/fuel mixture by approximating isothermal compression instead of isentropic compression. The sum of the benefits of vaporizing liquid methanol at various times in various places in the engine can probably approach the benefits derived from external vaporization (an increase of 6% in fuel lower heating value, and therefore, system efficiency).

Note that thermal efficiency test data from liquid methanol engines will include the benefits of molar expansion and internal vaporization. Similarly, data showing thermal efficiency of engines burning dissociated methanol and hydrogen/carbon monoxide will include the disadvantages of molar contraction and lack of internal vaporization of methanol.

3. ENGINE DYNAMOMETER DATA

Figure 3-1 presents "bottom-line" data from the Nissan Motor Company, Ltd. (Reference 6), Ford Motor Company (Reference 7), and Texas

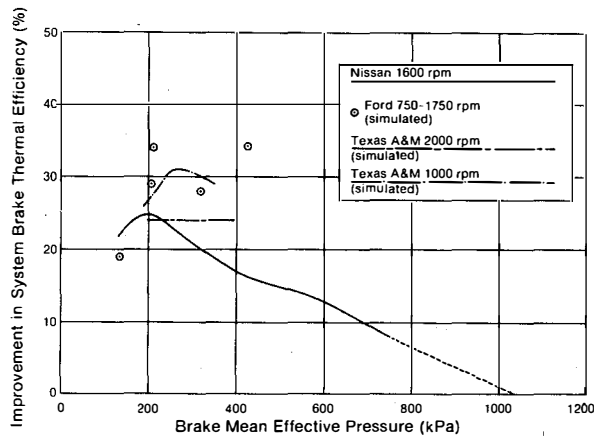


FIGURE 3-1. REFORMED METHANOL ADVANTAGE OVER LIQUID METHANOL (References 6,7, and 8)

A&M University (Reference 8) showing the improvement in system brake thermal efficiency of dissociated methanol and simulated dissociated methanol compared to liquid methanol. These data include all of the above advantages and disadvantages of dissociated and liquid methanol. The conclusions are as expected: a dissociated methanol system will have a significant advantage (e.g., 20%-35%) in brake thermal efficiency over a liquid methanol fuel system at light loads.

Dividing by the theoretical fuel processing system efficiency (120%) shows that a dissociated methanol engine offers a 0%-15% improvement in brake thermal efficiency over liquid methanol at light loads and has a worse thermal efficiency at heavy loads. There is insufficient information available from any of the references used for Figure 3-1 to determine whether the exhaust emissions resulting from each fuel's calibration are satisfactory without treatment.

In general, engine design or calibration changes made to increase its thermal efficiency result in a decrease in exhaust energy and temperature. These, of course, are detrimental to reformer yields and, hence, fuel processing efficiency. The most dramatic example of this is the selection of equivalence ratio. Decreasing the equivalence ratio to the value of the engine lean flammability limit will generally increase the engine efficiency, lower the exhaust temperature, and lower the exhaust energy content. Figure 3-2 (Reference 9) shows this effect as well as the effect of spark advance set to a value less than MBT (minimum advance for best torque).

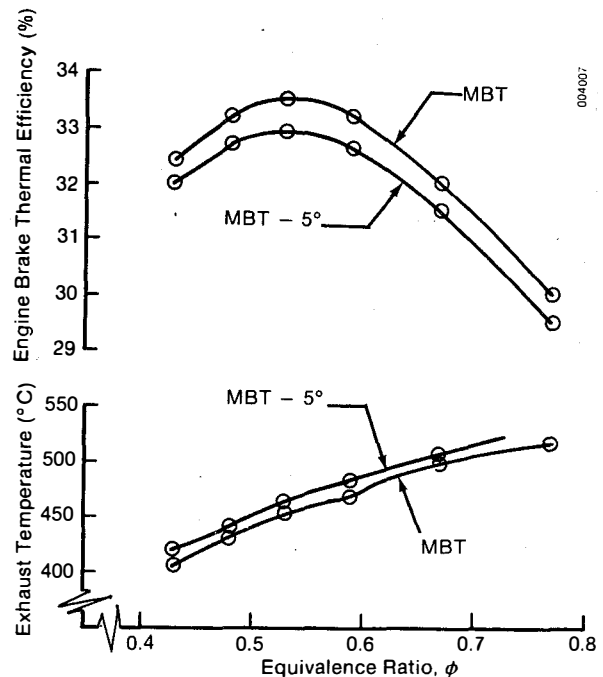


FIGURE 3-2. EFFECT OF EQUIVALENCE RATIO AND SPARK RETARD ON ENGINE BRAKE THERMAL EFFICIENCY AND EXHAUST TEMPERATURE (Reference 9)

Note that the data in Figure 3-1 for an actual reformed methanol system are in the same range as for the simulated reformed methanol data. This indicates, but does not prove, that the system optimum values of equivalence ratio and spark advance do not cause major deleterious effects on engine or fuel processing system efficiencies.

4. SYSTEM DESIGN

An engine will be able to achieve much higher power output when burning liquid methanol than when burning dissociated methanol for two reasons: (1) dissociated methanol is a gaseous fuel and therefore displaces air in the intake process, and (2) liquid methanol has a very high latent heat of vaporization, which can be used to cool the air/fuel charge, increasing its density. For these reasons, an engine system designed to burn dissociated methanol at modest power output conditions and liquid methanol for maximum power output is preferred.

The original system design was documented in Reference 10. In actual vehicle implementation there were few changes. Figure 4-1 is a

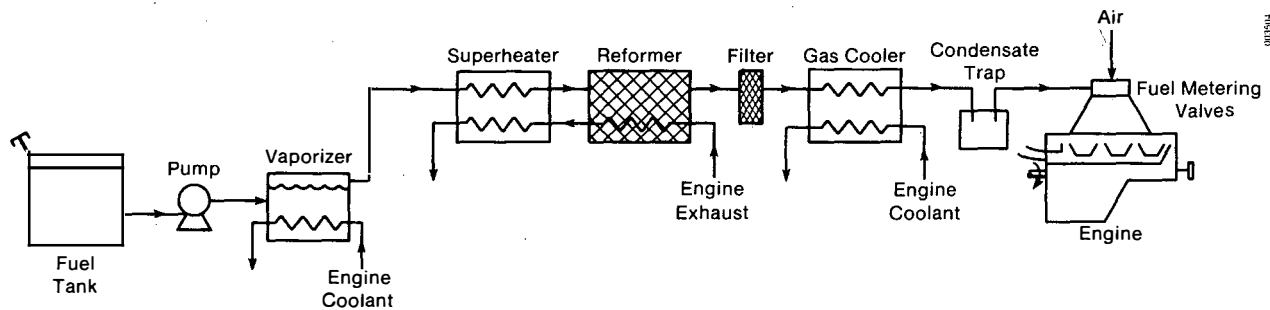


FIGURE 4-1. REFORMED METHANOL FUEL SYSTEM

simplified schematic drawing of the fuel system. Methanol is pumped from the fuel tank to the vaporizer. Heat is supplied by engine coolant at approximately 100°C . The vaporizer is a conventional tube-and-shell heat exchanger (2200 cm^2) with engine coolant flowing vertically through the tubes in a two-pass arrangement. Methanol boils on the shell side. Boiler level control is obtained with a pair of level switches activating relays to open and close a liquid methanol fill solenoid valve. The pressure in the vaporizer varies from approximately 100 kPa to 250 kPa.

Methanol vapor is superheated with engine exhaust gas leaving the dissociation reactor in an 880-cm^2 tube-in-tube superheater. The superheated methanol vapor is then admitted into the dissociation reactor (reformer). The reactor is of conventional tube-and-shell design with catalyst pellets for methanol dissociation packed inside the two-pass tubes. The catalyst used is United Catalyst T-2107: copper-zinc on alumina pellets. Engine exhaust gas flows in the shell side of the reactor in a two-pass arrangement with baffles every 15 cm. The reactor is 1.1 m long and 22 cm in diameter excluding insulation applied around it. It has 4.0 m^2 of heat transfer area. Significant (ca. 1 cm) gaps between the baffles and the shell were recently discovered. The exhaust gas flow is, therefore, not strictly cross-counter-flow as intended.

The design, construction, and testing of the reactor (including screening for the selection of the catalyst) was subcontracted to the Jet Propulsion Laboratory (Reference 11). They had the reactor fabricated by Repco Engineering, who assigned it model #8-3-36-BEV. It has 70 tubes of 0.8 cm inside diameter. The high-pressure gases are filtered to remove any catalyst fines. A con-

densate trap was added to remove excess unconverted methanol.

The filtered dissociated methanol is cooled in a conventional tube-and-shell heat exchanger (2200 cm^2) by engine coolant at its coolest point (at the water pump inlet).

The pressure is reduced to within a few kilopascals of ambient. The cooled, low-pressure, clean gases are metered and mixed with air in a pair of Impco model CA-100 air-valve mixers calibrated to deliver equivalence ratios of from 0.3 to 1.0 as shown in Figures 4-2 and 4-3.

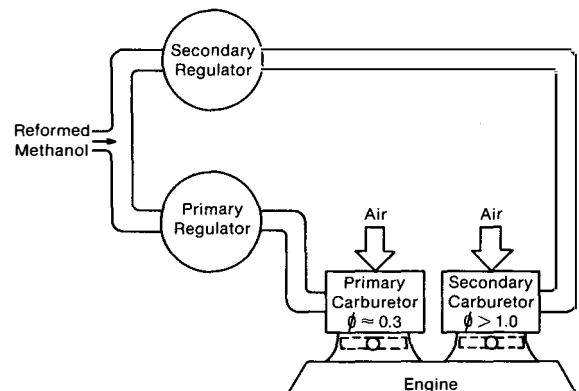


FIGURE 4-2. DUAL CARBURETOR MECHANICAL ARRANGEMENT

The original thermostat was replaced with a bypass thermostat from a Mercedes Benz 1973 250C. This allowed full engine coolant flow through the vaporizer under all conditions.

Engine modifications were kept simple for this phase of the project. The compression ratio was increased from 8.3:1 to 14:1 by substituting high compression height, flat-top pistons, and by milling the cylinder

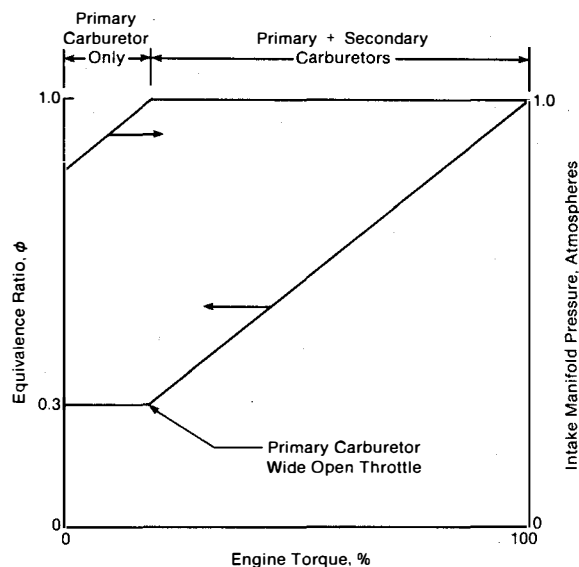


FIGURE 4-3. DUAL CARBURETOR EQUIVALENCE RATIO SCHEDULE

head. Hot water intake manifold heating was removed to improve volumetric efficiency. All exhaust emission control devices were removed from the engine.

The spark advance requirements of the dissociated methanol system are unusual due to the wide range of equivalence ratios used. Equivalence ratios of from 0.3 to 1.0 can be obtained at constant engine speed and manifold vacuum.

Spark advance control was initially obtained by modifying the stock mechanical centrifugal and vacuum advance units. This did not permit accurate enough control, so an early generation automotive microcomputer was used. It offered somewhat better control, but was still not entirely satisfactory.

Electromagnetic interference (EMI) plagued this microcomputer. Solenoids, in particular, caused major excursions in spark advance. All solenoids and other actuators were isolated. Despite these precautions, the problems persisted (albeit to a much lesser extent) until the load control circuits in the microcomputer failed. At that point the microcomputer was discarded in favor of a cable system.

A cable was attached to the throttle of the secondary carburetor to obtain spark retard upon enrichment. The driving cycle data in Section 6 were obtained with this system. It

was subsequently moved to the accelerator pedal to allow greater flexibility in calibration.

Exhaust diversion capability was added to protect the catalyst from overheating by the incorporation of two butterfly valves in the exhaust actuated by solenoids controlled by temperature switches as shown in Figure 4-4.

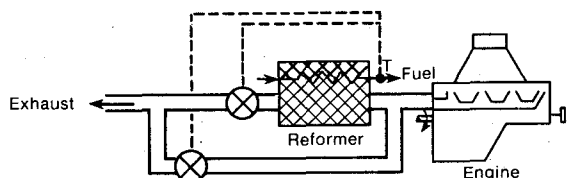


FIGURE 4-4. EXHAUST DIVERSION

The exhaust flow is diverted to maintain a preset maximum temperature at the fuel exit from the reformer.

Thermal shielding was added around the custom-built starter motor. Air flow is directed at it from under the front of the vehicle.

5. STEADY-STATE VEHICLE TESTING

Table 5-1 presents data on the composition of dissociated methanol products for steady-state vehicle testing at SERI. Note the excellent agreement of the atomic balances achieved. No condensate was detected, even with high methanol concentrations.

Dissociation percentage is defined in terms of the molecular weight of the dissociated methanol gases as follows:

$$\% \text{ dissociated} = \frac{32 - MW}{32 - 10.7} \times 100 ,$$

where MW is the molecular weight of the dissociated methanol gases, 32 is the molecular weight of methanol, and 10.7 is the molecular weight of completely dissociated methanol. This definition was chosen because we believe it may be possible to build a molecular weight sensor for on-board use that is suitable for mass production.

Note that the percent hydrogen is from 1 to 2 times the percent dissociated. Thus it is possible to obtain significant hydrogen concentrations required for ultra-lean engine operation with small reaction yields.

TABLE 5-1. DISSOCIATED METHANOL REFORMER PRODUCTS COMPOSITION

Run No.	Catalyst (hours)	Velocity (km/h)	Torque	Diss. (%)	Composition (%) ^a								Atomic Balance		
					H ₂	CO	CO ₂	CH ₄	H ₂ O	CH ₃ OH	CH ₃ OCH ₃	CH ₃ OOCH	Carbon	Hydrogen	Oxygen
SERI T1	0.8	idle	0	58	64	16	11	0	trace	1.0	8.3	0	0.98	0.99	1.02
SERI T2	1.6	65	road load	62	63	18	9.6	trace	trace	2.7	5.9	0	0.97	0.97	1.03
SERI T3	2.4	84	road load	6	13	2.1	2.3	trace	trace	80	1.3	0	1.00	1.01	0.98
				12	23	3.8	4.0	trace	0.6	66	2.4	0	1.00	1.02	1.00
SERI 3	9.1	90	road load	43	52	14	7.1	trace	1.6	20	5.4	0	0.97	1.03	1.02
SERI 8	14.6	90	road load	34	48	8.9	7.6	trace	0	28	7.2	0	0.99	1.05	0.98
SERI 11	17.6	90	road load	28	43	9.9	6.8	0.1	0.7	33	6.4	trace	0.99	1.02	1.00
SERI 13.5	23.2	idle	0	18	31	8.1	4.7	trace	0.3	52	4.1	yes	1.00	1.00	1.00
SERI 14.5	24.5	90	2.5-road	21	34	8.0	4.6	trace	0.4	49	4.1	yes	0.99	1.03	1.00
SERI 15	34.6	idle	0	4	7.1	1.7	0.6	trace	0.1	90	0.5	trace	1.00	1.01	1.00
				23	36	7.3	4.6	trace	0.8	47	4.6	trace	1.00	1.05	1.00
SERI 16	35.8	65	road load	16	24	5.4	1.7	trace	1.0	65	1.2	1.8	0.99	1.05	1.00

^aTrace is defined as less than 0.1%.

Table 5-2 presents steady-state dissociated methanol vehicle data. Test runs labeled SERI 10 and SERI 9 represent two different calibrations of equivalence ratio. Unfortunately, there is no liquid methanol data available for comparison. The gasoline baseline data result from internal General Motors' tests of a vehicle similar to the production gasoline vehicle modified by SERI (1980 Chevrolet Citation, 2.5 liter, 4-cylinder engine, 4-speed manual transmission) tested at the same dynamometer settings (Reference 12). The better calibration yielded a 48% improvement in energy economy compared to the gasoline baseline at 65 km/h (see Figure 5-1). In addition to the previously discussed advantages, it should be noted that the dissociated methanol engine

had a higher compression ratio than the gasoline engine. The other 65 km/h calibration yielded a much smaller improvement despite being calibrated leaner (with more excess air). This graphically demonstrates that the leanest possible equivalence ratio is not always the system optimum. In this case (SERI 10), some lean misfire was evident, reducing both the engine efficiency and the exhaust temperature.

Test runs SERI 3, SERI 4, and SERI 8 represent three different calibrations of spark advance for relatively constant equivalence ratios at 90 km/h. Note that all three points yield 40%-44% improvement in energy economy compared to the gasoline baseline despite a variation of 15° in spark advance

TABLE 5-2. STEADY-STATE DISSOCIATED METHANOL VEHICLE DATA

Run No.	Velocity (km/h)	Equivalence Ratio	Spark Advance	Fuel Economy		Energy Economy (km/GJ)	Improvement (%)
				Methanol (km/L)	Gasoline (km/L)		
GM Baseline ^a	65	NA	NA	--	18.6	566	--
SERI 10	65	0.33	62	10.1	--	638	13
SERI 9	65	0.39	62	13.3	--	840	48
GM Baseline ^a	90	NA	NA	--	16.4	499	--
SERI 3	90	0.41	43	11.4	--	720	44
SERI 4	90	0.40	46	11.1	--	701	40
SERI 8	90	0.39	58	11.4	--	720	44

^aReference 12.

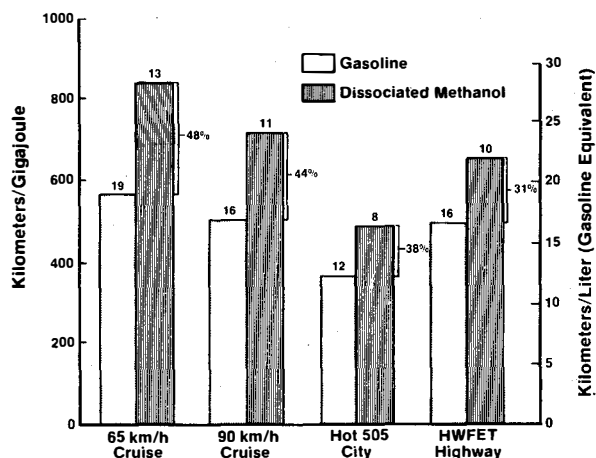


FIGURE 5-1. ENERGY ECONOMY IMPROVEMENTS: DISSOCIATED METHANOL VS. GASOLINE

(Figure 5-1). At lean equivalence ratios, the system efficiency is not a strong function of spark advance. Emissions of oxides of nitrogen are, however, a strong function of spark advance. The best calibration is SERI 3 since it offers the best energy economy and the minimum spark advance. Note in Table 5-1 that this calibration yielded only 43% dissociation. With better thermal management (e.g., exhaust port liners) and a catalyst with a lower activity temperature, the already large improvement in thermal efficiency might be able to be improved upon since there is considerable room for improvement in extent of dissociation.

6. DRIVING CYCLE VEHICLE TESTING

After the steady-state vehicle tests described in Section 4, EPA '74 hot start ("hot 505") and highway fuel economy tests (HWFET) were performed. The equivalence ratio calibration was not optimum because it was set at only three vehicle speed-load points: idle, 65 km/h road load, and 90 km/h road load. Minor adjustments were made, however, to improve driveability.

Spark advance calibration was far from optimum because there was limited time to calibrate the new mechanical control system after the failure of the microcomputer system. Evidence of over-advance (knock) and over-retard (backfire) were found at different speed-load and temperature conditions.

Despite the coarseness of the calibrations, very good fuel economy improvement was obtained as shown in Table 6-1 and Figure 5-1. The associated exhaust emissions are shown in Table 6-2.

TABLE 6-1. FUEL ECONOMY OF THE SERI DISSOCIATED METHANOL CITATION

	Methanol (km/L)	Gasoline (km/L)	Energy Economy (km/GJ)	Improvement (%)
EPA 1974-hot start				
GM (Baseline) ^a	NA	11.6	354	--
ETC (8/83)	7.74	--	489	38
HWFET				
GM (Baseline) ^b	NA	16.2	493	--
ETC (8/83)	10.2	NA	645	31

^aReference 12.

^bReference 13.

TABLE 6-2. EXHAUST EMISSIONS OF THE SERI DISSOCIATED METHANOL VEHICLE

	NO _x (g/km)	CO (g/km)	HC (g/km)	km/L
EPA 1974 hot start				
ETC (8/83)	0.52	2.27	0.53	7.74
GM (6/82)	0.35	5.61	1.09	6.27
EPA 1978 FTP (cold start)				
GM (Baseline gasoline) ^a	0.99	1.78	0.16	
HWFET				
ETC (8/83)	0.41	1.87	0.55	10.2
GM (Baseline gasoline) (79/80) ^a	0.79	0	0.02	

^aReference 13.

7. SUMMARY AND CONCLUSIONS

The following conclusions have been reached:

- The dissociation of methanol on board a vehicle is technically feasible.
- Lean combustion of dissociated methanol resulted in fuel economy of 7.74 km/L (18.2 mpg) over the EPA '74 CVS hot start city driving cycle and 10.2 km/L (24.0 mpg) over the EPA highway fuel economy test.
- Transient response of the reformer and vaporizer has been excellent, based on subjective driving cycle testing.
- The expected small engine brake thermal efficiency debit due to molar contraction upon combustion has not prevented the attainment of excellent system brake thermal efficiency.
- Despite low exhaust temperature and insufficient heat to dissociate all of the fuel, the dissociated methanol system has its largest thermal efficiency advantage over gasoline and liquid methanol at

low speed and light load conditions. This is attributed to the overriding importance of throttling and heat transfer losses reduced by the ultra-lean equivalence ratios employed.

- Exhaust emissions from a dissociated methanol vehicle are modest and appear easy to control.
- Considerable further research is required before a decision can be made as to the extent of its advantages over methanol, a more likely competitor than gasoline.

8. ACKNOWLEDGEMENTS

The work reported herein was performed by many people, but I would like to single out Gerard Glinsky, SERI Master Technician, for his contributions and high level of dedication to this project. He played key roles in developing, modifying, and testing the system.

I also thank the Office of Alcohol Fuels, U. S. Department of Energy, for their strong support from the project's early days to the present.

9. REFERENCES

1. Smith, O.; June 4, 1982; Personal Communication; General Motors Technical Center, Warren, MI.
2. Edo, T. and D. Foster; 1984; "A Computer Simulation of a Dissociated Methanol Engine"; Proceedings VI International Symposium on Alcohol Fuels Technology. Ottawa, Canada, to be published.
3. Cowley, S. W. and S. Gebhard; 1983; "The Catalytic Decomposition of Methanol into Syngas for Use as an Automotive Fuel"; Proceedings 8th Symposium of the Rocky Mountain Fuel Society. Salt Lake City, UT.

4. Stocky, J. F., M. W. Dowdy and T. G. Vanderbrug; 1975; An Examination of the Performance of Spark Ignition Engines Using Hydrogen-Supplemented Fuels. SAE #750027.

5. Inagaki, T., T. Hirota, and Z. Ueno; 1979; "Combustion and Emission of Gaseous Fuel from Reformed Methanol in Automotive Engine"; Proceedings of the 3rd International Symposium on Alcohol Fuels Technology. Asilomer, CA.

6. Lombardo, M.; 1984; Personal Communication; Nissan Motor Company, Ltd., Ann Arbor, MI.

7. Adams, T. G.; 1984; "A Comparison of Engine Performance Using Methanol or Dissociated Methanol as the Fuel," SAE #845128, Proceedings 20th FISITA Conference. Vienna, Austria, to be published.

8. Lalk, T., and D. McCall; 1983; "Evaluation of Reformed Methanol as an Automotive Engine Fuel"; presented at the Alternative Fuels Contractors' Coordination Meeting Workshop, Windsor, Canada.

9. Hirota, T.; 1981; "Study of the Methanol Reformed Gas Engine"; JSAE Review.

10. Finegold, J., M. Karpuk, and T. McKinnon; 1980; "Demonstration of Dissociated Methanol as an Automotive Fuel: System Design"; SERI/TP-731-830, Proceedings of the 4th International Symposium on Alcohol Fuels Technology. Guaruja, Brazil.

11. Voecks, G., S. Dawson, and J. Houseman; 1980; "Operation of a Catalytic Methanol Decomposition Reactor for Vehicular Use"; Proceedings of the 4th International Symposium on Alcohol Fuels Technology. Guaruja, Brazil.

12. King, J.; June 25, 1982; Personal Communication; General Motors Technical Center, Warren, MI.

13. Environmental Protection Agency; 1980; Test Car List; Ann Arbor, MI.