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METHANOL AS AN AUTOMOTIVE
FUEL: SYSTEM PERFORMANCE

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NOTICE

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ABSTRACT

This paper presents the results of system performance testing of an automotive system devised to provide hydrogen-rich gases to an internal combustion engine by dissociating methanol on board the vehicle. The dissociation of methanol absorbs heat from the engine exhaust and increases the lower heating value of the fuel by 22%. The engine thermal efficiency is increased by raising the compression ratio and burning with excess air.

1. INTRODUCTION

The objective of the work underway at the Solar Energy Research Institute (SERI) is to demonstrate the feasibility of fueling an automobile with dissociated methanol to obtain higher vehicle efficiency than that of cars burning pure alcohol or alcohol blends. A previous paper (1) introduced this project and presented the system design. This paper describes the system tested on an engine dynamometer and the results of that testing.

Alcohols can be dissociated to hydrogen and carbon monoxide or carbon dioxide in an endothermic reaction, resulting in an increase in the lower heating value of the fuels as shown in Table 1. The energy of reaction can be supplied by engine waste heat. In terms of the energy increase, the reactions yielding carbon monoxide are more attractive than those yielding carbon dioxide.

Table 1.

Reaction			Increase in Lower Heating Value
Methanol			
$CH_3OH +$	heat $\rightarrow 2H_2 + CO$		22%
$CH_3OH + H_2O +$	heat $\rightarrow 3H_2 + CO_2$		15%
Ethanol			
$C_2H_5OH + H_2O +$	heat $\rightarrow 4H_2 + 2CO$		20%
$C_2H_5OH + 3H_2O +$	heat $\rightarrow 7H_2 + 2CO_2$		13%

Due to the extended lean misfire limit of the hydrogen-rich dissociated alcohol, an engine burning the reaction products can be operated with considerable excess air resulting in increased thermal efficiency (2). Very high compression ratios can also be used owing to the combustion characteristics of the dissociated alcohol (2). These two factors result in an engine which has significantly higher thermal efficiency than one burning gasoline or liquid alcohol.

2. SYSTEMS DESCRIPTION

The dissociated methanol system comprises a fuel system to dissociate the methanol and a modified internal combustion engine to burn it. They are shown together in a simplified schematic drawing in Figure 1.
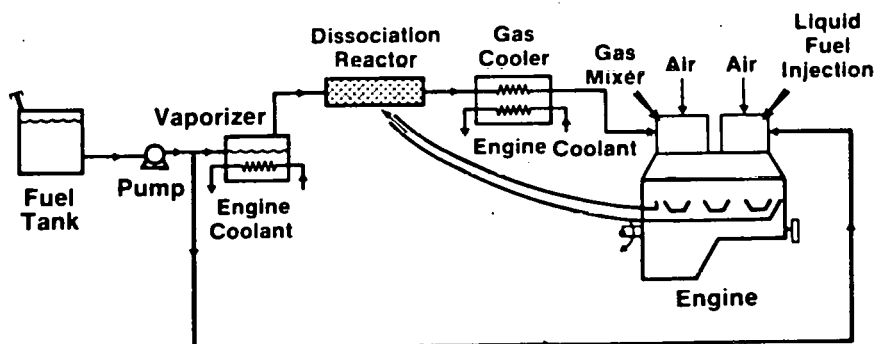

Figure 1. Conceptual Flowsheet

2.1 Fuel System

The function of the fuel system is to vaporize and dissociate liquid methanol and deliver it to a gas mixer at a regulated pressure. The system is a small chemical processing train involving heat and mass transfer operations and chemical reactions. The major components of the fuel system are the vaporizer, superheater, reactor, and gas cooler. We sized all the components to fit in the engine compartment of the Chevrolet Citation test vehicle.

Methanol is pumped from the fuel tank, through filters, to the vaporizer. The methanol is vaporized at approximately 180 kPa using heat from engine coolant coming directly from the engine outlet. The vaporizer is a commercially available stainless steel shell-and-tube heat exchanger with 2200 cm^2 of heat transfer area. The engine coolant flows through the tubes, while methanol is boiled in the shell. We mounted a cylinder directly above the vaporizer that serves as a vapor-liquid disengaging space. A level probe mounted in the disengaging cylinder monitors liquid level in the vaporizer. A signal from this probe is processed to open and close a solenoid valve in the liquid methanol line directly upstream of the vaporizer to control the liquid level.

The methanol leaves the vaporizer as a saturated vapor, and passes through a double pipe heat exchanger where engine exhaust superheats the vapor. The superheater, which has 880 cm^2 of heat transfer area, superheats the vapor to approximately 250° C.

This superheated vapor enters the dissociation reactor which was designed, built, and tested by the Jet Propulsion Laboratory (3). The dissociation reactor is a stainless steel shell-and-tube heat exchanger with 4.0 m^2 of heat transfer area. The methanol vapor flows over the catalyst spheres in the tubes, countercurrent to the engine exhaust in the shell. The endothermic dissociation reaction occurs on the surface of a Cu-ZnO catalyst supported on 3 mm alumina spheres. The reaction is driven with heat from the engine exhaust gas, which enters the reactor at approximately 600° C.

The gaseous fuel leaves the reactor at approximately 300° C and consists primarily of hydrogen and carbon monoxide, with smaller amounts of methanol, methane, and dimethyl ether. The gaseous fuel is cooled to approximately 100° C with engine coolant from the radiator in a small (1200 cm^2) shell-and-tube heat exchanger. The decrease in temperature increases the energy density of the fuel from 5.4 MJ/m^3 to 8.3 MJ/m^3. High energy density fuel increases the engine power output because the fractional volume required for fuel in the air-fuel mixture is reduced.

The pressure of this gaseous fuel is controlled with a conventional gas regulator upstream of the carburetor. The final step in fuel processing is to filter any catalyst fines from the fuel stream to protect the engine. We use a filter, designed for refrigeration systems, with a felt element. At this point, the carburetor can draw on a supply of cool synthesis gas at a regulated pressure.

Since the fuel processing system requires engine heat to operate, a separate start-up system is required. For the test stand, we use propane, plumbed to the fuel line directly upstream of the carburetor. After the engine has been adequately warmed up, the methanol flow is started and the propane flow shut off. On board the vehicle, fuel injected liquid methanol will be used for start-up.

2.2 Engine

The engine is a General Motors 2.5 liter in-line four-cylinder engine rated at 65 kW from a 1980 Chevrolet Citation. The block and cross-flow head are cast iron. The GM High Energy Ignition system is used.

We modified the engine itself only slightly for operation on dissociated methanol. We increased the compression ratio from stock, 8.3:1, to approximately 14:1 by installing flat-top pistons with greater compression height and milling the head. We replaced the original carburetor with an Impco air-valve carburetor designed for propane use and added a General Motors closed-loop feedback spark advance controller. This device senses engine knock and retards the spark timing until only trace knock is present. We made no changes to valve timing, but we removed the exhaust gas recirculation, exhaust air injection equipment, and exhaust catalyst.

The engine power is absorbed with a Stuska Model 800 water brake dynamometer modified to improve stability under varied speed and load conditions.

3. INSTRUMENTATION AND CONTROL

Instrumentation requirements fall into two basic categories: system diagnostics and performance data. The instrumentation requirements for the diagnostic functions are temperatures, pressures, and flow rates. For performance data, engine speed, torque, spark timing, and fuel consumption are required. We fitted the engine test stand with transducers whose output is displayed at the operator's console in the engine control room.

Temperature measurements are made with type K thermocouples and pressure measurements are made with strain gauge transducers. Fuel flow is measured with a positive displacement flow meter mounted in the fuel line directly upstream of the vaporizer. Torque readings are taken with a strain gauge load cell.

To remotely measure spark timing, we mounted an optical shaft encoder to the crankshaft pulley. The signal from the encoder is processed with custom-built circuitry to display spark advance in

degrees of crank angle. The same encoder is also used to measure engine speed. We calculate equivalence ratio (actual fuel/air ratio divided by the stoichiometrically correct fuel/air ratio) from the oxygen content of the engine exhaust.

We set the system up so most of the engine variables could be remotely set. We control the throttle and spark timing with linear actuators and the load by adding or draining water from the water brake loop with solenoid valves. Equivalence ratio is controlled by manually adjusting the fuel pressure to the carburetor.

4. RESULTS

Figures 2 and 3 present brake thermal efficiency compared to torque at 1000 and 2000 rpm for both the gasoline system and the dissociated methanol system. The improvement is in the range of 55% to 82% at 1000 rpm and from 40% to 97% at
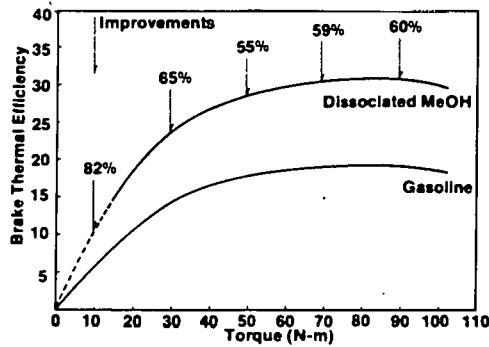
2000 rpm. We used these data together with data at other engine speeds to plot the brake thermal efficiency maps for the gasoline system and the dissociated system. (See Figs. 4 and 5.)
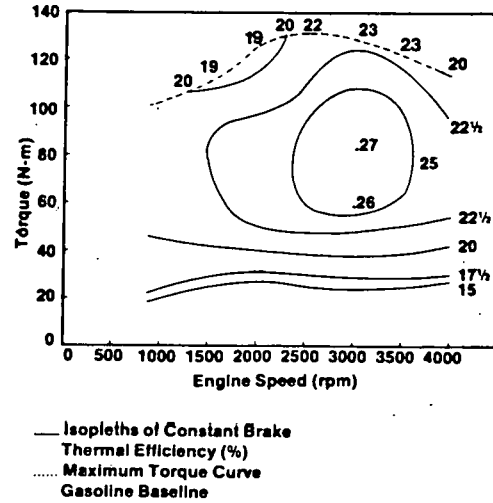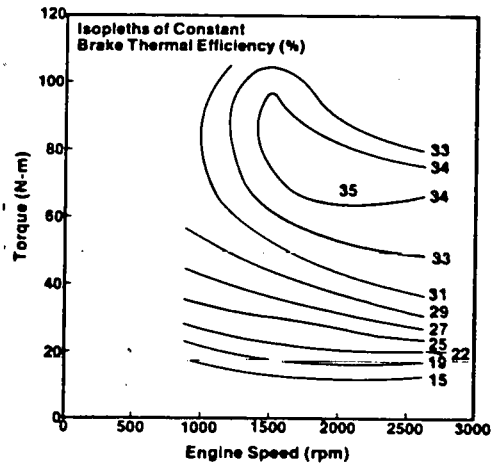

__ Isopleths of Constant Brake
  Thermal Efficiency (%)
...... Maximum Torque Curve
  Gasoline Baseline

Figure 4. Gasoline Engine Map

**Figure 2.   Brake Thermal Efficiency Vs.
Torque at 1000 rpm**

Figure 5. Dissociated Methanol Engine Map

**Figure 3. Brake Thermal Efficiency Vs.
Torque at 2000 rpm**

5. DISCUSSION

The data presented in the previous section demonstrate substantial improvements in brake thermal efficiency for the dissociated methanol system compared to the gasoline system. We attribute the improvements to three basic differences between the conventional gasoline system and the dissociated methanol system. The first difference, which also makes the other two possible, is that

the liquid methanol is vaporized and then catalytically dissociated into hydrogen and carbon monoxide in a 2:1 ratio. This process increases the energy content of the fuel by about 22%. This energy increase is divided between thermal energy (approximately 30% of the improvement) and chemical energy (approximately 70% of the improvement). This hydrogen-rich fuel allows the selection of the very high compression ratio (14:1). A high compression ratio increases engine efficiency by more fully expanding the combustion gases, thus extracting more work.

The third major difference is that the hydrogen-rich fuel allows the engine to be run at very low equivalence ratios. The optimum equivalence ratio was as low as 0.3 (greater than 200% excess air), depending on the engine torque and speed. The low equivalence ratio yields combustion products with a higher specific heat ratio, more closely approaching the air-standard cycle yielding higher brake thermal efficiencies. Furthermore, very lean operation requires greater throttle openings for a given power output, thereby reducing pumping power requirements (throttling losses). Finally, very lean combustion results in low combustion temperatures and reduced heat losses that increase the fraction of input energy producing work.

Note in the upper right hand corner of the dissociated methanol map that the brake thermal efficiency isopleths do not form the typical islands, but become concave with respect to that corner. The reason for this is abnormal combustion that occurred at sustained high torque and speed conditions. The cause of this problem, and its cure are the subjects of future testing, but we believe that the high coolant temperature used (105°C) is at least one contributing factor. When this problem is resolved, an area of even higher brake thermal efficiency may be available.

Chassis dynamometer and on-road testing of the dissociated methanol test vehicle is scheduled for spring and summer of 1981. These tests will be important in assessing the transient response of the system and its exhaust emission characteristics. We will report results of those tests soon thereafter.

6. ACKNOWLEDGMENTS

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