

# DEVELOPMENT OF A DIMETHYL ETHER-FUELED SHUTTLE BUS

Shirish Bhide, Elana Chapman, Jennifer Stefanik, Howard Glunt,  
Louis I. Boehman and André L. Boehman

The Energy Institute  
The Pennsylvania State University  
405 Academic Activities Building  
University Park, PA 16802

Francis J. Waller

Air Products and Chemicals, Inc.  
Allentown, PA

## Introduction

Dimethyl ether has been considered a potential ultra-clean replacement fuel for diesel engines [1]. Dimethyl ether (DME) burns “smokeless”, permits high levels of EGR for in-cylinder NO<sub>x</sub> control and can be produced from synthesis gas derived from fossil fuel or biomass resources. These potential benefits of DME have motivated studies of the physical properties, the lubricity concerns and the combustion performance of DME [2,3]. In the present work, we seek to operate a laboratory engine and a campus shuttle bus on DME. To overcome the low lubricity and low viscosity of DME so as to be able to operate a conventional, common rail, DI diesel engine on DME, we have chosen to blend DME and diesel fuel. The conversion of the laboratory engine and the shuttle bus required development of a pressurized fuel delivery system to maintain the DME-diesel fuel blend above the vapor pressure of DME. This paper summarizes the outcomes from analyses of fuel properties, the laboratory engine studies and the conversion of the shuttle bus.

## Experimental

**Viscosity of DME-Diesel Blends.** Quantitative measurements of the viscosity of blends of DME in a federal low sulfur fuel were obtained using a high pressure viscometer, using capillary tubes that provided optimal measurement accuracy depending on the viscosity of the fuel mixture [4]. Measurements were obtained over a range of pressures with the viscometer housing immersed in a constant temperature bath at 100°F (38°C). Results obtained at three different levels of chamber pressure are plotted in Figure 1 to show the impact of DME content on viscosity.

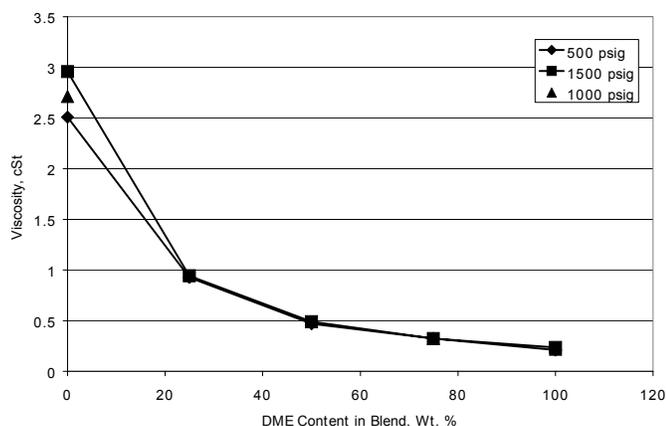


Figure 1. Blend response of viscosity to DME addition at various pressures [4].

**Laboratory Engine Studies.** The fuel system on the Navistar 7.3L V-8 “T444E” turbodiesel engine had to be modified to permit delivery of the fuel blend at elevated pressure [5]. The fuel rail in the cylinder head of the engine receives fuel at a pressure of about 70 psi. Fuel from this rail is then fed to the injectors.

A study was performed using #2 diesel fuel to measure the temperature rise of the fuel in the fuel rail. This measurement, coupled with the fuel consumption gave an approximate heat transfer rate between the cylinder head and the fuel in the gallery. A maximum target temperature was chosen for the diesel-DME blend based on the vapor pressure curve of DME and the pressure rating of the fuel rail. The required change in fuel recirculation flow rate was then calculated based on the above observations. This recirculated fuel was then cooled down using a water cooled heat exchanger. The fuel delivery pump was sized based on the above calculations.

Selecting a pump for DME was challenging due to the properties of DME. Gasket material for the pump had to be modified, as common materials such as Viton and buna-N have been found to be unsatisfactory. A fuel filter with a high filter surface area and high pressure capacity was needed. A modified propane filter was selected for the application. The fuel tank consisted of a modified 60 lb capacity LPG cylinder which was pressure tested at 120 psi prior to use.

From previous studies on this same engine for 2 wt.% oxygen in the diesel fuel, the cooling capacity of the heat exchanger and fuel circuit was found to be insufficient, based on the fuel temperatures recorded, as well as, observed engine instabilities. Therefore, the system shown in Figure 2 presents the modifications made, which included the addition of a second fuel coil in the cooled bath, and a larger chiller unit for cooling the bath. Additionally, the system was pressurized to 150 psi, which then increases the allowable fuel temperature before the DME becomes vapor.

Operation of the laboratory engine on blends of DME and diesel fuel resulted in reduction of particulate matter emissions. As shown in Figure 3, blending at up to 25 wt.% DME in diesel, corresponding to 10 wt.% oxygen addition resulted in significant reduction in particulate matter emissions.

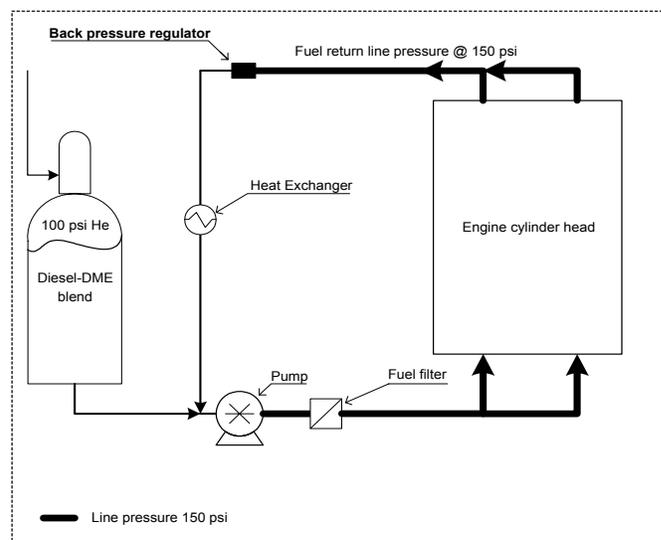
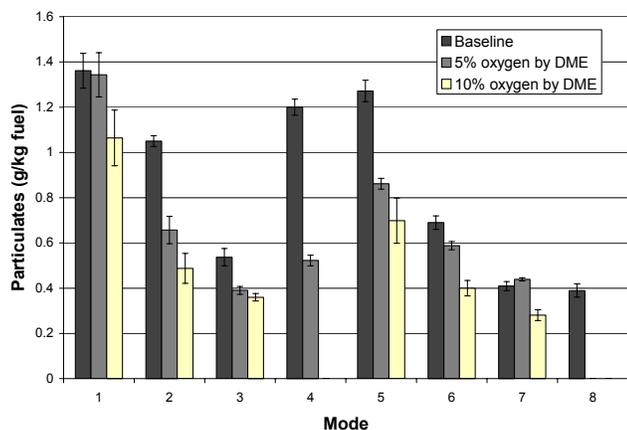


Figure 2. Diagram of the pressurized fuel system [5].



**Figure 3.** Particulate Matter Results per unit fuel consumed, g/kg fuel [5].

### Shuttle Bus Conversion

The final stage of this project was the conversion of a campus shuttle bus and operation of the bus on the DME-diesel fuel blends. To accomplish this goal, the pressurized fuel system on the laboratory engine was adapted for application to a Champion Motorcoach “Defender” model bus with the same model engine (Navistar T444E) as was used in the laboratory study. To simplify the requirements for the fueling station for the shuttle bus, mixing of the DME and diesel fuel is performed onboard the bus. Figure 4 shows the shuttle bus used in this study. The final design and the operational procedures were reviewed and modified in a detailed “HAZOP” or failure modes effects analysis (FMEA). The outcome of the HAZOP analysis was to increase the number of check valves, manual valves and redundancy in the system.

The system on the bus consists of a transfer pump that delivers diesel fuel from the existing diesel fuel tank to the tank for the blended fuels, a propane tank for a recreational vehicle. This LPG tank was modified only by replacing o-ring materials with Kalrez™ o-rings. The connections on the LPG tank permit diesel fuel to be transferred to the tank, while the tank is vented to the atmosphere. Then, DME is transferred into the LPG tank. During the refueling processes, a handheld controller notifies the operator of the fill level in the LPG tank so that the desired proportions of fuel are transferred. Finally, a compressed cylinder of helium is connected to the LPG tank to provide a blanket of inert gas to maintain a minimum of 120 psig in the LPG tank and keep the DME in the liquid phase. A magnetically coupled gear pump serves to draw fuel from the LPG tank and transfer the fuel blend to the fuel rails in the cylinder heads of the engine. A backpressure regulator maintains the pressure in the fuel rails at a minimum of 150 psig, although during operation the rail pressure is typically near 200 psig. Fuel rejected from the rails passes through a pair of fuel coolers mounted in front of the radiator to keep the fuel temperature from rising above a bulk temperature of 50°C.

Upon completion of the majority of the conversion process, the bus was operated with the pressurized fueling system on diesel fuel but without DME blending. The bus was operated over several days at the Pennsylvania Transportation Institute’s test track near the Penn State University Park campus. During this shakedown process, emissions measurements were obtained in collaboration with Clean



**Figure 4.** Particulate Matter Results per unit fuel consumed, g/kg fuel.

Air Technologies (Buffalo, NY) using their portable diesel emissions analyzer (XXX). Among the chief challenges faced during the conversion and shakedown tasks was the power requirements and stability of operation of the gear pump. However, in-field adjustments and modifications resulted in consistent and stable operation of the components of the pressurized fueling system. The shuttle bus will operate on the DME-diesel fuel blend, at 25 wt.% DME, through Fall 2002 during which time periodic performance, emissions and system integrity tests will be performed.

### Conclusions

Operation of a commercial diesel engine on DME-diesel blends has been accomplished with minimal modification to the engine, apart from addition of a pressurized fuel delivery system. This technique permits operation of vehicles, in part, on DME without jeopardizing the long term durability of the engine. Consistent with operation of diesel engines on oxygenated fuels, particulate emissions with the DME-diesel fuel blends are substantially reduced.

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### References

- (1) Fleisch, T., McCarthy, C., Basu, A., Udovich, C., Charbonneau, P., Slodowske, W., Mikkelsen, S.-E., and McCandless, J., **1995**, SAE Paper No. 950061.
- (2) Sivebaek, I. M., Sorenson, S. C., and Jakobsen, J., **2001**, SAE Paper No. 2001-01-2013.
- (3) Teng, H., McCandless, J.C. and Schneyer, J.B., **2002**, SAE Paper No. 2002-01-0862.
- (4) Bhide, S.V., Boehman, A.L. and Perez, J.M., Prepr. – *Am. Chem. Soc., Div. Fuel Chem.*, **2001**, 46(2), 400.
- (5) Chapman, E.M., Boehman, A.L., Tijm, P.J.A. and Waller, F.J., **2001**, SAE Paper No. 2001-01-3683.