Use of DME as a Gas Turbine Fuel

Arun Basu, Mike Gradassi, and Ron Sills: Upstream Technology Group, BP Exploration
Theo Fleisch, and Raj Puri: Gas & Power, BP Exploration

Presented at the ASME Turbo-Expo, New Orleans, June 2001

Abstract: A new, ultra-clean fuel for gas turbines - a blend consisting primarily of dimethyl ether (DME) with lesser amounts of methanol and water - has been identified by BP. This fuel, containing no metals, sulfur and aromatics, burns like natural gas and it can be handled like LPG. The turbine-grade DME fuel can be manufactured from natural gas, coal and other hydrocarbon or biomass feedstocks. High-purity DME, manufactured from methanol, is currently used as an aerosol propellant due to its environmentally benign characteristics. Fuel-grade DME is used commercially as a LPG-substitute in China.

BP initiated key programs to test various fuel mixtures containing DME in General Electric test combustors with equivalent electricity production of nearly 16 MW. Later, BP collaborated with EPDC (Electric Power Development Corporation, Japan) to conduct additional follow-up tests. These tests show that DME is an excellent gas turbine fuel with emissions properties comparable to natural gas. Based on the results of the BP/GE combustion test programs, GE is prepared to pursue commercial offers of DME-fired E class and F class heavy duty gas turbines. BP is currently working with the Indian Oil Corporation (IOCL), the Gas Authority of India Limited (GAIL) and the Indian Institute of Petroleum to evaluate the potential of DME as a multi-purpose fuel for India. In June 2000, the India Ministry of Power issued a notification permitting the use of DME as a fuel for power generation subject to its meeting all the environmental and pollution regulations. This paper presents key gas turbine combustor test results and discusses how DME can be used as a fuel in gas turbines.

Introduction : DME, or Dimethyl Ether (chemical formula : CH3-O-CH3) is a clear colorless environmentally benign and nontoxic compound that is currently used commercially as a propellant for various aerosols products including perfumes, and other health products (1,2). Yunnan Methanol Fuel Company in China has been selling methanol-derived fuel-grade DME (referred to as "fine" grade) as a LPG substitute; five other companies in China have also built DME plants for this purpose.(3) DME is also not a carcinogen/teratogen/mutagen, and does not form peroxides even after prolonged exposure to air. It is not harmful to the ozone layer (unlike the previously used CFC gases) and is easily degraded to water and carbon dioxide in the troposphere (4,5). Importantly, it is physically similar to liquefied petroleum gas (LPG) which primarily contains propane and butane. Thus, DME can be handled like LPG, a proven commercial product traded and shipped globally. The key properties of pure DME are compared below with those of propane and butane:

Property	DME (pure)	Propane	Butane
Boiling Point, °C @ 1 atm	-24.9	-42.1	-0.5
Vapor Pressure @ 20 °C, bar	5.1	8.4	3.1
Liquid Density @ 20 °C, kg/m3	668	501	610
Lower Heating Value, KJ/Kg Liquid	28,360	45,990	45,367
Lower/Upper Flammability Limit in Air, vol.%	3.4 - 17	2.1 - 9.4	1.9 - 8.5

The total world production capacity for aerosol-grade DME is about 150,000 ton/year, and is today exclusively made by several manufacturers from methanol by a dehydration process. Although the current production of DME is limited, it is an important intermediate for the manufacture of synthetic gasoline (in New Zealand; ref. 6), and for the production of acetic acid (7). DME is currently attracting world-wide attention due to its potential as an ultra-clean diesel

fuel alternative.(8,9) Initial diesel engine tests indicate that DME would lead to ultra-low emissions that would surpass California's ULEV (Ultra Low Emission Vehicles) regulations.(8)

Recent publications from BP (10,11), EPDC (12), Chiyoda Corp. (13) and Haldor Topsoe & Snamprogetti/ENI S.p.A. (14) indicate the growing interest on the potential of DME as a gas turbine fuel for niche markets that can not be easily reached by natural gas supplies. As shown in Figure 1, BP's vision is to commercialize DME as an integrated gas project.

For gas turbine applications, a fuel-grade DME (with about 7-8 wt% methanol and 2.9-3.5 wt%

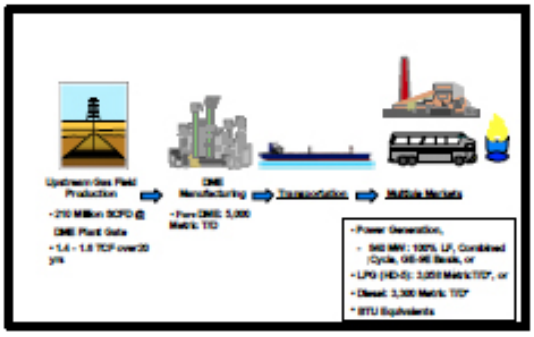
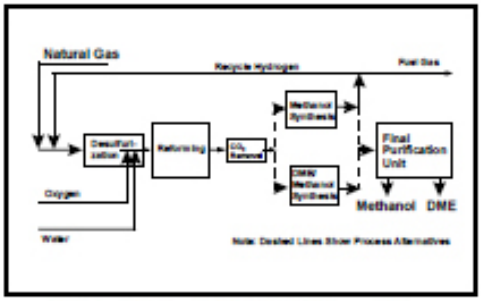


Fig 1: An Integrated DME Full Value Chain Project



DME and Methanol Manufacturing Process Steps are Very Similar

water) has been formulated to reduce manufacturing costs, and to enhance shipping as well as gas turbine operations.

Large-Scale Manufacture of DME : For effective commercial uses of DME as a low-cost multi-purpose fuel, DME should be produced in very large quantities. Haldor Topsoe A/S (HTAS) of Denmark has developed and demonstrated, in a 50 kg/day pilot plant, an integrated process for the direct production of DME from synthesis gas (mixture of hydrogen plus carbon monoxide) made from natural gas.(15) As shown in Figure 2, the process is very similar to commercial methanol manufacturing processes. Other companies, such as Air Products(16) and NKK Corp.(17) are also developing DME synthesis technologies. Haldor Topsoe and Snamprogetti have claimed that very large scale DME plants (e.g., : about 7,500 metric tons/day of pure DME which is equivalent to about 10,435 metric tons of methanol/day) with single-train DME synthesis reactors can be built using the current HTAS AutoThermal Reforming and DME synthesis technologies.(14)

Performance in Gas Turbines ; DME ***Infrastructure and safety Requirements :*** Since DME can be handled like LPG, ocean transport of DME can use conventional LPG tankers. It can be offloaded and stored at a receiving power plant site using equipment that is similar to conventional LPG-type unloading and storage equipment. We at BP are also evaluating alternative designs for unloading DME and supplying nearby power plants, including : *Single Point Mooring System (SPM) design that uses a cantenary anchor mooring system for DME off-loading.(11)*

As DME can be totally vaporized quite effectively at inlet conditions (e.g., at 150-250 psig) of gas turbine combustors, it can be used in modern efficient Dry-Low-NOx (DLN) type gas turbines and meet NOx emissions at limits of 25 ppmvd (at 15% oxygen level). Liquid DME, stored as either refrigerated liquid (about minus 25 C, 1 atm) or under pressure (at ambient temperature), can be first pumped to a higher pressure (say 350-450 psig) and then vaporized by the utilization of hot water/steam produced as a part of the combined cycle power plant.(10) As discussed in page 5, this type of process integration for a DME terminal and a power plant would allow improved power generation efficiency through heat recovery from the flue gas leaving a combined

cycle power plant. For DME, specific industrially proven materials for gaskets/seals will be used. The environmental, health and safety aspects of pure DME are very acceptable as demonstrated by its use as a CFC aerosol-propellant replacement. However, similar to LPG and other combustible fuels, DME needs to be handled with care. The LPG and the DME-as-aerosol industries have an outstanding safety record. Fuel-grade DME would contain some methanol (typically about 8 wt%) which is toxic; however, due to LPG-like closed vessel handling, it can be handled safely with appropriate procedures.

- *BP/EPDC/GE Combustor Tests ; Background*

The power generation efficiency (E) is usually expressed via a "heat rate" number that corresponds to the amount of thermal energy needed (LHV or HHV basis) to generate one unit of electrical energy (e.g., Btu/kwhr). A *lower* heat rate number reflects *higher* power generation efficiency. The significant products of combustion in gas turbine emissions are : (1) oxides of nitrogen (NOx), (2) carbon monoxide (CO), (3) Unburned hydrocarbons (UHC) that are formed due to incomplete combustion and (4) oxides of sulfur (SO2 and SO3) particulates. Modern GE DLN (Dry Low NOx) Combustors are designed to improve E values and reduce NOX and other emissions.

Figure 3 shows the schematic of the GE DLN-1 combustion system that includes four major components: fuel injection, liner, venturi and cap/center body assembly.(13) As described by Davis (GE Power Systems; Ref. 18), the DLN-1 system operates in four distinct modes, namely : Primary, Lean-Lean, Secondary and Premix. The primary-only mode, used for start-up and low-load operation, is a "diffusion flame" mode. This mode was tested on DME to verify operations for GE "diffusion" machines. Intermediate loads are run in the lean-lean mode. The "premixed" mode of operation is utilized from mid- to full-load on the gas turbine. The key GE gas turbines with DLN technologies are, for example, (1) MS-3000, MS-5000, MS-7000B/E, MS-7001EA and MS-90001E machines with DLN-1 combustors, and (2) higher firing temperature machines including FA, EC and H class machines that use DLN-2 class combustors.

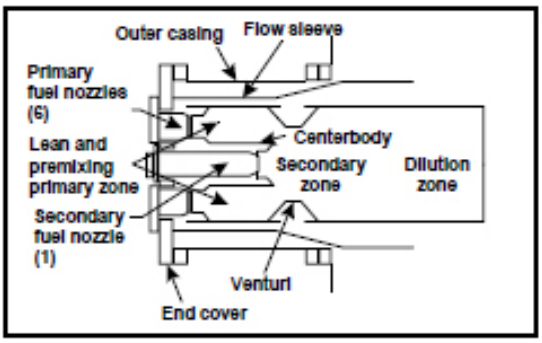


Fig. 3: DLN-1 combustor schematic

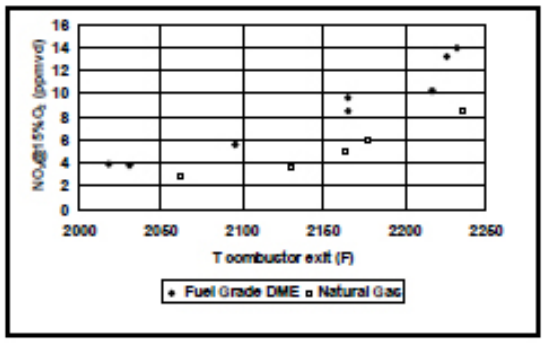


Fig. 4: MS9001E DLN-1 - Premix Emissions

- *Combustion Test Facilities :* The pressurized combustion tests with pure and fuel-grade DME were performed at the GE Power Generation Engineering Laboratory in Schenectady, NY.(10) This facility houses single combustor test stands designed to simulate the operating conditions of a turbine in the field. The test stand (1) tests a full-size combustor (each containing multiple DLN-1 or DLN-2 class burners) at machine rated flows, pressures, and temperatures, and (2) models a section of the gas turbine from the compressor discharge to the first-stage turbine inlet, matching the boundary conditions representative of those in the machine. The GE 9E machine has 14 such full-size combustion chambers. For the DME tests, an existing 30,000 gallon propane fuel storage, associated delivery system, and a fuel vaporizer/superheater were modified which included retrofit of all shut off, control and relief valves with gaskets and seals compatible to the DME fuel.