Use of DME as a Gas Turbine Fuel

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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, ^{o}C @ 1 atm	-24.9	-42.1	-0.5
Vapor Pressure @ 20 ^{o}C, bar	5.1	8.4	3.1
Liquid Density @ 20 ^{o}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%

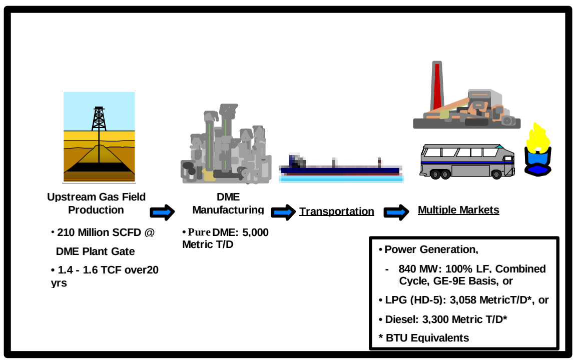
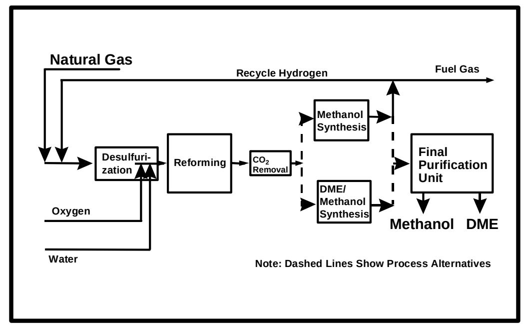


Fig 1: An Integrated DME Full Value Chain Project



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.

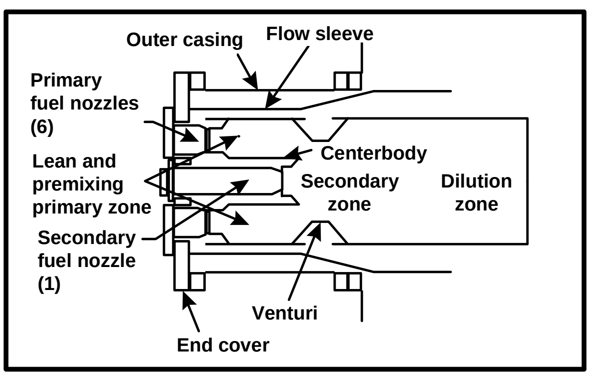


Fig. 3: DLN-1 combustor schematic

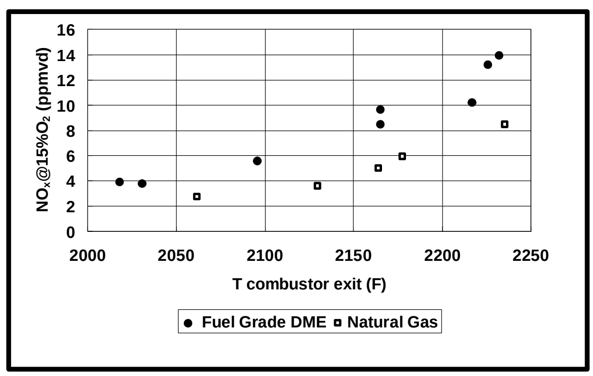


Fig. 4: MS9001E DLN-1 - Premix Emissions

- ***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.

- ***Results of MS9001E DLN-1 Tests Initiated by BP :*** Results of the combustor testing demonstrated that the BP DME fuel can be successfully used in all modes of operation, and it is an excellent gas turbine fuel with emission properties comparable to natural gas. As shown in Figure 4, NOx emissions in the premixed mode were less than 15 ppm. CO (see Figure 5) and UHC emissions were typically lower than those for natural gas in all modes; for premix mode, the UHCs were near "zero" for DME. *The emission data reflect : no diluent injection, and without any stack gas scrubbing*. With regard to dynamic pressures, there was no unusual activity in the primary or lean-lean mode, and the pressure levels were comparable to natural gas. Similarly, the combustor metal temperatures were comparable to those operating on natural gas. The formaldehyde emissions were below the detection limit of the measurement method of 300 ppb by volume.

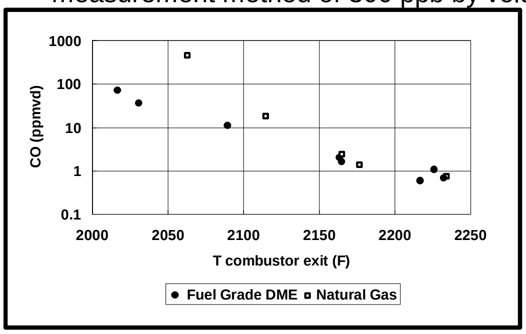


Fig. 5: MS9001E DLN-1 - Premix Emissions

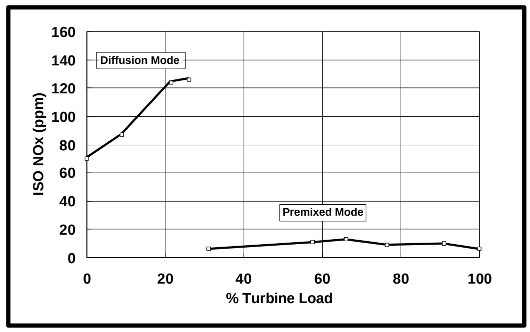


Fig. 6: Fuel Grade DME in DLN-2.6 7FA+ System - NO_x Emissions

- ***Results of the 7FA+e DLN2.6 Tests -- BP/EPDC Collaborative Programs :*** The DLN-1 combustor test programs for DME were followed by extensive tests using the 7FA+e DLN-2.6 advanced combustor. These tests show that the DLN-2.6 performs very well with the DME fuel, achieving less than 6 ppm NOx (see Figure 6; @ 15% O2) at full load conditions with low CO and UHC emissions. The combustion dynamic pressures (Figure 7; *for premixed mode*), metal temperatures and formaldehyde emissions were also acceptably low.

The frequencies measured for the dynamic pressures were also consistent with DLN 2.6 behavior using natural gas; for DME operation in the premixed mode, the frequencies were less than 275 Hz. In general, the performance was very similar to natural gas operations. Additional tests would be performed to complete the basis for a commercial design for DME in DLN-2 class combustor applications.

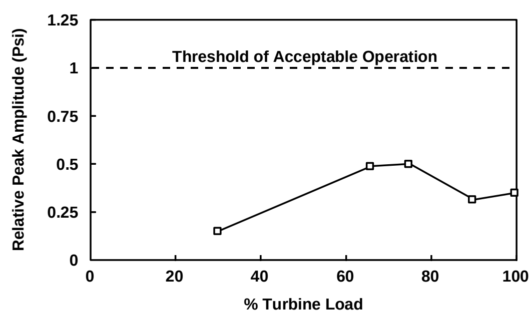


Fig 7: DLN 2 Class Combustor: Relative Dynamic Pressure Data

- ***GE Commercial Position on DME Gas Turbine Products*** : Based on the test results, GE is prepared to pursue commercial offers of DME-fired E class and F class heavy duty gas turbines. Such offers can be made with standard commercial terms, including guarantees of output and heat rate. The gas turbine models and configurations available are as follows:

Gas Turbine	Combustion Technology	NOx emissions, ppmvd @15% O2
6B, 6FA, 7EA, 7FA, 9E, 9 FA	Diffusion	37
6B, 7EA, 9E	Dry Low NOx	25

According to GE, DME can be fired in existing gas turbines, currently using natural gas or distillate/naphtha liquid fuels, with some hardware modifications to the fuel delivery system. Critical component life of DME-fired gas turbines is anticipated to be comparable to those using natural gas. The initial application of DME fuel will require two inspections during the first year of operation to verify inspection and maintenance schedules.

- ***Estimated Performance of Combined Cycle Power Plants (using GE 9FA Gas Turbine)***

As a part of a research guidance study funded by BP, the performance of combined cycles fueled with DME (with 8 wt% methanol and 3 wt% water) and natural gas were estimated by Fluor Daniel (USA). The combined cycle plant design involved (1) three gas turbines and a single reheat steam turbine to produce a nominal 1000 MW of electric power for a 50 cycle grid, (2) three heat recovery steam generators (HRSGs) to produce triple pressure steam from the gas turbine exhaust heat, and (3) the bottoming steam system consisting of a reheat steam cycle corresponding to 1865 psia/1000 F/1000 F at the steam turbine inlet. ISO conditions (with an ambient dry bulb temperature of 59^{o}F and a relative humidity of 60% and Sea Level elevation) . were used in developing the plant performance. The key comparative performance data are:

Fuel	**Natural Gas**	**Fuel Grade DME**
Fuel Feed to the Plant Gate	Gas at 60^{o} F and 500 psia	Liquid at 60^{o}F & 77 psia
Fuel Flow, per Gas Turbine, lb/hr	103,401	190,010
Air Flow per Gas Turbine, lb/hr	4,806,227	4,806227
Total Gas Turbine Power Output, MW	683.7	708.7
Total Steam Turbine Power, MW	384.0	384.5
Total Aux. Power Consumption, MW	23.9	24.6
Net Plant Power Output, MW	1,043.8	1,068.6
Net Heat Rate, Btu/kwhr (LHV)	6,278	6,106
Power Generation Efficiency, LHV %	54.4	55.9
Flue Gas Stack Temperature	205	189
CO2 generated, lb/MW-hr	819.5	959.9
LHV at 77^{o}F, Kcal/kg	Natural Gas : 11,800	Liquid DME : 6,420

For the DME case, the liquid feed is vaporized and preheated against boiler feed water in a shell and tube heat exchanger to a temperature of 330^{o}F in order to enhance the cycle efficiency as well as to take advantage of the use of DLN-1 combustor. As shown in the above Table, the heat rate of the DME case is about 2.7% lower than the corresponding natural gas case. The key reasons for this *higher* power generation efficiency are: (1) within the power plant, low temperature heat is utilized to vaporize the DME and (2) partial heat recovery from the flue gas exhaust. The liquid DME feed provides a heat sink for the low temperature (LT) heat whereas the natural gas case does not require the heat in the LT region. In the DME case, the minimum stack temperature is set by the water/carbonic acid dew point rather than the sulfuric/sulfurous acid dew point as is the case with natural gas. Note that the tube wall temperature of the last set of coils in the HRSG may be controlled by recirculating how water through this coil while not effecting the stack temperature. The estimated dew point of the stack gas in the DME case is about 115^{o}F.

In a similar study, funded by BP, IOCL and GAIL, the performance of a nominal 700 MW 60-cycle grid combined cycle power plant using GE PG9171E gas turbine and fueled with turbine-grade DME, natural gas (NG) and naphtha were estimated by Fluor Daniel.(10) *In this study, the liquid DME feed conditions were assumed to be 1 atm and at minus 25 C.* The DME Case (with DLN 1 combustor) indicated the highest power generation efficiency with the lowest heat rate; the estimated heat rate for DME is about (1) 1.6% lower than that for the NG case (DLN-1) and (2) 6.3% lower than that for the naphtha case (Diffusion combustor plus water injection).

- ***Comparative Emissions from a Combined Cycle Power Plant :*** Based on the combustor test results, GE estimated key emissions from a combined cycle plant based on a GE PG9171E gas turbine. The data indicate that DME (with DLN-1 technology) would have about 5% lower (lb/MW-hr basis) NOx emission than natural gas (DLN-1), and about 50% lower NOx than a liquid distillate fuel (Diffusion technology + water injection).(10) The total CO2 emission for the DME case would be about (1) 17% lower than the naphtha case and (2) about 18% higher than the natural gas case.

Economics of DME as a Gas Turbine Fuel ; Literature Data : Currently, LNG (Liquefied Natural gas) remains the most economical option for natural gas monetization on a large scale for niche markets (e.g. : Japan, Korea, Taiwan) that can not be directly reached by cheap natural gas supplies. Romani et al (14) and Kikkawa et al (13) have published key comparative data on the economics of LNG and DME. Romani et al have concluded that: *"DME offers an attractive solution for the valorization of associated gas when the size of the gas reserves or the destination market are not appropriate for LNG."* According to these authors, the key capital cost and natural gas consumption data for a Middle East location are :

- the total "facilities" capital cost of a 5,000 metric tons/day (MTPD) DME plant would be about $400 million (Year 2000 $) compared to about $510 million for a 7,500 MTPD plant.
- the approximate natural gas consumption for a 5,000 MTPD DME plant is estimated at 210 million standard cubic feet per day (MMSCFD*).*

Summary : DME is a promising new gas turbine fuel that could offer economically attractive niche market opportunities for small scale electric power generation facilities in countries that can not be easily reached by cheap natural gas supplies. Test results at General Electric show that its emission properties and other key combustor operating parameters, including dynamic pressures and metal temperatures, are comparable to natural gas. Estimated performance of nominal 700-1000 MW combined cycle power plants based on the GE 9E and 9FA machines indicate that the power generation efficiency (LHV basis) using liquid DME fuel would be about *1.6-2.8% higher* than that using natural gas, and about *6-7% higher* than that using liquid naphtha (for the 700 MW case using GE 9E gas turbine).

Acknowledgment : The authors wish to (1) thank the management of BP for the encouragement and permission in publishing this paper, and (2) acknowledge EPDC (Japan) for their support in completing a part of the Test Program. The authors would also like to acknowledge (1) Dr. Carl Udovich (BP), Mr. Dave Redeker (BP), Mr. Richard Jones (BP), Mr. John Wainright (GE), Ms. K. Cairns (GE), Mr. R. Lavigne (GE), Mr. Tom Chance (GE), Mr. R. Beaudoin (GE), Mr. Mike Jandrisevits (GE), Dr. Ashok Rao (Fluor Daniel), Mr. Y. Arai (EPDC) and T. Inohira (EPDC) for the significant technical and business development assistance that they provided throughout the project.

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