Fuel DME Plant in East Asia

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Abstract
DME (Di-Methyl Ether) is a non-toxic chemical currently used as aerosol propellant etc. as a substitute of chlorofluorocarbons. However the future DME market would be fuel considering its attractive property for a substitute of LPG and diesel oil etc. as a clean fuel without SOx and soot. LPG existing infrastructures such as tank and tanker could be used with minor modification. The total investment cost of DME plant would be smaller compared with LNG and GTL (FT Synthesis). In China DME plants for fuel use already started their commercial operation.

In East Asia many studies for DME application have been done and are under going. For Japanese market there are several large scale DME projects under detailed feasibility study to introduce around 2008. In China there are many small and middle scale projects planned for local fuel use. Lutianhua Group Incorp. constructed a 10,000 t/y (30 t/d) commercial DME plant for fuel use under licensed by TOYO and started in August 2003, which was the first commercial plant in the world for energy use. After achieving the excellent DME plant performance 110,000 t/y (340 t/d) DME project started in December 2003 under licensed by TOYO. The plant was the world largest commercial DME plant and will start in the end of 2005 or the beginning of 2006.

A Jumbo DME Plant based on methanol dehydration process is combination of methanol plant and DME synthesis plant consisting a single train concept and the both plants are commercially proven in the world. DME synthesis plant is very similar to methanol synthesis, but simpler than methanol synthesis considering lower reaction heat and lower synthesis pressure. Therefore scale-up technology of methanol plant could be easily applied for a Jumbo DME Plant. Oxygen consumption is a very important factor for selection of DME process scheme. Oxygen is not required for a Jumbo DME Plant of 3,500 t/d. An economic study shows DME production cost from a Jumbo DME Plant could be economically feasible compared with LPG and LNG.

1. Introduction
DME is non-toxic and is currently used as a chemical for aerosol propellants etc. instead of chlorofluorocarbons. DME for chemical use is currently produced by methanol dehydration process in small
scale plants with an order of 10,000 t/y in Japan and 150,000 t/y in the world in total. In China DME plants for fuel use already started in 2003.

The physical properties of DME are very attractive for a substitute of LPG, diesel oil etc. as a clean fuel without SOx and PM (particulate matter).

<table>
<thead>
<tr>
<th></th>
<th>LNG (as CH₄)</th>
<th>LPG (as C₃H₈)</th>
<th>DME</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point °C</td>
<td>-161.5</td>
<td>-42</td>
<td>-25.1</td>
<td>180-360</td>
</tr>
<tr>
<td>Low heating value (kcal/kg)</td>
<td>12,000</td>
<td>11,100</td>
<td>6,900</td>
<td>10,200</td>
</tr>
<tr>
<td>Specific gravity (liquid)</td>
<td>-</td>
<td>0.49</td>
<td>0.7</td>
<td>0.84</td>
</tr>
<tr>
<td>Ignition point (deg. C)</td>
<td>632</td>
<td>504</td>
<td>350</td>
<td>250</td>
</tr>
<tr>
<td>Explosion limit (%)</td>
<td>5 ~ 15</td>
<td>2.1 ~ 9.4</td>
<td>3.4 ~ 17</td>
<td>0.6 ~ 7.5</td>
</tr>
<tr>
<td>Cetane number</td>
<td>-</td>
<td>5</td>
<td>55 - 60</td>
<td>40 - 55</td>
</tr>
</tbody>
</table>

DME boiling point is below minus and close to LPG, which is easily liquefied and stored. LPG existing infrastructures such as tank and refrigerated tanker could be used. DME cetane number is very similar to diesel oil. DME could be used in diesel engines. DME is not corrosive for conventional construction materials. On the other hand, DME has lower heating value, lower viscosity, lower lubricity and a tendency of swelling of specific rubber and specific plastics. Only minor modification would be required on existing LPG infrastructures and diesel engines for such substitute.

The principle of DME production by methanol dehydration process is as follows.

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\begin{align*}
(1) \text{MeOH-1} & : \quad \text{CO} + 2 \text{H}_2 = \text{CH}_3\text{OH} \quad \text{(90.3)} \\
(2) \text{MeOH-2} & : \quad \text{CO}_2 + 3 \text{H}_2 = \text{CH}_3\text{OH} + \text{H}_2\text{O} \quad \text{(49.4)} \\
(3) \text{MeOH De-H}_2\text{O} & : \quad 2\text{CH}_3\text{OH} = \text{CH}_3\text{OCH}_3 + \text{H}_2\text{O} \quad \text{(23.4)}
\end{align*}
\]

The dehydration of methanol (3) is gas phase and exothermic reaction. The heat of reaction (approx. 23 kj/mol) is considerably small compared with methanol synthesis reaction (1) & (2). Therefore scale-up technology of methanol plant could be easily applied for a DME Plant.

2. DME Potential Market and Development

DME is produced mainly for aerosol propellants in small-scale plants. However the future DME market would be fuel considering its attractive property. One of DME features is lower investment cost compared with LNG and GTL (FT Synthesis). Another feature is that DME has various potential markets. The followings are considered as potential markets for DME.
(1) Power plant fuel

LNG, LPG, fuel oil and coal are used for power plant. Fuel oil and coal need environmental countermeasures and emission of carbon dioxides is very large compared with DME. LNG and LPG are relatively clean fuels, but LNG investment cost is very huge. LPG supply source is limited mainly from Middle East. DME is a clean fuel and the total investment cost would be small because existing LPG infrastructures could be used with minor modification. DME is multi-source energy and could be mass-produced from synthesis gas converted from various feedstocks such as natural gas, fuel oil, coal etc. DME combustion in gas turbine was already tested and a new type burner has been developed in Japan.

(2) LPG substitute

LPG is mainly used as residential & industrial. The demand is increasing in Japan, China, India and Southeast Asia. LPG price is estimated to be increasing due to market growth in future. DME is very competitive against LPG price and LPG substitute is one of most potential market for DME. Pure DME combustion with household cooking gas stove for LPG was tested in Japan and it was reported that some modification would be needed. In China DME is mixed with LPG and the mixture is used as fuel for household cooking gas stove in restaurant etc without modification.

(3) Diesel oil substitute

The present diesel oil is a major source of air pollution from diesel engine of trucks and busses in large city like Tokyo. The potential market of diesel oil substitute is larger than LPG. DME is one of ideal fuel for diesel engine. DME vehicles were demonstratively manufactured in Japan, China and Korea and their driving test already started. Practical durability fleet test of a DME truck is under going in Japan.

(4) Hydrogen for fuel cell and chemicals

Since DME has an advantage of decomposition at lower temperature than methane and LPG, R&D for hydrogen source for fuel cell has been carried out. DME has a potential of feedstock for chemicals. DME to olefins is under development in Japan.

3. DME Current Situation in East Asia

In China DME was mainly used as aerosol propellant up to 2002, but DME plants for fuel use, especially residential use as substitute of LPG started in 2003 and the demand in 2003 was estimated approx. 50,000 t/y including chemical use like propellant and fuel use. In addition many small and middle scale DME projects are planned for local fuel use.

Japan DME Forum (JDF) was established in 2000 and many studies have been done and under going. A 100 t/d demonstration unit based on direct synthesis process started in the end of 2003 and under test for about three years in Kushiro Japan. For Japanese market there are several large scale DME projects under detailed feasibility study, which produce fuel DME in natural gas rich countries like Middle East and transport it to Japan by tanker. DME utilization in various fields has been studied and tested under JOGMEC.
(Japan Oil, Gas & Metals National Corporation) programs with finance by Japanese Government to introduce DME in Japan around 2008-2010.

In Korea DME Forum was established in 2002 and many studies are under going to introduce DME in Korea. 50 kg/d DME pilot plant was constructed and is under testing. 10 t/d demonstration unit is also planned as a next step.

In China DME Forum was established in 2005 and many studies are under going. DME bus was developed and achieved good performance and lower emission level.

4. Lutianhua Fuel DME Plants in China

Lutianhua Group Incorporated (Head Office in Luzhou City, Sichuan Province, P.R.China) constructed a 10,000 t/y (30 t/d) commercial DME plant for fuel use under licensed by TOYO and started in August 2003 achieving about one year for the project schedule. The performance test was successfully carried out in September 2003 with the excellent performance for the acceptance of the plant. The DME Plant at Lutianhua was the first commercial plant in the world for energy use. Figure 1 indicates a photograph of Lutianhua 10,000 t/y DME plant.

![Figure 1. 10,000 t/y Commercial Fuel DME Plant for Lutianhua in P.R. China](image)

The feedstock methanol is supplied from an existing methanol plant at Lutianhua and the product DME is actually used as LPG substitute based on Lutianhua’s market research and development for many years.
After achieving the excellent DME plant performance in the 10,000 t/y plant and commercial sales of DME as fuel use, Lutianhua Group had a confidence of another DME plant construction with a larger capacity.

110,000 t/y (340 t/d) DME project started in December 2003 under licensed TOYO. The plant was the world largest commercial DME plant and will start in the end of 2005 or the beginning of 2006. The feedstock is methanol which will be supplied from 450,000 t/y methanol plant under construction with TOYO’s participation in the methanol synthesis section. TOYO’s proprietary MRF-Z\textsuperscript{i} was incorporated as a methanol reactor. This plant is DME production from natural gas feedstock. The balanced methanol of 290,000 t/y is delivered to outside as domestic chemical use. Figure 2 indicates process scheme of Lutianhua 450,000 t/y Methanol and 110,000 t/y DME Plant. Figure 3 indicates 3D layout of Lutianhua 110,000 t/y DME plant.

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**Figure 2. Process Scheme of Lutianhua 450,000 t/y Methanol and 110,000 t/y DME Plant**

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The 110,000 t/y DME plant was originally planned as a part of Sichuan West Chemical City development project supported by local government. In Sichuan Province of China there is abundant natural gas resource, but a shortage of liquid fuel. So DME is expected as a clean fuel for pollution control and a substitute of liquid fuel like diesel and LPG. DME plant performance was improved by TOYO with Lutianhua through technical alliance. Lutianhua Group already established DME supply chain as fuel use in China. DME will be transported by tank lorry and rail way to users.

5. DME Synthesis Technology by Methanol Dehydration Process

DME synthesis based on methanol dehydration process is very simple. The dehydration of methanol is gas phase and exothermic reaction. The heat of reaction (approx. 23 kJ/mol) is considerably small compared with methanol synthesis reaction. The selectivity of DME in methanol dehydration is very high and is approx. 99.9%. Dehydration catalyst is of ?-alumina basis available in the market. A typical flow description of DME synthesis is as follows.

Feed methanol is fed to a DME reactor after vaporization. The synthesis pressure is 1.0 - 2.0 MPaG. The inlet temperature is 220 - 250 °C and the outlet is 300 - 350 °C. Methanol one pass conversion to DME is 70 - 85% in the reactor. Produced DME with by-product water and unconverted methanol is fed to a DME column after heat recovery and cooling. In the DME column DME is separated from the top as a product. Water and methanol are discharged from the bottom and fed to a methanol column for methanol recovery. The purified
methanol from the column is recycled to the reactor after mixing with feedstock methanol. The methanol consumption for DME production is approximately 1.4 ton-methanol per ton-DME. Figure 4 indicates a typical flow scheme of DME synthesis.

![Figure 4. Typical Flow Scheme of DME Synthesis](image)

6. Feature of a Jumbo DME Plant

A Jumbo DME Plant based on methanol dehydration process is combination of methanol plant and DME synthesis plant. TOYO developed a Jumbo Methanol Plant consisting minimum train concept for equipment configuration. TOYO's proprietary methanol reactor MRF-Z® can handle 5,000 - 6,000 t/d methanol capacity (equivalent to DME 3,500 - 4,200 t/d) in a single train. Oxygen consumption is a very important factor for selection of DME process scheme. Oxygen is produced from a cryogenic air separation unit, which is very expensive and an energy consumed unit. Oxygen is not required for a Jumbo DME Plant of 3,500 t/d since steam reforming along configuration with TOYO's proprietary ISOP steam reforming catalyst is employed for the synthesis gas generation unit. The features of Jumbo DME Plant are as follows.

1) Scheme and DME synthesis catalyst are commercially proven.
2) Any ratio of methanol (0 - 100 %) and DME (100 - 0 %) can be produced as per market demand.
3) DME synthesis is very simple and the investment cost is less.
   DME synthesis unit could be installed beside the existing methanol plant as one of derivatives.
4) A single train concept can be applied based on commercially proven technologies.
5) Oxygen is not required for 3,500 t/d DME production.
6) Less total investment cost.
Figure 5 indicates flow scheme of 3,500t/d Jumbo DME Plant.

Figure 5. Flow Scheme of 3,500 t/d Jumbo DME Plant

7. Economics of a Jumbo DME Plant

An economic study for DME 2.4 million t/y of a Jumbo DME Plant constructed in Middle East for Japanese market was carried out considering natural gas price. About 87 US$/MT of DME FOB cost at Middle East can be achieved at NG 0.5 US$/MMBtu and IRR 15 % before tax. The 87 US$/MT is equivalent to about 2.9 US$/MMBtu (HHV). About 113 US$/MT (equivalent to about 3.8 US$/MMBtu (HHV)) of DME cost CIF Japan can be achieved at NG 0.5 US$/MMBtu and IRR 15 % before tax by adding 26 US$/MT as sea freight rate. About 122 US$/MT (equivalent to about 4.1 US$/MMBtu (HHV)) can be also achieved at NG 0.7 US$/MMBtu and IRR 15 % before tax. Figure 6 indicates the result of economic study.

In Japan about 50 million metric tons of LNG was imported in 2004. LNG average price CIF Japan in the past five year was about 4.75 US$/MMBtu (HHV). About 14 million tons of LPG including butane was imported in 2004 in Japan. LPG average price CIF Japan in the past five year was about 335 US$/MT (equivalent to about 7.0 US$/MMBtu (HHV)). The comparison of DME, LNG and LPG price CIF Japan shows that DME is economically more feasible than LPG and LNG. Figure 7 indicates the comparison among DME, LNG and LPG price CIF Japan.
Typical performance of a Jumbo DME plant of 3,500 t/d including utility and off-site is as follows.

- **Natural gas**: approx. 163 mmSCFD = 182,000 Nm³/h (approx. 1.4 TCF for 25 year project life)
- **Raw water**: approx. 1,150 m³/h as make-up
- **Required area**: Total approx. 15 ha, Process & utility 400 m x 250 m, DME storage tank 300 m x 120 m

**Figure 6. DME Price of 2.4 million t/y Jumbo DME Plant**

**Figure 7. DME/LNG/LPG Price CIF Japan**
8. Conclusion

1) Commercial DME plants for fuel use started in 2003 in China and DME supply chain as LPG substitute was established at Lutianhua.

2) Large scale DME projects for Japanese market are under feasibility study and many studies for DME application are under going in East Asia.

3) DME synthesis technology is ready for market based on commercially proven experience.

4) A Jumbo DME Plant is combination of methanol plant and DME synthesis plant incorporating commercially proven technologies.

5) The total investment cost of a Jumbo DME Plant is less and the production cost could be feasible compared with LNG and LPG.