

CONTENTS

Preface to the English Edition	i
Preface	ii
DME handbook editorial board and contributors	iii
contents	vi

Chapter 1	Meaning of DME introduction	1
------------------	------------------------------------	----------

1.1	What is DME?	2
1.2	Future of energy and environmental trend and DME's role	4
1.2.1	Introduction	4
1.2.2	Energy trend	4
1.2.3	Environmental trend	7
1.2.4	Environmental characteristics of DME	12
1.2.5	Availability of stranded resources	13
1.2.6	Availability of biomass	14
1.3	Perspectives of DME penetration	15
1.3.1	Introduction	15
1.3.2	Penetration scenario in Japan	15
1.3.3	Penetration scenario in Asia	19
1.4	Current status of technologies and challenges to DME introduction	20
1.4.1	Characteristics of DME as fuel	20
1.4.2	Current status of technological developments in production, distribution and utilization	21
1.4.3	Construction of DME fuel chain	24
1.4.4	Establishment of fuel standard for DME	25
1.4.5	Social enlightening activity to introduce DME	25
1.4.6	Challenges for the future	26

Chapter 2	Properties of DME	31
------------------	--------------------------	-----------

2.1	Introduction	32
2.2	Physical properties	33
2.2.1	Molecular and structural formula	33
2.2.2	Boiling and melting point	33
2.2.3	Critical point	36

2.2.4	Permittivity and electric conductivities	36
2.2.5	Density	38
2.2.6	Bulk modulus of elasticity	40
2.2.7	Viscosity	41
2.2.8	Surface tension	42
2.3	Phase equilibrium	43
2.3.1	Introduction	43
2.3.2	Equation of state	43
2.3.3	Vapor pressure	46
2.3.4	The P-V-T relationship	48
2.3.5	Solubility in water and clathrate hydrate of DME	49
2.3.6	Vapor-liquid equilibrium	51
2.4	Thermal properties	57
2.4.1	Thermal capacity and specific heat	57
2.4.2	Latent heat of evaporation and latent heat of fusion	59
2.4.3	Enthalpies of formation and Gibbs' free energy	60
2.4.4	Thermal conductivity	60

Chapter 3

Combustion and reforming characteristics of DME 65

3.1	Introduction	66
3.2	Combustion of DME	68
3.2.1	Combustion characteristics	68
3.2.2	Ignition	73
3.2.3	Combustion reaction scheme	76
3.2.4	Flame propagation and flammability limit	81
3.2.5	Premixed flame	88
3.2.6	Diffusion flame	93
3.2.7	Spray and ignition characteristics	96
3.3	Reforming of DME	104
3.3.1	Steam reforming	104
3.3.2	Partial oxidation	107

Chapter 4

DME production technologies

113

4.1	Introduction	114
4.1.1	Basics of DME synthesis	114
4.1.2	Development trends in indirect synthesis technology	116
4.1.3	Development trends in direct synthesis technology	116

4.1.4	Movement towards commercial DME production	118
4.1.5	DME production from various raw materials	119
4.2	Synthesis gas production technology	120
4.2.1	Outline	120
4.2.2	Synthesis gas production from natural gas	121
4.2.3	Synthesis gas production from coal	131
4.2.4	Synthesis gas production from coke oven gas	135
4.2.5	Synthesis gas production from biomass	137
4.2.6	Synthesis gas production from waste plastic	143
4.3	DME synthesis reaction	149
4.3.1	Reaction and catalyst	149
4.3.2	Reactor types	153
4.3.3	Development history of DME synthesis process	154
4.4	Direct synthesis technology	161
4.4.1	JFE process	161
4.4.2	Air products process	167
4.5	Indirect synthesis technology	171
4.5.1	MGC process	171
4.5.2	TEC process	175
4.5.3	Lurgi process	181
4.5.4	Topsøe Process	185

Chapter 5

DME utilization technologies

195

5.1	Introduction	196
5.1.1	Outline	196
5.1.2	Properties of DME	196
5.1.3	Applications of DME	197
5.1.4	Feature as fuel	198
5.1.5	Feature as chemical feedstocks	198
5.1.6	Feature of other applications	199
5.2	Power generation and industrial application	201
5.2.1	Outline	201
5.2.2	Spray combustion in gas turbines	203
5.2.3	High efficiency combustion system for fuel grade DME	207
5.2.4	Low NO _x combustor for a gas turbine burning DME	211
5.2.5	Retrofit application for existing boilers	215
5.2.6	DME-fueled chemically recuperated gas turbine system	220
5.2.7	Small-scale distributed power generation system	226

5.2.8	DME conversion of industrial heavy oil boiler	229
5.2.9	Diesel power generation system	232
5.2.10	Diesel Engine Co-generation.....	235
5.2.11	Micro gas turbine	238
5.3	Vehicle use	242
5.3.1	Outline of development for vehicle technology	242
5.3.2	DME combustion in diesel engines	248
5.3.3	DME combustion in HCCI engine	259
5.3.4	DME fuel supply system	262
5.3.5	After-treatment of DME combustion exhaust gas (Oxidation catalyst and DeNOx catalyst)	272
5.3.6	Medium sized bus and truck	276
5.3.7	Public road tests of a 2 ton DME truck	282
5.3.8	Hybrid bus with DME engine	287
5.3.9	DME vehicle with distributor type injection pump	291
5.3.10	Fleet test of medium duty DME truck	295
5.3.11	Heavy duty DME truck.....	302
5.3.12	Technical standards for DME vehicles	307
5.3.13	DME blended fuels	310
5.3.14	DME Fueled shuttle bus demonstration project at the Pennsylvania State University	314
5.3.15	DME research at the technical university of Denmark.	316
5.3.16	Development of a Production Feasible DME Common Rail Fuel Injection System	318
5.4	Household use	322
5.4.1	Outline	322
5.4.2	Supply-demand situation of LPG	323
5.4.3	DME as LPG fuel supplement.....	324
5.4.4	Combustion test of household gas apparatus	325
5.4.5	Conclusion	328
5.5	Chemical feedstock	328
5.5.1	Chemicals (lower olefins) manufacturing	328
5.5.2	Town gas manufacturing	336
5.6	Fuel cell	339
5.6.1	Outline	339
5.6.2	Polymer electrolyte fuel cell	340
5.6.3	Compact and highly-effective fuel cell	344
5.6.4	Phosphoric-acid fuel cell	347
5.6.5	Direct dimethyl ether fuel cell	350

5.7	Propellant	357
5.7.1	Current state of DME	357
5.7.2	Aerosol product	357
5.7.3	DME use in the aerosol industry	358
5.7.4	DME use of the aerosol manufacturers	359

Chapter 6**DME distribution and technologies****367**

6.1	Introduction	368
6.2	Storage facilities	370
6.2.1	Cryogenic storage	370
6.2.2	Incidental equipment for cryogenic storage facilities	371
6.2.3	High pressure storage	371
6.2.4	Spherical storage tank	372
6.2.5	Cylindrical storage tank	374
6.3	Storage terminal	375
6.3.1	Import terminal	375
6.3.2	Secondary terminal	379
6.4	Transportation	380
6.4.1	Outline	380
6.4.2	Marine transportation	381
6.4.3	Land transportation	385
6.5	Container and filling	393
6.5.1	Container	393
6.5.2	Filling facilities for DME tank	394
6.5.3	Filling station for DME vehicle	395
6.6	Other equipments	398
6.6.1	Loading arm	398
6.6.2	Pump	398
6.6.3	Compressor	399
6.6.4	Flow meter	399
6.6.5	Liquid-level meter	400
6.6.6	Vaporizer	400
6.7	Seal materials	401
6.7.1	Classification of seal material	401
6.7.2	Seal material used in LPG facilities	402
6.7.3	Screening experiment	403
6.7.4	Evaluation of rubber O-ring	408
6.7.5	Verification of seal materials with DME equipment	413
6.7.6	Summary	413

7.1	Introduction	416
7.2	Stability	417
7.2.1	Long term stability	417
7.2.2	Incompatibility hazard	422
7.2.3	Influence of metal material	423
7.2.4	Hydrates	424
7.3	Fires and explosion	425
7.3.1	Diffusion	425
7.3.2	The pool fire experiment	427
7.3.3	Safety at time of external fire	430
7.3.4	Explosion power	431
7.3.5	Explosion characteristics	433
7.4	Safety	443
7.4.1	Risk assessment	443
7.4.2	Leakage detection technology	444
7.4.3	Examination of odorant	444
7.4.4	Examination of fire extinction technology	445
7.5	Influence on living organisms	447
7.5.1	Influence on animals	447
7.5.2	Influence on the human body	449

8.1	Introduction	454
8.2	Regional environmental influence	455
8.2.1	Photochemistry reaction when DME is emitted to the atmosphere	455
8.2.2	Influence of DME spill on soil environment	458
8.2.3	DME combustion exhaust gas characteristics	461
8.3	Global environmental influence	464
8.3.1	Outline	464
8.3.2	Outline of environmental impact assessment of DME (technique and idea)	465
8.3.3	Case study of LCI (life cycle inventory) analysis	469
8.3.4	Case study of the overall evaluation of environmental impact using LIME (Life cycle Impact assessment Method based on Endpoint modeling)	474

Chapter 9**Economics and Markets****479**

9.1	Introduction	480
9.2	Production cost	482
9.2.1	Conditions of DME production cost estimation	482
9.2.2	DME production cost estimation results for each feedstock	487
9.2.3	Price comparison with other fuels	491
9.3	Logistics cost	496
9.3.1	Marine transportation	496
9.3.2	Import terminals	499
9.3.3	Domestic circulation	501
9.4	Market	504
9.4.1	Outline	504
9.4.2	Market in Japan	506
9.4.3	Asian market	510

Chapter 10**Global activities outside Japan****515**

10.1	Introduction	516
10.2	Commercialization projects	519
10.2.1	China	519
10.2.2	Iran	522
10.2.3	Sweden	523
10.2.4	Brazil, Russia and South Korea	525
10.3	Production technology development	527
10.3.1	China	527
10.3.2	Europe and U.S.A.	527
10.3.3	Brazil, Russia and South Korea	528
10.4	Utilization technology development	530
10.4.1	DME Vehicle	530
10.4.2	Household use	534
10.4.3	Power generation	535

Chapter 11**Organizations for DME development****537**

11.1	Introduction	538
11.2	Organizations in Japan	540
11.2.1	Japan DME Forum	540
11.2.2	Organizations related to Japanese government	542

11.2.3	Organizations related to local governments	548
11.2.4	Private Organizations	549
11.3	Organizations in the world	550
11.3.1	Activity of IEA	550
11.3.2	International DME Association	555
11.3.3	Korea DME forum	556
11.3.4	China DME Association	558
11.3.5	WLPGA (World LP Gas Association)	558
11.3.6	International conferences and seminars related to DME	558

Chapter 12 **Standards, test methods, and regulations 561**

12.1	Introduction	562
12.2	Standards	563
12.2.1	JIS standard	563
12.2.2	International standard (ISO)	565
12.2.3	Marine transport	565
12.3	Test methods	566
12.3.1	Test equipment in general	566
12.3.2	Specimen collection method	566
12.3.3	DME test method premised on household use	567
12.3.4	DME standards as a diesel engine fuel	582
12.3.5	Other DME test methods	590
12.4	Laws and regulations	591
12.4.1	Physical properties of DME	591
12.4.2	Is DME subject to any laws and regulations?	591
12.4.3	About notification and permission	592
12.4.4	Laws and regulations related to technical standards in distribution processes	595

Appendix table **597**

Unit Conversion Table	598
Abbreviation related to economic evaluation	599
Comparison of physical properties and characteristics as fuels	600