

Medhat A. Nemitallah · Ahmed A. Abdelhafez ·
Mohamed A. Habib

Approaches for Clean Combustion in Gas Turbines

Springer

Contents

1	Global Warming and Emission Regulations	1
1.1	Introduction	1
1.2	Global Warming Issue	2
1.3	Status of Renewables	3
1.4	Carbon Capture Technologies	5
1.5	Adaptation of Gas Turbines to Regulations of Pollutant Emissions	7
1.6	Emission Regulatory Overview	7
1.6.1	Clean Air Act (CAA)	7
1.6.2	New Source Performance Standards (NSPS)	7
1.6.3	New Source Review (NSR)	8
1.6.4	Best Available Control Technology (BACT)	8
1.6.5	Lowest Achievable Emission Rate (LAER)	9
1.7	Clean Power Production for Gas Turbine Applications	9
	References	11
2	Premixed Combustion for Gas-Turbine Applications	13
2.1	Introduction	13
2.2	Instabilities of Premixed Combustion	16
2.2.1	Static Instabilities	17
2.2.2	Dynamic Instabilities	25
2.3	NO _x Emissions in Lean Premixed Air Combustion	30
2.3.1	Prompt NO _x	30
2.3.2	Fuel NO _x	31
2.4	Approaches for Efficient Combustion	33
2.4.1	Fuel/Oxidizer-Flexibility Approach	34
2.4.2	Variable Operating Conditions Approach	57
2.4.3	Variable Flame Characteristics	57

2.5	Swirl Stabilization for Stability Enhancement and Emission Reduction	63
2.5.1	Stabilization Mechanism and Swirl Number	63
2.5.2	Effect of Swirl on Flame Stability	67
2.5.3	Effect of Swirl on NO _x and CO Emissions	69
2.6	Numerical Modeling of Premixed Combustion	73
2.6.1	Turbulent Premixed Combustion	73
2.6.2	Turbulent Combustion Modeling Schemes	73
2.6.3	LES Governing Equations	74
2.6.4	LES for Turbulent Premixed Combustion	76
2.7	Premixed Combustion in a Gas-Turbine Model Combustor: Numerical Case Study	77
2.7.1	Model Validation	78
2.7.2	Case Study of Premixed Oxy-fuel Combustion	80
2.7.3	Results and Discussion of the Case Study	81
2.8	Concluding Remarks	84
	References	84
3	Burner Designs for Clean Power Generation in Gas Turbines	99
3.1	Introduction	99
3.2	Lean Premixed Air Combustion	101
3.2.1	Combustion and Emissions Characteristics	101
3.2.2	NO _x Emissions Under Lean Premixed Combustion	104
3.2.3	Combustion Instabilities and Solution Techniques	107
3.3	Oxy-combustion for Carbon Capture	110
3.3.1	Oxy-fuel Combustion Technology	110
3.3.2	Comparison of Air-Fuel Versus Oxy-fuel Combustion Concepts	110
3.3.3	Premixed Oxy-fuel Combustion	111
3.4	Fuel-Flexible Combustion Approach	113
3.4.1	Fuel Flexibility	113
3.4.2	Fuel-Flexible Combustion Approaches	115
3.4.3	Fuel-Flexible Premixed Oxy-fuel Combustion	118
3.5	Gas Turbine Combustion Systems	122
3.5.1	Stagnation Point Reverse Flow (SPRF) Burners	122
3.5.2	Dry Low-NO _x /Low-Emissions (DLN/DLE) Burners	125
3.5.3	EnVironmental (EV/AEV/SEV) Burners	128
3.5.4	Micromixer (MM) Combustion Technology	134
3.6	High-Temperature Membrane Reactors (HTMRs)	138
3.7	International Trends in CCS/CCUS Technologies	143
3.8	Concluding Remarks	143
	References	147

4	Gas Turbine Performance for Different Burner Technologies	165
4.1	Introduction	165
4.2	Dry Low-NO _x /Low-Emissions (DLN/DLE) Burners for Gas Turbines	167
4.3	Combustor Operability of Premixed Oxy-methane Flames	170
4.3.1	Test Conditions	170
4.3.2	Combustor Stability Maps	175
4.3.3	Flame Macrostructure	179
4.3.4	Flame Temperature	183
4.3.5	LES of Premixed Oxy-flames	185
4.4	Oxy-methane Versus Oxygen-Enriched-Air Flames for Gas Turbine Applications	201
4.4.1	Air Flames Versus Oxy-flames	201
4.4.2	Role of Adiabatic Flame Temperature for Controlling Flame Stabilization	203
4.4.3	Role of Adiabatic Flame Temperature for Controlling Flame Structure	208
4.5	Role of Flow Reynolds for Controlling Flame Structure and Stabilization	213
4.5.1	Effect of Inlet Flow Conditions on Flame Stability	215
4.5.2	Role of Flow Reynolds for Controlling Flame Stabilization	218
4.5.3	Role of Flow Reynolds for Controlling Flame Structure	222
4.6	Micromixer Burners for Gas Turbines	229
4.7	Operability of Micromixer Combustor Holding Premixed Oxy-methane Flames	230
4.7.1	Combustor Design	230
4.7.2	Combustor Stability Maps	232
4.7.3	Flame Temperature	233
4.8	Performance of Solar-Integrated Oxy-combustion Cycles Adopting Membrane Reactors	236
4.8.1	Oxygen Separation Techniques for Oxy-combustion Cycles	236
4.8.2	Proposed Power Generation Cycles	237
4.8.3	Performance of the Proposed Cycles	243
4.8.4	Modified Power Generation Cycles	246
4.9	Concluding Remarks	248
	References	251
5	Operability of Fuel/Oxidizer-Flexible Gas Turbine Combustors	259
5.1	Introduction	259
5.2	Oxidizer Flexibility in Gas Turbines	260
5.2.1	Oxy-combustion Flames	261
5.2.2	Oxidizer Dilution	262

5.3	Fuel Flexibility in Gas Turbines	262
5.4	Stability of Oxy-flames	263
5.5	Combustor Operability of H ₂ -Enriched Premixed Oxy-methane Flames	265
5.5.1	Operating Conditions	269
5.5.2	Combustor Stability Maps	272
5.5.3	Effect of Inlet Velocity on Flame Stability	276
5.5.4	Flame Shape Analysis	280
5.5.5	Modeling H ₂ -Enriched Oxy-methane Flames	284
5.6	Combustor Operability Under Stoichiometric H ₂ -Enriched Conditions	300
5.6.1	Flame Stability Mapping	300
5.6.2	Effect of Inlet Velocity on Flame Stability	304
5.7	Combustor Operability of Premixed Oxy-propane Flames	309
5.7.1	Test Conditions	309
5.7.2	Stability Map of Oxy-propane Flames	309
5.7.3	Operability of Oxy-methane Versus Oxy-propane Flames	310
5.8	Concluding Remarks	311
	References	314
6	Hybrid Membrane and Porous-Plates Reactors for Gas Turbine Applications	321
6.1	Introduction	321
6.2	Concept of Membrane Separation	322
6.2.1	Ceramic Membranes	323
6.2.2	Polymeric Membranes	325
6.3	Polymeric Membranes for Oxygen-Enriched Air Combustion Applications	328
6.3.1	Description of Membrane Unit and Ranges of Parameters	328
6.3.2	CFD Modeling and Validation	330
6.3.3	Effect of Sweep Gas Flow Rate	334
6.3.4	Effect of Feed Gas Flow Rate	338
6.3.5	Effect of Feed Pressure	340
6.3.6	Effect of Polymer Material	342
6.3.7	Multi-stage Separation	343
6.4	Ceramic Membrane Reactors for Oxy-fuel Combustion Applications	345
6.5	Hybrid Polymeric-Ceramic Membrane Reactor for Gas Turbine Applications	348
6.5.1	Design of Polymeric Membrane Unit	350
6.5.2	Design of Oxygen Transport Membrane Reactor (OTMR) Unit	351

6.5.3	Analysis of the Hybrid Unit	356
6.5.4	Effect of Feed O ₂ Mass Fraction	359
6.5.5	Effect of Swept Fuel Mass Fraction	362
6.5.6	Effect of Feed Flow Rate	363
6.5.7	Effect of Sweep Flow Rate	366
6.5.8	Design and Energy Analysis of the Hybrid Unit	369
6.6	Low-Power Porous-Plate Reactors	375
6.6.1	Combustion Characteristics in Porous-Plate Reactors	376
6.6.2	Operating Conditions	378
6.6.3	Modeling Non-reactive Flow in Porous-Plate Reactor	383
6.6.4	Modeling Reactive Flow in Porous-Plate Reactor	385
6.6.5	Non-reactive Flow Field Characteristics	387
6.6.6	Reactive Flow Field Characteristics	394
6.7	Operability Limits of Porous-Plate Reactor Mimicking OTMR Operation	395
6.7.1	Combustor Setup	398
6.7.2	Flame Shape	402
6.7.3	Combustion Temperature	404
6.7.4	Lean Blowout Limits	407
6.8	Concluding Remarks	409
	References	411