

---

# WORLDWIDE REFINERY PROCESSING REVIEW

*Monitoring Technology Development and Competition in One Single Source*

---

## First Quarter 2018

*Sulfur Plant, and Alkylation and Olefin Oligomerization*

*Plus*

*Latest Refining Technology Developments & Licensing*



**HYDROCARBON PUBLISHING COMPANY**

*Translating Knowledge into Profitability®*

P.O. Box 815, Paoli, PA 19301-0815 (U.S.A.)

Phone: (610) 408-0117/ Fax: (610) 408-0118

[Review@Hydrocarbonpublishing.com](mailto:Review@Hydrocarbonpublishing.com)

# 1Q 2018 Review

## Sulfur Plant, and Alkylation and Olefin Oligomerization

<b>1. INTRODUCTION.....</b>	<b>1</b>
<b>2. SULFUR PLANT.....</b>	<b>5</b>
2.1 <i>Market/Technology Trends &amp; Opportunities .....</i>	5
2.1.1 Introduction.....	5
2.1.2 Market Conditions and Outlook .....	5
2.1.2.1 Fuel Specifications and Unit Emissions Considerations.....	5
2.1.2.1.1 Transportation Fuels .....	5
2.1.2.1.1.1 Motor Gasoline.....	6
2.1.2.1.1.2 Middle Distillates.....	9
2.1.2.1.1.3 Bunker Fuel .....	11
2.1.2.1.2 Refinery Units Emitting Sulfur .....	13
2.1.2.2 Sulfur Production, Demand, and Pricing.....	14
2.1.2.2.1 Global Sulfur Production and Demand.....	15
2.1.2.2.1.1 Sulfur Production .....	15
2.1.2.2.1.2 Sulfur Demand.....	18
2.1.2.2.2 Sulfur Prices.....	20
2.1.2.3 Sulfur Plant Capacity and Expansion.....	21
2.1.3 Technology Competition, Directions, and Future Prospects .....	22
2.1.3.1 Acid Gas Removal .....	24
2.1.3.2 Claus.....	28
2.1.3.3 Tailgas Treating .....	35
2.1.3.4 Alternative Sulfur Production and Handling Methods.....	40
2.1.3.5 Advanced Process Control .....	42
2.1.4 Conclusion.....	43
2.2 <i>State-of-the-Art Technology .....</i>	44
2.2.1 Introduction.....	44
2.2.2 Commercial Process Technology .....	45
2.2.2.1 Acid Gas Removal .....	45
2.2.2.1.1 Amec Foster Wheeler.....	46
2.2.2.1.2 BASF.....	47
2.2.2.1.2.1 PuraTreat R.....	47
2.2.2.1.2.2 aMDEA.....	47
2.2.2.1.3 Dow Gas Treating Products and Services .....	49
2.2.2.1.4 ExxonMobil.....	50
2.2.2.1.5 Fluor .....	53
2.2.2.1.6 Huntsman .....	58
2.2.2.1.7 INEOS Oxide.....	59
2.2.2.1.8 Lurgi/Air Liquide .....	60
2.2.2.1.9 Shell Global Solutions.....	61
2.2.2.1.9.1 ADIP.....	61
2.2.2.1.9.2 Sulfinol.....	62
2.2.2.1.9.3 ADIP-X and Sulfinol-X .....	63
2.2.2.1.10 Uhde.....	64
2.2.2.1.10.1 Morphysorb.....	64
2.2.2.1.10.2 Genosorb .....	65
2.2.2.1.11 UOP .....	66

2.2.2.2	Acid Gas Enrichment .....	67
2.2.2.2.1	BASF .....	68
2.2.2.2.2	ExxonMobil .....	69
2.2.2.2.3	Fluor.....	71
2.2.2.2.4	TKK Technology Co.....	72
2.2.2.2.4.1	HIGHSULF PLUS.....	72
2.2.2.2.4.2	TC.....	73
2.2.2.3	Claus.....	74
2.2.2.3.1	Oxygen Enriched Claus.....	75
2.2.2.3.1.1	Air Liquide.....	75
2.2.2.3.1.2	CB&I.....	76
2.2.2.3.1.3	Duiker Combustion Engineers .....	76
2.2.2.3.1.4	Fluor.....	77
2.2.2.3.1.5	Goar, Allison & Associates .....	78
2.2.2.3.1.6	Linde/BOC Gases/WorleyParsons.....	80
2.2.2.3.1.6.1	Low-level Enrichment .....	83
2.2.2.3.1.6.2	SURE Single Combustion.....	83
2.2.2.3.1.6.3	SURE Double Combustion.....	84
2.2.2.3.2	Sub-dew Point Claus .....	86
2.2.2.3.2.1	BP.....	86
2.2.2.3.2.2	Black & Veatch .....	87
2.2.2.3.2.3	DEG-ITS .....	90
2.2.2.3.2.4	Jacobs Comprimo Sulfur Solutions .....	91
2.2.2.3.2.5	Lurgi/Air Liquide .....	92
2.2.2.3.3	Direct Oxidation.....	93
2.2.2.3.3.1	GTC Technology .....	93
2.2.2.3.3.2	Jacobs Comprimo Sulfur Solutions .....	94
2.2.2.3.3.2.1	SUPERCLAUS .....	94
2.2.2.3.3.2.2	EUROCLAUS .....	97
2.2.2.3.3.3	Lurgi/Air Liquide .....	99
2.2.2.3.3.4	Prosernat .....	100
2.2.2.3.3.5	Rameshni & Associates Technology & Engineering (RATE) .....	104
2.2.2.3.3.6	UOP/WorleyParsons .....	104
2.2.2.3.4	Other Claus Processes.....	105
2.2.2.3.4.1	Amec Foster Wheeler .....	105
2.2.2.3.4.2	GTC Technology .....	109
2.2.2.3.4.2.1	GT-SPOC.....	109
2.2.2.3.4.2.2	GT-Claus.....	110
2.2.2.3.4.2.3	GT-SSR.....	111
2.2.2.3.4.2.4	GT-SULFCAT .....	112
2.2.2.3.4.3	Siirtec Nigi.....	113
2.2.2.3.4.3.1	Modified Claus Process.....	113
2.2.2.3.4.3.2	Advanced Ammonia Claus Technology.....	114
2.2.2.3.4.4	Sulfur Operations Support, Inc. ....	116
2.2.2.3.4.5	WorleyParsons.....	117
2.2.2.3.4.5.1	Modified Claus Process.....	117
2.2.2.3.4.5.2	Ammonia Destruction.....	118
2.2.2.4	Tailgas Treatment.....	118
2.2.2.4.1	Amec Foster Wheeler .....	119
2.2.2.4.2	BASF.....	119
2.2.2.4.3	CANSOLV Technologies.....	120

2.2.2.4.3.1	CANSOLV SO <sub>2</sub> Scrubbing Process.....	120
2.2.2.4.3.2	CANSOLV Integrated SO <sub>2</sub> -CO <sub>2</sub> System .....	122
2.2.2.4.3.3	CANSOLV TGT+ .....	123
2.2.2.4.4	CB&I.....	125
2.2.2.4.5	CS Combustion Solutions.....	126
2.2.2.4.6	DuPont Sustainable Solutions .....	126
2.2.2.4.7	ExxonMobil.....	128
2.2.2.4.8	Fluor .....	129
2.2.2.4.8.1	Direct Contacting Condenser .....	129
2.2.2.4.8.2	SO <sub>x</sub> Clean-up Process .....	130
2.2.2.4.9	GTC Technology.....	130
2.2.2.4.10	Jacobs Comprimo Sulfur Solutions.....	130
2.2.2.4.11	John Zink Hamworthy Combustion .....	131
2.2.2.4.12	Lurgi/Air Liquide.....	132
2.2.2.4.13	Macrotek Inc. ....	132
2.2.2.4.14	MECS .....	133
2.2.2.4.14.1	DynaWave .....	133
2.2.2.4.14.2	ClausMaster.....	136
2.2.2.4.15	Prosernat.....	137
2.2.2.4.15.1	CLAUSPOL.....	137
2.2.2.4.15.2	Sultimate .....	139
2.2.2.4.16	Shell Global Solutions.....	140
2.2.2.4.16.1	SCOT .....	140
2.2.2.4.16.2	LT-SCOT .....	141
2.2.2.4.16.3	SCOT ULTRA.....	142
2.2.2.4.16.4	LS-SCOT .....	145
2.2.2.4.17	Siirtec Nigi .....	146
2.2.2.4.18	SWAPSOL.....	147
2.2.2.4.19	TechnipFMC.....	149
2.2.2.4.19.1	Reduction Absorption Recycle .....	149
2.2.2.4.19.2	Multipurpose Reduction Absorption Recycle.....	150
2.2.2.4.20	TKK Technology Co. ....	151
2.2.2.4.21	UOP/WorleyParsons.....	153
2.2.2.4.21.1	Beavon Sulfur Removal .....	153
2.2.2.4.21.2	Catalytic Thermal Incineration .....	156
2.2.2.4.21.3	Ammonia Combustion.....	157
2.2.2.5	Alternative Sulfur Removal Processes .....	157
2.2.2.5.1	Adding a Redox Process for Increased Sulfur Recovery .....	157
2.2.2.5.1.1	Gas Technology Products (GTP) .....	158
2.2.2.5.1.1.1	LO-CAT.....	158
2.2.2.5.1.1.2	LO-CAT II.....	162
2.2.2.5.1.1.3	MINI-CAT .....	163
2.2.2.5.1.2	Prosernat/Le Gaz Integral.....	164
2.2.2.5.1.3	Shell Global Solutions.....	164
2.2.2.5.2	Production of Sulfuric Acid.....	165
2.2.2.5.2.1	DuPont STRATCO.....	165
2.2.2.5.2.2	Haldor Topsoe .....	167
2.2.2.5.2.2.1	WSA.....	167
2.2.2.5.2.2.2	SNOX.....	172
2.2.2.5.3	Other Processes.....	175
2.2.2.5.3.1	Alfa Laval/KT-Kinetics Technology/Univ. of Milan .....	175

2.2.2.5.3.2	Black & Veatch .....	176
2.2.2.5.3.3	CrystaTech/URS .....	176
2.2.2.5.3.4	Paques BV/Shell Global Solutions.....	178
2.2.2.5.3.5	Paques BV/Shell Global Solutions/UOP .....	179
2.2.2.5.3.5.1	THIOPAQ.....	179
2.2.2.5.3.5.2	THIOPAQ-SG.....	184
2.2.2.5.3.6	ThioSolv .....	185
2.2.2.6	Sulfur Degasification .....	187
2.2.2.6.1	Black & Veatch .....	188
2.2.2.6.2	Brimrock Group Inc.....	188
2.2.2.6.3	Enersul .....	189
2.2.2.6.4	ExxonMobil .....	190
2.2.2.6.5	Fluor.....	191
2.2.2.6.6	Prosernat .....	191
2.2.2.6.7	Shell Global Solutions .....	192
2.2.2.6.8	Siiirtec Nigi.....	192
2.2.2.6.9	WorleyParsons.....	193
2.2.2.7	Sulfur Finishing Processes .....	193
2.2.2.7.1	Brimrock Group Inc.....	193
2.2.2.7.2	Devco USA.....	194
2.2.2.7.3	Enersul .....	195
2.2.2.7.3.1	GX.....	197
2.2.2.7.3.2	WetPrill .....	199
2.2.2.7.4	Sandvik Process Systems .....	199
2.2.3	Commercial Catalysts .....	202
2.2.3.1	Axens .....	202
2.2.3.1.1	Claus Catalysts .....	202
2.2.3.1.2	Tailgas Treating Catalysts.....	205
2.2.3.2	BASF Catalysts .....	208
2.2.3.3	Clariant Catalysts.....	209
2.2.3.4	Criterion Catalysts & Technologies.....	211
2.2.3.5	Haldor Topsoe .....	212
2.2.3.6	New Technology Ventures Inc.....	212
2.2.3.7	UOP .....	213
2.2.4	Advanced Process Control and Simulation.....	213
2.2.4.1	Axens .....	213
2.2.4.2	Aspen Technology .....	213
2.2.4.3	Bryan Research and Engineering.....	215
2.2.4.4	Jacobs Comprimo Sulfur Solutions.....	217
2.2.4.5	KT-Kinetics Technology .....	218
2.2.4.6	Optimized Gas Treating.....	219
2.2.4.7	Shell Global Solutions.....	223
2.2.5	Analyzers and Instrumentation.....	223
2.2.5.1	AMETEK Process Instruments .....	223
2.2.5.2	Applied Analytics.....	224
2.2.5.3	Fives Pillard.....	224
2.2.5.4	Metso .....	225
2.2.5.5	PAC LP.....	226
2.2.6	Summary of Commercially Available Sulfur Plant Technologies.....	226
2.2.7	Comparison of Commercial Sulfur Plant Catalysts.....	241

2.3	<i>Plant Operations and Practices</i> .....	242
2.3.1	Acid Gas Removal .....	242
2.3.1.1	Amine Solvent Replacement.....	242
2.3.1.2	Optimizing an Amine Unit.....	244
2.3.1.3	Amine System Operating Issues.....	247
2.3.1.3.1	Contaminants .....	247
2.3.1.3.1.1	Importance of Chemical Analysis .....	247
2.3.1.3.1.2	Hydrocarbon Carryover in Amine Acid Gas.....	248
2.3.1.3.1.3	Filtration and Separation of Contaminants.....	250
2.3.1.3.1.4	Removal of HCN .....	252
2.3.1.3.2	Amine System Corrosion .....	252
2.3.1.3.3	Foaming.....	256
2.3.1.3.4	Amine Losses .....	257
2.3.1.3.5	Instability in Amine Regenerator.....	258
2.3.1.4	Proper Heat Exchanger Design for Acid Gas Removal Units.....	260
2.3.1.5	Safe Acid Gas Handling .....	261
2.3.1.6	Refractory Upgrade.....	262
2.3.2	Claus Process .....	262
2.3.2.1	Increasing Sulfur Recovery Capacity .....	262
2.3.2.2	The Effects of Extreme Turndowns.....	266
2.3.2.3	Benefits and Drawbacks of Oxygen Enrichment.....	267
2.3.2.4	Claus Unit Shutdowns .....	270
2.3.2.5	Claus Catalyst Life and Reuse.....	272
2.3.2.6	Advanced Control Systems for Claus Plants.....	273
2.3.2.7	Preventing Overpressure in Claus Units .....	274
2.3.2.8	Preventing Liquid Sulfur Accumulation in Claus Units.....	275
2.3.2.9	Processing SWS Offgas in Claus Units .....	276
2.3.2.10	Analyzing Sulfur Content in Claus Tailgas .....	277
2.3.2.11	Neural Network for Claus Temperature Control .....	279
2.3.2.12	Benefits of Partial Oxidation Process vs. Modified Claus.....	279
2.3.3	Tailgas Treating .....	280
2.3.3.1	Experience with Designing a TGTU .....	280
2.3.3.2	Proper TGT Catalyst Selection.....	284
2.3.3.3	Cold Bed Adsorption Units for Tailgas Treating .....	286
2.3.3.4	Amine Degradation in TGTUs.....	287
2.3.3.5	Preventing Corrosion in TGTUs.....	289
2.3.3.6	SO <sub>2</sub> Breakthrough in TGTUs .....	290
2.3.4	General Sulfur Plant.....	290
2.3.4.1	Small-scale Sulfur Plants .....	290
2.3.4.2	Modular Sulfur Plants .....	291
2.3.4.3	Improving Energy Efficiency of Sulfur Plants .....	292
2.3.4.4	Improving Sulfur Plant Reliability.....	293
2.3.4.5	Liquid Scavengers for H <sub>2</sub> S Removal.....	294
2.3.5	Sulfur Storage and Handling .....	295
2.3.5.1	Premium Sulfur Specifications .....	295
2.3.5.2	Liquid Loading and Transport .....	296
2.3.5.3	Blocking.....	299
2.4	<i>Refining R&amp;D Alert!</i> .....	299
2.4.1	Introduction .....	299
2.4.2	Acid Gas Removal .....	302
2.4.2.1	Simultaneous Removal of H <sub>2</sub> S and CO <sub>2</sub> .....	302

2.4.2.2	Absorbent Materials.....	303
2.4.2.2.1	Patents.....	303
2.4.2.2.2	Research.....	303
2.4.3	Acid Gas Enrichment.....	304
2.4.3.1	Patents.....	304
2.4.3.2	Research.....	304
2.4.4	Claus Technology.....	305
2.4.4.1	Process.....	305
2.4.4.1.1	Multiple Claus Reactors/Reaction Zones.....	305
2.4.4.1.2	Oxygen Enrichment.....	307
2.4.4.1.2.1	Patents.....	307
2.4.4.1.2.2	Research.....	307
2.4.4.1.3	Sub-dew Point.....	308
2.4.4.1.4	Process and Reaction Modeling.....	308
2.4.4.1.4.1	Patents.....	308
2.4.4.1.4.2	Research.....	309
2.4.4.1.5	Improving Energy and/or Process Efficiency.....	310
2.4.4.1.6	Miscellaneous.....	313
2.4.4.2	Catalyst.....	314
2.4.5	Tailgas Treating.....	315
2.4.5.1	Process.....	315
2.4.5.2	Catalyst.....	320
2.4.5.2.1	Patents.....	320
2.4.5.2.2	Research.....	321
2.4.6	Sulfur Degasification.....	321
2.5	<i>Worldwide Installed Capacity</i> .....	322
2.6	<i>Construction</i> .....	324
2.6.1	Recent Construction Activity.....	324
2.6.2	Completed Construction Projects.....	331
2.7	<i>References</i> .....	366
<b>3.</b>	<b>ALKYLATION AND OLEFIN OLIGOMERIZATION.....</b>	<b>389</b>
3.1	<i>Market/Technology Trends &amp; Opportunities</i> .....	389
3.1.1	Introduction.....	389
3.1.2	Market Conditions and Outlook.....	391
3.1.2.1	Gasoline Supply and Demand.....	392
3.1.2.1.1	North America.....	393
3.1.2.1.2	Europe.....	395
3.1.2.1.3	Africa.....	396
3.1.2.1.4	Asia-Pacific.....	396
3.1.2.2	Alkylation Capacity and New Construction Projects.....	398
3.1.2.3	Mandated Blending of Ethanol and the Impact on the Gasoline Pool.....	399
3.1.2.4	Impact of Shale Boom on Alkylation Operations.....	401
3.1.2.5	Safety and Environmental Concerns.....	401
3.1.3	Technology Competition, Directions, and Future Prospects.....	403
3.1.3.1	Liquid Acid Alkylation.....	403
3.1.3.1.1	HF.....	404
3.1.3.1.2	H <sub>2</sub> SO <sub>4</sub> .....	404
3.1.3.2	Ionic Liquid Alkylation.....	405
3.1.3.3	Solid Acid Alkylation.....	406

3.1.3.4	Olefin Oligomerization .....	407
3.1.3.5	Revamping Liquid Acid Units to Solid Acid and Ionic Liquid Units .....	407
3.1.3.6	R&D Trends .....	408
3.1.4	Conclusion .....	409
3.2	<i>State-of-the-Art Technology</i> .....	409
3.2.1	Introduction .....	409
3.2.2	Commercially Available Technologies .....	414
3.2.2.1	Alkylation Feed Pretreatment .....	415
3.2.2.1.1	Axens .....	415
3.2.2.1.2	Honeywell UOP .....	416
3.2.2.2	HF Alkylation .....	417
3.2.2.2.1	Honeywell UOP .....	418
3.2.2.2.1.1	Gravity Circulated HF Alkylation .....	418
3.2.2.2.1.2	Forced Circulation HF Alkylation .....	420
3.2.2.2.1.3	ReVAP .....	421
3.2.2.2.1.4	Inventory Management Process .....	423
3.2.2.3	H <sub>2</sub> SO <sub>4</sub> Alkylation .....	423
3.2.2.3.1	CB&I .....	425
3.2.2.3.1.1	CDAlky .....	425
3.2.2.3.1.2	CDAlkyPlus .....	430
3.2.2.3.2	DuPont Clean Technologies .....	431
3.2.2.3.2.1	Feed Segregation .....	431
3.2.2.3.2.2	Butenes Feed Fractionation .....	432
3.2.2.3.2.3	STRATCO Alkylation .....	433
3.2.2.3.2.4	ALKYSAFE .....	437
3.2.2.3.2.5	ConvEx .....	438
3.2.2.3.2.6	Integrated Alkylation and Onsite SAR/SGR .....	441
3.2.2.3.3	ExxonMobil .....	442
3.2.2.3.4	Refining Hydrocarbon Technologies (RHT) .....	444
3.2.2.4	Solid Acid Alkylation .....	446
3.2.2.4.1	CB&I/Albemarle .....	446
3.2.2.4.2	Exelus .....	449
3.2.2.4.3	KBR .....	450
3.2.2.4.4	Lurgi .....	454
3.2.2.5	Ionic Liquid Alkylation .....	455
3.2.2.5.1	China Univ. of Petroleum/PetroChina/Well Resources .....	455
3.2.2.5.2	Honeywell UOP .....	459
3.2.2.6	Butane Oxydehydrogenation .....	460
3.2.2.6.1	Uhde .....	460
3.2.2.7	Renewable Alkylation .....	464
3.2.2.7.1	Exelus .....	464
3.2.2.8	Olefin Oligomerization .....	465
3.2.2.8.1	Axens .....	465
3.2.2.8.1.1	Dimersol .....	465
3.2.2.8.1.2	Polynaphtha and Selectopol .....	466
3.2.2.8.2	CB&I/Saipem .....	468
3.2.2.8.3	Honeywell UOP .....	469
3.2.2.8.4	KBR .....	473
3.2.2.8.5	LyondellBasell/Kvaerner .....	474
3.2.2.8.6	Refining Hydrocarbon Technologies .....	476
3.2.2.8.7	Saipem .....	478



3.2.3	Summary of Alkylate and Olefin Oligomerization Technologies .....	479
3.2.4	Comparison of Commercially Available Advanced Control and Optimization Systems .....	486
3.3	<i>Plant Operations and Practices</i> .....	488
3.3.1	Feed Considerations.....	488
3.3.1.1	Feed Contaminants .....	488
3.3.1.2	Alkylating Alternative Feedstocks .....	489
3.3.1.2.1	Propylene.....	489
3.3.1.2.2	Amylenes .....	492
3.3.1.2.3	Isobutene.....	494
3.3.1.2.4	Isomerization Butane Slop Stream .....	495
3.3.1.2.5	Light Ends.....	495
3.3.1.2.6	Feed from Cokers.....	496
3.3.2	HF Alkylation .....	496
3.3.2.1	Disposing of Acid Soluble Oils from HF Plants.....	496
3.3.2.2	Corrosion .....	496
3.3.2.3	Chemical Cleaning in HF Alkylation Units Prior to Turnaround.....	499
3.3.2.4	Online Monitoring of HF Acid Catalyst .....	500
3.3.2.5	Safety and Mitigation Techniques.....	501
3.3.2.6	Optimizing HF Alkylation Feed Nozzles .....	503
3.3.2.7	Improved Valve Design.....	504
3.3.2.8	Pump Seal Selection .....	505
3.3.2.9	Inspecting Joints in HF Alkylation Unit .....	506
3.3.2.10	Treating HF Alkylation Products to Remove Organic Fluorides.....	506
3.3.2.11	Revamping HF Alkylation Units .....	507
3.3.2.11.1	Revamping to H <sub>2</sub> SO <sub>4</sub> Alkylation .....	507
3.3.2.11.2	Revamping to Solid Acid Alkylation .....	509
3.3.3	H <sub>2</sub> SO <sub>4</sub> Alkylation .....	510
3.3.3.1	Boosting H <sub>2</sub> SO <sub>4</sub> Alkylation Unit Capacity and Throughput.....	510
3.3.3.2	ASO Formation and Disposal.....	511
3.3.3.3	Corrosion and Fouling .....	511
3.3.3.4	Optimizing Propane Content in Refrigeration Section .....	515
3.3.3.5	Spent H <sub>2</sub> SO <sub>4</sub> Regeneration and Treatment .....	515
3.3.3.5.1	Regeneration .....	515
3.3.3.5.2	Treatment .....	516
3.3.3.6	Maintaining Good Reliability of pH Analyzers.....	516
3.3.3.7	Electrostatic Precipitator Use in Caustic Wash Systems .....	518
3.3.4	Acid Management .....	518
3.3.4.1	Acid Runaway .....	518
3.3.4.2	Acid Storage .....	519
3.3.4.3	Rapid Acid Dumping .....	521
3.3.5	Process Control, Monitoring, and Optimization.....	522
3.3.5.1	Dynamic Simulation for Debottlenecking a Deisobutanizer .....	522
3.3.5.2	Response Surface Methods for Optimizing an Alkylation Unit .....	523
3.3.5.3	Measuring and Maintaining Circulating Acid Strength and Acid Levels .....	523
3.3.5.3.1	Employing Multi-Objective Optimization to Alkylation Processes .....	526
3.3.5.3.2	IsoStripper Advanced Process Control (APC) .....	527
3.3.5.4	Effective Instrumentation to Optimize Alkylation Unit Process Control.....	527
3.4	<i>Refining R&amp;D Alert!</i> .....	528
3.4.1	Introduction .....	528
3.4.2	Feedstock Pretreatment .....	532

3.4.3	Liquid Alkylation .....	533
3.4.3.1	General .....	533
3.4.3.2	HF Alkylation .....	537
3.4.3.2.1	Process .....	537
3.4.3.2.2	Equipment .....	539
3.4.3.3	H <sub>2</sub> SO <sub>4</sub> Alkylation .....	539
3.4.3.3.1	Process .....	539
3.4.3.3.1.1	Patents .....	539
3.4.3.3.1.2	Research .....	545
3.4.3.3.2	Catalysts and Additives .....	545
3.4.3.3.2.1	Patents .....	545
3.4.3.3.2.2	Research .....	547
3.4.3.3.3	Equipment .....	547
3.4.3.3.3.1	Reactor .....	547
3.4.3.3.3.2	Separation .....	555
3.4.3.3.3.3	Recycle .....	557
3.4.3.3.3.4	Other .....	557
3.4.3.4	Lewis Acid Alkylation .....	560
3.4.3.5	Ionic Liquid Alkylation .....	561
3.4.3.5.1	Process .....	561
3.4.3.5.1.1	Patents .....	561
3.4.3.5.1.2	Research .....	566
3.4.3.5.2	Catalysts .....	567
3.4.3.5.2.1	Patents .....	567
3.4.3.5.2.2	Research .....	571
3.4.3.5.3	Equipment .....	573
3.4.3.5.3.1	Patents .....	573
3.4.3.5.3.2	Research .....	576
3.4.3.6	Mixed Acid Alkylation .....	577
3.4.4	Solid Acid Alkylation .....	580
3.4.4.1	Process .....	580
3.4.4.1.1	Patents .....	580
3.4.4.1.2	Research .....	585
3.4.4.2	Catalyst .....	585
3.4.4.2.1	Patents .....	585
3.4.4.2.2	Research .....	590
3.4.4.3	Equipment .....	591
3.4.5	Alkylation with Liquid or Solid Catalysts .....	593
3.4.6	Olefin Oligomerization .....	594
3.5	<i>Worldwide Installed Capacity</i> .....	595
3.6	<i>Construction</i> .....	596
3.6.1	Recent Construction Activity .....	596
3.6.2	Completed Construction Projects .....	599
3.7	<i>References</i> .....	604
<b>4.</b>	<b>LATEST REFINING TECHNOLOGY DEVELOPMENTS &amp; LICENSING</b> .....	<b>623</b>
4.1	<i>Fluid Catalytic Cracking</i> .....	623
4.2	<i>Hydrotreating (including HDS)</i> .....	625
4.3	<i>Hydrocracking</i> .....	626

4.4	<i>Catalytic Reforming</i> .....	627
4.5	<i>Coking</i> .....	627
4.6	<i>Solvent Deasphalting</i> .....	627
4.7	<i>Visbreaking</i> .....	628
4.8	<i>Hydrogen Production and Purification</i> .....	628
4.9	<i>Gas Concentration Plant/Vapor Recovery</i> .....	629
4.10	<i>Lube Production</i> .....	630
4.11	<i>Aromatics and Light Olefins Production</i> .....	631
4.12	<i>Catalyst and Carrier Support Developments</i> .....	634
4.13	<i>Process Controls and Simulation</i> .....	634
4.14	<i>Industrial Internet of Things (IIoT)</i> .....	635
4.15	<i>XTL (Biomass-, Coal-, and Gas-to-liquid)</i> .....	640
4.16	<i>Biofuels Production</i> .....	640
4.17	<i>CO<sub>2</sub> Emissions (Carbon Capture and Sequestration)</i> .....	641
4.18	<i>Site Emissions</i> .....	643
4.19	<i>Plant Safety</i> .....	644
4.20	<i>References</i> .....	644