
WORLDWIDE REFINERY PROCESSING REVIEW

Monitoring Technology Development and Competition in One Single Source

First Quarter 2017

Sulfur Plant and Refinery Internet of Things

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

1Q 2017

Hydrocarbon Publishing Co./Copyright Protected

TABLE OF CONTENTS

1Q 2017 Review " Sulfur Plant and Refinery Katernet of Vhing

1. INTRODUCTION.....	1
2. SULFUR PLANT	5
2.1 MARKET/TECHNOLOGY TRENDS & OPPORTUNITIES.....	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/Middle Distillates.....	6
2.1.2.1.1.2 Bunker Fuel.....	8
2.1.2.1.2 Refinery Units Emitting Sulfur.....	10
2.1.2.1.3 GHG Emissions.....	11
2.1.2.2 Sulfur Production, Demand, and Pricing.....	13
2.1.2.2.1 Global Sulfur Production and Demand.....	13
2.1.2.2.1.1 Sulfur Production.....	13
2.1.2.2.1.2 Sulfur Demand.....	16
2.1.2.2.2 Sulfur Prices.....	18
2.1.2.3 Sulfur Plant Capacity and Expansion.....	18
2.1.3 Technology Competition, Directions, and Future Prospects.....	19
2.1.3.1 Acid Gas Removal.....	21
2.1.3.2 Claus.....	25
2.1.3.3 Tailgas Treating.....	31
2.1.3.4 Alternative Sulfur Production and Handling Methods.....	37
2.1.3.5 Advanced Process Control.....	39
2.1.4 Conclusion.....	40
2.2 STATE-OF-THE-ART TECHNOLOGY.....	41
2.2.1 Introduction.....	41
2.2.2 Commercial Process Technology.....	42
2.2.2.1 Acid Gas Removal.....	42
2.2.2.1.1 Amec Foster Wheeler.....	42
2.2.2.1.2 BASF.....	43
2.2.2.1.2.1 PuraTreat R.....	43
2.2.2.1.2.2 aMDEA.....	43
2.2.2.1.3 Dow Gas Treating Products and Services.....	45
2.2.2.1.4 ExxonMobil.....	46
2.2.2.1.5 Fluor.....	49
2.2.2.1.6 Huntsman.....	50
2.2.2.1.7 INEOS Oxide.....	51
2.2.2.1.8 Lurgi/Air Liquide.....	52
2.2.2.1.9 Shell Global Solutions.....	53
2.2.2.1.9.1 ADIP.....	54
2.2.2.1.9.2 Sulfinol.....	54
2.2.2.1.9.3 ADIP-X and Sulfinol-X.....	55
2.2.2.1.10 Uhde.....	56
2.2.2.1.10.1 Morphosorb.....	56
2.2.2.1.10.2 Genosorb.....	57
2.2.2.1.11 UOP.....	58
2.2.2.2 Acid Gas Enrichment.....	59
2.2.2.2.1 BASF.....	60
2.2.2.2.2 ExxonMobil.....	61
2.2.2.2.3 Fluor.....	63

TABLE OF CONTENTS

	2.2.2.2.4 TKK Technology Co.	64
	2.2.2.2.4.1 HIGHSULF PLUS.....	64
	2.2.2.2.4.2 TC.....	65
2.2.2.3	Claus.....	66
	2.2.2.3.1 Oxygen Enriched Claus	67
	2.2.2.3.1.1 Air Liquide.....	67
	2.2.2.3.1.2 CB&I.....	68
	2.2.2.3.1.3 Duiker Combustion Engineers	68
	2.2.2.3.1.4 Fluor.....	69
	2.2.2.3.1.5 Goar, Allison & Associates	69
	2.2.2.3.1.6 Linde/BOC Gases/WorleyParsons.....	72
	2.2.2.3.1.6.1 Low- level Enrichment.....	73
	2.2.2.3.1.6.2 SURE Single Combustion	73
	2.2.2.3.1.6.3 SURE Double Combustion	74
	2.2.2.3.2 Sub-dew Point Claus.....	76
	2.2.2.3.2.1 BP.....	76
	2.2.2.3.2.2 Black & Veatch.....	77
	2.2.2.3.2.3 DEG-ITS.....	80
	2.2.2.3.2.4 Jacobs Comprimo Sulfur Solutions	81
	2.2.2.3.2.5 Lurgi/Air Liquide	82
	2.2.2.3.3 Direct Oxidation	83
	2.2.2.3.3.1 GTC Technology.....	83
	2.2.2.3.3.2 Jacobs Comprimo Sulfur Solutions	84
	2.2.2.3.3.2.1 SUPERCLAUS	84
	2.2.2.3.3.2.2 EUROCLAUS.....	87
	2.2.2.3.3.3 Lurgi/Air Liquide	88
	2.2.2.3.3.4 Prosernat	88
	2.2.2.3.3.5 Rameshni & Associates Technology & Engineering (RATE)	92
	2.2.2.3.3.6 UOP/WorleyParsons	93
	2.2.2.3.4 Other Claus Processes	94
	2.2.2.3.4.1 Amec Foster Wheeler	94
	2.2.2.3.4.2 GTC Technology.....	97
	2.2.2.3.4.2.1 GT-SPOC.....	97
	2.2.2.3.4.2.2 GT-Claus	98
	2.2.2.3.4.2.3 GT-SSR.....	99
	2.2.2.3.4.2.4 GT-SULFCAT	100
	2.2.2.3.4.3 Siirtec Nigi.....	101
	2.2.2.3.4.3.1 Modified Claus Process	101
	2.2.2.3.4.3.2 Advanced Ammonia Claus Technology	102
	2.2.2.3.4.4 Sulfur Operations Support, Inc.	104
	2.2.2.3.4.5 WorleyParsons.....	105
	2.2.2.3.4.5.1 Modified Claus Process	105
	2.2.2.3.4.5.2 Ammonia Destruction	106
2.2.2.4	Tailgas Treatment	106
	2.2.2.4.1 Amec Foster Wheeler	107
	2.2.2.4.2 BASF	107
	2.2.2.4.3 CANSOLV Technologies	108
	2.2.2.4.4 CB&I.....	111
	2.2.2.4.5 CS Combustion Solutions.....	113
	2.2.2.4.6 DuPont Sustainable Solutions	113
	2.2.2.4.7 Fluor	115
	2.2.2.4.7.1 Direct Contacting Condenser.....	115
	2.2.2.4.7.2 SO _x Clean-up Process.....	116
	2.2.2.4.8 GTC Technology.....	116
	2.2.2.4.9 John Zink Hamworthy Combustion	116
	2.2.2.4.10 Lurgi/Air Liquide	116
	2.2.2.4.11 Macrotek Inc.	117

TABLE OF CONTENTS

2.2.2.4.12	MECS.....	117
2.2.2.4.12.1	DynaWave.....	118
2.2.2.4.12.2	SUPERCLAUS/DynaWave.....	120
2.2.2.4.12.3	ClausMaster.....	122
2.2.2.4.13	Prosernat.....	122
2.2.2.4.13.1	CLAUSPOL.....	122
2.2.2.4.13.2	Sultimate.....	124
2.2.2.4.14	Shell Global Solutions.....	126
2.2.2.4.14.1	SCOT.....	126
2.2.2.4.14.2	LT-SCOT.....	127
2.2.2.4.14.3	SCOT ULTRA.....	127
2.2.2.4.14.4	LS-SCOT.....	129
2.2.2.4.15	Siirtec Nigi.....	129
2.2.2.4.16	SWAPSOL.....	131
2.2.2.4.17	Technip.....	132
2.2.2.4.17.1	Reduction Absorption Recycle.....	132
2.2.2.4.17.2	Multipurpose Reduction Absorption Recycle.....	133
2.2.2.4.18	TKK Technology Co.....	134
2.2.2.4.19	UOP/WorleyParsons.....	136
2.2.2.4.19.1	Beavon Sulfur Removal.....	136
2.2.2.4.19.2	Catalytic Thermal Incineration.....	139
2.2.2.4.19.3	Ammonia Combustion.....	140
2.2.2.5	Alternative Sulfur Removal Processes.....	140
2.2.2.5.1	Adding a Redox Process for Increased Sulfur Recovery.....	140
2.2.2.5.1.1	Gas Technology Products (GTP).....	141
2.2.2.5.1.1.1	LO-CAT.....	141
2.2.2.5.1.1.2	LO-CAT II.....	143
2.2.2.5.1.1.3	MINI-CAT.....	145
2.2.2.5.1.2	Prosernat/Le Gaz Integral.....	145
2.2.2.5.1.3	Shell Global Solutions.....	145
2.2.2.5.2	Production of Sulfuric Acid.....	146
2.2.2.5.2.1	DuPont STRATCO.....	147
2.2.2.5.2.2	Haldor Topsøe.....	147
2.2.2.5.2.2.1	WSA.....	147
2.2.2.5.2.2.2	SNOX.....	152
2.2.2.5.3	Other Processes.....	154
2.2.2.5.3.1	Alfa Laval/KT-Kinetics Technology/Univ. of Milan.....	154
2.2.2.5.3.2	Black & Veatch.....	155
2.2.2.5.3.3	CrystaTech/URS.....	156
2.2.2.5.3.4	Paques BV/Shell Global Solutions.....	157
2.2.2.5.3.5	Paques BV/Shell Global Solutions/UOP.....	159
2.2.2.5.3.6	ThioSolv.....	162
2.2.2.6	Sulfur Degasification.....	164
2.2.2.6.1	Black & Veatch.....	165
2.2.2.6.2	Brimrock Group Inc.....	165
2.2.2.6.3	Enersul.....	166
2.2.2.6.4	ExxonMobil.....	167
2.2.2.6.5	Goar, Allison & Associates.....	168
2.2.2.6.6	Prosernat.....	169
2.2.2.6.7	Shell Global Solutions.....	169
2.2.2.6.8	Siirtec Nigi.....	170
2.2.2.6.9	WorleyParsons.....	170
2.2.2.7	Sulfur Finishing Processes.....	170
2.2.2.7.1	Brimrock Group Inc.....	171
2.2.2.7.2	Devco USA.....	172
2.2.2.7.3	Enersul.....	173
2.2.2.7.3.1	GX.....	174

TABLE OF CONTENTS

2.2.2.7.3.2	WetPrill	176
2.2.2.7.4	Sandvik Process Systems	176
2.2.3	Commercial Catalysts	179
2.2.3.1	Axens.....	179
2.2.3.1.1	Claus Catalysts.....	179
2.2.3.1.2	Tailgas Treating Catalysts	182
2.2.3.2	BASF Catalysts	184
2.2.3.3	Clariant Catalysts.....	186
2.2.3.4	Criterion Catalysts & Technologies	187
2.2.3.5	Haldor Topsøe	189
2.2.3.6	New Technology Ventures Inc.	189
2.2.3.7	UOP	189
2.2.4	Advanced Process Control and Simulation	190
2.2.4.1	Axens.....	190
2.2.4.2	Aspen Tech.....	190
2.2.4.3	Bryan Research and Engineering.....	190
2.2.4.4	Jacobs Comprimo Sulfur Solutions.....	193
2.2.4.5	KT-Kinetics Technology	194
2.2.4.6	Optimized Gas Treating.....	194
2.2.4.7	Shell Global Solutions.....	196
2.2.5	Analyzers and Instrumentation	196
2.2.5.1	AMETEK Process Instruments	196
2.2.5.2	Applied Analytics.....	197
2.2.5.3	Fives Pillard	197
2.2.5.4	Metso	198
2.2.5.5	PAC LP	199
2.2.6	Summary of Commercially Available Sulfur Plant Technologies	199
2.2.7	Comparison of Commercial Sulfur Plant Catalysts	213
2.3	PLANT OPERATIONS AND PRACTICES	214
2.3.1	Acid Gas Removal	214
2.3.1.1	Amine Solvent Replacement	214
2.3.1.2	Optimizing an Amine Unit	216
2.3.1.3	Amine System Operating Issues.....	219
2.3.1.3.1	Contaminants	219
2.3.1.3.1.1	Importance of Chemical Analysis.....	219
2.3.1.3.1.2	Hydrocarbon Carryover in Amine Acid Gas	220
2.3.1.3.1.3	Filtration and Separation of Contaminants	222
2.3.1.3.1.4	Removal of HCN.....	224
2.3.1.3.2	Wet Acid Gas Corrosion.....	225
2.3.1.3.3	Amine Solution Corrosion	225
2.3.1.3.4	Foaming.....	228
2.3.1.3.5	Amine Losses.....	229
2.3.1.3.6	Instability in Amine Regenerator.....	231
2.3.1.4	Proper Heat Exchanger Design for Acid Gas Removal Units	232
2.3.1.5	Safe Acid Gas Handling.....	233
2.3.1.6	Refractory Upgrade.....	234
2.3.1.7	Fuel Gas Sweetening in a Hydrocracker Fractionation Section	235
2.3.2	Claus Process	236
2.3.2.1	Increasing Sulfur Recovery Capacity	236
2.3.2.2	The Effects of Extreme Turndowns	239
2.3.2.3	Benefits and Drawbacks of Oxygen Enrichment	240
2.3.2.4	Claus Unit Shutdowns	243
2.3.2.5	Claus Catalyst Life and Reuse.....	244
2.3.2.6	Advanced Control Systems for Claus Plants	246
2.3.2.7	Preventing Overpressure in Claus Units.....	247
2.3.2.8	Preventing Liquid Sulfur Accumulation in Claus Units	248

TABLE OF CONTENTS

2.3.2.9	Processing SWS Offgas in Claus Units.....	249
2.3.2.10	Analyzing Sulfur Content in Claus Tailgas	250
2.3.2.11	Neural Network for Claus Temperature Control	251
2.3.2.12	Benefits of Partial Oxidation Process vs. Modified Claus	252
2.3.3	Tailgas Treating	252
2.3.3.1	Experience with Designing a TGTU	252
2.3.3.2	Proper TGT Catalyst Selection	257
2.3.3.3	Cold Bed Adsorption Units for Tailgas Treating.....	258
2.3.3.4	Amine Degradation in TGTUs	260
2.3.3.5	Preventing Corrosion in TGTUs.....	261
2.3.4	General Sulfur Plant	262
2.3.4.1	Small-scale Sulfur Plants.....	262
2.3.4.2	Modular Sulfur Plants	263
2.3.4.3	Improving Energy Efficiency of Sulfur Plants	264
2.3.4.4	Liquid Scavengers for H ₂ S Removal	265
2.3.5	Sulfur Storage and Handling	266
2.3.5.1	Premium Sulfur Specifications.....	266
2.3.5.2	Liquid Loading and Transport.....	266
2.3.5.3	Blocking	269
2.4	REFINING R&D ALERT!.....	270
2.4.1	Introduction.....	270
2.4.2	Acid Gas Removal.....	273
2.4.2.1	Simultaneous Removal of H ₂ S and CO ₂	273
2.4.2.2	Sorbent Materials.....	274
2.4.2.2.1	Solid Adsorbents.....	274
2.4.2.2.2	Liquid Absorbents.....	274
2.4.2.2.2.1	Patents	274
2.4.2.2.2.2	Research.....	275
2.4.2.3	Solvent Regeneration	275
2.4.2.4	Miscellaneous.....	276
2.4.3	Claus Technology	276
2.4.3.1	Process	276
2.4.3.1.1	Multiple Claus Reactors/Reaction Zones	276
2.4.3.1.2	Oxygen Enrichment	278
2.4.3.1.2.1	Patents.....	278
2.4.3.1.2.2	Research.....	279
2.4.3.1.3	Process and Reaction Modeling.....	279
2.4.3.1.4	Miscellaneous Claus Process Improvements	280
2.4.4	Tailgas Treating	283
2.4.4.1	Process	283
2.4.4.1.1	Patents.....	283
2.4.4.1.2	Research	286
2.4.4.2	Catalyst.....	286
2.4.5	Sulfur Degasification	287
2.5	WORLDWIDE INSTALLED CAPACITY.....	288
2.6	CONSTRUCTION	289
2.6.1	Recent Construction Activity	289
2.6.2	Completed Construction Projects.....	295
2.7	REFERENCES	330
3.	REFINERY INTERNET OF THING.....	351
3.1	STATE-OF-THE-ART TECHNOLOGY	351
3.1.1	Introduction.....	351
3.1.2	Digitalization	352
3.1.2.1	Sensors, Actuators, and Transmitters.....	352

TABLE OF CONTENTS

3.1.2.2	Drones	354
3.1.2.3	Data Collection and Management	355
3.1.2.3.1	ABB	355
3.1.2.3.2	Amec Foster Wheeler	356
3.1.2.3.3	DNV GL	357
3.1.2.4	Big Data Analytics and Machine Learning	357
3.1.2.4.1	Aspen Technology	358
3.1.2.4.2	Casantec	359
3.1.2.4.3	Honeywell.....	359
3.1.2.4.3.1	Uniformance.....	359
3.1.2.4.3.2	Connected Performance Services.....	360
3.1.2.4.4	Intertek.....	361
3.1.2.4.5	Metso	361
3.1.2.4.6	Microsoft.....	361
3.1.2.4.7	Rockwell Automation	362
3.1.2.4.8	Schneider Electric.....	362
3.1.2.4.9	Yokogawa Electric.....	363
3.1.3	<i>IloT Platforms and Ecosystems</i>	364
3.1.3.1	Emerson	364
3.1.3.1.1	Plantweb Digital Ecosystem	364
3.1.3.1.2	Operational Certainty.....	365
3.1.3.2	GE Digital.....	366
3.1.3.3	Honeywell Process Solutions	366
3.1.4	<i>Commercial IloT Applications</i>	367
3.1.4.1	MOL.....	368
3.1.4.2	Permasense.....	369
3.1.5	<i>Cyber Security Solutions</i>	370
3.1.5.1	Deloitte, Dragos	373
3.1.5.2	Honeywell Process Solutions	373
3.1.5.3	Schneider Electric.....	374
3.1.5.4	Siemens, Atos.....	375
3.1.5.5	Veracity, SEL, Sempra.....	375
3.1.6	<i>Conclusion</i>	375
3.2	REFERENCES.....	377
4.	LATEST REFINING TECHNOLOGY DEVELOPMENTS & LICENSING	381
4.1	FLUID CATALYTIC CRACKING	381
4.2	HYDROTREATING (INCLUDING HDS)	382
4.3	HYDROCRACKING	382
4.4	CATALYTIC REFORMING	383
4.5	ISOMERIZATION	383
4.6	ALKYLATION	384
4.7	COKING.....	384
4.8	HYDROGEN PRODUCTION AND PURIFICATION	384
4.9	CRUDE BLENDING.....	385
4.10	LUBE PRODUCTION.....	385
4.11	AROMATICS AND LIGHT OLEFINS PRODUCTION	386
4.12	CATALYST AND CARRIER SUPPORT DEVELOPMENTS	389
4.13	PROCESS CONTROLS AND SIMULATION	390
4.14	BIOFUELS PRODUCTION	390
4.15	ENERGY MANAGEMENT	391
4.16	CO ₂ EMISSIONS (CARBON CAPTURE AND SEQUESTRATION).....	392
4.17	SITE EMISSIONS	393
4.18	REFERENCES.....	394