Contents

Introduction

The Three Sisters – CCS, AGI, and EOR
Ying Wu, John J. Carroll and Zhimin Du

Section 1: Data and Correlation

1. Prediction of Acid Gas Dew Points in the Presence of Water and Volatile Organic Compounds
   Ray. A. Tomcej
   1.1 Introduction
   1.2 Previous Studies
   1.3 Thermodynamic Model
   1.4 Calculation Results
   1.5 Discussion
   References
   3

2. Phase Behavior of China Reservoir Oil at Different CO₂ Injected Concentrations
   Fengguang Li, Xin Yang, Changyu Sun, and Guangjin Chen
   2.1 Introduction
   2.2 Preparation of Reservoir Fluid
   2.3 PVT Phase Behavior for the CO₂ Injected Crude Oil
   2.4 Viscosity of the CO₂ Injected Crude Oil
   2.5 Interfacial Tension for CO₂ Injected Crude Oil/Strata Water
   2.6 Conclusions
   Literature Cited
   13

3. Viscosity and Density Measurements for Sour Gas Fluids at High Temperatures and Pressures
   B.R. Giri, P. Blais and R.A. Marriott
   3.1 Introduction
   3.2 Experimental
   23

v
4. Acid Gas Viscosity Modeling with the Expanded Fluid Viscosity Correlation

H. Motahhari, M.A. Satyro, H.W. Yarranton

4.1 Introduction

4.2 Expanded Fluid Viscosity Correlation

4.2.1 Mixing Rules

4.2.2 Modification for Non-Hydrocarbons

4.3 Results and Discussion

4.3.1 Pure Components

4.3.2 Acid Gas Mixtures

4.4 Conclusions

4.5 Acknowledgements

References

5. Evaluation and Improvement of Sour Property Packages in Unisim Design

Jianyong Yang, Ensheng Zhao, Laurie Wang, and Sanjoy Saha

5.1 Introduction

5.2 Model Description

5.3 Phase Equilibrium Calculation

5.4 Conclusions

5.5 Future Work

Reference

6. Compressibility Factor of High CO₂-Content Natural Gases: Measurement and Correlation

Xiaoqiang Bian, Zhimin Du, Yong Tang, and Jianfen Du

6.1 Introduction

6.2 Experiment

6.2.1 Measured Principles

6.2.2 Experimental Apparatus and Procedure

6.2.3 Experimental Results
Section 2: Process Engineering

7. Analysis of Acid Gas Injection Variables
   Edward Wichert and James van der Lee
   7.1 Introduction 89
   7.2 Discussion 90
   7.3 Program Design 93
   7.4 Results 94
   7.5 Discussion of Results 96
      7.5.1 General Comments 96
      7.5.2 Overall Heat Transfer Coefficient, U 101
      7.5.3 Viscosity 104
   7.6 Conclusion 105
   References 105

8. Glycol Dehydration as a Mass Transfer Rate Process
   Nathan A. Hatcher, Jaime L. Nava
   and Ralph H. Weiland
   8.1 Phase Equilibrium 108
   8.2 Process Simulation 110
   8.3 Dehydration Column Performance 111
   8.4 Stahl Columns and Stripping Gas 114
   8.5 Interesting Observations from a Mass Transfer Rate Model 115
   8.6 Factors That Affect Dehydration of Sweet Gases 118
   8.7 Dehydration of Acid Gases 119
   8.8 Conclusions 119
   Literature Cited 120
9. Carbon Capture Using Amine-Based Technology 121
   Ben Spooner and David Engel
   9.1 Amine Applications 121
   9.2 Amine Technology 122
   9.3 Reaction Chemistry 124
       9.3.1 Nucleophilic Pathway 124
       9.3.2 Acid-Base Pathway (Primary,
           Secondary and Tertiary Amines) 125
   9.4 Types of Amine 126
   9.5 Challenges of Carbon Capture 128
       9.5.1 Prevention 128
       9.5.2 Reclaimers 129
       9.5.3 Purging and Replacing Amine 129
       9.5.4 High Energy Consumption 129
       9.5.5 Size of the Amine Facility 130
       9.5.6 Captured CO₂ 130
   9.6 Conclusion 131

10. Dehydration-through-Compression (DTC): Is It Adequate? A Tale of Three Gases 133
    Wes H. Wright
    10.1 Background 133
    10.2 Water Saturation 138
    10.3 Is It Adequate? 138
    10.4 The Gases 141
    10.5 Results 147
    10.6 Discussion 151
    References 152

11. Diaphragm Pumps Improve Efficiency of Compressing Acid Gas and CO₂ 155
    Josef Jarosch, Anke-Dorothee Braun
    11.1 Diaphragm Pumps 162
    11.2 Acid Gas Compression 164
    11.3 CO₂ Compression for Sequestration 167
    11.4 Conclusion 171
    Literature 172
Section 3: Reservoir Engineering

12. Acid Gas Injection in the Permian and San Juan Basins: Recent Case Studies from New Mexico 175

*David T. Lescinsky; Alberto A. Gutierrez, RG; James C. Hunter, RG; Julie W. Gutierrez; and Russell E. Bentley*

12.1 Background 175

12.2 AGI Project Planning and Implementation 178

12.2.1 Project Planning and Feasibility Study 178

12.2.2 Reservoir/Cap Rock Identification and Regulatory Permitting 181

12.2.3 Well Drilling and Testing 183

12.2.4 Well Completion and Construction 186

12.2.5 Reservoir and Seal Evaluation 186

12.2.6 Documentation, System Start-up and Reporting 188

12.3 AGI Projects in New Mexico 190

12.3.1 Permian Basin 190

12.3.1.1 Linam AGI #1 193

12.3.1.2 Jal 3 AGI #1 196

12.3.2 San Juan Basin 199

12.3.2.1 Pathfinder AGI #1 200

12.4 AGI and the Potential for Carbon Credits 204

12.5 Conclusions 207

References 208

13. CO$_2$ and Acid Gas Storage in Geological Formations as Gas Hydrate 209

*Farhad Qanbari, Olga Ye Zatsepina, S. Hamed Tabatabaei, Mehran Pooladi-Darvish*

13.1 Introduction 210

13.2 Geological Settings 211

13.2.1 Depleted Gas Reservoirs 211

13.2.1.1 Mixed Hydrate Phase Equilibrium 211

13.2.1.2 Assumptions 213

W. Zhu, Y. Long, Q. Liu, Y. Ju, and X. Huang

14.1 Introduction

14.2 The Mathematical Model of Multiphase Complex Flow

14.2.1 Basic Supposition

14.2.2 The Mathematical Model of Gas-liquid-solid Complex Flow in Porous Media

14.2.2.1 Flow Differential Equations

14.2.2.2 Unstable Differential Equations of Gas-liquid-solid Complex Flow

14.2.2.3 Relationship between Saturation and Pressure of Liquid Phase

14.2.2.4 Auxiliary Equations

14.2.2.5 Definite Conditions

14.3 Mathematical Models of Flow Mechanisms

14.3.1 Mathematical Model of Sulfur Deposition

14.3.2 Thermodynamics Model of Three-phase Equilibrium

14.3.3 State Equations
14.3.4 Solubility Calculation Model 236
14.3.5 Influence Mathematical Model of Sulfur Deposition Migration to Reservoir Characteristics 237
14.4 Solution of the Mathematical Model Equations 238
14.4.1 Definite Output Solutions 238
14.4.2 Productivity Equation 239
14.5 Example 240
14.5.1 Simulation Parameter Selection 240
14.5.2 Oil-gas Flow Characteristics near Borehole Zones of Gas-well 240
14.5.3 Productivity Calculation 240
14.6 Conclusions 242
14.7 Acknowledgement 242
References 242

**Section 4: Enhanced Oil Recovery (EOR)**

15. Enhanced Oil Recovery Project: Dunvegan C Pool 247

*Darryl Burns*

15.1 Introduction 248
15.2 Pool Data Collection 249
15.3 Pool Event Log 252
15.4 Reservoir Fluid Characterization 255
15.4.1 Fluid Characterization Program Design Questions 255
15.4.2 Fluid Characterization Program 257
15.4.3 Solubility of Acid Gas Mixtures in the Dunvegan C Oil 263
15.5 Material Balance 263
15.6 Geological Model 264
15.7 Geological Uncertainty 269
15.7.1 Formation Bulk Volume 269
15.7.2 Porosity 269
15.7.3 Permeability 269
15.7.4 Residual (Immobile) Fluid Saturations 270
15.7.5 Relative Permeability Curve Parameters 270
15.7.6 Fluid Contacts 272
15.8 History Match 272
15.9 Black Oil to Compositional Model Conversion 282
16. CO₂ Flooding as an EOR Method for Low Permeability Reservoirs
   Yongle Hu, Yunpeng Hu, Qin Li, Lei Huang,
   Mingqiang Hao, and Siyu Yang
   16.1 Introduction 319
   16.2 Field Experiment of CO₂ Flooding in China 320
   16.3 Mechanism of CO₂ Flooding Displacement 321
   16.4 Perspective 324
   16.5 Conclusion 326
   References 326

17. Pilot Test Research on CO₂ Drive in Very Low Permeability Oil Field of in Daqing Changyuan
   Weiyao Zhu, Jiecheng Cheng, Xiaohe Huang,
   Yunqian Long, and Y. Lou
   17.1 Introduction 329
   17.2 Laboratory Test Study on CO₂ Flooding in Oil Reservoirs with Very Low Permeability
       17.2.1 Research on Phase Behavior and Swelling Experiments 330
       17.2.2 Tubule Flow Experiments 331
       17.2.3 Long Core Test Experiments 332
   17.3 Field Testing Research 333
       17.3.1 Geological Characteristics of Pilot
           17.3.1.1 Structural Characteristics 334
           17.3.1.2 Characteristics of Reservoir 334
Contents

17.3.1.3 Reservoir Properties and Lithology Characteristics 336
17.3.2 Distribution and Features of Fluid 339
17.3.3 Designed Testing Scheme 339
17.3.4 Field Test Results and Analysis 340
  17.3.4.1 Low Gas Injection Pressure and Large Gas Inspiration Capacity 340
  17.3.4.2 Production Rate and Reservoir Pressure Increase after Gas Injection 341
  17.3.4.3 Reservoir Heterogeneity Is the Key to Control Gas Breakthrough 342
  17.3.4.4 CO₂ Throughput as the Supplementary Means of Fuyu Reservoir’s Effective Deployment 343
  17.3.4.5 Numerical Result Shows that Carrying Out Water Flooding after Injecting Certain Amount of CO₂ Slug is Better 344

17.4 Conclusion 346
17.5 Acknowledgement 349
References 349

18. Operation Control of CO₂-Driving in Field Site. Site Test in Wellblock Shu 101, Yushulin Oil Field, Daqing 351
   Xinde Wan, Tao Sun, Yingzhi Zhang, Tiejun Yang, and Changhe Mu
18.1 Test Area Description 352
  18.1.1 Characteristics of the Reservoir Bed in the Test Area 352
  18.1.2 Test Scheme Design 352
18.2 Test Effect and Cognition 353
  18.2.1 Test Results 353
  18.2.2 The Stratum Pressure Status 354
  18.2.3 Air Suction Capability of the Oil Layer 356
  18.2.4 The Different Flow Pressure Control 356
  18.2.5 Oil Well with Poor Response 358
18.3 Conclusions 359
References 359
19. Application of Heteropolysaccharide in Acid Gas Injection
   Jie Zhang, Gang Guo and Shugang Li

19.1 Introduction 361
19.2 Application of Heteropolysaccharide in CO₂
   Reinvjection Miscible Phase Recovery 363
   19.2.1 Test of Clay Polar Expansion Rate 364
   19.2.1.1 Test Method 364
   19.2.1.2 Testing results as the Figure 2
          and Table 1 shows 366
   19.2.2 Test of Water Absorption of Mud Ball
   in Heteropolysaccharide Collosol 367
19.3 Application of Heteropolysaccharide in H₂S
   Reinvjection formation 370
   19.3.1 Experiment Process, Method
          and Instruction 370
   19.3.1.1 Experiment Process 370
   19.3.1.2 Experiment Method 370
   19.3.1.2 Experiment Results 372

19.4 Conclusions 373
References 373

Section 5: Geology and Geochemistry

20. Impact of SO₂ and NO on Carbonated Rocks
    Submitted to a Geological Storage of CO₂:
    An Experimental Study 377

    Stéphane Renard, Jérôme Sterpenich,
    Jacques Pironon, Aurélien Randi, Pierre Chiquet
    and Marc Lescanne

20.1 Introduction 377
20.2 Apparatus and Methods 379
   20.2.1 Solids and Aqueous Solution 379
   20.2.2 Gases 380
20.3 Results and Discussion 381
   20.3.1 Reactivity of the Blank Experiments 381
   20.3.2 Reactivity with pure SO₂ 384
   20.3.3 Reactivity with pure NO 387
20.4 Conclusion 391
Acknowledgments 392
References 392
21. Geochemical Modeling of Huff ‘N’ Puff Oil Recovery With CO₂ at the Northwest McGregor Oil Field
   Yevhen I. Holubnyak, Blaise A. F. Mibeck, Jordan M. Bremer, Steven A. Smith, James A. Sorensen, Charles D. Gorecki, Edward N. Steadman, and John A. Harju
   21.1 Introduction 393
   21.2 Northwest McGregor Location and Geological Setting 395
   21.3 The Northwest McGregor Field, E. Goetz #1 Well Operational History 395
   21.4 Reservoir Mineralogy 397
   21.5 Preinjection and Postinjection Reservoir Fluid Analysis 398
   21.6 Major Observations and the Analysis of the Reservoir Fluid Sampling 400
   21.7 Laboratory Experimentations 401
   21.8 2-D Reservoir Geochemical Modeling with GEM 402
   21.9 Summary and Conclusions 403
   21.10 Acknowledgments 404
   21.11 Disclaimer 404
   References 405

22. Comparison of CO₂ and Acid Gas Interactions with reservoir fluid and Rocks at Williston Basin Conditions
   Yevhen I. Holubnyak, Steven B. Hawthorne, Blaise A. Mibeck, David J. Miller, Jordan M. Bremer, Steven A. Smith, James A. Sorensen, Edward N. Steadman, and John A. Harju
   22.1 Introduction 407
   22.2 Rock Unit Selection 409
   22.3 CO₂ Chamber Experiments 411
   22.4 Mineralogical Analysis 412
   22.5 Numerical Modeling 413
   22.6 Results 413
   22.7 Carbonate Minerals Dissolution 414
   22.8 Mobilization of Fe 416
Section 6: Well Technology

23. Well Cement Aging in Various $\text{H}_2\text{S}-\text{CO}_2$ Fluids at High Pressure and High Temperature: Experiments and Modelling

Nicolas Jacquemet, Jacques Pironon, Vincent Lagneau,
Jérémie Saint-Marc

23.1 Introduction
23.2 Experimental equipment
23.3 Materials, Experimental Conditions and Analysis
  23.3.1 Cement
  23.3.2 Casing
  23.3.3 Environment
  23.3.4 Exposures (Figure 3):
  23.3.5 Analyses
23.4 Results and Discussion
  23.4.1 Cement
  23.4.2 Steel
23.5 Reactive Transport Modelling
23.6 Conclusion
Acknowledgments
References

24. Casing Selection and Correlation Technology for Ultra-Deep, Ultra-High Pressure, High $\text{H}_2\text{S}$ Gas Wells

Yongxing Sun, Yuanhua Lin, Taihe Shi,
Zhongsheng Wang, Dajiang Zhu, Liping Chen,
Sajun Liu, and Dezhi Zeng

24.1 Introduction
24.2 Material Selection Recommended Practice
24.3 Casing Selection and Correlation Technology

References
25. Coupled Mathematical Model of Gas Migration in Cemented Annulus with Mud Column in Acid Gas Well

Hongjun Zhu, Yuanhua Lin, Yongxing Sun, Dezhi Zeng, Zhi Zhang, and Taihe Shi

25.1 Introduction 449
25.2 Coupled Mathematical Model 450
   25.2.1 Gas Migration in Cement 451
   25.2.2 Gas Migration in Stagnant Mud 452
   25.2.3 Gas Unloading and Accumulation at Wellhead 454
   25.2.4 Coupled Gas Flows in Cement and Mud 456

25.3 Illustration 458
25.4 Conclusions 459
25.5 Nomenclature 460
25.6 Acknowledgment 461
References 461

Section 7: Corrosion

26. Study on Corrosion Resistance of L245/825 Lined Steel Pipe Welding Gap in H₂S+CO₂ Environment

Dezhi Zeng, Yuanhua Lin, Liming Huang, Daijiang Zhu, Tan Gu, Taihe Shi, and Yongxing Sun

26.1 Introduction 466
26.2 Welding Process of Lined Steel Pipe 466
26.3 Corrosion Test Method of Straight and Ring Welding Gaps of L245/825 Lined Steel Pipe 467
26.4 Corrosion Test Results of Straight and Ring Welding Gaps of L245/825 Lined Steel Pipe 472
CONTENTS

26.4.1 Atmospheric Corrosion Test Results 472
26.4.2 Corrosion Test Results at High Pressure 472
26.4.3 Field Corrosion Test Results 474
26.5 Conclusions 477
26.6 Acknowledgments 477
References 477

Index 479