A Working Party Report on

CO₂ Corrosion Control in Oil and Gas Production

Design Considerations

Edited by

M. B. KERMANI & L. M. SMITH

Published for the European Federation of Corrosion by The Institute of Materials

THE INSTITUTE OF MATERIALS
1997
# Contents

*Series Introduction* ................................................................. vii

*Preface* .................................................................................. ix

*Acknowledgements* ................................................................. x

1  *Introduction* ........................................................................ 1

2  *Scope* .................................................................................. 3

3  *The Mechanism of CO₂ Corrosion* ...................................... 4

4  *Types of CO₂ Corrosion Damage* ....................................... 6

4.1  Localised Corrosion of Carbon Steel ................................. 6

4.2  Localised Corrosion of Carbon Steel Welds ..................... 7

5  *Key Parameters Affecting Corrosion* ................................. 9

5.1  Water Wetting ................................................................. 9

5.1.1  Water Characteristics .................................................. 10

5.1.2  Hydrocarbon Characteristics ....................................... 10

5.1.3  Top-of-the-Line Wetting ............................................. 11

5.2  Partial Pressure and Fugacity of CO₂ ............................... 12

5.3  Temperature .................................................................... 12

5.4  pH .................................................................................. 14

5.5  Carbonate Scale ............................................................. 15

5.6  The Effect Of H₂S .......................................................... 15

5.7  Wax Effect ...................................................................... 16

6  *Prediction of the Severity of CO₂ Corrosion* ................. 18

6.1  CO₂ Corrosion Prediction Models For Carbon Steel .......... 19

7  *CO₂ Corrosion Control* ...................................................... 24

7.1  Micro-alloying of Carbon and Low Alloy Steels ............... 24

7.1.1  Effect of Chromium .................................................... 24

7.1.2  Effect of Carbon ........................................................ 25

7.1.3  Effect of Other Alloying Elements .............................. 25

7.2  Effect of Glycol and Methanol ........................................ 26
Contents

7.3. pH Control ................................................................. 27
  7.3.1. The Role of pH .................................................. 27
  7.3.2. Wet Gas Transportation Lines ................................. 27
  7.3.3. Different Chemicals and Their Mechanisms ................... 27
  7.3.4. pH Monitoring .................................................. 28
7.4. Corrosion Inhibition .................................................. 28
  7.4.1. Inhibitor Mechanism .......................................... 29
  7.4.2. Inhibitor Efficiency and Inhibitor Performance .......... 30
  7.4.3. Inhibitor Partitioning and Persistency ...................... 31
  7.4.4. Commercial Inhibitor Packages ............................... 34
  7.4.5. Inhibitor Compatibility ...................................... 34
  7.4.6. Inhibitor Deployment ........................................ 35
  7.4.7. Inhibitor Distribution in Multiphase Pipelines .......... 36
  7.4.8. Effect of Flow on Inhibition .................................. 36

8 Corrosion Allowance Determination ................................. 37
8.1. Design Corrosion Allowance ....................................... 38
  8.1.1. Design Corrosion Rate ....................................... 38
  8.1.2. Design Corrosion Allowance Assessment ..................... 38

9 Design Considerations .................................................. 41
9.1 Well Completions ..................................................... 41
  9.1.1. Corrosion Design ............................................. 42
  9.1.2. Corrosion Monitoring ........................................ 43
9.2. Production Facilities ............................................... 44
  9.2.1. Corrosion Design ............................................. 44
  9.2.2. Multiphase Fluid Behaviour .................................. 46
  9.2.3. Corrosion Monitoring ........................................ 47
9.3 Gas Reinjection ....................................................... 49
  9.3.1. General Requirements for Gas Reinjection ................. 49
  9.3.2. Onshore Delivery Lines ...................................... 49
  9.3.3. Offshore Delivery Lines ..................................... 50
  9.3.4. Injection Wells And Gas Lift Annuli ....................... 50

References ................................................................. 51
Preface

Corrosion is a natural potential hazard associated with oil and gas production and transportation facilities. This results from the fact that an aqueous phase is normally associated with the oil and/or gas. The inherent corrosivity of this aqueous phase is then dependent on the concentration of dissolved acidic gases and the water chemistry. The presence of \( \text{H}_2\text{S}, \text{CO}_2, \) brine and/or condensed water with the hydrocarbon not only give rise to corrosion, but also can lead to environmental fracture assisted by enhanced uptake of hydrogen atoms into the steel. \( \text{CO}_2 \) is usually present in produced fluids and, although it does not cause the catastrophic failure mode of cracking associated with \( \text{H}_2\text{S} \), its presence can nevertheless result in very high corrosion rates particularly where the mode of attack on carbon and low alloy steels is localised. In fact \( \text{CO}_2 \) corrosion, or ‘sweet corrosion’, is by far the most prevalent form of attack encountered in oil and gas production and is a major source of concern in the application of carbon and low alloy steels. Hence, the need to have a document which systematically addresses the steps, considerations and parameters necessary to design oil and gas facilities with respect to \( \text{CO}_2 \) corrosion.

This document sets the scene on design considerations specifically related to \( \text{CO}_2 \) corrosion. It has been developed from feedback of operating experience, research results and operators’ in-house studies. Particular attention has been given to the chemistry of the produced fluid, the fluid dynamics and physical variables which affect the performance of steels exposed to \( \text{CO}_2 \)-containing environments. The focus is on the use of carbon and low alloy steels as these are the principal construction materials used for the majority of facilities in oil and gas production offering economy, availability and strength.

This document is a practical, industry oriented guide on the subject for use by design engineers, operators and manufacturers. It incorporates much of the recent developments in the understanding of the ways in which detailed environmental and physical conditions affect the risk of \( \text{CO}_2 \) corrosion. It also describes means of corrosion control. It is comprehensive in addressing \( \text{CO}_2 \) corrosion of all major items of oilfield equipment and facilities incorporating, production, processing and transportation. As such, it provides a key reference for materials and corrosion engineers, product suppliers and manufacturers working in the oil and gas industry.

* ‘Sour corrosion’, resulting from the presence of \( \text{H}_2\text{S} \), is the subject of EFC Publications Numbers 16 and 17.
Acknowledgements

The CO$_2$ Corrosion Work Group of the EFC Working Party on Corrosion in Oil and Gas Production held its first meeting in September 1993. Since then, several meetings have been held to address industry-wide issues related to engineering design for CO$_2$ corrosion. The organisation of the Work Group was undertaken by representatives from worldwide oil and gas producers, manufacturers, service companies and research institutions.

In achieving the primary objective, parameters affecting CO$_2$ corrosion, its mechanism and methods of control have been discussed during the Work Group meetings. These aspects form the core of the present document, Sections of which have been prepared by the Work Group members.

The chairmen of the Working Party and Work Group would like to thank all who have contributed their time and effort to ensure the successful completion of this document. In particular we wish to acknowledge a significant input from these individuals and their respective companies:

J Pattinson, A McMahon and D Harrop, BP, UK
J-L Crolet, Elf, France
A Dugstadt, IFE, Norway
G Schmitt, MFI, Germany
Y Gunaltun, Total, France
E Wade, previously with Marathon, UK
O Strandmyr, Statoil, Norway
W Lang, Bechtel, UK
J Palmer, CAPCIS, UK
M Swidzinski, Phillips, UK
M Celant, MaC, Italy
P O Gartland, CorrOcean, Norway
R S Treseder, CorrUPdate, USA
J Kolt, Conoco, USA
N Farmilo, AEA Technology, UK

In addition, valuable comments from R Connell and B Pots (Shell, The Netherlands) and T Gooch (TWI, UK) are appreciated.

Finally, one of the editors (MBK) wishes to thank BP for their support and permission to publish some of the information in this document.

Bijan Kermani
Chairman of CO$_2$ Corrosion Group Workshop

Liane Smith
Chairman of EFC Working Party on Corrosion in Oil and Gas Production