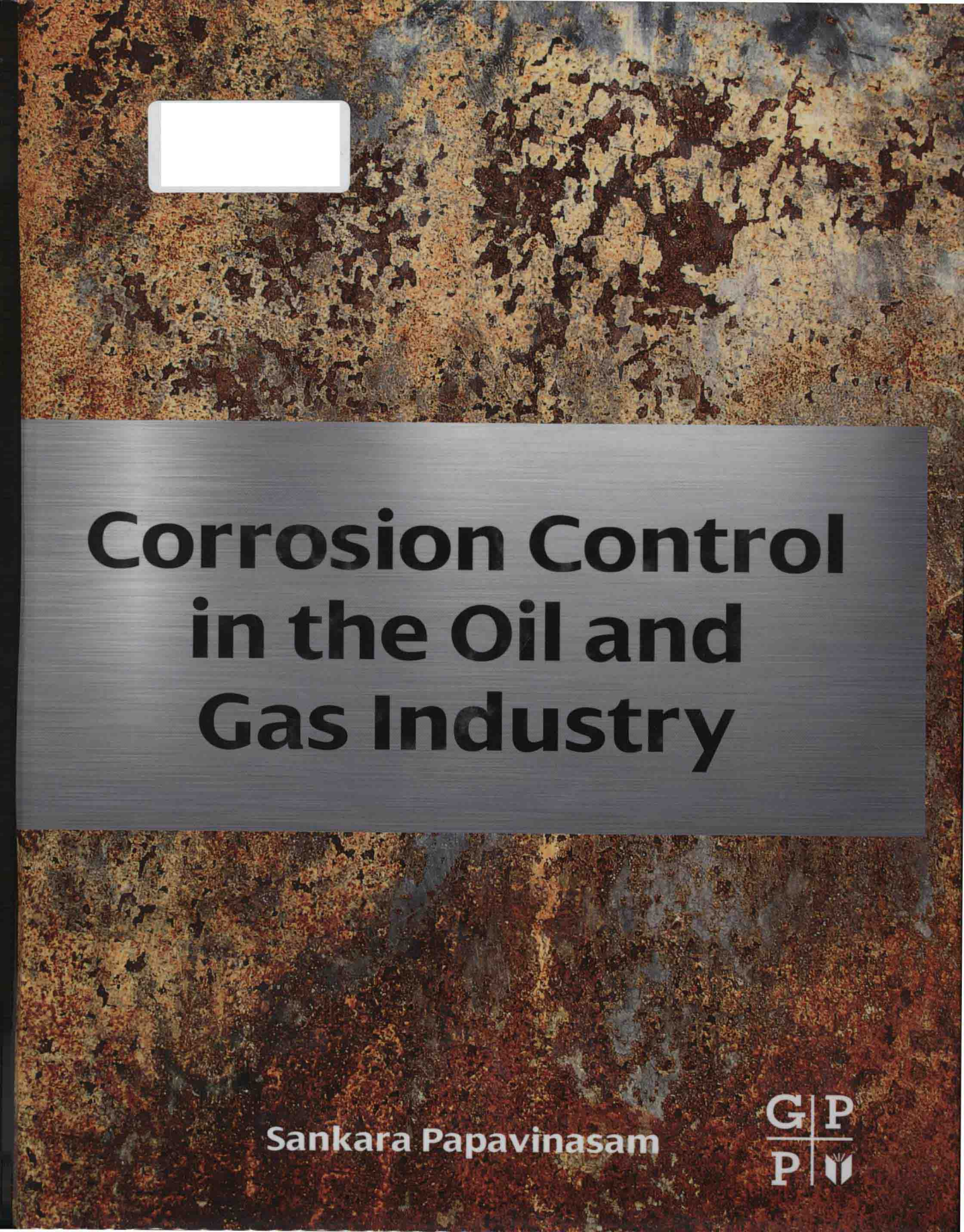
Corrosion Control in the Oil and Gas Industry
Sankara Papavinasam
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Foreword

This book will help oil and gas practitioners responsible for corrosion management make technically sound, effective, and efficient decisions. Its greatest strength is that it strikes a middle-ground between corrosion science textbooks and technical practice documents.

The demographics in our profession are such that the bulk of our most experienced oil and gas corrosion practitioners will retire in the next ten years. This is creating demand for new entrants, many of which will be drawn either from universities or the oil and gas generalist community.

The university-educated corrosion scientist will benefit from the background chapters on the oil and gas industry, giving the necessary context to convert their scientific knowledge into engineering practice. The chapter on corrosion management, including risk, will be especially valuable because this topic is core to optimally managing corrosion threats but is normally absent from university corrosion science curricula.

The oil and gas generalist who is trained in operations and engineering decision-making can use this book to learn about corrosion from a facility operation context. Available corrosion science textbooks are like a foreign language to those outside of our profession. After reading this book, this new corrosion practitioner can keep it as a reference to help identify unfamiliar corrosion threats and determine when they require the help of a corrosion specialist.

Finally, the book is informative even for those of us who have spent many years inside the oil and gas corrosion professional practice community, and I plan to have one on my bookshelf as a reference. For sure, its presence will remind me of our genuine wish that our present and future colleagues will find success in our corrosion profession.

Oliver Moghissi, Past NACE President (2011–2012)

Preface

The annual cost of corrosion in the USA oil and gas industry is over $27 billion; leading some to estimate the global annual corrosion cost of the oil and gas industry as exceeding $60 billion. For companies with oil or gas infrastructure, the need to reduce corrosion-related costs is pressing. Further, public awareness and regulatory scrutiny of the environmental impact of releases of oil and gas have enormously increased in recent years.

The oil and gas industry is striving to reach 'zero failure'. The key elements to reach 'zero failure' due to corrosion include:

- Precise assessment of corrosion risks,
- Implementation of cost-effective methods to control corrosion,
- Accurate monitoring of corrosion rates at various stages of the infrastructure,
- Maintenance of corrosion control strategies for the entire duration of the infrastructure,
- Incorporation of industry best practices and standards in corrosion management, and
- Treatment of oil and gas infrastructures as one system in order to avoid the impacts of one segment's corrosion management program on another segment.

The overall objective of this book is to present the unique 5-M methodology to help the industry to reach this 'zero failure' goal. The book discusses the characteristics of each of the methodology's five pillars: Modeling, Mitigation, Monitoring, Maintenance, and Management. It describes implementation of the 5-M methodology in various sectors of the oil and gas industry including production, transmission, storage, refining, and distribution.

This book also provides the reader a gateway to industry's best practices, 1,000+ international standards, and fundamental scientific and engineering principles. It is based on the author's two decades of experience in the field and on reviewing 10,000+ references and case histories.

Chapter 1 provides a bird's eye view of the oil and gas industry. It discusses the importance of energy from hydrocarbons, describes their different types, indicates their sources, and provides a brief history of the industry. This chapter then explains how the industry is regulated by various government agencies in North America, and finally presents the impact of corrosion on the industry.

To use hydrocarbons as energy source, they must be extracted from underground, all other non-energy containing products separated from them, and the different types of hydrocarbons separated from one another. These processes occur in different segments of the oil and gas industry network operating between the underground wells where the hydrocarbons are found and the locations where they are used as fuels, for example, in an automobile. Chapter 2 presents various operating conditions in different segments, the different types of materials used in those segments, and the different types of corrosion that may take place.

The oil and gas industry uses various materials, both metals and non-metals. More than 90% of the materials used are metals, but non-metals serve critical functions in the industry. Chapter 3 discusses the basic properties of metals and non-metals, classification of materials, and types of materials used in the oil and gas industry.

The rate at which the corrosion takes place depends on several environmental factors including flow, pressure, temperature, composition of oil phase, composition of water phase, composition of gas

phase, solids, microbes, pH, organic acids, and mercury. Chapter 4 discusses the influence of environmental factors.

Different types of corrosion occur in various segments of oil and gas industry depending on the interaction between the material and the environment. The predominant types include general corrosion, localized pitting corrosion, hydrogen induced cracking, erosion-corrosion, microbiologically influenced corrosion, erosion-corrosion, sulfide stress cracking, stress corrosion cracking (intergranular or transgranular), chloride stress corrosion cracking, corrosion fatigue, high temperature corrosion, hydrogen flaking, corrosion under insulation, metal dusting, carburization, and graphitization. Chapter 5 describes these types of corrosion and their mechanisms, as well as general methods of controlling them.

Based on several years of field experience and laboratory experiments, several models have been developed to predict the risk of corrosion occurring inside the infrastructure. Chapter 6 presents models to predict hydrogen effects, general corrosion, pitting corrosion, erosion-corrosion, microbiologically influenced corrosion (MIC), high temperature corrosion, and top-of-the line corrosion (TLC).

A decision should be taken at the design stage either to use corrosion-resistant alloys (CRA) or carbon steel. In either option, implementation of appropriate mitigation activities is required. Chapter 7 discusses some time-tested and proven strategies to mitigate internal corrosion including pigging, corrosion inhibitors, biocides, internal lining and coating, cladding, cathodic protection (CP), and process optimization.

Successful selection of materials and successful implementation of mitigation strategies ensure that the infrastructure is safe for continued operation. It is also important that under the actual field operating conditions, corrosion proceeds according to the anticipated low rate. Various techniques are used to monitor corrosion at different stages. Chapter 8 discusses techniques to monitor internal corrosion as well as to inspect wall loss resulting from internal corrosion.

The external surface of oil and gas infrastructure is exposed either to the atmosphere (above-ground structures) or to underground conditions (buried in soil or submerged in water). Electrically insulating coatings are applied to control the external corrosion of structures exposed to the atmosphere, and for underground structures, electrically insulated coatings and cathodic protection (CP) are used. Chapter 9 provides an overview of coatings and CP, as used to mitigate external corrosion in oil and gas infrastructures.

Corrosion may take place when the coating deteriorates and when the CP does not adequately protect the areas where this occurs. Chapter 10 discusses models to predict the effectiveness of corrosion control strategies and the rate of corrosion when the corrosion control strategies fail.

Strategies to control external corrosion are integral to the infrastructure, i.e., the coating is applied as the material (e.g., steel) is produced and the CP is applied immediately after the installation of the infrastructure. For this reason, monitoring techniques focus on estimating the effectiveness of the external corrosion control strategies as well as on estimating the external corrosion rate of the infrastructure. Chapter 11 discusses various monitoring techniques, including holiday detection, above-ground monitoring, remote monitoring, inline inspection, hydrostatic test, and below-ground inspection.

Chapter 4 discusses the environmental factors which influence corrosion. These factors are normally measured for reasons other than corrosion control. Chapter 12 discusses general types of measurements, factors measured, importance of quality control during the measurement, and precautions when using these factors in developing corrosion control strategies.

All strategies (selection of appropriate materials that can withstand corrosion in a given environment, development of appropriate model to predict the behavior of the system, implementation of

mitigation strategies to control corrosion, and monitoring of system to ensure that the corrosion of the system is under control) would be inadequate if a good maintenance strategy was not developed and implemented. A comprehensive and effective program requires maintenance of five interdependent entities (equipment, workforce, data, communication, and associated activities). Chapter 13 describes the general characteristics of these entities.

Corporate management implements a top-down approach (risk-avoidance, goal-based, finance-oriented) to minimize the risks of corrosion. On the other hand, corrosion professional estimates risk by a bottom-up approach (field experience, fact-based, technically-oriented). Corrosion management provides a vital, seamless link between the two approaches. In a way, corrosion management is a combination of art and science to balance financial and technical requirements. Chapter 14 describes critical aspects of corrosion management. This chapter also describes methodologies to integrate the information presented in Chapter 1 through 13 for developing an effective corrosion management program.

Corrosion professionals with a 'bottom-up' orientation may start reading the book from Chapter 1, whereas readers with 'top-down' orientation may start reading the book from Chapter 14. Either starting point will help the development and implementation of a risk-minimized, technically sound, and cost-effective corrosion management program.

Both imperial and metric units are alternatively used in the oil and gas industry. For this reason, both imperial and metric units are used to the extent possible without losing the flow of the book. In equations only unit used in the original reference is presented. Factors to convert values from one unit to another are listed in Appendix.

I would like to thank the companies and individuals for granting permission to use copyright materials. Every effort has been made to obtain copyright permission from the sources and they are acknowledged. I would be happy to hear and correct any errors or omission in providing proper acknowledgment.

Lastly, I would like to quote:

What we learned is smaller than handful
*What we need to learn is larger than the universe**

Avvaiyyar (A respected poet from first century)

I would be happy to hear suggestions and ideas to further the knowledge.

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Acknowledgements

Seeds for the 5-M methodology and for this book were planted one afternoon in 2005 when a group of corrosion professionals brain-stormed key elements for developing effective corrosion strategies. Each one of us emphasized the importance of one key element:

- Mechanism/model (Tom Jack)
- Mitigation (Joseph Boivin)
- Monitoring (Yours truly)
- Maintenance (Bich Nguyen)
- Management (Tanis Lindberg)

We all soon realized that each of the element is equally important in developing effective control strategies. Experience of organizing presentations, tutorials, workshops, and courses under the 5-M methodology title has been fruitful. Many industry leaders pointed out that they have come across proposals and reports organized under the 5-M methodology.

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I have written this book based on two virtues that my father lives by and my mother helps me to follow: 'nothing other than being honest brings satisfaction' and 'do not come to any conclusion until you hear the other side of the story'. I dedicate this book to my parents.

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