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INTRODUCTION

1.1 THE PHENOMENON OF CORROSION

The term rusting has been in vogue long before the human kind initiated any systematic study on corrosion of metals. This term, however, refers to uniform corrosion of steels. If the metal is carbon steel and if the environment is simple humid air, the former corrodes giving “rust” as the final corrosion product, which is seen as a brownish crust/porous scale over the steel surface. The result of such a corrosion phenomenon is the general uniform loss of thickness of the metal and this type of corrosion is generally called “Uniform Corrosion” and is the most common form of corrosion accounting for a major percentage of overall metal losses. Unfortunately, the phenomenon of corrosion is spontaneous in nature supported by thermodynamics. That is to say corrosion lowers the energy of metals, ironically supplied by the mankind to produce metal from their respective ores, to transform to their natural lower energy states such as oxides, sulfides, chlorides, etc.

The environments that give rise to corrosion of metals vary from mildest humid air atmosphere which we all breath-in daily to the most aggressive highly acidic solutions and high temperature gases in which processes such as chlorination, sulfidation, etc. take place. While the mild atmospheres occur mostly under the domestic conditions, including marine atmospheres affecting coastal structures, the severe atmospheres occur among industrial

processes like pickling of metals, chemical processes, power generation, oil and gas production, electronic component processing, transportation industries, etc. Among the industrial processes, the size of the metallic components involved varies from microscopic as in electronics industries to very macroscopic, such as storage and pressure vessels, cross-country piping, heat exchangers, etc.

“Corrosion Failure” is the ultimate result of corrosion. The component, structure, or equipment loses its functionality as a result of corrosion leading to grave consequences. Ultimate failure due to corrosion occurs because, among several reasons, the phenomenon of corrosion has been occurring unabated over a long period without a warning signal. Corrosion phenomenon is in general, not always, a time bound phenomenon. Failures of structures and components due to corrosion in mild atmospheres such as humid air and marine atmospheres would be of minor consequences such as premature replacement cost, temporary public discomfort, etc. On the other hand, unexpected corrosion failures of equipments in chemical process equipments, which the present book addresses, would result in major consequences such as possible leakage of corrosive fluids/vapors, very expensive replacement of equipments, heavy production losses, and at times human fatalities also.

1.2 IMPORTANCE OF CORROSION

Before giving the basics and the case studies, an attempt is made in the following section of this chapter to briefly present the existing information available on the overall costs of corrosion affecting an industrialized nation, both direct and indirect, particularly with respect to chemical process industries

1.2.1 Cost of Corrosion: Direct and Indirect

Metallic corrosion is a major loss-producing phenomenon in many sectors of a nation's economy. This is because corrosion results in loss of metals and materials, energy, labor, etc., which would have been contributively productive otherwise for some other useful purpose. Revie and Uhlig (2008) divide the losses due to corrosion into two categories:

- Direct loss and
- Indirect loss.

Direct losses include:

- Cost of replacing corroded/failed structures/equipments/components,
- Painting and re-painting of corrosion-prone structures to prevent general atmospheric corrosion,

- Costs involved in all other protective measures, such as cathodic protection, inhibitor addition, protective coating/wrapping/cladding, galvanizing, electroplating, etc.,
- Extra cost involved in choosing corrosion-resistant alloys (CRAs) such as stainless steels, nickel base alloys, titanium, etc. in the place of carbon steels which would have been otherwise suitable from mechanical/structural points of view, and
- Cost of dehumidifying storage rooms for storing metallic components/equipments and spare parts, etc. before they are put into use.

Indirect losses are like consequential losses that add heavily, many times very heavily, to the direct losses outlined above. These indirect losses include:

- Loss-of-Production (Downtime) Cost: This factor alone, many times, is orders of magnitude higher than the direct replacement cost,
- Product loss through leaks/failures due to corrosion: This also would be very heavy if the equipment is concerned is a pressure vessel and high pressure pipeline carrying huge quantities of finished products under pressure like utility gas separated from oil, purified potable water through water mains, high pressure steam, etc.,
- Loss of efficiency in heat transfer equipments and pipelines: Accumulation of corrosion product scales on pipelines and on heat transfer surfaces reduces the pumping and heat transfer efficiency, respectively, thereby necessitating increased power to the pumps and heat exchangers,
- Contamination and hence rejection of product: Heavy metal impurities as a result of corrosion of the container equipments and transfer pipelines would result in total rejection of several batches (huge quantities) of the carefully produced (value added) chemical product,
- Over-design: Giving “corrosion allowance,” thereby using vessels with thickness much greater than that demanded by mechanical requirements amounts to over-design and adds up to huge indirect cost involved in providing excess metal for corrosion to take place.

The above direct and indirect losses are somewhat quantifiable. But loss of life due to leakage, corrosion fracture, explosion and similar unpredictable corrosion-related failures and accidents cannot be easily quantified but would result in huge compensation losses.

As far as corrosion costs in terms of money values are concerned, the most often quoted estimate is that of the 1998 US Study jointly carried out by US Department of Transportation, and the NACE, the results of which were first published in 2002 (Koch et al. 2002). As per this study report, corrosion

TABLE 1.1 Summary of Industry Sector Direct Corrosion Costs Analyzed in 1998 US Study (with Permission from Federal Highway Administration, USA)

Category	Estimated Direct Cost of Corrosion Per Category	
	\$x Billion	%
Infrastructure (highway bridges, gas & liquid transmission pipelines, waterways and ports, hazardous materials storage, airports, railroads)	\$22.6	16.4
Utilities (gas distribution, drinking water and sewer systems, electrical utilities, telecommunications)	\$47.9	34.7
Transportation (motor vehicles, ships, aircraft, railroad cars, hazardous materials transport)	\$29.7	21.5
Production and manufacturing (oil and gas exploration and production, mining, petroleum refining, chemical, petrochemical and pharmaceutical, pulp and paper, agricultural, food processing, electronics, home appliances)	\$17.6	12.8
Government (defense, nuclear waste storage)	\$20.1	14.6
Total	\$137.9	100

losses suffered by Industry and by Government (Total Economy) amount to many billions of dollars annually, approximately US \$276 billion in USA alone, about 3.1% of Gross Domestic Product. Out of these, loss in Industries alone amounted to \$138 billion annually, as shown in the following break-ups extracted from the above study, Table 1.1.

The figures corresponding to Production and Manufacturing from Table 1.1 amounting to \$17.6 billion are shown in the break-up pie-chart form in Figure 1.1 of this chapter, again extracted from the reference Koch et al. (2002).

The costs shown in the above illustrations are direct costs only. The figures do not include indirect costs of production outages resulting from unexpected failures, quite common in chemical process industries. Also the figures do not include those of operation and maintenance related to corrosion only. This is an annual recurring expenditure.

One can notice that for Production and Manufacturing alone, mostly varieties of chemical processing, with which the present book is concerned, the sub total cost is \$17.6 billion, 12.8% of total Industry Cost of \$137.9 billion. This is an enormous figure by any standard and every attempt should be continuously made to reduce/prevent this great loss due to corrosion.

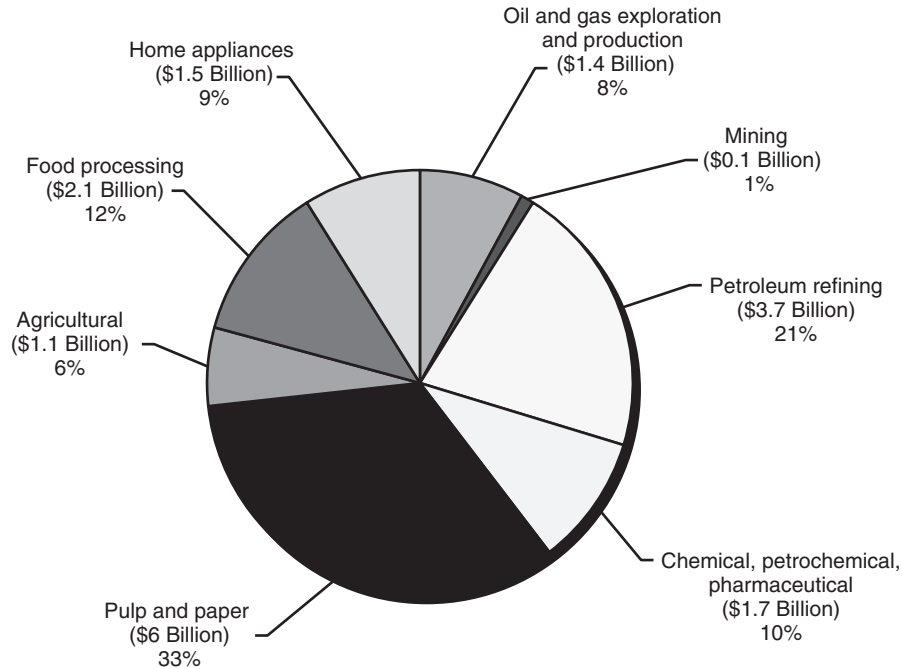


Figure 1.1 Annual cost of corrosion in the production and manufacturing category in US (\$17.6 Billion). Koch et al. (2002) (courtesy Federal Highway Administration, USA.)

Among the overall corrosion prevention management strategies suggested include the following Koch et al. (2002):

- Dissemination of corrosion awareness information generated in various industry sectors.
- Increase awareness of significant corrosion costs and potential cost savings.
- Improve education and training of personnel in recognition of corrosion damage and its control.
- Implement advance design practices for better corrosion management.
- Improve corrosion technology through research, development, and implementation.

The present book, giving real-life case histories of major corrosion failures, is aimed at contributing to the above corrosion prevention strategies to varying extent. The case studies originate from various industry sectors and the knowledge gained in analysis is disseminated through the book to the overall corrosion-conscious industry/research personnel and graduate students in

general. The book is presented in a simple practical way, without going in depth to advanced scientific and theoretical aspects, so that there is increase in corrosion awareness among the plant personnel and there is improvement in training in corrosion control. Further, the case studies contain remedial measures relating to design improvements, to improved corrosion prevention technologies such as use of CRAs, and to use of improved inspection techniques.

The book would have fulfilled its purpose if it helps to avoid corrosion failures, similar to those presented in the case studies, which are quite likely to happen in the chemical process industries throughout the world.

1.3 THE PURPOSE AND FORMAT OF THE BOOK

The present book addresses itself to the latter failures mentioned above, namely those occurring in chemical process industries. Each unexpected failure deserves a detailed failure analysis study. Due to the social pressure of maintaining production levels of various essential products such as electric power, drinking water, chemicals for human needs, etc., immediate replacement of the failed component/equipment is of utmost priority. But, just the replacement alone would not give assurance/confidence against reoccurrence of similar failures in future in the replaced fresh equipment. Towards this assurance, a detailed scientific analysis/study of the occurred failure with the purpose of arriving at the root cause of the failure (corrosion or otherwise, type of corrosion, what caused it, etc.) should be carried out within a short period from the failure incident date.

The authors of the present book have carried out several such analyses in the past two or three decades and are presenting them in this book in an organized systematic manner in the form of case studies. Dissemination of information/experience gained in each of the failure analysis study thus conducted is the primary purpose of the book.

There are several books and handbooks that either deal with “Corrosion” or “Failure Analysis.” But there seems to be no book devoted exclusively to deal with Case Histories related to Corrosion Failures in Chemical Process Industries. Hence, we felt a need for book devoted to this subject. However, understanding any technical phenomenon occurring in any industry requires some familiarity with the scientific basis of the phenomenon. This is true for corrosion failures also. With this latter requirement in mind, the book devotes a few chapters to Basics of Corrosion and Corrosion Monitoring, Forms of Corrosion, Materials of Construction, and Failure Analysis Procedures in a non-elaborative way before describing the case histories in detail. These initial chapters provide the necessary basics to understand the case-studies presented in the last Chapter. So, the Case Studies and the related basics are given in the same book. Such a combination is not available presently.

REFERENCES

- Koch, H. G., Brongers, M. P. H., Thompson, N. G., Virmani, Y. P. and Payer, J. H., (2002), Corrosion Costs and Preventive Strategies in the United States. Publication No. FHWA-RD-01-156, Federal Highway Administration, USA.
- Revie, W. R. and Uhlig, H. H., (2008), *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, 4th Edition, Wiley Interscience, Chapter 1, pp. 02–04.

