Handbook of Fire and Explosion Protection Engineering Principles

for Oil, Gas, Chemical and Related Facilities

Second Edition

Dennis P. Nolan

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NEW YORK • OXFORD • PARIS • SAN DIEGO • SAN FRANCISCO
SINGAPORE • SYDNEY • TOKYO
Gulf Professional Publishing is an imprint of Elsevier

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Gulf Professional Publishing is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA

Second edition 2011

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

British Library Cataloguing Number: 660.2'804-dc22

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

Library of Congress Control Number: 2010937556

ISBN: 978-1-4377-7857-1

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Printed and bound in the United States of America

11 12 13 14 15 16 11 10 9 8 7 6 5 4 3 2 1

Preface

The security and economic stability of many nations and multinational oil and chemical companies is highly dependent on the safe and uninterrupted operation of their oil, gas and chemical facilities. One of most critical impacts that can occur to these operations is fire and explosion events from an incident.

This publication is intended as a general engineering handbook and reference guideline to those individuals involved with fire and explosion prevention, and protection aspects of these critical facilities. The first edition of this book was published when there was not much information available on process safety, the US CSB had not been established and the CCPS was just beginning to publish its guidance books on process safety. At that time there was a considerable void of process safety information that may have lead to some serious incidents that occurred in the industry. The main objective of the 2nd Edition of this book is to update and expand the information to the current practices of process safety management and technical engineering improvements which have occurred since its original publication.

The main objective of this handbook is to provide some background understanding of fire and explosion problems at oil, gas and chemical facilities, and as a general reference material for engineers, designers and others facing fire protection issues that can be practically applied. It should also serve as a reminder for the identification of unexpected hazards that can exist at a facility.

As stated, much of this book is intended as a guideline. It should not be construed that the material presented herein is the absolute requirement for any facility. Indeed, many organizations have their own policies, standards and practices for the protection of their facilities. Portions of this book are a synopsis of common practices being employed in the industry and can be referred to where such information is outdated or unavailable. Numerous design guidelines and specifications of major, small and independent oil companies, as well as information from engineering firms and published industry references, have been reviewed to assist in its preparation. Some of the latest practices and research into fire and explosion prevention have also been mentioned.

This book is not intended to provide in-depth guidance on basic risk assessment principles nor on fire and explosion protection foundations or design practices. Several other excellent books are available on these subjects and some references to these are provided at the end of each chapter.

The scope of this book is to provide practical knowledge on the guidance in the understanding of prevention and mitigation principals and methodologies from the effects of hydrocarbon fires and explosions.

Explosions and fire protection engineering principles for the hydrocarbon and chemical industries will continually be researched, evolved and expanded, as is the case with any engineering discipline. This handbook does not profess to contain all the solutions to fire and explosion concerns associated with the industry. It does however, try to shed some insight into the current practices and trends being applied today. From this insight, professional expertise can be obtained to examine detailed design features to resolve concerns of fires and explosions.

Updated technical information is always needed so that industrial processes can be designed to achieve optimum risk levels from the inherent material hazards but still provide acceptable economical returns.

The field of fire protection encompasses various unrelated industries and organizations, such as the insurance field, research entities, process industries and educational organizations. Many of these organizations may not realize that their individual terminology may not be understood by individuals or even compatible with the nomenclature used, outside their own sphere of influence. It is therefore prudent to have a basic understanding of these individual terms in order to resolve these concerns.

This book focuses on terminology that is applied and used in the fire protection profession. Therefore NFPA standards and interpretations are utilized as the primary guidelines for the definitions and explanations.

This book is based mainly on the terminology used in United States codes, standards, and regulations. It should be noted that some countries may use similar terminology, but the terminology may be interpreted differently.

The term accident often implies that the event was not preventable. From a loss prevention perspective, use of this term is discouraged, since an accident should always be considered preventable and the use of "incident" has been recommended instead. Therefore, the term accident has generally been replaced by incident.

A companion website with colour images dedicated to this book can be found at: www.elsevierdirect.com/companions/9781437778571

About the Author

Dennis P. Nolan has had a long career devoted to fire protection engineering, risk engineering, loss prevention engineering, and system safety engineering. He holds a Doctor of Philosophy Degree in Business Administration from Berne University, Master of Science degree in Systems Management from Florida Institute of Technology. His Bachelor of Science degree is in Fire Protection Engineering from the University of Maryland. He is also a U.S.-registered Fire Protection Engineering, Professional Engineer, in the State of California.

Dr. Nolan is currently associated with the Loss Prevention executive management staff of the Saudi Arabian Oil Company (Saudi Aramco). He is located in Abqaiq, Saudi Arabia, site of some of the largest oil and gas operations in the world. The magnitude of the risks, worldwide sensitivity, and foreign location make this one the most highly critical operations in the world. He has also been associated with Boeing, Lockheed, Marathon Oil Company, and Occidental Petroleum Corporation in various fire protection engineering, risk analysis, and safety roles in several locations in the United States and overseas. As part of his career, he has examined oil production, refining, and marketing facilities under severe conditions and in various unique worldwide locations, including Africa, Asia, Europe, the Middle East, Russia, and North and South America. His activity in the aerospace field has included engineering support for the NASA Space Shuttle launch facilities at Kennedy Space Center (and for those undertaken at Vandenburg Air Force Base, California) and "Star Wars" defense systems.

He has received numerous safety awards and is a member of the American Society of Safety Engineers, National Fire Protection Association, Society of Petroleum Engineers, and the Society of Fire Protection Engineers. He was a member of the Fire Protection Working Group of the UK Offshore Operators Association (UKOOA). He is the author of many technical papers and professional articles in various international fire safety publications. He has also written several other books which include, *Application of HAZOP and What-If Safety Reviews to the Petroleum, Petrochemical and Chemical Industries* (1st and 2nd Editions), *Fire Fighting Pumping Systems at Industrial Facilities*, *Encyclopedia of Fire Protection* (1st and 2nd Editions) and *Loss Prevention*, and *Safety Control Terms and Definitions*. Dr. Nolan has also been listed for many years in *Who's Who in California*, has been included in the sixteenth edition of *Who's Who in the World* and listed in "Living Legends" (2004) published by the International Biographical Center, Cambridge, England.

Contents

1 Introduction

1.1 Fire, Explosions, and Environmental Pollution

Fire, explosions and environmental pollution are the most serious "unpredictable" issues affecting life and business losses in the hydrocarbon and chemical industries today. The issues have existed since the inception of industrial-scale petroleum and chemical operations during the middle of the last century. They continue to occur with ever-increasing financial impacts and highly visible news reports. Management involvement in the prevention of these incidents is vital if they are to be avoided. Although from some perspectives, "accidents" are thought of as non-preventable, in fact all accidents, or more correctly "incidents", are preventable.

Research and historical analyses have shown that main cause of incidents or failures can be categorized into the four following basic areas:

- Ignorance, for example:
  - Assumption of responsibility by management without an adequate understanding of risks;
  - Supervision or maintenance occurs by personnel without the necessary understanding;
  - Incomplete design, construction or inspection occurs;
  - There is a lack of sufficient preliminary information;
  - Failure to employ individuals to provide guidance in safety with competent loss prevention knowledge or experience;
  - The most prudent and current safety management techniques (or concerns) are not known or applied; or advised to senior staff.
- Economic considerations, such as:
  - Operation, maintenance or loss prevention costs are reduced to a less than adequate level;
  - Initial engineering and construction costs for safety measures appear uneconomical.
- Oversight and negligence, with examples such as:
  - Contractual personnel or company supervisors knowingly assume high risks;
  - Failure to conduct comprehensive and timely safety reviews or audits of safety management systems and facilities;
  - Unethical or unprofessional behavior occurs;
  - Inadequate coordination or involvement of technical, operational or loss prevention personnel, in engineering designs or management of change reviews;
  - Otherwise competent professional engineers and designers commit errors.
- Unusual occurrences:
  - Natural disasters such as earthquakes, floods, weather extremes, etc., that are out of the normal design range planned for the installation;
  - Political upheaval and/or terrorist activities;
  - Labor unrest, vandalism, sabotage.

Handbook of Fire and Explosion Protection Engineering Principles. DOI: 10.1016/B978-1-4377-7857-1.00001-X

As can be seen, the real cause of most incidents is what is considered human error. The insurance industry has estimated that 80 percent of incidents are directly related to, or attributed to, the individuals involved. Most individuals have good intentions to perform a function properly, but it should be remembered that where shortcuts, easier methods or considerable (short term) economic gain opportunities present themselves, human vulnerability usually succumbs to the temptation. Therefore it is prudent in any organization, especially where high risk facilities are operated, to have a system in place to conduct considerable independent checks, inspections and safety audits of the operation, maintenance, design and construction of the installation.

This book is all about the engineering principles and philosophies to identify and prevent incidents associated with hydrocarbon and chemical facilities. All engineering activities are human endeavors and thus they are subject to errors. Fully approved facility designs and later changes can introduce an aspect from which something can go wrong. Some of these human errors are insignificant and may never be uncovered. However, others may lead to catastrophic incidents. Recent incidents have shown that many "fully engineered" and operational process plants can experience total destruction. Initial conceptual designs and operational philosophies have to address the possibilities of a major incident occurring and provide measures to prevent or mitigate such events.

1.2 Historical Background

The first commercially successful oil well in the US was drilled in August 1859 in Titusville (Oil Creek), Pennsylvania by Colonel Edwin Drake (1819-1880). Colonel Drake's famous first oil well caught fire and some damage was sustained to the structure shortly after its operation. Later in 1861, another oil well at Oil Creek, close to Drake's well, caught fire and grew into a local conflagration that burned for three days, causing 19 fatalities. One of the earliest oil refiners in the area, Acme Oil Company, suffered a major fire loss in 1880, from which it never recovered.

The State of Pennsylvania passed the first anti-pollution laws for the petroleum industry in 1863. These laws were enacted to prevent the release of oil into waterways next to oil production areas. At another famous and important early US oil field named Spindletop, located in Beaumont, Texas, one individual smoking a cigarette set off the first of several catastrophic fires that raged for a week, only three years after the discovery of the reservoir in 1901. Major fires occurred at Spindletop almost every year during its initial production. Considerable evidence is available that hydrocarbon fires were a fairly common sight at early oil fields. These fires manifested themselves as either from man-made, natural disasters, or from deliberate and extensive use of the then-"unmarketable" reservoir gas. Hydrocarbon fires were accepted as part of the perils of early industry and generally little effort was made to stem their existence.

Since the inception of the petroleum industry, the level of incidents for fires, explosions and environmental pollution that has precipitated from it, has generally paralleled its growth. As the industry has grown, so too has the magnitude of the incidents. The production, distribution, refining, and retailing of petroleum, taken as a whole, represents the world's largest industry in terms of dollar value. Relatively recent major high profile incidents such as Flixborough (1974), Seveso (1976), Bhopal (1984), Shell Norco (1988), Piper Alpha (1988), Exxon Valdez (1989), Phillips Pasadena (1989), BP Texas City (2005), Buncefield, UK (2005), Puerto Rico (2009), Deepwater Horizon/BP (2010) have all amply demonstrated the loss of life, property damage, extreme financial costs, environmental impact and the impact to an organization's reputation that these incidents can produce.

After the catastrophic fire that burned ancient Rome in 64 AD, the emperor Nero rebuilt the city with fire precaution measures that included wide public avenues to prevent fire spread, limitations in building heights to prevent burning embers drifting far distances, provision of fireproof construction to reduce probabilities of major fire events, and improvements to the city water supplies to aid fire fighting efforts. Thus it is evident that the basis of fire prevention requirements such as limiting fuel supplies, removing the available ignition sources (wide avenues and building height limitations) and providing fire control and suppression (water supplies) have essentially been known since civilization began.

Amazingly to us today, Heron of Alexandria, the technical writer of antiquity (circa 100 AD) describes in his journals a two cylinder pumping mechanism with a dirigible nozzle for fire fighting. It is very similar to the remains of a Roman water supply pumping mechanism on display in the British Museum in London. Devices akin to these were also used in the eighteenth and ninetieth century in Europe and America to provide fire fighting water to villages and cities. There is considerable evidence that society has generally tried to prevent or mitigate the effects of fires, admittedly usually only after a major mishap has occurred.

The hydrocarbon and chemical industries have traditionally been reluctant to immediately invest capital where direct return on the investment to the company is not obvious and apparent. Additionally, fire losses in the petroleum and chemical industries were relatively small up to the 1950s. This was due to the small size of the facilities and the relatively low value of oil, gas, and chemicals to the volume of production. Until 1950, a fire or explosion loss of more than $5 million dollars had not occurred in the refining industry in the US. Also in this period, the capital-intensive offshore oil exploration and production industry was only just beginning. The use of gas was also limited early in the 1900s, as its value was also very low. Typically production gas was immediately flared (i.e., disposed of by being burnt off) or the well was capped and considered an uneconomical reservoir. Since gas development was limited, large vapor cloud explosions were relatively rare and catastrophic destruction from petroleum incidents was unheard of. The outlays for petroleum industry safety features were traditionally only the absolute minimum required by governmental regulations. The development of loss prevention philosophies and practices were not effectively developed within the industry until the major catastrophic and financially significant incidents of the 1980s and 1990s.

In the beginnings of the petroleum industry, usually very limited safety features for fire or explosion protection were provided, as was evident by the many early blowouts and fires. The industry became known as a "risky" operation or venture, not only for