Francis Stoessel

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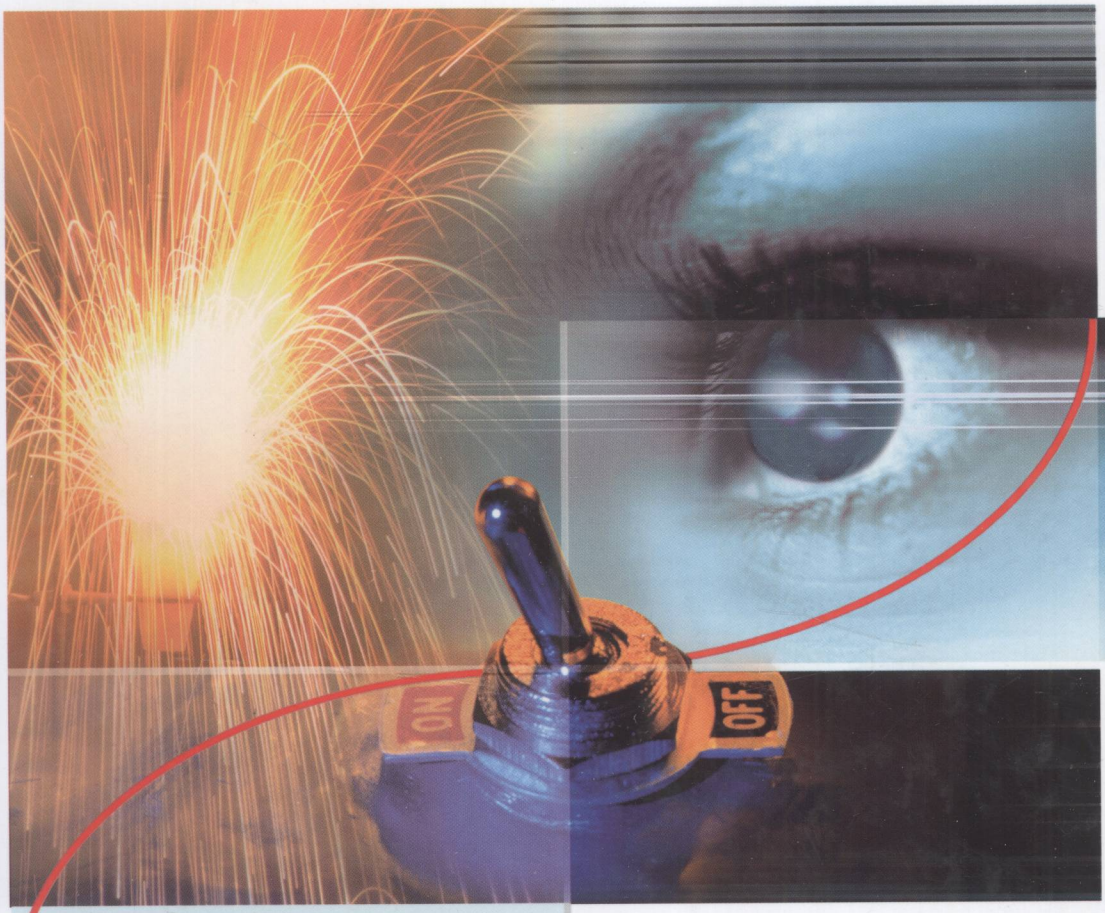
Thermal Safety of Chemical Processes

Risk Assessment and Process Design



Thermal Safety of Chemical Processes

Risk Assessment and Process Design

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Preface

Often, chemical incidents are due to loss of control, resulting in runaway reactions. Many of these incidents can be foreseen and avoided, if an appropriate analysis of thermal process data is performed in the proper way and in due time. Chemical process safety is seldom part of university curricula and many professionals do not have the appropriate knowledge to interpret thermal data in terms of risks. As a result, even though responsible for the safety of the process, they do not have easy access to the knowledge. Process safety is often considered a specialist matter, thus most large companies employ specialists in their safety departments. However, this safety knowledge is also required at the front, where processes are developed or performed, that is in process development departments and production. To achieve this objective of providing professionals with the required knowledge on the thermal aspects of their processes, the methods must be made accessible to non-specialists. Such systematic and easy-to-use methods represent the backbone of this book, in which the methods used for the assessment of thermal risks are presented in a logical and understandable way, with a strong link to industrial practice.

The present book is rooted in a lecture on chemical process safety at graduate level (Masters) at the Swiss Federal Institute of Technology in Lausanne. It is also based on experience gained in numerous training courses for professionals held at the Swiss Institute for the Promotion of Safety & Security, as well as in a number of major chemical and pharmaceutical companies. Thus it has the character of a textbook and addresses students, but also addresses professional chemists, chemical engineers or engineers in process development and production of fine chemicals and pharmaceutical industries, as support for their practice of process safety.

The objective of the book is not to turn the reader into a specialist in thermal safety. It is to guide those who perform risk analysis of chemical processes, develop new processes, or are responsible for chemical production, to understand the thermal aspects of processes and to perform a scientifically founded–but practically oriented–assessment of chemical process safety. This assessment may serve as a basis for the optimization or the development of thermally safe processes. The methods presented are based on the author's long years of experience in the practice of safety assessment in industry and teaching students and professionals

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in this matter. It is also intended to develop a common and understandable language between specialists and non-specialists.

The book is structured in three parts:

Part I gives a general introduction and presents the theoretical, methodological and experimental aspects of thermal risk assessment. The first chapter gives a general introduction on the risks linked to the industrial practice of chemical reactions. The second chapter reviews the theoretical background required for a fundamental understanding of runaway reactions and reviews the thermodynamic and kinetic aspects of chemical reactions. An important part of Chapter 2 is dedicated to the heat balance of reactors. In Chapter 3, a systematic evaluation procedure developed for the evaluation of thermal risks is presented. Since such evaluations are based on data, Chapter 4 is devoted to the most common calorimetric methods used in safety laboratories.

Part II is dedicated to desired reactions and techniques allowing reactions to be mastered on an industrial scale. Chapter 5 introduces the dynamic stability of chemical reactors and criteria commonly used for the assessment of such stability. The behavior of reactors under normal operating conditions is a prerequisite for safe operation, but is not sufficient by itself. Therefore the different reactor types are reviewed with their specific safety problems, particularly in the case of deviations from normal operating conditions. This requires a specific approach for each reactor type, including a study of the heat balance, which is the basis of safe temperature control, and also includes a study of the behavior in cases where the temperature control system fails. The analysis of the different reactor types and the general principles used in their design and optimization is presented in Chapters 6 to 8. Chapter 6 presents the safety aspects of batch reactors with a strong emphasis on the temperature control strategies allowing safe processes. In Chapter 7, the semi-batch reactor is analysed with the different temperature control strategies, but also with the feed control strategies reducing the accumulation of non-converted reactants. In Chapter 8, the use of continuous reactors for mastering exothermal reactions is introduced. The temperature control requires technical means that may strongly influence operation safety. Therefore Chapter 9 is dedicated to the technical aspects of heat transfer, and the estimation of heat transfer coefficients. Since risk reducing measures are often required to maintain safe operation, such as in the failure of the process control system, Chapter 10 is specifically dedicated to the evaluation of the control of a runaway reaction and the definition and design of appropriate risk reducing measures.

Part III deals with secondary reactions, their characterization, and techniques to avoid triggering them. Chapter 11 reviews the general aspects of secondary reactions, determination of the consequences of loss of control and the risk assessment. Chapter 12 is dedicated to the important category of self-accelerating reactions, their characteristics, and techniques allowing their control. The problem of heat confinement, in situations where heat transfer is reduced, is studied in Chapter 13. The different industrial situations where heat confinement may occur are reviewed and a systematic procedure for their assessment is presented together with techniques that may be used for the design of safe processes.

Each chapter begins with a case history illustrating the topic of the chapter and presenting lessons learned from the incident. Within the chapters, numerous examples stemming from industrial practice are analysed. At the end of each chapter, a series of exercises or case studies are proposed, allowing the reader to check their understanding of the subject matter.

Acknowledgements

The methodology presented in this book is the result of long-term experience and concerns with the assessment of thermal risks in the chemical process industry gained in the Central Safety Research Laboratories of Ciba. Therefore the author would like to thank his colleagues: K. Eigenmann, F. Brogli, R. Gygax, H. Fierz, B. Urwyler, P. Lerena, and W. Regenass, who all participated in the development of the methodology and techniques covered in this book. He would also like to thank the management of the Swiss Institute for the Promotion of Safety & Security, M. Glor and H. Rüegg, who encouraged him to persevere in the project.

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Writing a book like this is a long-term project, which cannot be brought to its end without some sacrifices. Thus my last thoughts go to my family, especially my wife Michèle, who not only accepted neglect during the course of writing, but also encouraged and supported me and the work.

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