Safety Assessment for Chemical Processes

Jörg Steinbach

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Prof. Dr.-Ing. Jörg Steinbach
Ladiusstr. 14
D-14165 Berlin
Germany

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Preface

Loss prevention represents an interdisciplinary area of teaching and research activities. The integral term itself emphasizes this characteristic as it combines substance related process and equipment related plant safety. The comprehensive approach of loss prevention led to its development into an independent discipline. Taking courses to learn about the fundamentals should be mandatory to all students in chemical engineering. Today process safety is regarded to be equally important as ensuring quality, environmental sustainability and economic feasibility for all manufacturing processes in the chemical industry.

This book in its condensed presentation of these fundamentals is written for chemical engineers and chemists either working in research, development, production or engineering departments as well as to those working for supervising authorities. At the same time it can be used as a textbook in graduate courses at university.

The above-mentioned comprehensive approach of loss prevention necessitates the description of all of the following topics in a balanced way:

- determination and interpretation of substance related safety data, as they characterize the hazard potential
- organizational and engineering safety concepts, as they influence the probability of the occurrence of an event
- methods of hazard analysis as they ensure the procedure to obtain the safety assessment to be systematic
- methods of reliability analysis and risk quantification including simulation techniques
- a discourse of the *man/machine* interface
- relevance of legal requirements and voluntary programs such as Responsible Care

This book is intended to cover the first three topics with emphasis on engineering safety concepts.

The introduction to loss prevention terminology is followed by an outline of the systematic approach to obtaining hazard assessments for chemical processes and physical unit operations. Subsequently, experimental methods for safety investigations of substances and mixtures are described and the interpretation of the results is discussed. The main part of the book deals with the investigation and assessment of chemical reactions under normal as well as under upset operating conditions.

A separate chapter addresses the problems related to handling dust explosible substances. This is followed by a short description of the main hazard identification methods.

Two selected examples demonstrate the plant related safety concepts and the variety of accompanying aspects. One of them, the design of emergency relief systems including catch tanks, was chosen because of ongoing discussions and research activities.

Finally some personal remarks should be granted. I learned most of the theoretical background to in this book from my teacher and mentor Professor Peter Hugo. For the industrial experience reflected here I have to give special credit to my friend and former colleague Dr. Theodor Grewer, who helped me with my first steps more than twelve years ago. I must not forget to mention Dr. Barbara Böck, Linda Mundt and Cornelia Clauß, who always assisted me from the publisher's side.

Finally, none of this would have been possible without the support and tolerance which my wife Barbara and my sons Andreas, Matthias and Michael have now given me for the second time in three years. To all mentioned here I would like to express my gratitude at this point.

Berlin 1998
Jörg Steinbach

Symbols and frequently used abbreviations

A	mass transfer area, heat transfer area
B	thermal reaction number
BR	batch reactor
c	concentration
c_p	specific heat capacity
CSTR	continuously stirred tank reactor
d	diameter of the agitator
d_p	particle diameter
D	diameter
D^*	dimensionless reactor diameter
D_{eff}	effective diffusion coefficient
Da	Damkoehler number
E	activation energy
f	radical yield factor, friction factor
g	gravitational constant
G	mass flow per unit area
h	Thiele modulus
h(t)	equivalent isothermal reaction time
H	height
He	Henry coefficient
HR	heating rate
$\bar{j}$	material flow per unit area
$j_{1,2}$	Antoine constant
k	rate constant
$k^*(T)$	zero-order rate constant
k_∞	pre-exponential factor
L	length
m	mass
MG	molecular weight
n	number of moles, reaction order, agitator revolutions
Ne	Newton number
Nu	Nusselt number
$\bar{o}$	vector of a surface element

p	pressure
P	stability parameter
PFTR	plug flow tube reactor
Pr	Prandtl number
$\dot{q}$	specific heat output rate
$\dot{Q}$	heat output rate
r	radius
r, r(T)	rate of reaction
R	universal gas constant
Re	Reynolds number
S	sensitivity
SBR	semibatch reactor
St	Stanton number
t	time
T	temperature
TMR	time to maximum rate
u	velocity
u^*	dimensionless velocity
U	overall heat transfer coefficient
v	specific volume
V	volume
$\dot{V}$	volume flow
x	vapour mass fraction
X	conversion
Y	relative amount of accumulated substance
z	axial coordinate
Z	real gas factor
α	heat transfer coefficient, stability parameter, relative degree of filling, outflow coefficient
β	mass transfer coefficient, stability parameter
γ	mass fraction
Δh	specific enthalpy
ΔH	enthalpy
ΔT_{ad}	adiabatic temperature rise
ε	volume increase factor, volumetric vapour fraction
η	degree of utilization of porous particles, viscosity
ϑ	dimensionless temperature difference

Θ	dimensionless feed time
κ	dilution factor, isentropic coefficient
λ	stoichiometric input ratio, heat conductivity
ν	stoichiometric coefficient
ξ	friction factor
ρ	density
σ	surface tension
τ	residence time
τ_C	time constant of cooling
τ_D	feed time
φ	volume factor
Φ	thermal inertia
$\Phi(X)$	dimensionless reaction rate
ψ	ratio of reaction to mass transfer rate, dimensionless temperature overheating
ω	entropy parameter

A	limiting component
App	apparatus
C	cooling
D	dosage
eff	effective
end	end of time
g	gaseous
l	liquid
lg	liquid/gas two-phase
max, Max	maximal, maximum value
R	reaction
S	steady state
B.P.	boiling point
W	wall
Z	decomposition
∞	referenced to the pre-exponential factor
0	initial or reference state

Contents

1 Basic Terminology in Loss Prevention

It is essential to the assessment of safety measures, from a legal as well as from a societal point of view, to have a common understanding of the basic terminology used. Examples are words like hazard or safety. In this context it must be emphasized that the majority of terms expresses probabilities, which are not generally quantifiable. Day to day practice, however, requires certain safety definitions to come up with concrete measures in order to fulfil the promise of safe manufacturing processes.

1.1 General Safety Terms

One source among others for the definition of safety terms is the German Industrial Standard *DIN 31000 Part 1* [1]. Mentioned are

- damage
- risk
- limit risk
- hazard
- safety
- safety standards
- protection

The definitions given are quite abstract and in part even use legal language. Besides the necessity to be correct, which has to be met by an official standard, the wording must be applicable not only to the chemical process industry but to all industrial activities, which also causes it to be very general. Consequently, these definitions have to be translated into a specific terminology which renders the phrasing relevant and comprehensible to the chemical industry. Assistance for this task can be obtained from several sources, such as the *German Federal Law on Immission Protection*, the *OSHA-PSM* guideline, the HSE-guide on *Chemical Reaction Hazards* or the CCPS guidelines, *Guidelines For Chemical Reactivity Evaluation And Application To Process Design* and *Chemical Process Quantitative Risk Assessment*, [2, 3, 4, 5, 6].

Of the afore-mentioned safety terms, damage and protection are probably the two most generally understood. Their interrelation supports this. Protection is the effect of a selected measure to preserve a value against damage. According to today's understanding, human beings, the environment and goods in general are values to be protected with equal efforts. However, it is more reasonable to begin the logical chain with a different term.

1.1.1 Hazard Potential and Expectable Damage

The initial point of all considerations with the aim of a safety assessment is the so-called *hazard potential*. It results from the combination of the handled amount of substance and its dominant hazardous property (Figure 1-1).

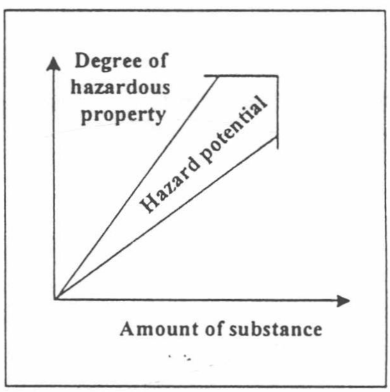

Fig. 1-1. Hazard Potential

An example for a hazardous property is the flammability of a solvent, which can be scaled from low to high using the flash point.

In order to deduce the *expectable damage* from the hazard potential, the mode of operation has taken into account, as presented in Figure 1-2. In this context the expectable damage is often referred to as the *weighted hazard potential*, because the event is only anticipated.