Design of a safe hazardous materials warehouse

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Foster Wheeler has been involved in the design of chemical warehouse buildings. This paper describes the main challenges associated in developing a safe design, which requires the identification and understanding of all of the hazardous and harmful properties of the substances likely to enter and be stored in the warehouse, compliance with the applicable regulations and standards, and the implementation of multi-disciplinary competencies in order to manage impacts on the environment and on human health. This paper describes the most significant aspects of the design relative to the packaging and warehousing of chemicals with a broad range of potential hazards, including high toxicity, flammability, combustibility, water and side reactivity, and incompatibility. An integrated design team has identified and developed mitigation strategies for the risks associated with the handling and storage of these chemicals, complying with project standards and design specifications. The article also highlights how hazardous materials warehousing differs from traditional outdoor storage and process plant, and considers the critical design issues.

Keywords: warehouse, reactive hazard assessment, chemical compatibility, spacing, layouting

Introduction

Safe warehousing of hazardous chemicals is a design challenge in chemical and petrochemical projects. The wide range of properties and regulatory constraints requires the full understanding of all of the predictable implications over the various engineering disciplines engaged in the design and a high degree of integration of the competences. Foster Wheeler has developed a systemic methodology for safe warehouse design, with the aim at identifying the hazards, considering the regulatory requirements, assessing the risks, addressing adequate design criteria and implementing all necessary mitigation and risk reduction measures. This is a complex process, which involves, at different levels, different specialist expertise. This paper presents Foster Wheeler's methodology for designing a safe warehouse and identifies the various implications and operating aspects in the design activity. A typical case study has been described, which shows the high level of the analysis and integration required.

Warehousing Incident Case History

According to the International Labour Organization (ILO), as reported by Bogdanović (2009), 24% of major chemical accidents happen in warehouses. A long series of incidents related to storage of chemicals is reported in the literature. On 4 January 1977, in Renfrew, Scotland, a chemical warehouse, the Braehead Container Clearance Depot, was destroyed by a fire and explosion. The event involved sodium chlorate under intense heat condition, as stated by the Health and Safety Executive (1979). Sodium chlorate storage had been involved in similar incidents since 1899, according to Kletz (1993), such as the fire and explosions at River Road, Barking, Essex in 1980 (HSE, 1980). On 1 February 1980 a fire and a series of explosions occurred at a warehouse in a factory at Trubshaw Cross, Longport, Stoke-on-Trent (HSE, 1980). On the morning of the fire the warehouse contained some 49 tonnes of liquefied petroleum gas in cartridges and aerosol containers as well as about 1 tonne of petroleum mixtures in small containers, raw materials, and packaging materials. It is almost certain that the source of ignition was the electrical system of a battery operated fork lift truck. On 14 December 1984, fire broke out in a very large furniture repository in Sheffield (HSE, 1985), which also contained hazardous chemicals that fortuitously were not involved in the fire. On 1 November 1986 a fire developed in a warehouse operated by Sandoz in Schweizerhalle, Switzerland. Thirty tonnes of the chemicals stored in the warehouse were drained along with water by the fire-fighting into the nearby River Rhine, resulting in a severe ecological damage over a length of about 250 km. This accident triggered serious concern in at least four European countries (Switzerland, France, Germany, and The Netherlands). On Tuesday, 21 July 1992, a series of explosions leading to an intense fire broke out in a storeroom in the raw materials warehouse of Allied Colloids Ltd, Low Moor, Bradford, West Yorkshire (HSE, 1993). The fire was preceded by the rupture of two or three containers of azodiisobutyronitrile about 50 minutes earlier. These were accidentally heated by an adjacent steam condensate pipe. The fire spread rapidly to the remainder of the warehouse and external chemical drum storage.

Dramatic warehouse incidents have also occurred more recently. A massive explosion at a fertilizer storage and distribution facility of West Fertilizer caused fifteen fatalities and hundreds of injuries on 17 July 2013. According to U.S. Chemical and Hazard Investigation Board (2013), the explosion resulted from an intense fire in a wooden warehouse building that led to the detonation of approximately 30 tonnes of ammonium nitrate stored inside in wooden bins. Not only were the warehouse and bins combustible, but the building also contained significant amounts of combustible seeds, which likely contributed to the intensity of the fire. The building lacked a sprinkler system or other systems to automatically detect or suppress fire. U.S. federal codes covering fire and safety, such as OSHA's Process Safety Management standard (29 CFR 1910.119) and EPA's Risk Management Program rule (40 CFR Part 68) were largely not followed, despite the high reactivity of ammonium nitrate and its inclusion in these codes. On 8 August 2013 an explosion occurred in Opa-Locka, Florida, at the American Vinyl Company warehouse, which caused one fatality and five injured. According to police hazmat crews, a storage container in the building that held 20,000 gallons of liquid inexplicably exploded. The storage container blew a hole in the roof of the building.

Benintendi and Alfonzo (2013) have analysed sixty one major chemical disasters which happened since 1955 to 2002, which have been grouped by their occurrence during processing, transport and storage of reactive chemicals and by intentional or unintentional chemistry. The conclusion is that nearly 15% of the incidents occurred when material was being stored and that all of them underwent chemical reactions which did not belong to the design chemistry for the involved substances.

Rationale for a Safe Design for Chemical Warehousing

The Health and Safety Executive (2009) has identified the following common causes of incidents in hazardous chemical warehousing:

- lack of awareness of the properties of the dangerous substances;
- operator error, due to lack of training and other human factors;
- inappropriate storage conditions with respect to the hazards of the substances;
- inadequate design, installation or maintenance of buildings and equipment;
- exposure to heat from a nearby fire or other heat source;
- poor control of ignition sources, including smoking and smoking materials, hot work, electrical equipment;
- horseplay, vandalism or arson.

Most of these causes are directly or indirectly related to inadequate design. Accordingly, safe design of a hazardous chemical warehouse is required. Safe design is defined by many characteritics:

- chemical substances may potentially interact and react according to any combination, depending on logistical and handling factors;
- warehouse is a context which is not generally subject to the systemic process safety studies relative to the equipment nor it is a "one-way working system" like a process plant, so some behavioural and operating aspects can be unpredictable;
- warehouse can be unmanned for a long time and the hazard detection measures need to be effective to prevent all harmful effects;
- people working in warehouse areas do not generally possess the same background and expertise which can be found in process or plant operators;
- warehouse is an indoor system which entails particular design and operating aspects;
- spacing and lay-out safety constraints often clash with design requirements;
- regulatory constraints and design specifications can affect all design disciplines, and require a high degree of integration.
- warehouse domain often includes complementary operations such as conveying, filling, dispensing packaging of materuials, which imply an additional spectrum of issues in the design.

These and many other reasons make the safe design of a hazardous chemical warehouse challenging and demanding.

Methodology of a Safe Design

Foster Wheeler's methodology for a warehouse safe design has been summarised in the flow chart reported on Figure 1. Rhombus-shaped boxes identify safety design phases, the rectangular boxes indicate any design input/output, the round boxes represent the regulations, standards and company work practices which are adopted in the design.

1. Hazardous material table and process data collection

   These sources provide all data to exactly identify chemicals, their status, phase, packaging and warehouse handling modalities and any other process data.

2. Chemicals identification

   On the basis of all the information collected in the previous step, chemical substances shall be identified. Due to the traditional uncertainty of the chemical nomenclature, reference will be made to validated sources such as the European Regulation CLP (2008), the ECHA, Classification and Labelling database and data provided by NIOSH, Pocket Guide to Chemical Hazards) and OSHA, Occupational Chemical Database and IUPAC databases.

3. Hazardous properties identification, classification and coding.

   Identification of hazardous properties of the chemical substances is a key phase of the design. As a project requirement, the design team may have to adopt particular standards and local regulations or can be free to select the most appropriate sources. This is a potentially critical step of the design activity. A wide range of validated sources and information will be analysed and collected. In addition to the cited institutional references, other international standards and validated sources can be adopted such as NFPA 704 and NFPA 400, Bretherick (2007), Yaws (2012). Proprietary material safety data sheets are not in general considered to be a reliable document, because information included hereto does not necessarily reflect validated and checked data. Foster Wheeler has also implemented and applied company work practices (2012). Figure 2 illustrates the chemical screening relative to the intrinsic hazardous characteristics of the substances with specific reference to their reactive potential, as addressed by the relevant Foster Wheeler work practice. Identification and classification relative to their toxicity and to other potential harmful effects on human targets and the environment are carried out in this step.

4. Chemical HAZID/ENVID

   This step considers and assesses the potential effects and mutual interactions of chemical substances within the specific warehouse with respect to all site entities and constraints, such as other chemicals, adjacent buildings and equipment, environmental targets, population and the local community. A typical categorization relative to the reactive hazard according to the company work practice (2012) has been given on Figure 3. Here the NFPA 704 codes have been further investigated by means of a configuration factor, which accounts for any logistic factors, including spacing, layout, potential for contact, etc. This can result in a hazard downgrade or can confirm the original NFPA code. The company work practice considers a further process factor that is applicable in warehouses only if a significant process segment is present, such as a drum filling station.

5. Warehouse HSE design requirements

   The identification of the HSE design requirements is probably the key phase of the design and is the starting point of the multi-disciplinary design approach, which typically involves process, civil, electrical, machinery and health and safety integrated competences. On the basis of the design data, the hazard identification and classification, and the results of the hazard assessment, all the design requirements will be defined. Depending on the site, building Eurocodes (2009) in the European frame or the International Building Code (2012) and the International Fire Code in the American (2012) frame will apply. Should flammable or combustible liquid or powder chemicals be present in the normal operation of the warehouse, depending on the standard, hazardous area classification will be performed in the ATEX frame or according to the American Approach. Accordingly, IEC-EN-60079-10-1/2, IP 15 or NFPA 497 can be adopted. Other important codes are GOST-R and GOST-K.

On the basis of the hazard and regulation assessment, the following safety design requirements will result:

- the maximum allowable inventory of chemical products, depending on their toxicity, flammability, combustibility, chemical reactivity;
- rules for proper location of incompatible susbstances, or substances whose configuration factor (ref. Figure 3) suggests a specific location strategy;
- fire rating compartments for all chemicals and protection levels, if applicable;
- distances from internal and external walls, from other buildings and equipment, from sensitive targets;
- fire fighting strategy;
- spill control and drain systems, which will take into account chemical compatibility, heat generation, water reactivity, gas formation and any other potential issue;
- HVAC, mechancal or natural ventilation systems, which will have to account for any potential hazardous gas formation in case of fire or in case of unintentional reactions;
- smoke and gas detector systems;
- external emergency switchboards and associated equipment.

A Typical Example of Application

A typical approach to the design of a warehouse where solids and liquids are processed and/or stored is illustrated in Table 1. All of the typical potential issues of multiphase storage and liquid processing have been considered, including the design phases and the specific data included in the flow chart illustrated on Figure 1.

Conclusion

The design of safe warehousing of hazardous chemicals is a complex task. It is a particular challenge, because it requires a different harmonised blending of disciplines and competences with respect to the general buildings and process plant design. Very specific and sometimes conflicting issues are to be considered and covered by the design team, because of the numerous factors that set the rules of this engineering game. Foster Wheeler has acquired substantial experience, working in top level international projects, as described in this paper.

Nomenclature

ACGIH	American Conference of Industrial Hygienists
ATEX	ATmosphères ed EXplosibles
B.P.	Boiling Point
CCPS	Center for Chemical Process Safety
CHD	Configuration Hazard Degree

CLP	Classification Labelling Packaging
ECHA	European Chemical Agency
EPA	Environmental Protection Agency
F.P.	Flash Point
FW	Foster Wheler
HSE	Health Safety Environment
IDLH	Immediately Dangerous to Life and Health
IEC	International Electrotechnical Committee
IHD	Inherent Hazard Degree
MAQ	Maximum Allowable Quantity
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Health
OSHA	Occupational Safety and Health Administration
PHD	Process Hazard Degree
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time Weighted Average

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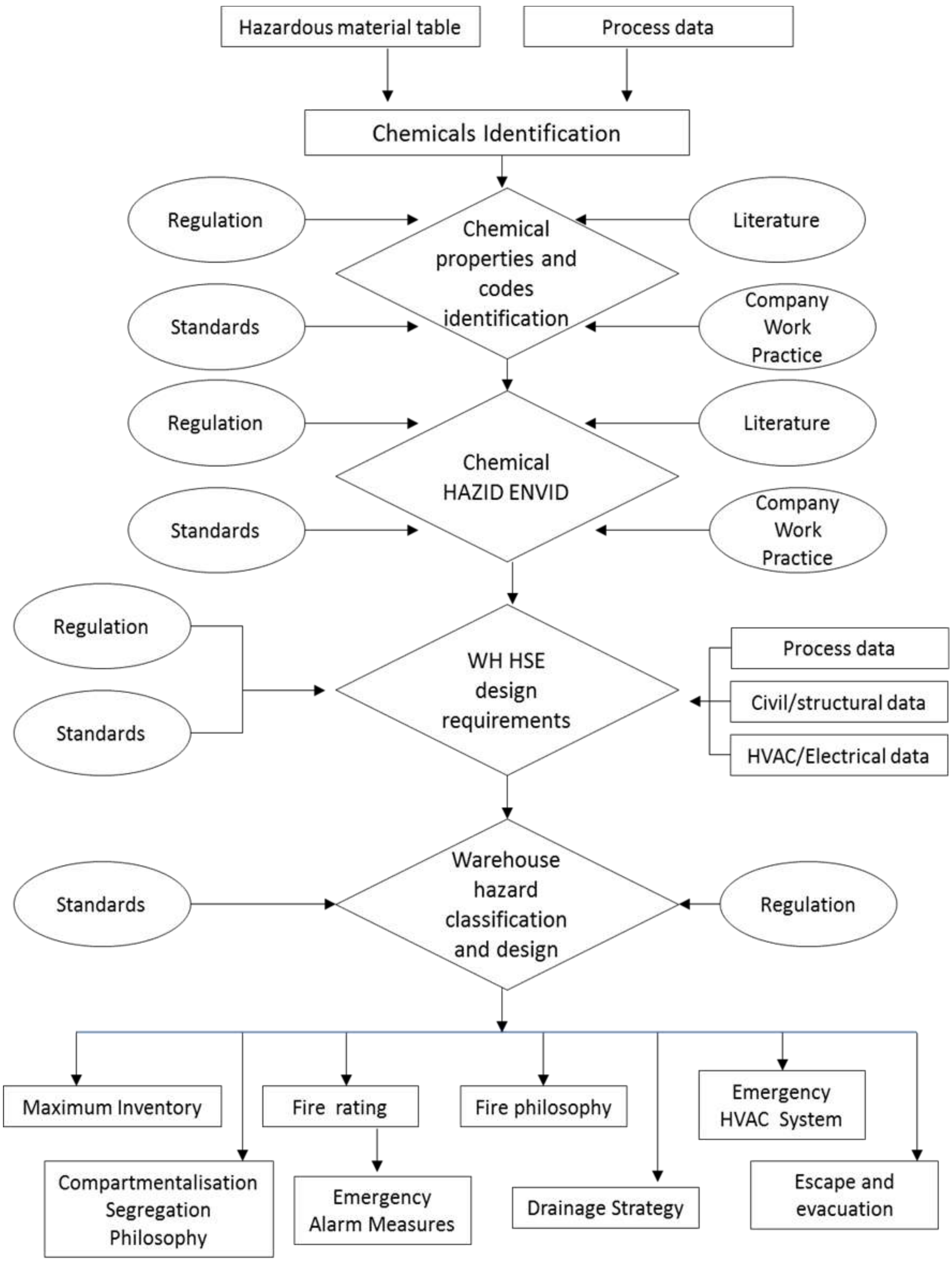

Figure 1: Warehouse safe design flow-chart

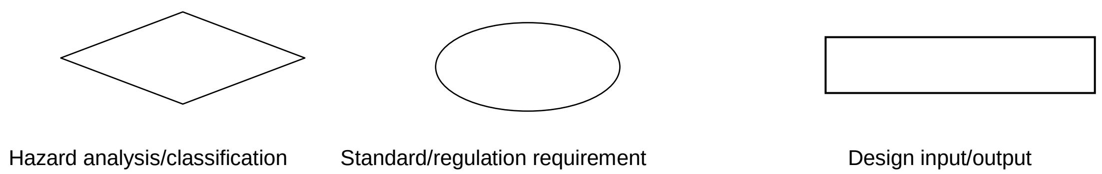

Figure 2: Reactive hazard screening (ref. FW work practice, 2012)

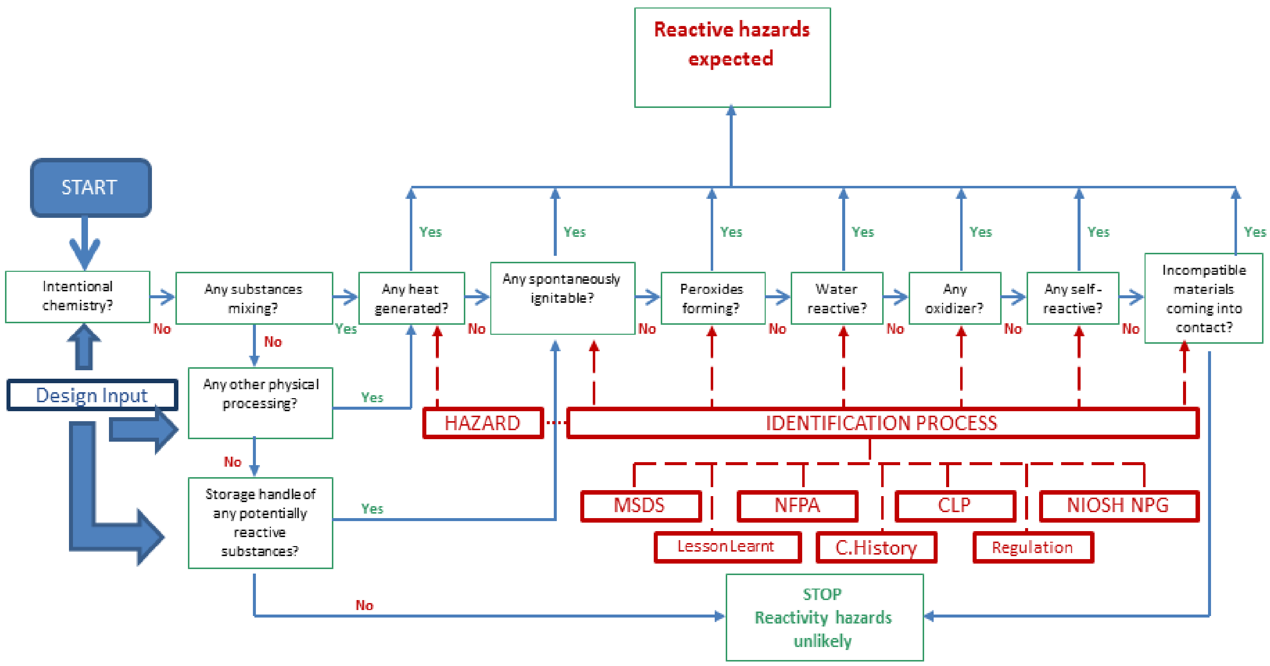

Figure 3: Reactive hazard classification (ref. FW work practice, 2012)

CONFIGURATION:
Location, logistic, handling, storage, potential for contact

INHERENT HAZARD DEGREE (IHD)		
4	NFPA 4	Extremely Reactive
3	NFPA 2	Highly Reactive
2	NFPA 1	Moderately Reactive
1	NFPA1	Weakly Reactive
0	NFPA 0	Unreactive

CONFIGURATION HAZARD DEGREE (CHD)	
4	IHD is 4 and the plant configuration hazard is high
3	IHD is 4 and the plant configuration factor is medium OR IHD is 3 and the plant configuration factor is high
2	IHD is 4 and the plant configuration factor is low OR IHD is 3 and the plant configuration factor is medium OR IHD is 2 and the plant configuration factor is high
1	IHD is 4 and the plant configuration factor is very low OR IHD is 3 and the plant configuration factor is low OR IHD is 2 and the plant configuration factor is medium OR IHD is 1 and the plant configuration factor is high

PROCESS HAZARD DEGREE (PHD)	
4	CHD is 4 and the process hazard is high
3	CHD is 4 and the plant configuration factor is medium OR CHD is 3 and the plant configuration factor is high
2	CHD is 4 and the plant configuration factor is low OR CHD is 3 and the plant configuration factor is medium OR CHD is 2 and the plant configuration factor is high
1	CHD is 4 and the plant configuration factor is very low OR CHD is 3 and the plant configuration factor is low OR CHD is 2 and the plant configuration factor is medium OR CHD is 1 and the plant configuration factor is high

SOLID AND LIQUID WAREHOUSE DESIGN HIGHLIGHTS					
	Chemical identification	Chemical properties	HAZID/ENVID	HSE Design requirements	Multidisciplinary design activity
Project documents	- Physical Properties of Chemicals - Process data	- Basic identification	- Warehouse plot plans - Warehouse storage rack views - Drum filling sketches	- Warehouse plot plans - Warehouse storage rack views - Drum filling sketches	- Hazardous area classification summary - Hazardous area classification drawings - Sprinkler system design - Safe lay outing and spacing - Architectural design • Required egresses • No corridor dead ends • Maximum travel distances to exits • NFPA rack maximum heights • Fire department access door • Non combustible doors, sills, dikes, sumps • Exterior walls • Distance to property line - Mechanical ventilation - Drain system • Separate sewer • Secondary containment - Electrical • Outside manual shutoff system
Regulations	CLP - CAS number	CLP - Classification, Risk Phrases	CLP - Water reactivity - Gas formation - Toxicity - Heat generation - Chemical incompatibility		
Standards		NIOSH - F.P., B.P., IDLH	International Building Code - use and occupancy classification of • filling centre • packaging centre • storage centre • control room • mechanical room • battery room • MCC switchboard	International Building Code - Fire Barrier requirements	
		ACGIH - TLV-TWA, TLV-STEL		International Fire Code - Sprinkler requirements	
		NFPA 30 - Flammability, Combustibility	NFPA 400 - Hazard level	NFPA 1 - Protection levels	
				NFPA 13 - Sprinkler system design	
				NFPA 30 - Control area MAQ - Drainage system requirements	
				NFPA 400 – Hazardous Materials Code - MAQ exceedance - Protection levels	
				NFPA 5000 - Spill Control	
		NFPA 13 - Classification of solids	NFPA 497 - Filling station hazardous area classification	NEC 70/IEC 60079 - Equipment to be used in hazardous areas	
Company work practice	CLP (Company chemicals classification reference				
Literature	- Bretherick - Yaws - CCPS	- Reactivity data - Physical chemical data - Overview information			

Table 1 – Design summary table for a typical Solid and Liquid Warehouse