Journal of Loss Prevention in the Process Industries 49 (2017) 18–35

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

A perspective on Seveso accident based on cause-consequences analysis by three different methods

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ARTICLE INFO

Article history:
Received 10 October 2016
Received in revised form
20 January 2017
Accepted 21 January 2017
Available online 22 January 2017

Keywords:
AcciMap
Black swan
Energy barrier
Seveso accident
System dynamics

ABSTRACT

Seveso incident happened on Saturday 10th July 1976 within the production plant of 2,4,5-trichlorophenol at the ICMESA factory represents a watershed because it gave off a specific legislation in the field of safety regarding activities subjected to Major Accident Hazards (MAH) and the handling of dangerous substances. Although the severity of the mishap, still nowadays the real cause of the accident remains, at least partially, shrouded in uncertainty and different mechanism hypotheses were proposed. These doubts could lead considering Seveso mishap as a "black swan" incident, i.e. an improbable event characterized by three peculiarities: it is not expected; it has an extreme impact; it is explainable and predictable after the fact. Further investigation appears to be essential, analyzing the available material and processing a deep analysis towards several methods, which provide different views and interpretations of the fact. To this purpose, three methods were selected: AcciMap approach; the Energy Barrier Model; the System-Theoretic Accident Model & Processes (STAMP) coupled with a dynamic approach. The last part of this work is dedicated to a specific modelling of the incident through system dynamics technique using a customized framework covering technical, human and organizational aspects.

1. Introduction

A large part of current process safety management systems are a consequence of root cause identified and shared within the scientific and industrial community after high profile accidents like Seveso one. With no doubts, as revealed by accident statistics both on the process side (e.g. Fabiano and Currò, 2012) and the personnel side of safety (Fabiano et al., 1995), human error still represents the larger contribution to accidents, notwithstanding the attention given to human factors in process/plant design, structuring organizations and drafting procedures. This paper has been developed starting from the historical interest viewpoint and aims at investigating additional lessons that could be learned, with the benefit of hindsight and new theoretical approaches. In the following paragraph, we firstly provide an overview of the accident, subsequently we critically discuss known facts and competing theories on root accident causes.

1.1. Overview

The ICMESA Company (Industrie Chimiche Meda Società Azionaria) was engaged in the production of 2,4,5-trichlorophenol (TCP) by a process designed by Givaudan, a parent company of Hoffman-La Roche. The plant was located in Meda, at 20 km North of Milan, in Italy, and the TCP production unit included two 10,000 L reactors and various columns, condensers, pumps and equipment set out over an area of 230 m^2. Subsequently, the produced TCP was transported to another site of the same company to produce herbicides such as hexachlorophene and antiseptics (Mazza and Scatturin, 1976). The Meda plant used a discontinuous batch process starting from the reactants fed at the beginning of the operation summarized in Table 1 (Cardillo and Girelli, 1981).

The process consisted of two steps:

Step 1: TCP and NaOH, the reactants, were introduced in the alkaline hydrolysis reactor along with the solvents EG and xylene, according to the reaction shown in Fig. 1.

The reactor was equipped with a condenser to eliminate the

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http://dx.doi.org/10.1016/j.jlp.2017.01.021
0950-4230/

Table 1
The reactants of Seveso process.

Reactants	kg
Ethylene Glycol (EG)	3235
Xylene	609
2,4,5 – trichlorophenol (TCB)	2000
Caustic Soda	1100

water and to feedback xylene into the reactor. The choice of the solvents lay in the fact that NaOH is soluble in glycol, while the TCB and the product of the first step (sodium trichlorophenate) are soluble in xylene. Furthermore, xylene eliminates water by azeotropic distillation promoting the reaction with a high conversion rate. According to the Givaudan patent, TCP was heated at about 160 °C, using steam at 12 bar for 6–8 h. The entire xylene and part of glycol were then vacuum distilled in order to recover solvents; then, about 3000 L of water was added to cool to 50–60 °C.

Step 2: the product of stage 1, sodium trichlorophenate, was hydrolyzed with an aqueous solution of hydrochloric acid, in order to obtain the TCP through the reaction shown in Fig. 2.

The end product was then washed with water purified by vacuum distillation (Ferraiolo, 1979). Traces of dioxin can be produced as an unwanted by-product through an exothermal condensation reaction between two molecules of sodium trichlorophenate, as shown in Fig. 3.

While dioxine concentration would not exceed 1 ppm at T < 180 °C, it could reach 1600 ppm at higher temperatures (Marshall, 1980). A simplified scheme of the Cr–Mo–Ni alloy alkaline hydrolysis reactor is depicted in Fig. 4.

On Saturday 10th July 1976, the alkaline hydrolysis reactor, switched off without completing its cycle, released a huge amount of 2,4,7,8-TCDD at 12:37 p.m., because of the rupture of the bursting disc, which was set at 3.5 atm. It should be noted that on Friday 9th July, the production cycle started at 4 p.m., ten hours later than usually. The distillation of xylene was completed before the shut-down, but the same could not occur for EG, whose distillation was accomplished just for the 15% in spite of the 50%. On Saturday morning, at 5 a.m., the reactor was shut-down, the stirring stopped 15 min later and any cooling operation was performed. At 12:37 p.m., the maintenance staff heard a whistling noise and for 20 min a cloud of vapour, dense and reddish was seen to blow off from a vent on the roof, forming a cloud of considerable altitude (Marshall, 1980). A shift foreman entered the plant and, by applying cooling water, stopped the emission. The toxic cloud was carried by the wind (4 m/s) to the southwest of the plant, towards a farming area. Within a few hours, many small animals died, but no deaths occurred among humans. In the following days, some children showed intestinal problems and burns appeared on their skins. 27 h after the fact, the company told that "a cloud of herbicides had been released", but any word was spent about dioxin. Six days later, 15 children were hospitalized, four of which in serious conditions; because the dioxin presence was ignored, the doctors were not

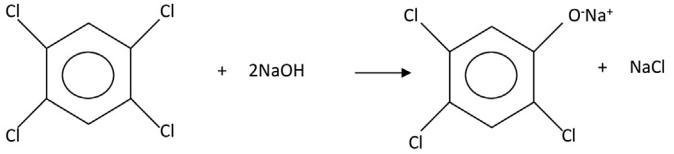

Fig. 1. 2,4,5-Sodium trichlorophenate formation through alkaline hydrolysis of 1,2,4,5-TCB.

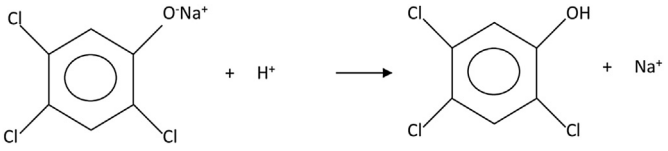

Fig. 2. 2,4,5-TCP formation through acidification of sodium trichlorophenate.

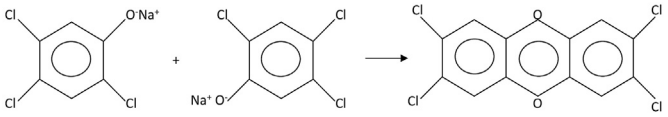

Fig. 3. 2,3,7,8-TCDD formation.

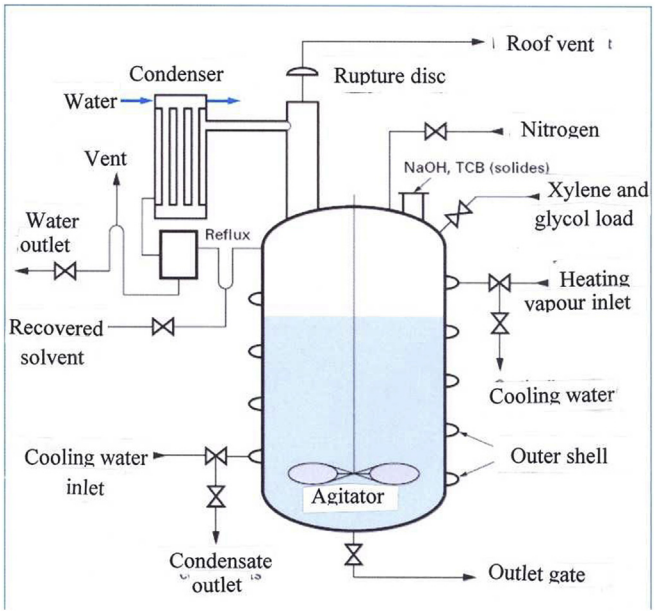

Fig. 4. Alkaline hydrolysis reactor (adapted from Gustin, 2002).

aware of the therapy to be followed. Just nine days later, the presence of dioxin in the release was made public; only fourteen days after the most affected areas were officially identified and at last eleven towns were declared impacted. The authorities classified the contamination zones on the basis of dioxine concentration measured in the ground (Lees, 2005):

Zone A: about 110 ha around the towns of Meda and Seveso with dioxin concentrations averaging 240 μg/m^2 and rising to over 5000 μg/m^2; about 733 inhabitants were evacuated in July 1976.
Zone B: about 269 ha with dioxin concentrations averaging 3 μg/m^2 with a maximum of 43 μg/m^2; resident population 4613 people, children below 12 years and pregnant women were evacuated.
Zone R: about 1430 ha of zone of Respect, with traces of dioxin and maximum concentration 5 μg/m^2; resident population 30,774 people, farming activities were prohibited.

This approach however did not allow evaluating the actual exposition dose of residents, as revealed in the follow-up clinical studies; an estimation considered a TCDD concentration of 3500 p.p.m. in the release and an approximate total TCDD amount of 2 kg (Gustin, 2002). A more accurate evaluation of the source