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Case study: T2 Laboratories explosion

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ABSTRACT

A tragic explosion resulting from a runaway chemical reaction occurred at the T2 Laboratories, Inc. facility in December 2007. The U.S. Chemical Safety Board (CSB) completed an incident investigation of the T2 explosion, identifying the root cause as a failure to recognize the runaway reaction hazard associated with the chemical it was producing. Understanding the consequences of process upset conditions is critical to determine risk. This paper will focus on lessons learned from this incident including a comprehensive hazard assessment for reactive chemicals as well as proper collection and application of adiabatic calorimetry data to characterize the chemical reaction and determine appropriate mitigation strategies. Examples will be provided to establish safer operating conditions, implement safeguards and reduce the overall risk.

1. Introduction

On December 19, 2007, a powerful explosion and subsequent chemical fire killed four employees, injured 32 people and destroyed T2 Laboratories, Inc. (T2) in Jacksonville, Florida. The incident occurred while T2 was producing its 175th batch of methylcyclopentadienyl manganese tricarbonyl (MCMT). As a result of their investigation, the CSB found that a runaway exothermic reaction occurred during the first (metalation) step of the MCMT process. A loss of sufficient cooling during the process likely resulted in the runaway reaction, leading to an uncontrollable pressure and temperature rise in the reactor. Shortly thereafter, the reactor burst and its contents ignited, resulting in an explosion equivalent to 1400 pounds of TNT (CSB 2009).

Lessons learned presented in this paper are based on experimental testing performed by Fauske & Associates, LLC in support of the CSB investigation as well as the final incident report issued by the CSB (CSB 2009). The focus areas are hazard identification, risk evaluation and management strategies for reactive chemical systems. This case study will present the process information available at each stage of development and production. Methods to identify and characterize the hazards present at each stage will be identified. Some of the lessons learned from this incident include lack of process safety information, not understanding the runaway reaction potential of the chemistry involved, improper emergency relief system design, and a lack of a process hazard analysis (PHA) on the process which could have identified critical safety systems such as cooling water.

2. Process description

T2 Labs manufactured MCMT which is a gasoline additive sold under the trade name Ecotane. T2 manufactured MCMT using a sequence of three steps performed within a single process reactor. The first step (Step 1) of the MCMT process is performed as a batch reaction using three materials: methylcyclopentadiene (MCPD) dimer and diethylene glycol dimethyl ether (diglyme) and sodium. The MCPD and diglyme are added as a mixture to the reactor, followed by the addition of solid sodium. Process protocol began by heating the mixture with the hot oil piping system, setting reactor pressure control at 50 psig and hot oil temperature control at 360 °F (182 °C). Heating the mixture began the metalation reaction by melting the sodium and splitting each MCPD dimer molecule into two individual MCPD molecules. The melted sodium then reacted with two individual MCPD molecules to form sodium methylcyclopentadiene, hydrogen gas, and heat. This reaction and operating conditions are shown in Fig. 1 (CSB 2009).

The hydrogen gas is vented to the atmosphere through the pressure control valve and 1-inch vent line. Once the temperature of the reaction mixture reached 99 °C (near the melting point of sodium), the process operator started the agitator. At a temperature of about 149 °C, the process operator turned off the hot oil system; heat generated by the metalation reaction continued to increase the mixture temperature. At a temperature of about 182 °C, the

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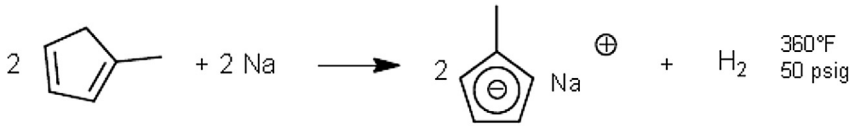

Fig. 1. Step 1 metalation reaction and operating conditions.

process operator initiated the control system cooling program, which intermittently injected water into the jacket based on the rate of reaction temperature increase (CSB 2009).

3. Process development

3.1. Laboratory testing stage

The process was developed in the laboratory based on patent information that provided guidance on how to manufacture the material. The T2 owner/chemist performed laboratory testing in a 1-L glass reactor to establish the MCMT process chemistry and determine maximum product yield. He reported that extreme exothermic behavior was not observed during testing and that test temperatures never exceeded 193 °C. The laboratory reactor required occasional heating, but did not require cooling. The owner/chemical engineer was aware that hydrogen was produced during the desired reaction (CSB 2009).

3.2. Process design stage

The owner/chemist ran approximately 110 batches of MCMT in a 1 L glass reactor between 2000 and 2001. Almost three years later, on January 9, 2004, T2 began manufacturing its first full-scale MCMT batch (Batch 1) in the new process line specifically designed and built for production of this material. It is not clear how the owners determined that laboratory scale test results were adequate for scale-up.

The maximum allowable working pressure of the reactor was 600 psig. The reactor was outfitted with a 4″ rupture disk and a set pressure of 400 psig. A pressure control valve was connected to the outlet pipe on the reactor prior to the rupture disk. The reactor had internal heating coils and an external jacket which used water for cooling. Step 1 of the process was not designed to require cooling. The plant procedure at the time of the accident indicated that the set point pressure for the hydrogen control valve was 50 psig and the temperature set point was 182 °C. The emergency relief system design was based on the maximum amount of hydrogen generation for the desired reaction at the intended operating temperature (CSB 2009).

3.3. Production scale operation

During the first ten batches of MCMT produced by T2, three batches resulted in unanticipated exotherms. Each of these occurred during the metalation step (Step 1), and in each instance the batch recipe was slightly different. Batch 1 produced an unexpected exotherm such that cooling was added to this step of the process. Cooling was not included in the design (but was available on the reactor because it was used in subsequent steps of the process). Batch 5 resulted in a runaway reaction and Batch 10 yielded a higher maximum temperature than expected. T2 changed recipes in each of the first 10 batches in an attempt to isolate the problem. Further changes were made on Batch 42 when T2 increased the batch size by one third. No records of a chemical or process analysis were available for this change to the process (CSB 2009).

4. Results and discussion

4.1. Hazard evaluation

4.1.1. Laboratory testing stage hazard evaluation results

At the laboratory testing stage of development, it was known that the desired reaction generated both heat and gas. The raw materials used in the chemistry were also known. It is not clear if the hazards of each individual chemical were identified, or if any chemical interactions were understood. The generation of both heat and gas could lead to an overpressure situation in a reactor. This should have prompted the owners to perform adiabatic testing to characterize the amount and rate of heat and gas generation.

If one is not able to identify the need for adiabatic testing based on the laboratory data, several resources provide guidance for safe process scale-up, design considerations and identifying chemical reactivity hazards (HSE, 2002; Johnson, Rudy, & Unwin, 2003; Mannan, 2005). A first step could be to complete the screening document for chemical reactivity hazards (Johnson et al., 2003). Table 1 shows an example of how this document could be completed for Step 1 (metalation) of the MCMT manufacturing process. Of the eleven questions, an affirmative answer is given for eight questions, indicating that the potential for reactive chemical hazards is present for this process.

In Essential Practices for Managing Chemical Reactivity Hazards, the Center for Chemical Process Safety (CCPS) identifies ten essential practices for managing reactive chemical hazards which are shown in a flow chart in Fig. 2 (Johnson et al., 2003). This management system should be considered an ongoing effort that is continually used to identify and characterize potential chemical reactivity hazards. It is not clear if such a system was in place at T2. The focus for this discussion will be on practices 1–6. The first practice is to develop/document a chemical reactivity hazard management system.

The next practice is to collect reactivity hazard information and identify chemical reactivity hazards. This can be done using a variety of resources including the National Oceanic and Atmospheric Administration (NOAA) Chemical Reactivity Worksheet (CRW) (NOAA) and others (Bretherick, Urben, & Pitt, 1999; Johnson et al., 2003). The CRW can be completed for the raw materials used in the process to determine what hazards could exist based on their chemical interaction. For Step 1 of the MCMT process, one hazardous interaction was identified between sodium and methylcyclopentadiene. The potential effects of this interaction include:

- Risk of explosion by shock, friction, fire or other sources of ignition
- May become highly flammable or may initiate a fire, especially if other combustible materials are present
- Combination liberates gaseous products, at least one of which is flammable. May cause pressurization
- Potential gases: Hydrogen
- Unsaturated hydrocarbons may be further unsaturated by the presence of group I metals, liberating flammable hydrogen gas

Results from the CRW also showed that diglyme is categorized as a Class II peroxidizable compound. This is important because it