Learning about process safety

Process Safety

On September 15, 2009 the US Chemical Safety and Hazard Investigation Board (CSB) issued its final report on a runaway reaction incident which occurred on December 19, 2007 at T2 Laboratories, Inc. in Jacksonville, FL, resulting in four fatalities and 32 injuries.[1] The CSB identified the root cause as "T2 did not recognize the runaway reaction hazard associated with the MCMT it was producing." Some of the specific findings from the CSB report include:

- The explosion was due to a runaway exothermic reaction in a chemical batch reactor during the production of methylcyclopentadienyl manganese tricarbonyl (MCMT).
- The runaway reaction occurred during the first (metalation) process step. A desired exothermic reaction in this step ran away due to a cooling system failure, leading to a second (undesired) exothermic reaction.
- The reactor cooling system lacked redundancy and was vulnerable to a single-point failure. There was no emergency cooling. The pressure relief system was not designed to relieve the second exothermic reaction, and did not have sufficient capacity to prevent the reactor from being overpressurized beyond its failure pressure.
- T2 was likely unaware of the second exothermic reaction that occurred at the high temperature which the batch reached following cooling failure.
- T2 technical personnel did not have reactive chemistry hazard experience. Most baccalaureate chemical engineering curricula in the U.S. do not specifically address reactive hazard recognition and management.

One thing that is particularly striking about this incident report is the many similarities to previous CSB incident investigations of reactive chemistry incidents, including, for example:

- Synthron Chemical Explosion, Morganton, NC, January 31, 2006.
- MFG Chemical Inc. Toxic Gas Release, Dalton, GA, April 12, 2004.
- Concept Sciences Hydroxylamine Explosion, Allentown, PA, February 19, 1999.
- Morton International Inc. Runaway Chemical Reaction, Paterson, NJ, April 08, 1998.

I was especially interested in the similarities between the 2007 T2 Laboratories explosion and the 1998 Morton International explosion. I have some familiarity with the Morton incident because my former employer, Rohm and Haas Company, acquired Morton in 1999, and I spent some time working with the Paterson plant to improve process safety management systems to prevent future incidents. In both of these explosions, the immediate cause was a single failure (to provide adequate cooling) resulting in loss of control of the intended exothermic reaction. The batch temperature increased to a point where a second exothermic reaction (most likely some kind of decomposition reaction) occurred, generating even more heat and non-condensable gas. Pressure relief systems were inadequate for the unanticipated reaction (which should not be surprising for an "unanticipated" reaction). So, although the proximate cause was a cooling failure, the root cause was a lack of understanding of the reactive chemistry hazard and its potential consequences. Because of this lack of hazard awareness, the facility designers and operators did not recognize the need for more robust systems to control reaction conditions (including temperature), and for adequate emergency pressure relief based on gas generation from a runaway reaction. At Paterson, the reactor manway blew off, and provided sufficient vent area to prevent a complete reactor rupture, but the material released into the process building ignited and injured 9 people. The T2 Laboratories reactor did rupture and the explosion caused the fatalities and injuries. These two incidents are fundamentally identical:

- A lack of awareness of the potential for loss of control of an intended exothermic reaction results in inadequate temperature control systems.
- Failure to understand the potential for a second exothermic reaction which occurs when the batch reaches elevated temperature because of the loss of control of the intended reaction.
- Failure to design appropriate emergency pressure relief systems for runaway reaction conditions.

Dennis Hendershot is a staff consultant for the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE). He worked for Rohm and Haas Company for 35 years, in process research and development, plant design and startup, and, since the late 1970s, in development and implementation of process safety management systems, process hazard analysis, incident investigation, and process risk assessment. He has also worked as a Principal Process Safety Specialist for Chilworth Technology, Inc. Dennis is an AIChE Fellow, a past member of the AIChE Board of Directors, and a member of the American Chemical Society and its Division of Chemical Health and Safety. (email: dennis.hendershot@gmail.com)

[1] http://www.csb.gov/assets/document/T2_Final_Copy_9_17_09.pdf.

1871-5532/$36.00
doi:10.1016/j.jchas.2009.11.008

The CSB recommendations recognize an important issue in preventing reactive chemistry incidents in the future. Specifically, the CSB recommends that the Accreditation Board for Engineering and Technology, Inc. (ABET) and the American Institute of Chemical Engineers (AIChE) work together to add reactive hazard awareness to baccalaureate chemical engineering curricula requirements.[2] While the CSB has been criticized by some for this recommendation for education, rather than recommending further regulation of reactive chemicals, I believe the recommendation is highly appropriate. Regulation of reactive chemicals has been discussed for many years, and has been controversial because there is a lot of disagreement on how to go about it. The issue is not really "reactive chemicals", but rather "reactive chemistry". Nearly every chemical is reactive with *something*! It is almost impossible to put together a list of "reactive chemicals", and, if you do that, the list had better include water, which is a highly reactive chemical when mixed with many other materials. Water even reacts with iron and steel, and this reaction has caused at least one tank collapse that I am aware of–a wet tank was completely closed off, the oxygen in the air in the tank reacted with the steel tank (to form rust), reducing the pressure in the tank and causing it to collapse. So, while additional regulations may be appropriate, this has been recommended in the past and is still being discussed. But, recognizing a basic problem in the education of chemical engineers has the potential to have a greater long term beneficial impact.

The problem is really broader than just incorporating education on reactive chemistry hazards into chemical engineering education. ABET requirements for accreditation of chemical engineering programs include specific criteria for "a working knowledge, including safety and environmental aspects, of material and energy balances applied to chemical engineering processes." The AIChE Code of Ethics includes the following requirements[3]:

- Hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties.
- Formally advise their employers or clients (and consider further disclosure, if warranted) if they perceive that a consequence of their duties will adversely affect the present or future health or safety of their colleagues or the public.

But, in my experience with newly hired engineers directly out of college, and from talking to students, most chemical engineering programs do not accomplish this very effectively. The CSB has pointed out one important area which is not well covered–reactive chemistry hazards. After all, the degree is called *chemical* engineering, so is not *chemistry* and its hazards an important aspect? There are others. For example, it is possible, and in fact likely, that a student can get a BS degree in chemical engineering and never learn that almost any solid material that will burn can be a major explosion hazard if it is ground up into a sufficiently fine powder, dispersed into the atmosphere as a dust cloud, and ignited. Perhaps that is an important root cause of dust explosions–a lack of awareness of the potential hazard because engineering students are never taught about dust explosions.

We do not need to make all students experts in all process hazards. What we need is a basic awareness so that engineers can recognize when they have a potential hazard, and can find the expertise to properly characterize and manage the hazard. It does not take much time to provide the basic background and awareness. The AIChE SAChE (Safety and Chemical Engineering Education)[4] Committee has produced a web based self-teaching module on reactive chemistry hazards. It takes a few hours to complete, and covers the basic concepts. I have taught a basic awareness seminar on dust explosions many times for in-house training programs and to college students and it only takes an hour or so. It does not make the students experts – that takes years of study – but it gives them enough information to recognize hazards and look for expert help. Surely we can find enough time in a four-year chemical engineering program for a few hours to provide basic awareness education for reactive chemistry hazards, dust explosion hazards, toxic hazards, fire and explosion hazards, and other important process safety fundamentals.

[2] http://www.csb.gov/recommendations/details.aspx?SID=8.

[3] http://www.aiche.org/About/Code.aspx.

[4] http://www.sache.org.