

SOME OBSERVATIONS ABOUT MAJOR CHEMICAL ACCIDENTS FROM RECENT CSB INVESTIGATIONS

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The U.S. Chemical Safety Board (CSB) conducts independent investigations of major chemical accidents that occur in the United States. Since 1998 the CSB has investigated nearly 50 chemical releases, fires, and explosions that resulted in death, injuries, community evacuations, and/or significant property damage.

While each accident is unique and presents its own lessons, taken together CSB-investigated accidents shed light on where major chemical accidents have been occurring, and some of the recurring characteristics of these accidents. The paper presents summaries of investigations, and identifies recurring features of recent CSB-investigated accidents.

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INTRODUCTION

“Having paid the price of an accident ... we should use the opportunity to learn from it. Failures should be seen as educational experiences. ... Having paid the tuition fee we should learn the lessons.” (Trevor Kletz, *Still Going Wrong*)

After several major accidents at chemical plants in the 1980's brought worldwide attention to the issue, in 1990 the U.S. Congress passed the Clean Air Act Amendments, which included a three pronged approach to improve chemical accident prevention and increase public accountability for safety at companies and worksites involved in chemical production, processing, handling and storage in the United States.

Both the U.S. Environmental Protection Agency and the U.S. Occupational Safety and Health Administration were given new regulatory responsibilities.¹ The law also created a separate agency, the U.S. Chemical Safety Board (CSB), to conduct independent investigations of major chemical accidents (“any accidental release resulting in a fatality, serious injury or substantial property damages”), and to report “to the public” on the facts, conditions, and circumstances and the cause or probable cause of the accident.²

Since 1998 the CSB has completed 40 investigations and three safety studies, and currently has 7 additional investigations underway. The reports on all of the completed investigations are available on the agency website, www.csb.gov. In addition, short videos

¹EPA's Risk Management Plan (RMP) rule and OSHA's Process Safety Management (PSM) standard.

²42 USC 7412(c)(6)(i)

are available on several recent investigations. The videos include animation that visually depict the accident and describe the accident's causes and the CSB's recommendations. The videos are available, for free, either by download or on DVD which can be requested on the website.

Each accident that the CSB investigates is unique and presents its own lessons for chemical safety and preventing similar accidents. There are also aspects and features in the accidents CSB investigates that seem to be particularly prominent and recurring. This paper surveys recent CSB investigations, and identifies three recurring features in this small, but growing, set of chemical accidents.³

I. WHERE MAJOR ACCIDENTS ARE OCCURRING

A news article from 1991, around the time that the CSB was created, described 14 major chemical accidents in the United States that occurred between 1987 and 1991, which together resulted in 79 fatalities, nearly 1000 injuries, and over \$2 billion in damages. All of the incidents occurred at large chemical or oil and gas companies.⁴

If one compares this five year list of chemical accidents with the list of accidents that the CSB investigated during the five years from 2002–2007, there is a rather remarkable change. While two of the largest accidents that the CSB has investigated in recent years occurred at large companies (discussed in part III, below), most of chemical accidents that the CSB has investigated over the past five years occurred at small chemical companies or at companies that were not primarily involved in chemical processing, but used chemicals as a part of their operation.⁵ A recurring feature in many of these accidents is a lack of awareness and prevention against chemical hazards that are well known, and, in most cases, are addressed by local, state, or national codes, standards, or regulations. Some recent examples follow.

³Using CSB-investigated accidents as a “database” of sorts requires an explanation of how such accidents are selected. As resources permit, CSB attempts to investigate the most serious – based on the consequences – chemical accidents that occur in the U.S. In order to do that, the staff monitors a wide variety (over 6000) news sources for reports on chemical accidents, and also receive daily reports of incidents from two government sources, the National Transportation Safety Board and the National Response Center. More serious accidents are evaluated against a simple incident selection tool that considers the number of fatalities, injuries, community impacts (evacuation, shelter in place), property damage, public interest, and potential lessons. In recent years 15 to 20 incidents have been considered for investigation using the criteria listed above, and of those the CSB initiates investigations at about 10 of the most serious.

⁴Schneider, K. (1991, June 19). Petrochemical disasters raise alarm in industry. *New York Times*. Entered in the Congressional Record, June 20, 1991, S 8235.

⁵The list of Completed Investigations and Current Investigations is available on the agency website, www.csb.gov

1. CONCRETE PRODUCTS MANUFACTURER

A concrete products manufacturing plant near Chicago, Illinois, Universal Form Clamp, Inc.(UFC), had converted a small portion of its plant into a chemical mixing area, where it produced chemicals used to treat concrete for certain purposes. The area had a 2200 gallon open top tank with steam coils to heat mixtures of chemicals. On the day of the date of the accident, the tank contained approximately 6000 pounds of heptane and 3000 pounds of mineral spirits. The tank had a temperature controller, consisting of a liquid filled temperature sensing bulb and pneumatic control unit. Investigation after the accident found that it likely malfunctioned due to not being installed or maintained in accordance with manufacturer specifications. The only additional safeguard against overheating the mixture was that at some point during the mixing operation an operator was supposed to climb to the top level of the tank and hand check the temperature of the mixture. There were no alarms and no temperature displays that would indicate a rising temperature. Contrary to existing building and fire codes (NFPA 30), exhaust fans for that area of the facility were at ceiling level; there were no floor level exhaust registers to remove vapors that accumulated near the floor. The local exhaust system on the mixing tank itself was broken and not working at the time of the accident. Design and construction of the chemical mixing area had taken place under the direction of a chemist and contract construction engineers. Apparently neither they nor the local government which approved the construction permit, recognized the hazard and the discrepancy from fire code requirements.

The accident occurred while a mixture was being heated. The temperature controller malfunctioned, causing the steam valve to remain open and the mixture to heat to the boiling point. The boiling mixture produced a heavy, flammable vapor, which spread to the adjacent areas where it was ignited by one of several possible ignition sources. Workers in the immediate vicinity of the tank saw the vapor cloud and were able to evacuate the facility. However a delivery man who happened to be coming into the facility at about the same moment that it was rocked by a large explosion was killed.

2. WASTEWATER TREATMENT PLANT

Another CSB-investigated accident that occurred at a worksite that was not primarily a chemical operation but maintained and used chemicals, occurred at a wastewater treatment plant in Florida, the Bethune Wastewater Treatment Plant. Workers were dismantling a metal roof that had sheltered a 10,000 gallon methanol storage tank but had become damaged during a recent storm. At the time of the accident the tank contained between 2000 and 3000 gallons of methanol. Although the workers were using a cutting torch to dismantle the roof, they did not assure that the methanol tank had been emptied before beginning their work. The employer (the city) also did not have a safety program for hot work, and workers had had infrequent training in chemical hazards. Sparks from the torch ignited fumes from the storage tank. A defective flame arrestor on the top of the tank allowed the flame to flash back into the tank, causing it to explode. Leaking fuel from the tank engulfed the ground operator of the lift truck from which the workers dismantling the roof were working, and both he and worker using the torch were killed. A third worker survived but was severely injured.

3. COMBUSTIBLE DUST EXPLOSIONS

In 2003 and 2004, the CSB investigated three large combustible dust explosions, each of which occurred in a manufacturing facility that used chemicals. A factor in all three of the incidents was a lack of awareness of the hazard of dust explosion from the materials used and the dust being generated in the production process. The largest of the three accidents (West Pharmaceutical) occurred at a manufacturer of rubber stoppers and similar products for medical devices and pharmaceuticals. The manufacturing process involved running rubber strips through a slurry of polyethylene and water. As the rubber was dried by running it in front of a fan, some of the polyethylene particles became airborne. The work areas of the plant were kept clean, but dust accumulated above a suspended ceiling; those who were aware of the accumulated dust did not know of its explosive properties, and the Material Safety Data Sheet for the slurry did not include information or warning about the combustibility of dust when the material dried. An unknown source ignited the dust and a secondary explosion largely destroyed the plant, killing 6 workers and injuring 38 others.

The lack of hazard awareness around combustible dusts in manufacturing settings in the three dust explosions investigated by the CSB led the agency to undertake a study of combustible dust incidents and explosions in the United States, and to take other steps (including a forthcoming video on dust explosions) to bring more awareness of the hazard of dust explosion.

Although several of the accidents that CSB investigated involved a general lack of chemical hazard awareness by personnel at facilities that are not primarily involved in chemical processing, other accidents occurred at small chemical processing plants that also did not consider or apply chemical process safety or hazard information to their process operations.

4. PAINT ADDITIVE MANUFACTURER/CHEMICAL PROCESSOR

One such incident investigated by the CSB occurred at a small chemical plant in North Carolina in January, 2006. The company manufactured a variety of powder coating and paint additives by polymerizing acrylic monomers in a 1500 gallon reactor. The company had received an order for slightly more of the additive than a normal recipe would make, so plant managers scaled up the recipe to produce the larger amount, and also changed the process by adding all of the monomer in the initial charge to the reactor. The impact of the changes, which plant managers did not fully calculate before beginning the reaction, was to increase the rate of heat release in the reaction to at least 2.3 times that of the standard recipe. The heat release rate exceeded the capacity of the reactor's cooling system, and the result was loss of control of the reaction. The reactor lacked additional safeguards to quench the reaction, and the reactor manway had been secured with only 4 of 18 clamps. It began to leak as the pressure in the reactor increased, forming a flammable cloud inside the building. The vapors found an ignition source, and the resulting explosion killed one worker and injured 14 others.

5. POLYETHYLENE WAX PROCESSOR

The CSB investigated a large fire at a polyethylene wax processing facility (Marcus Oil and Chemical) that caused considerable offsite damage. The process involved heating the wax to approximately 300 degrees (F). The system was designed to use nitrogen to move the molten material through the process system, but over time workers and supervisors found that the nitrogen generator on site did not always produce enough nitrogen, so they added an air compressor to the system. In addition, the company had altered the pressure tanks in which the wax was heated by installing steam lines, and the welding to repair the patch was poorly done and not in accordance with good industry practice. On the day of the accident the welded section of the tank gave way, creating a spark as it hit the concrete. The spark ignited the liquid and vapor hydrocarbons that poured out of the opening caused by the weld failure, and the fire backtracked into the tank. The oxygen introduced by the air compressor created an explosive environment in the tank; the 50 foot long tank was lifted about 250 feet, and the resulting fire ignited other parts of the facility, and burned for nearly 7 hours.

6. CHEMICAL “TOLLING” OPERATION

A small chemical plant located in Georgia (MFG) was contracted to manufacture triallyl cyanurate (TAC). In the course of the first production-size batch the reaction went out of control and overpressurized the 4000 gallon reactor. The overpressure activated the emergency vent, and released highly toxic and flammable allyl alcohol into the surrounding residential community. The release caused the evacuation of about 200 families, and 154 people received decontamination and treatment at the local hospital, including 15 police officers and emergency responders who assisting with the evacuation.

The company had conducted laboratory-scale testing of the reaction, and had also run smaller batches prior to conducting a production size reaction. The investigation found that in addition to a larger amount, the company had also changed the recipe, and did not account for the larger reactor (and reduced surface to volume ratio) in calculating the temperature of the reaction and the ability of the reactor’s cooling system to contain it.

7. OIL FIELD CONSTRUCTION WORK

Another accident which the CSB investigated which resulted from a lack of basic safety precautions required by codes and standards occurred at an oil field in Mississippi (Partridge Raleigh). Contractors were connecting several adjacent storage tanks, and were welding an overflow pipe to the side of one of the tanks. While the workers had checked the tank on which they were welding for flammable vapors, they did not assure that the adjacent tanks were empty. Vapors from the two connected adjacent tanks vented near to where the welding was taking place; the vapors ignited and flames backtracked into the storage tanks, causing an explosion in the tanks. Three workers, standing on top of the tanks and without fall protection, were killed.

II. RELIANCE ON ADMINISTRATIVE CONTROLS

Lack of awareness of or precautions against well recognized chemical hazards, generally in smaller operations, has been one recurring feature in CSB-investigated accidents in recent years. Another has been the vulnerability of chemical plants and processes which rely on human reliability and judgment and/or administrative controls to safeguard against potentially catastrophic accidental release. The accidents underline the importance of companies realistically taking into consideration “the human factor” in their process safety. They also encourage companies to pay particular attention to this point in their process operations, especially of examining their training and hazard communication programs for operators and supervisors, and of utilizing automated controls when the risk or severity of an accidental release is high.

1. MEDICAL EQUIPMENT STERILIZATION PLANT

One such incident occurred at a medical equipment sterilization facility (Sterigenics). The facility used ethylene oxide to soak the medical equipment. The plant’s regular process involved loading the medical equipment into a chamber, soaking it, then purging the ethylene oxide to an acid scrubber, using several nitrogen gas washes. Low amounts of ethylene oxide remaining in the chamber were then vented to an oxidizer when the chamber door was opened. If too much ethylene oxide remained in the chamber when the vent was opened, the heat from the oxidizer would cause it to explode. On the day of the accident, the chamber was being tested. There was no medical equipment in the chamber, and operators surmised that the ethylene oxide would thus be purged more quickly and not require as many gas washes. There was no monitor to indicate the level of ethylene oxide in the chamber, operators relied on their intuition. The additional “safeguard” to premature opening of the vent was that only a supervisor had the combination to open the chamber door before the end of the full cycle. In this case the supervisor agreed with the operators, and opened the door before the full cycle of gas washes had been completed. A significant amount of ethylene oxide remained in the chamber, which vented to the oxidizer. The result was a violent explosion that blew apart the chamber. No one was injured, though the facility received considerable damage.

2. CHLORINE FACILITY

The CSB also investigated a chlorine gas release at a chlorine repackaging facility (DPC) in Arizona. The release resulted in the evacuation of 1.5 square miles of the surrounding community, and medical attention for 16 persons, including 11 police officers who responded to the incident. The facility used a system for transferring the chlorine which captured chlorine vapors and sent them to a scrubber, where the chlorine combined with caustic soda to produce bleach. The reaction depleted the caustic, so it was critical that before the caustic was fully depleted, that the system be turned off, the bleach unloaded, and reactor recharged with caustic. The facility relied on operators to take regular samples, and to shut off the flow of chlorine to the scrubber while the sample was tested to prevent

an accidental depletion of caustic. In practice, however, operators continued the flow of chlorine to the scrubber until the target concentration was reached, while periodically sampling the solution. The accident occurred while an operator was preparing to take a sample for laboratory analysis. The system did not have an automatic shut off, and reactor overchlorinated, causing the release.

3. ACETYLENE PRODUCER

The CSB investigated an acetylene explosion that killed 4 workers (ASCO) in New Jersey. The explosion took place when acetylene from the production generator flowed through water pipes to an outdoor shed where a propane heater was being used to keep recycled water tanks and piping from freezing during the winter. Ordinarily water in the pipes would be flowing into the generator when it was operating, and so would prevent acetylene from backflowing to the shed. The accident occurred when the operators switched off the public water supply that was used to start the production cycle, but forgot or was delayed in opening the recycled water line. The empty water line allowed the acetylene to backflow to the outdoor shed. A check valve that would have prevented the acetylene from backflowing failed to operate properly.

III. CORPORATE OVERSIGHT

While many of the accidents that the CSB has investigated in recent years have been at smaller companies which were unaware of or unprepared for well recognized or recognizable chemical hazards, incidents at larger companies can reflect the same lack of hazard awareness or prevention, though the causes may be different. Two of the largest accidents that CSB has investigated in the recent past have occurred at facilities of large chemical and oil and gas companies.

1. REFINERY EXPLOSION

Most notable was the March, 2005 explosion and fire at BP's Texas City, Texas refinery that killed 15 workers and injured about 180 others. The basic and immediate sequence of the accident is quite well known. Operators were restarting the raffinate splitter tower of the refinery's isomerization unit. For reasons not known but for which there were several possible explanations, they for several hours the operators allowed hydrocarbons to load into the tower without opening valves to allow liquid to flow out of the tower. The result was a liquid level 14-15 times the normal operating level. As the liquid in the tower was heated, it expanded and overflowed the tower, bursting pressure relief valves and overflowing the blowdown drum that was the only means of containment of an overflow from the splitter tower. Hot, flammable liquid and vapor erupted from a stack attached to the blowdown drum, causing a vapor cloud to form around ground level, which quickly found a source of ignition and exploded. Near the blowdown drum and in the path of the explosion were portable trailers where workers were meeting or

using for office space. All of the fatalities and many of the serious injuries occurred in the destruction of the trailers.

The CSB's report on the accident found many, many factors that contributed to the accident – from operator and supervisor errors and miscommunications on the day of the accident, to laxness about safety procedures for unit startups and trailer siting, to long-standing failures to address hazards in the design and operation of the pressure relief system of the unit in which the release of flammable liquid and vapor into the refinery took place, to corporate management and corporate culture that undervalued process safety at the refinery.

2. VINYL CHLORIDE PLANT

CSB also investigated a major accident at a vinyl chloride plant belonging to a large chemical company, Formosa Plastics, which occurred in 2004. An operator was cleaning one of several reactors at the facility. After cleaning the reactor from the top level, he went to the lower level to drain the reactor. However in the process he turned the wrong direction and went to the wrong reactor, one that was on cycle. When he attempted to open the drain valve the interlock that prevented the reactor from being opened while on cycle prevented him from opening it. However the facility had a readily accessible override to the interlock, which was supposed to be used in case of emergency, but apparently was not always so limited. He used the override, as he opened the valve on the on cycle reactor, vinyl chloride poured out of the reactor. It found a source of ignition and exploded, killing 5 workers and injuring 3 others, and destroying the plant.

Both of these incidents have numerous important lessons and reminders about process safety and process safety management for chemical and petrochemical operations. While a full description of these is well beyond the scope of this article, two specific lessons for corporate management of process operations are mentioned here.

One is that most large companies monitor the performance of individual units, facilities, operations, and managers by numerical measures. These numerical indicators are used not only to monitor performance, but to improve performance, by basing pay and bonuses, budgets, or other types of recognition, on them. Thus, “what gets measured gets managed,” and what gets reported to the corporate leaders is what gets attention and emphasis in operations, especially if pay and performance rewards are involved. BP's internal performance measurement and incentive systems for safety performance focused almost exclusively on injury rates, and did not include measurement of process safety performance. As a result, safety programs at the refinery focused on personal safety initiatives, and company officials received reports of improving safety performance at the refinery, based on lower injury rates, even as process safety deteriorated and the risk of major accident remained high. A principal lesson coming out of the Texas City refinery disaster is the importance of process safety indicators, in addition to personal safety measures, to monitor performance at any facility at which hazardous chemicals are used or processed.

The BP and Formosa accidents also highlight the important role that corporate oversight has in assuring that individual plants and facilities have pertinent information

on process hazards, and act upon it: that the “information flow is open” and the “action loop is closed.” For both BP and Formosa, previous incidents at other facilities of the company could have provided valuable lessons in identifying and correcting the hazards which ultimately led to a catastrophic accident, if the information had been used. BP’s previous accident at the Grangemouth refinery highlighted some of the same issues as later were highlighted in understanding what went wrong at Texas City. At Formosa Plastics, other facilities of the company had experienced operators overriding interlocks and had put in place additional safeguards. But those had not been incorporated at the Illinois facility.

Further, the specific vulnerability in both cases – the pressure relief system/blowdown drum in BP and operator access to open an on-cycle reactor in Formosa – had been identified by the plant prior to the accident, but was not corrected before the accident occurred. At BP, the vulnerability of atmospheric discharge from the blowdown drum had been identified years before the accident, but was not changed to send overflowing hydrocarbons to a flare system. At Formosa, another operator’s override of the interlock two months prior to the accident led the plant supervisors to appoint a team to come up with alternatives, but no changes were made before the accident occurred.

CONCLUSION

The chemical accidents that the CSB investigates are each unique, and the number of major accidents is relatively small. The “low probability, high impact” events that CSB investigates do not necessarily predict where the next accident may occur or where the greatest risk of future accidents lies. The BP refinery explosion described above was a reminder of the tragic consequences that can attend any large chemical release. Certainly the above discussion of recent CSB-investigated accidents does not give reason for any plant or facility to feel safe, become complacent, or reduce its own vigilance against chemical accident!

Nonetheless, taken together, recent CSB investigations highlight some common or recurring characteristics of major accidents that have occurred in the United States in recent years. They suggest that many of the hazards of major chemical accidents in the United States are occurring at companies that are not primarily chemical companies, but keep or use large quantities of chemicals for other purposes. They also suggest that a particular area of vulnerability for facilities that use or handle chemicals are the controls and safeguards that rely on human judgment and reliability in order to prevent accidental release, and thus emphasize the importance that management should give to these points in their operations. Finally, recent major accidents that occurred at large companies highlight the critical and essential role of that corporate leadership and oversight have in chemical process safety, particularly in assuring that process safety is included, measured and valued in individual and business unit performance standards, and in assuring that plants and facilities not only have systems in place to assure that they are aware of problems and deficiencies, including particularly legal deficiencies, but that there is also assurance of timely correction of deficiencies.



Figure 1. Universal Form Clamp, Bellwood, IL (June 14, 2006)

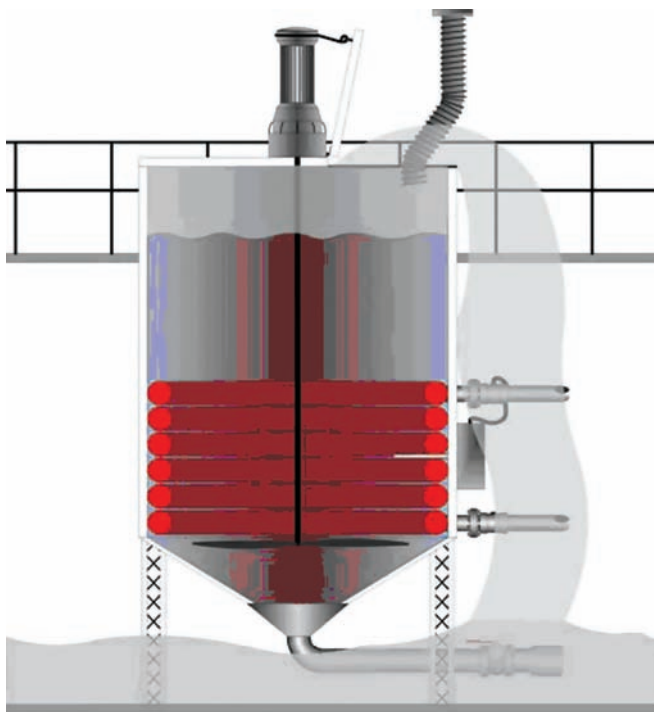


Figure 2. Vapor spilling from mixing tank

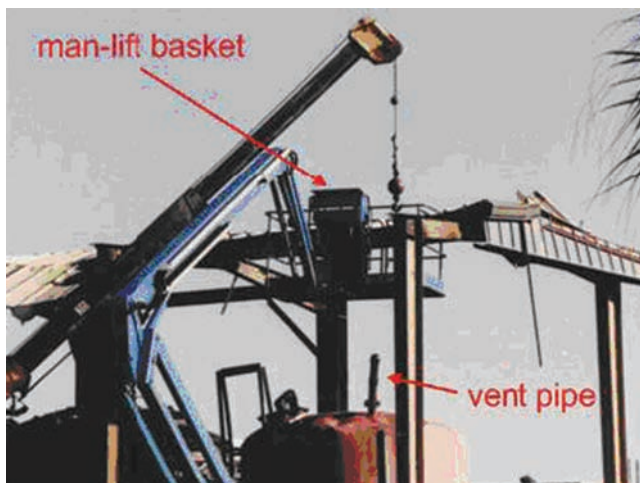


Figure 3. Bethune Point Wastewater Treatment Center: Daytona Beach, FL (January 11, 2006)
Location of man-lift basket and 4-inch vent pipe



Figure 4. West Pharmaceutical Services, Inc.: Kinston, NC (January 29, 2003)



Figure 5. Synthron, LLC: Morganton, NC (January 31, 2006)

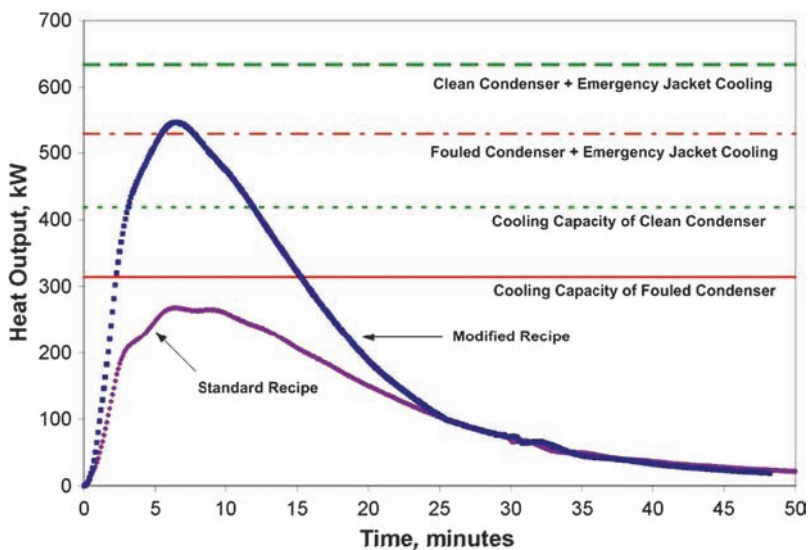


Figure 6. Reaction calorimetry heating curves for standard (lower) and modified (upper) recipes

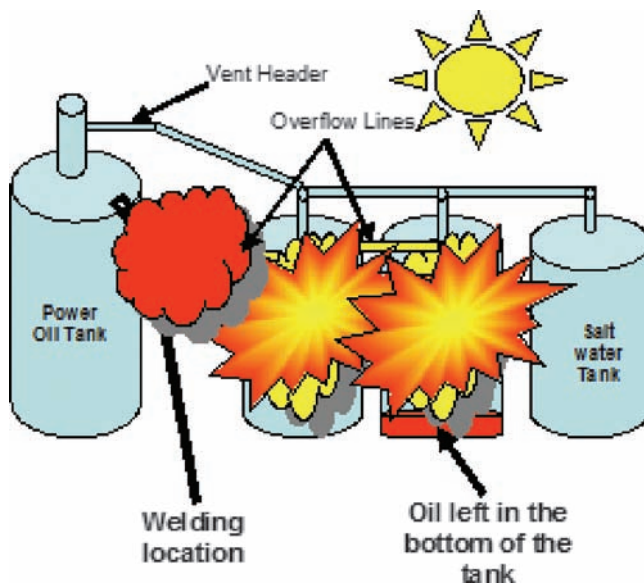


Figure 7. Oil Field Accident



Figure 8. ASCO: damage and debris around the decant water tanks

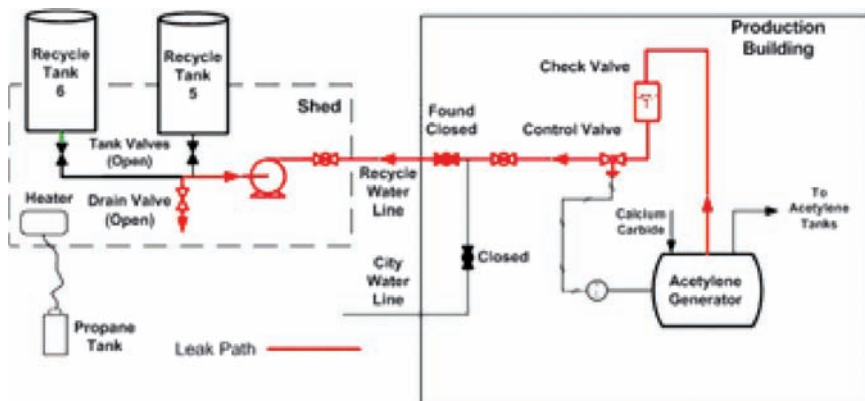


Figure 9. Acetylene system flow diagram



Figure 10. BP: Texas City, TX (March 23, 2005)

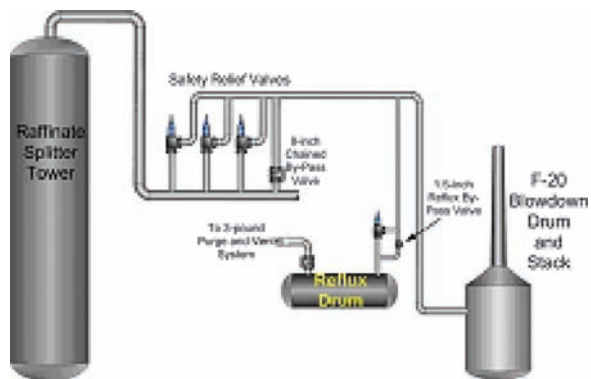


Figure 11. Disposal collection header system