Arcadian, Lake Charles Urea HP Reactor explosion
Lessons to be learned

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1. Introduction

This paper is part of SECRETARY OF LABOR, Complainant, v. ARCADIAN CORPORATION, Respondent. OSHRC Docket No. 93-0628 available on internet (http://www.oshrc.gov/decisions/html_2004/93-0628.html) and the main purpose of this paper is to draw lessons to be learned from this serious accident with the target to avoid similar future accidents.

On July 28, 1992, a pressurized urea reactor exploded after normal working hours at Arcadian Corporation's ("Arcadian's") fertilizer plant in Lake Charles, Louisiana, destroying the facility, injuring six Arcadian employees as well as four employees of other companies in the area and over 90 private citizens.

Mahesh Madhani, a metallurgic failure investigator has been involved in 1000 failure investigations, including investigations involving the analysis of corrosion in austenitic (corrosive resistant) steel. Madhani testified, without contradiction, that the explosion resulted from the failure of the clip weld-joint and liner above the C-7 circumferential weld. The welds between the sections of the outer shell were numbered C-1, C-3, C-5, C-7 and C-9, from bottom to top.

It was concluded that this serious accident could have been avoided by:

a) shutting down the reactor upon the previous detection of leaks in the vessel's lining;
b) implementing an adequate program to ensure that the reactor's leak detection system was properly monitored; and
c) assuring that critical welds were performed according to industry standards and design specifications.

Other Lessons to be learned on can draw from this detailed report are:

i) Any repair / modification should be well described and relevant construction drawings should be updated accordingly
ii) When a weep hole or a leak detection tube shows a leak the plant should be shut down and the leak should be located and repaired. When a leak detection tube first indicates a leak and then stops to show a leak it does not mean there is no leak anymore. On the contrary likely the leak detection system is clogged by crystallization of carbamate and/or urea and more severe corrosion of the carbon steel can take place leading to catastrophic situations

iii) Any HP equipment item with a loose liner should be connected to a proper continuous leak detection system detecting the gaseous leaks, so in an early stage
iv) Any HP equipment item should be internally inspected at regular intervals; Clips of tray support need special attention

Further please be aware that the use of steam in a leak detection system can lead to unacceptable risks; namely stress corrosion cracking of the carbon steel pressure wall from the inside or in the liner, thus in an area which is impossible to inspect.
Finally involve qualified people and companies to do the repair

2. Background - Urea Reactor Design and Operation

The reactor was approximately 90 feet tall and 6 feet in diameter and had a capacity of 1836 cubic feet. The reactor consisted of an outer shell composed of 14 layers of carbon steel and a stainless steel liner. The stainless steel liner was attached only at the top and bottom heads and was ½" thick. The reactor was constructed of four 20-foot high cylindrical sections stacked on top of each other, circumferentially welded together as well as to top and bottom "heads" on either end of the reactor. The weld joining the lowest section to the bottom head was designated C-1 and the weld between the top section to the upper head was designated C-9. The three intermediate section welds were designated C-3, C-5 and C-7.

Urea was created inside the reactor vessel by introducing a mixed stream of ammonia and carbon dioxide into the bottom of the reactor at a pressure of approximately 2750-2865 psig (pounds per square inch gauge) and at a temperature of approximately 340-375° Fahrenheit. The pressure on the mixed stream forced it upwards through the reactor where it was further mixed by "trays," attached by "tray clips" to various points inside the reactor. The mixed stream formed ammonium carbamate, an intermediate stage in urea synthesis. Urea would then be separated out of the ammonium carbamate.

Ammonium carbamate is highly corrosive, especially to carbon steel. To contain the corrosive material as well as the heat and pressure involved in creating urea, the reactor had a wall approximately 4 ¼ inches thick, consisting of a corrosion-resistant stainless steel inner lining surrounded by 14 layers of carbon steel, of which the outer 13 layers were used for "design stress." Between the stainless steel liner and the innermost layer of the carbon steel liner was an open space, or "annulus," which extended from the top to the bottom of the reactor. The reactor was constructed with 24 "weep holes"[1)] that ran from the outside of the reactor through the layers of carbon steel and terminated at the annulus.

Note 1) Weep holes that were installed into the reactor after repair work are sometimes identified in the record as "leak detection holes" or "leak detection tubes" to distinguish them from weep holes that were installed when the reactor was built.

The weep holes were composed of a low alloy steel, similar to the carbon steel wrapped outer layers, and were installed 120 degrees apart from each other, with three located 22 inches above the C-1 weld, three located 22 inches below the C-9 weld, and three located 22 inches both above and below the C-3, C-5 and C-7 welds. The weep holes had an inside diameter of approximately 3/8 of an inch and an outside diameter of ½ an inch. In the event of a breach of the inner stainless steel liner, the reactor's contents would leak out and pass through the weep holes, thereby providing an early warning that a potentially catastrophic condition was developing.

The urea manufacturing process was monitored by three sets of operators. The A operators' were responsible for monitoring the pressure and temperature inside the reactor from the control room board. The A operators also looked at the control room operator's logbook to see what the preceding shift had written, and wrote in the logbook any significant events that occurred on their watch. They also spoke about the reactor's operation with their replacement at the shift change. The only duties the B operators had was to make observations at the lower deck level and the feed lines that went into the reactor. The C operators' responsibilities included checking the reactor's weep holes on an hourly basis. If a C operator saw the reactor's contents coming out of a weep hole, the standard operating procedure was to notify the A operator and the reactor would eventually be shut down. C operators were also responsible for flushing out the affected weep hole with a steam lance to make sure it did not become plugged. Arcadian Urea Area Supervisor R.B. was the supervisor for the A, B and C operators.

3. June 1989 leak

The urea reactor had been shut down because of a leaking weep hole as recently as 1989, when Olin Mathieson Company ("Olin") owned the plant. On June 23, 1989, the urea plant was shut down after leaks were observed in two weep holes, approximately sixty feet from the bottom of the reactor. Operator D.S., who had discovered the leak, testified that urea was "blowing out roughly about a foot, foot and a half at the time it was first discovered." He described the leaking material as being whitish in color. Operator T.C. stated that the leak was "simply an emission of corroded rust colored material from a weep hole" that was "spitting out at a relatively low rate." Operator C.H. described the leak as being a "white substance" that was coming out in "little spurts."

D.S. notified the lead operator, M.S., who also observed the leak. M.S. then called urea unit superintendent D.B. D.B. described the leak as being "brownish-white-red looking, an off color looking urea." He described the stream as "much the same as you would expect to see if somebody was holding a water hose with a constricted nozzle at that point on the reactor, going out" and that it was streaming out approximately 10 to 15 feet. D.B. reviewed the reactor drawings and determined that there had been a breach of the liner, and within one hour of discovering the leak decided that the reactor should be shut down. When asked at the hearing "What was the basis on which you made your decision in 1989 to instruct Mr. M.S. to begin shutting down the reactor," D.B. replied: "I had been around this business long enough to know that a leak detection system or a weep hole system was a telltale system of something that told you you had a problem, a breach of the liner. So on that basis, that was the thing to do."

Within a day after the shutdown, Olin assembled a team to begin planning a response to the leak. The team shut the plant down, decontaminated it and cooled it to allow them to enter the reactor. Olin chose an Austrian firm, Schoeller-Bleckmann, to repair the reactor. Two representatives from Schoeller-Bleckmann, P.S. and J.P., arrived on June 30. After an extensive investigation, P.S. and J.P. determined that although the liner was thin in the C-5 weld area, it was repairable. That same day, P.S. and J.P. left but returned later to supervise Olin's employees as they performed the repairs.

During the 1989 repairs, stainless steel filler patches were welded flush into the reactor’s liner in the area of the C-3, C-5 and C-7 circumferential welds where portions of the original liner had been cut away. The filler patches were tack welded to keep them in place. Overlay patches were placed on the inner wall of the liner adjacent to the filler patches. The overlay patches were seal welded to keep the contents of the reactor from escaping. Three more weep holes were added; two along the C-5 weld and one in the C-7 weld area. They were welded to the carbon steel, not the stainless steel liner, and would monitor the space between the carbon steel wraps and the stainless steel liner. A total of 8 patches were installed, and all the tray clips were replaced. The repairs passed an ammonia leak test under Stamicarbon specifications, which showed that the reactor was not leaking. In addition, Olin established through an air pressure test that all the weep holes were clear of any blockage. Olin also performed dye penetrant testing of each weld as well as a hydrostatic test, both of which are non-destructive methods of determining whether the lining and welds were porous. Through these tests they determined that there were no leaks. The work was completed on August 16, 1989.

S. examined the leak detection tube at the C-7 weld, and testified that the only differences between the original weep holes and the 1989 leak detection tubes were the material the tubes were made of (stainless in 1989 vs. low alloy steel in the original construction), and the way the tubes were welded into the outer shell. Both the weep holes and the leak detection holes monitored the annulus between the outer shell and the liner. Under normal conditions, material coming out of the weep holes indicates that carbamate has gotten through the liner.

The final report from Schoeller-Bleckmann, containing repair specifications was made available to Arcadian. The report was not consulted between the time the leak was discovered and the July 28 explosion. As in the proposal, the specifications call for tack welds around the filler patch. A photograph of the completed C-7 weld, contained in the report, shows the tack welding around the filler patch. The specifications call for, and photographs of the C-7 filler patch show a hole drilled into the patch as part of the leak detection system.

4. Arcadian’s purchase of the reactor

That same month, Arcadian purchased from Olin the urea and ammonia facilities that were located within Olin’s Lake Charles complex. In September of 1989, Arcadian shut down the facility to address production problems in the ammonia unit and perform “minor maintenance” in the urea unit. The reactor was also shut down for maintenance repairs or revisions. Such shut downs were known as “turnarounds.” There were two later turnarounds, one in early 1990 and another in February 1991. Arcadian personnel, including D.B. and R.B., entered the reactor only during the third turnaround in 1991, when they checked the thickness of the stainless steel liner. D.B. and R.B. determined that there had been virtually no change in liner thickness based on their measurements compared to the ones made in 1989.

5. January 3, 1992 leak

On December 31, 1991, minor problems in Arcadian’s ammonia plant forced both the ammonia and urea plants to shut down. Both plants were restarted on January 2, 1992. At approximately 1:00 AM on January 3, 1992, operators D.R., Dd.B. and B.B. noticed a small brown blob of urea hanging from a weep hole in the area of the C-7 weld on the northeast side of the reactor. D.R., who described it as having “a milky color with a rusty color in it,” stated that it was approximately five inches long and two inches around and hung from the weep hole like an icicle. They showed it to A operator M.P.S. M.P.S. called D.B. at home and informed him of the blob. D.B. instructed the operators to check and clean out the weep holes. D.R. and Dd.B. found material in another weep hole to the northwest in addition to the one where the extrusion was found. D.R. steamed out the C-7 weep hole in order to clear it, but did not recall steaming the northwest weep hole. After steaming the weep holes, D.B. was informed by Dd.B., D.R., and B.B. that the weep holes that they had steamed were clear, although Dd.B. did not believe that the other weep holes on the south side and around the head of the reactor were clear. D.B. told the operators to continue monitoring the weep holes for further emissions and M.P.S. wrote down in the log book per D.B.’s instructions: “Note: There may be a possible hole in reactor, so please pay close attention to the weep hole above [valve] PCV 4 per D.B.”

Because no more material came from the weepholes that night, D.B. believed that the material had not come from a leak in the reactor liner but instead came from residual material from the 1989 leak. He believed that reactor shutdowns and startups created “temperature and pressure cycles” which squeezed the stainless steel lining to the pressure-bearing outer layers and that this action eventually forced the material out of the weepholes. D.B. believed that it did not signify a breach in the liner because a breach would have caused a steady stream of material from the weep holes as it did with the breach in 1989.

On the night he was notified of the leak, D.B. telephoned his supervisor, Plant Manager E.E., at home and told him of the situation. Although E.E.’s first reaction was that it was a leak and that a shut down was required, D.B. told E.E. that he believed that the extruded material came from material left behind from the 1989 repairs and that while it had leaked earlier, it was not leaking at the time of their conversation. E.E. decided to keep the reactor running but to continue monitoring because “B.D.’s reasoning and logic was sound and this probably was material that had been trapped behind the liner.” He further testified, “we did not know that it had come from the weep hole and the weep hole was not leaking.” E.E. did not think that he was risking the safety of employees in the plant “Because this reactor wasn’t supposed to fail” since “It had wraps and it was build in a specific way. That’s how it kept it from failing.” At the daily morning meeting conducted by E.E. and his staff the following Monday, D.B. told of the discovery of the blob and the decisions taken. No one at the meeting disagreed with D.B.’s decision to continue operations. When R.B., the urea area supervisor, returned from his vacation, he reviewed the operator’s logbook and talked to the operators. He did not remember anyone saying that the blob was found on a weep hole and never saw the blob itself.

6. June 14, 1992 leak

On Sunday, June 14, 1992, at about 6:00 pm, operators C.S. and M.P.S. discovered a leak from a weep hole in the C-5 weld area, near the center of the reactor. M.P.S. described the leak as “a flow of white liquid coming out of that weep hole, and as it came out, it was fizzling.” M.P.S. claimed that “It wasn’t spraying out” but that it was a “stream that was blowing out.” C.S. and M.P.S. called D.B. at home about the leak. M.P.S. testified that D.B. said he would look at it when he came in on Monday morning. C.S. wrote in the logbook: “Weep hole leaking on reactor at 4th floor level (blowing bubbles) informed D.B. of situation.”

R.B. was informed of the leak when he arrived at the unit on Monday morning shortly before 6:00 a.m. When he went to investigate, he found that the tube contained a “white crystal material” and noted that “every once in a while you could see a small bubble.” He flushed out the weep hole with a steam lance and left. When he returned "a little bit later," he saw that the tube again contained more material. He rodded out the tube again with the steam lance and flushed it out until it came out the other leak detection tube. R.B. thought the reactor should be shut down, so he went down to the control room, held the night shift over, and told the operators to begin reducing production levels in preparation for the shutdown. R.B. then drove to the administration building to discuss the leak with D.B.

R.B. believed that the one of the 1989 welds had failed. He told D.B. that he believed that the reactor needed to be shut down, but D.B. persuaded him that it was not necessary. Based on his review of drawings of the reactor, D.B. determined that the leak came from inside the reactor through a leak detection tube from the C-5 area repaired in 1989. D.B. showed his journal of the 1989 repairs as well as drawings, repair and reactor data to R.B. He explained to R.B. his belief that the overlay patch had a fillet weld that had a pinhole-sized leak that was filling the space between the stainless steel overlay and filler patches. He believed that the leak was not in contact with carbon steel because a seal welding of the flush patch protected the carbon steel outer shell. They agreed that the material leaking from the weep hole was not in contact with the carbon steel shell and that it was not necessary to shut down the reactor.

D.B.'s recommendation to R.B. was that while the current leak required observation, the reactor was safe and there was no need to immediately shut it down. D.B. believed that if the leak was in contact with carbon steel, there would have been a reddish discoloration in the discharge. He assumed that the leak was not in contact with the carbon steel liner because he thought that the insert patch at C-5 was full seal welded, and that the leak detection tube went through the carbon steel and was welded to the liner insert patch so that it monitored only the space between the two stainless steel liners.

R.B.'s response to the leak was based on his belief that it was not in contact with the reactor's carbon steel layers. According to R.B., if he knew that the leak detection tube that was leaking the reactor's contents did not monitor the space between the two stainless steel patches, but instead monitored the annulus between the carbon steel layer and the inner stainless steel layer, just like the older weep holes, he would have shut down the reactor. R.B. testified that if the leak had been coming out of one of the originally installed weep holes, he would have shut the reactor down. He also stated that if he had known the patch was actually tack welded and not full seal welded, he would have realized that the reactor's contents could have been in contact with the carbon steel and R.B. would have shut down the reactor. D.B. agreed that if the patch was not full seal welded, the reactor's contents would migrate into the carbon steel area "just the same way it did in 1989."

Later that morning, D.B. also explained to E.E. why he thought it was safe to continue using the reactor. After his meeting with D.B, R.B went to the urea operators and explained to them that they believed the C-5 insert patch was full seal welded. R.B. and the operators decided that they had to wash out the leak detection tube every shift. They then brought the reactor back up to production rates. They planned to make repairs in the area of the C-5 weld during the next scheduled turnaround. R.B. believed that the next turnaround would be in the fall of 1992, but he discovered after the accident that the next turnaround was pushed back to 1993. At the hearing, R.B. was unable to find anything in D.B.'s journal to show that the patch was full seal welded or that the tube that was installed was welded to the liner. R.B. could not remember what he and D.B. read that led them to conclude that the leak was not coming in contact with the carbon steel lining and that it was safe to operate the reactor.

7. July 28, 1992 explosion

According to A operator M.P.S., “Everything was running very well” on the night of the explosion. The explosion occurred at approximately 7:20 p.m. Subsequent investigations commissioned by Arcadian and the Secretary determined that the explosion resulted from the failure of the tray clip weld joint and liner above the C-7 circumferential weld in the northeast quadrant of the reactor due to stress corrosion cracking and weld toe corrosion. Once the stainless steel liner was penetrated, the carbamate corroded the carbon steel layers. Two weep holes in the northeast quadrant above and below the C-7 weld were completely obstructed with corrosion and process products.

Fire at Arcadian plant injures 25

08 October 1992 00:00 [Source: ICB]

TWENTY-FIVE PLANT workers and members of the local community were treated in hospital for respiratory problems and physical injuries after a major explosion on 28 July at Arcadian Partners LP's urea plant near Lake Charles, Louisiana. According to **Chemical Marketing Reporter,** the plant's main synthesis reactor, a high-pressure vessel containing ammonia and carbon dioxide ruptured.

Unconfirmed press reports quoted an Arcadian spokesman as saying the injuries were 'mostly a result of a release of ammonia used in the urea production'. The reports said the explosion caused substantial damage to the plant, the nearby ammonia facility and the surrounding Olin chemicals complex. The urea unit has been shut down and is expected to remain closed for three to six months.

8. Discussion points

Is this Arcadian case a unique story ?

Several similar incidents are reported in the past and others might not have been reported at all or as detailed as this Arcadian case:

- A urea reactor has failed in 1976 in Chattanooga, Tennessee, USA, where ammonia was released and the reactor had to be scrapped.
- Jojima's paper "Urea Reactor Failure" details the 1977 failure of a urea reactor in Columbia and was presented at the 1978 AIChE symposium. It was understood that in the Columbian incident the reactor's outer shell corroded until it wouldn't support the vessel pressure and exploded. Thirty-three people were killed by the ammonia fumes released.
- There seems to have been an incident in South Africa.
- There was an incident involving a multi-layered urea reactor operated by CF Industries, USA in which a leak developed in the liner, corroding the shell. When the shell could no longer sustain the interior pressure, the contents of the reactor were "ejected," through the head of the reactor.
- More recently a reactor exploded in Myanmar and in China (Pingyin), a detailed investigation report of the Pingyin case is enclosed the Urea E-Library of UreaKnowHow.com.

This list just gives some examples of incidents with urea reactor and the author believes the list is not complete. Further Incidents related to leaking loose liners in high pressure heat exchangers are not part of this list. The list shows already the Arcadian case is not unique.

What to do when a weep hole or leak detection tube shows a leak ?

When a weep or leak detection hole shows a leak the plant should be shut down and the leak should be located and repaired. Sometimes arguments are used such as we need urea production, maybe the leak will be too small to find or as in the Arcadian case maybe what we see is urea from an earlier leak.

In this respect a continuous leak detection system which can measure already the gasses from a leak and which can also measure an increase of leak size is of advantage as it confirms if there is a leak and how fast the leak grows.

Older HP equipment items have obviously more risks of a leak and the top area of a reactor is more prone to this risk because of condensation corrosion risks.

When a leak stops it does not mean there is no leak anymore: it can also mean the carbamate and/or urea has clogged the leak detection system and in that case carbamate will not dissociate anymore into gaseous ammonia and carbon dioxide and will cause corrosion to the liner and even worse the carbon steel pressure wall. This can lead to catastrophic situations as shown in this Arcadian case.

How a leak detection system should look like ?

The Arcadian case shows a situation that plant operators monitor hourly visually if a leak occurs and use a logbook to register their findings. The weep holes and leak detection tubes are not connected to an analyzer, so fumes or solids can only be detected visually. Some weep holes or leak detection tubes were not reachable which makes a detection impossible or very difficult. A regular check that the weep holes or leak detection tubes are not clogged is important and impossible in case these tubes are nor reachable. Any HP equipment item with a loose liner should be connected to a proper continuous leak detection system in order that an early leak detection at a non corrosive gaseous stage becomes possible.

Photo: A simple but effective way to monitor gaseous ammonia leaks from a leak detection system

Regarding the use of steam in a leak detection system different views exist in the industry. Be aware that the use of steam in a leak detection system can lead to unacceptable risks; namely stress corrosion cracking of the carbon steel pressure wall from the inside or in the liner, thus in an area which is impossible to inspect.

Repair procedures

Any repair / modification should be well documented and relevant construction drawings should be updated accordingly and made as built and available for the responsible people. Experienced and qualified companies should be involved in any repair or modification. Removing old process material like solid carbamate and urea by flushing and cleaning is best practice and is wise to avoid any doubts when a new leak is found.

Inspection procedures

Any HP equipment item should be internally inspected at regular intervals; legislation, age, condition and corrosion speeds should determine the interval time. A repair of modification should be inspected after one year operation. Clips of tray support need special attention. Experienced and qualified companies should be involved.

References:

1. SECRETARY OF LABOR, Complainant, v. ARCADIAN CORPORATION, Respondent. OSHRC Docket No. 93-0628
2. 2009 04 Brouwer UreaKnowHow.com Leak Detection Systems in Urea Plants

Mark Brouwer was born on July 6, 1966 in Groningen, The Netherlands. He graduated in 1988 at the Technical University of Eindhoven at the faculty of Chemical Engineering. His thesis was about the production of ethylene by partial oxidation of natural gas.
After University Mark joined Military Services, Dutch Royal Navy where he was working at the Prins Maurits Laboratory of TNO in Rijswijk. In this period he was involved in Process simulation studies on the absorption of poisonous gasses on active carbon.

In 1990 he joined DSM, working for the Ethylene Plant No.4 as a Process Engineer. In these seven years he was involved in the Basic Engineering of a debottlenecking project at Stone & Webster in London and in the implementation of the DSM Extraction Styrene project (from Conceptual Engineering up to the successful start up) .

In 1997 he joined Stamicarbon, the Licensing subsidiary of DSM as Licensing Manager Urea Revamps. Later he became Manager Stamicarbon Services responsible for all Stamicarbon's activities in existing urea plants, such as After Sales, Plant Inspections, Debottlenecking Projects, Reselling projects etc. In these nearly twelve years he did visit nearly one hundred urea plants worldwide and was involved in numerous revamp, relocation, debottlenecking and grass root projects.

Since January 1, 2009, Mark Brouwer left Stamicarbon and started up UreaKnowHow.com.
UreaKnowHow.com is an independent group of urea specialists with an impressive number of years experience in designing, maintaining and operating urea plants. UreaKnowHow.com's mission is to support, facilitate and promote the exchange of technical information in the urea industry with the target to improve the performance and safety of urea plants.

Please feel welcome at UreaKnowHow.com, the website where the urea industry meets.

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