Explosion Investigation Report

550 9th Ave East, Regina, Saskatchewan

Time: 14:06
Date: October 6, 2011
Location: 550 9th Ave East, Regina, Saskatchewan
Occupancy: Industrial
Owner: Consumers' Co-operative Refineries Limited (CCRL)
Injuries: 52 (reported as per document #108 provided by (CCRL)

Introduction

On October 6, 2011 at 14:06 hours a fire related incident occurred in the process area Middle Distillate Unifier 5,6,7 at the Consumers' Co-operative Refineries Limited in Regina, Saskatchewan.

Municipal and Provincial authorities, under their respective legislation, assembled to conduct an investigation into the incident. The investigation team consisted of representatives from:

- Regina Fire & Protective Services (RFPS) (Municipal)
- Emergency Management and Fire Safety (EMFS) (Provincial)
- Ministry of Labour Relations and Workplace Safety (OH&S) (Provincial)
- Technical Safety Authority of Saskatchewan (TSAS) (Provincial)

The findings and conclusions of this report, issued on behalf of investigation team members with the authority to enforce The Fire Prevention Act, address the determination of cause, origin and circumstances as per *"The Fire Prevention Act, 1992 Section 13(1)(a)(b)(c)(d)(e)"*.

Regina Fire & Protective Services initially secured the area with a third party security firm until a physical barrier was erected as determined by the investigation team. Security staff were located strategically to ensure continuity of the secured area and were supplemented by a 24 hour surveillance camera located on the coker unit. The security procedures were maintained 24/7 until the investigation team released the physical scene back to CCRL on December 5th, 2011 at 11:17 hours.

Overview

Consumers' Co-operative Refineries Limited fire/emergency response team controlled and extinguished the fire with mutual aid support on stand by from Regina Fire & Protective Services.

Multiple injuries were reported, triaged and treated on site and/or transported to Regina area hospitals.

The investigation team was briefed by CCRL engineers and experts of the processes and related component functions of the Middle Distillate Unifier (MDU) unit in area 5,6,7.

The Middle Distillate Unifier 5,6,7 was in operation at the time of the incident.

Initial observations indicated major damage to the compressor building, the pipe rack East of the compressor building and adjacent components.

Findings

1. Initial witness statements taken immediately after the evacuation indicate that the fire and subsequent explosions occurred in or near the Pipe Rack adjacent to the East side of the Compressor Building.
2. Numerous witnesses in the area of MDU 5,6,7 reported hearing a high pitched whistle immediately prior to the fireball that enveloped the East pipe rack.
3. Witnesses also indicated that there were 2 and possibly 3 explosions following the initial fireball.
4. The generation of the overpressure from the initial fireball or release was substantial enough to cause the boom on a crane located approx. 40 metres away to sway violently. The crane operator fell from the machine to the ground.
5. The effect of the overpressure on the boom was captured on video from a camera located on the Coker tower.
6. The camera on the Coker tower was capturing footage slightly east of the incident area and could not be re-positioned on the area of interest during the initial events, due to a computer malfunction.
7. After the initial fireball, the majority of heat release and by-products of combustion were carried in the plume over the Compressor building, traveling North-West.
8. Weather conditions during the initial event were as follows:
   14:00 hours Temp: 22.3 C Wind Speed 24 KM Wind Dir. 140 degrees
   15:00 hours Temp: 22.5 C Wind Speed 35 KM Wind Dir. 140 degrees
9. An initial scene overview conducted by the Investigation team on October 7th, indicated damage to portions of the MDU 5,6,7 site was extensive, but localized.
10. A safety audit was conducted by the Investigation team in consultation with Workplace Safety (OH&S) and CCRL experts prior to the start of the physical scene examination.
11. The physical scene examination commenced with processing the concrete pad east of the Compressor building.
12. The concrete pad measured 5.3 m in width and 32.5 m in length.
13. A grid system was incorporated to process debris on the concrete pad starting from the south end.

14. Grids 3-14 measured 2.6 m by 4.5 m and grids 1 & 2 measured 2.6 m by 5.1 m.
15. Examination of debris in this location revealed numerous items were present pre-incident, but the majority was dislodged from the pipe rack and compressor building during the incident.
16. Melted aluminum alloy was found solidified on top of the concrete pad in this area.
17. It was noted, masonry building materials from the compressor building were located on top of the solidified aluminum alloy. This indicates that the material from the compressor building east wall was dislodged after the initial failure within the East pipe rack.
18. The drive engine compartment of the compressor building received localized damage from fire, and at least 1 low order explosion/over-pressure.
19. Damage to the compressor compartment of the building was limited to fracture damage of the partition wall, as a result of the explosion in the drive engine compartment.
20. The majority of the blast damage to the structure occurred in the upper portion of the drive engine compartment. Damage was localized to the East wall and roof structure adjacent to the operating drive engine.
21. Fire damage to the structure was limited to an area above the operating drive engine.
22. Fire damage to material within the structure included, external surfaces of both drive engines, components and equipment in the immediate area of the operating drive engine.
23. The remainder of the engine compartment received smoke and moderate heat damage from the fires burning within the East pipe rack and interior of building.
24. One of two drive engines was operating at the time of the failure within the East pipe rack.
25. The operating drive engine referred to previously, is located near the center of the compartment and directly South of the second drive engine.
26. Computer data and evidence gathered during examination validates that this drive engine was operating.
27. The engine's air intake pipe is connected to the turbo-charger by a flexible rubber coupling.
28. Fire damaged material from the rubber flex coupling was drawn toward the intake impeller in the turbo charger, validating that the engine was operating during the fire in the East pipe rack.
29. Prior to the engine failing, it was subjected to an internal over-pressure, caused by the induction of an external flammable vapour-air mixture.
30. Evidence validating this over-pressure was observed on the engine and related components.
31. Excessive pressure in the crankcase dislodged the safety blast plates spilling engine oil down the side of the engine crankcase.
32. The engine oil dipstick was ejected from the dipstick tube.
33. The explosion/overpressure within the crankcase was violent enough to shear off 1 engine mounting bolt.

34. A flammable vapour –air mixture within the air intake ignited and dislodged the safety blast plate that was located near the air cleaner. Blast plates are designed and installed on stationary combustion engine's located in hazardous atmosphere's, to disperse excessive internal over pressure.
35. The flammable air –vapour mixture did not originate within the compressor building.
36. The Natural Gas supply lines within the building were pressure tested during the investigation and deemed serviceable.
37. Observations of the steel grating that forms part of the floor in the drive engine compartment, displayed signs of oxidation in random locations. The oxidation appeared mainly in the area of the operating drive engine and East wall adjacent.
38. The oxidized area of grating was damaged by heat and direct flame contact from below.
39. The fire below the walking surface was caused by flowing ignitable liquids entering from the East pipe rack area.
40. The remainder of the steel grating in the engine compartment was unaffected by heat from the fire.
41. The fire patterns that caused localized damage to the floor grating was validated by members of the investigation team after entry was made into the confined space below the engine compartment floor.
42. The fire and explosion damage to and within the Compressor building was a direct result of the initial fire that originated within the East pipe rack.
43. The damage to the compressor building and contents are classified as an exposure loss.
44. Materials, equipment and infrastructure on the roof of the compressor building was damaged by direct flame contact and radiant heat generated from the fire within the East pipe rack. This damage is considered an exposure loss.
45. Damage to perimeter equipment and infrastructure located North and West of the compressor building is considered an exposure loss.
46. Three hydrogen supply lines located within the East pipe rack area were compromised as a result of direct flame contact and radiant heat generated from the fire, resulting in a release of hydrogen gas.
47. A flash drum off gas line located in the East pipe rack area was compromised as a result of direct flame contact and radiant heat generated from the fire, resulting in the release of hydrogen gas.
48. Refer to document #127 "Line Integrity Evaluations 5-6-7" for pressure test results on lines in the damaged area.
49. Monitoring equipment supplying data to the control room operators indicated a loss of pressure in the reactor effluent line 07-P008-FA5M-6".
50. An uncontrolled pressure drop in this line was recorded at 14:03:11 hours from 674.38 psi to 105.31 psi at 14:03:31 hours as per CCRL document #46 – 5A Rev #1.
51. Scaffolding was erected at the location of the failure in the reactor effluent line 07-P008-FA5M-6 to allow the investigation team visual access.
52. Indications that a catastrophic failure occurred in the reactor effluent line 07-P008-FA5M-6 in the East pipe rack. The area of failure was protected from the

elements with a variety of coverings, following extinguishment and stabilization of the scene. Protection of this area was ordered by the Investigation team .

53. At this time, other experts were brought into the investigation to further analyze the failure area of the reactor effluent line 07-P008-FA5M-6.
54. Sections of pipe were sent to Anderson and Assoc. for detailed analysis. See Anderson and Associates file # 14593, Origin and Cause Metallurgical Examination.

Narrative

The circumstances surrounding the events that occurred at the CCRL facility on October 6th, 2011 are as follows.

The reactor effluent line 07-P008-FA5M-6 located within the Middle Distillate Unifier 5,6,7 suffered a catastrophic failure to a small portion of the line. The rupture area was located in a pipe rack adjacent to the East side of the compressor building. This failure is defined as a Mechanical Explosion. Data recorded indicates that the system was functioning as expected immediately prior to the failure, with no anomalies recorded in the hours leading up to the failure. Given the processes involved in that area of the facility, coupled with numerous ignition sources and an abundance of ignitable liquids, the fire that ensued would be inevitable.

The initial blast overpressure that was experienced immediately following the ignition of the Combustible liquid leaving the ruptured reactor effluent line is classified as a Combustion Explosion. These explosions are frequently characterized by the presence of a fuel with air as an oxidizer. In combustion explosions, overpressures are caused by the rapid volume production of heated combustion products as fuel burns. Given the large volume of product under pressure leaving the rupture, explosions of this nature are common in this circumstance.

All of the damage sustained in this portion of 5,6,7 is as a result of the ruptured reactor effluent line. Direct flame contact or radiant heat from the initial fire caused a number of Hydrogen product lines to breach, thus intensifying the ensuing fire on other portions of the affected area.

Through the detailed examination of CCRL documents relating to testing protocols and test results of product lines and vessels, the following observations were made,

1. Testing of the 6 inch reactor effluent line for mass reduction and general condition is carried out by CCRL on a regular basis, at 23 pre-determined locations. It cannot be determined how these locations were chosen by CCRL.
2. The majority of testing is done in locations of pipe where the product flow changes direction.
3. Straight run lengths are less frequently tested.
4. Documentation is very limited prior to the 1980's

5. The previous test results on the reactor effluent line 07-P008-FA5M-6 indicated the wall thickness and general condition were still within acceptable limits.

Observations made during the scene examination indicate that this particular length of pipe from weld to weld has a much reduced wall thickness than other lengths that attached.

Conclusion

The investigation concludes that this was a catastrophic failure.

This fire is classified as Accidental.

Signed July 16th, 2012 in Regina Saskatchewan

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29.0 Findings and Conclusions

1. Our preliminary examination of the fire scene confirmed that five separate pipe ruptures occurred in the MDU area of the CCRL refinery.
2. Our visual and metallurgical examination of these five pipe ruptures, as well as a review of the process and alarm data concluded that the first failure was the 6 inch Reactor Effluent Line 07-P008-FA5M-6.
3. Hydrogen gas, which has particularly low ignition energy in air, was likely the first fuel to be ignited. Ignition was likely due to the release of an electrostatic build up from product flowing from the rupture.
4. Following field cuts, it was determined that three pipe segments, 14593-4, 14593-5 and 14593-6, formed the one "stick" of pipe from weld to weld that contained the rupture in the 6 inch Reactor Effluent Line (07-P008-FA5M-6).
5. The rupture itself was in pipe segment 14593-6. This pipe initially opened up longitudinally or lengthwise along the pipe over an approximately 7.25 inches length between the 10 and 11 o'clock positions (when looking downstream). Following formation of this initial longitudinal rupture, cracking propagated circumferentially from either crack end forming two open flaps.
6. The pipe wall on either side of the rupture was reduced by internal corrosion well below CCRL's retirement wall thickness of 0.267 inch.
7. The pipe loss due to corrosion in the rupture area was substantial enough that the failure occurred at normal operating pressure.
8. There was no evidence of any pressure or temperature upsets leading up to the incident in the operating data.
9. Severe general internal corrosion was observed in the upper half to two thirds of the three pipe segments 14593-4, 14593-5 and 14593-6 with a moderate amount of scale or oxide build up.
10. Corrosion trends were similar to the ruptured pipe segment, which had uniform or general internal corrosion in the upper half to two thirds of each pipe segment, in all of the other older pipe segments (14593-2, 3, 7, 8, 9 and 10).
11. Wall thickness values below CCRL's retirement limit of 0.267 inch were identified in every pipe segment (14593-2, 3, 7, 8, 9 and 10) from the Reactor Effluent Line (07-P008-FA5M-6) with the exception of the pipe segment that was replaced in 2010 (14593-1).
12. Wall thickness measurements were substantially lower in the ruptured pipe joint (14593-4, 5 and 6) compared to all other pipe joints that were sampled. CCRL did not begin maintaining complete records until the late 1980s. Although there is no record of it, most likely pipe surrounding the ruptured pipe joint was replaced by CCRL in the past while the ruptured segment was not.

13. Nominal 6 inch schedule 40 pipe wall thickness is 0.280 inch. As the one 6 inch Reactor Effluent Line pipe joint (14593-4, 14593-5 and 14593-6) was greater in wall thickness than nominal, it's clear that this ruptured pipe joint was not schedule 40 but rather originally schedule 80.
14. Our mineralogical examination of the corrosion scale suggested that the general internal pipe corrosion was result of hydrochloric acid, water and hydrogen sulphide in the process stream.
15. It is likely that corrosion of the 6 inch Reactor Effluent Line was caused by a complex corrosion process involving ammonium bisulphide, hydrochloric acid, water and hydrogen sulphide, all present in the process stream under more recent process conditions from 2010 onward.
16. Non-annular product flow conditions directly contributed to asymmetrical or unequal wall thinning or corrosion that was observed in the 6 inch Reactor Effluent Line.
17. CCRL indicated that process stream conditions from 2008 onward may have shifted the tendency toward more active corrosion in the 6 inch Reactor Effluent Line upstream of the product condenser and downstream of a water wash injection. This was reflected by very high corrosion rates in the 6 inch Reactor Effluent Line piping between 2008 and 2010. This severely corroded piping was replaced in 2010, but no changes to the process were made to lower corrosion rates.
18. The measured corrosion rate in the newest pipe segment, 14593-1, was 45 mpy, thus confirming that no changes were made to the process to lower corrosion rates.
19. CCRL do not have a formalized Interval-Based or Risk-Based Pipe Inspection Plan.
20. No root cause or corrosion analysis, in accordance with CCRL's informal inspection plan, was ever conducted on any of the damaged piping that was removed from the 6 inch Reactor Effluent Line in 2010; therefore, it appears that this informal inspection plan is not adhered to rigorously.
21. CCRL did not inspect the 6 inch Reactor Effluent Line between TML 13 and 14 in 2010 for possible corrosion when they had just replaced the pipe downstream of TML 14.
22. It is unclear from our investigation CCRL's criteria for determining thickness monitoring locations (TML's). The current model or methodology in use did not accurately predict or prevent this catastrophic failure nor the extensive general corrosion that was identified in all of the 6 inch Reactor Effluent Line piping (with the exception of the newer 2010 piping) that was examined during this investigation. This suggests that more TML's are required.
23. Historical wall thickness measurements from TML 13 indicated an approximate 1 to 2 mpy corrosion rate over a roughly 50 year period with no increase in corrosion rate between 2008 and 2010. The rupture and the extensive general corrosion that was identified downstream of TML 13 suggests that the current corrosion monitoring system is not working effectively.

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24. Both the 4 inch Platformer Hydrogen Line 06-P605-CA5M-4 and the 3 inch Section III Hydrogen Line pipe 56-P059-FA5M-3 failed as a result of short term overheating causing stress rupture.

25. The 1.5 inch Flash Drum Off Gas Line 07-P031-AA5A-1-1/2 (AACE 14593-12) and the 2 inch Hydrogen Spillback Line 07-P020/021-FA5M-2 were not pressurized at the time rupture as they lost containment via failure of the 6 inch Reactor Effluent Line.

26. Both the 1.5 inch Flash Drum Off Gas Line 07-P031-AA5A-1-1/2 (AACE 14593-12) and the 2 inch Hydrogen Spillback Line 07-P020/021-FA5M-2 were damaged by exposure to hydrogen-fed fire. This fire caused extensive material loss due high temperature oxidization.

27. Mechanical testing of 6 inch Reactor Effluent Line (07-P008-FA5M-6) pipe material approximately 174.4 inches downstream of the rupture met the requirements of ASTM A53 Grade A Type S material, with the exception of elongation. Given the age of this pipe and the possibility that heat damage occurred during the fire, a decreased elongation could not considered unusual.

28. An optical emission spectrometry chemical analysis conducted on a sample from the 6 inch Reactor Effluent Line (07-P008-FA5M-6) ruptured pipe segment met all the requirements of ASTM A53 Grade A Type S with respect to chemistry.

29. The microstructure of pipe sample 14593-6.7 (main rupture) was typical for seamless, hot rolled pipe consisting of ferrite and pearlite with some non-metallic inclusions. No microstructural defects were identified in either location.

30. The hardness of the pipe material in the 6 inch Reactor Effluent Line away from the rupture and any heat effects was typical for seamless, hot rolled pipe and similar to measured hardnesses in the next downstream pipe segment.

I trust this report is satisfactory for your present purposes. If any questions exist or arise, please do not hesitate to contact the undersigned.

Yours truly,

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