Root Cause Analysis of the Uncontrolled Hydrocarbon Release from Aliso Canyon [well] SS-25

Blade Energy Partners, Frisco Texas 5-16-19

Executive Summary

The Standard Sesnon 25 (SS-25) well was shut in at 3:30 PM on October 23, 2015; a leak was discovered at 3:15 PM. The 7 in. production casing had axially ruptured and circumferentially parted. This resulted in a blowout and gas release into the atmosphere, which lasted for 111 days, until the well was eventually killed via a relief well on February 11, 2016.

SS-25 was drilled as an oil well in 1954. After the oil was considered depleted, SS-25 was converted to a gas storage well in 1973. Operationally, there were some key differences between the use of SS-25 in oil production mode and in gas storage mode. As an oil well, the oil was produced through a tubing string; the primary mechanical barrier to the oil was the tubing, and the secondary one was the casing; the pressure load decreased through the life of the oil well due to depletion of the oil. As a gas storage well, the gas was injected and withdrawn through the tubing and the casing, making the casing the primary barrier for the gas during gas storage operations. Operating pressure loads remained the same or at similar levels despite annual and seasonal variations caused by gas demand through the life of the well.

Pressure tests were conducted on the SS-25 casing in 1973 during the well's conversion from oil production to gas storage. The well's integrity was monitored using yearly temperature logs and occasional noise logs. If a leak in the casing had occurred, then the casing would have locally cooled, and consequently the temperature would have deviated at the leak location. The SS-25 temperature and noise logs had never shown an anomaly related to casing integrity. Pressure measurements, which were collected at SS-25 weekly, had not indicated a leak or failure prior to the incident. Well integrity issues went undetected until the leak event of October 23, 2015.

The Aliso Canyon storage wells had numerous casing leaks. Blade reviewed 124 gas storage wells and identified 63 casing leaks, 29 tight spots, 4 parted casings, and 3 other types of failures. Based on the data available to Blade, no details regarding the nature or cause of these leaks and failures were available because no failure analyses were done. Forty percent of the gas storage wells reviewed by Blade had casing failures with an average of two casing failures per well. The FF-34A well file mentioned a study of the possible external casing corrosion problems in the southeastern portion of the field, but Blade was not able to locate any documentation related to this study [1].

In addition, two Aliso Canyon wells had underground blowouts from casing leaks: Frew-3 in 1984 and FF-34A in 1990. These wells were successfully killed by pumping fluid down the tubing, and the consequences of a larger leak or a near-surface casing rupture were not anticipated until the SS-25 event.

Southern California Gas Company (SoCalGas) had a two-year plan in 1988 to determine the mechanical condition of the casing in 20 wells originally completed in the 1940s and 1950s. The wells, including SS-25, were prioritized based on gas deliverability, operational history, and length of time since their last workover. SS-25 was given a low priority. Of the 20 wells, SoCalGas ran inspection logs in 7 wells within the 2 year plan window. The inspection logs showed metal loss indications on the outside diameter (OD) of the casing ranging from 20% to 60% of wall thickness in 5 of the 7 wells logged from 1988 to 1990. Some of the wells had indications above the surface casing shoe, and many had indications below the casing shoe. Blade found no documentation indicating that investigations into the causes of external corrosion on any of these wells were ever conducted. SS-25 was never logged as part of this 1988 program or at any other time.

The approach to well integrity at Aliso Canyon had been reactive rather than proactive. The data collected by Blade supports this assessment, which was also SoCalGas's conclusion in the General Rate Case (GRC) submission in 2014. SoCalGas proposed a six-year Storage Integrity Management

Program (SIMP) in 2014 to "proactively identify and mitigate potential storage well safety and/or integrity issues before they result in unsafe conditions for the public or employees [2]."

Based on Blade's Root Cause Analysis (RCA), a direct cause of the SS-25 incident was outside surface corrosion of the 7 in. production casing. The injection gas was of pipeline quality and dry, and the withdrawn gas was undersaturated (that is, water never condensed); therefore, no significant internal corrosion in the 7 in. casing had occurred; the casing was corroding from the outside as a result of contact with groundwater.

Surface runoff water permeates the ground and follows fractures and faults to various depths. At the SS-9 location (approximately 600 ft away from SS-25) groundwater was observed at depths above 400 ft and below 900 ft. Except for runoff water, there are no other sources of groundwater at Aliso Canyon.

In the SS-25 well, the groundwater displaced the drilling fluid over a period of time and caused the 7 in. production casing to corrode from the outside. This groundwater and microbes—likely methanogens, a form of Archaea—caused the corrosion. Some of the 7 in. casing connections were seeping gas to the outside of the casing. The carbon dioxide in the gas was likely a nutrient for the methanogens. The corrosion patch at 892 ft was 9.25 in. in length and contained grooves from tunnels created by the microbes that coalesced over a period of time. The corrosion removed 85% of the wall thickness in a smaller patch of 2.13 in. within the larger 9.25 in. corroded region.

The shallow groundwater above 400 ft accessed the poorly cemented 11 3/4 in. surface casing and caused localized corrosion on the surface casing OD.

On the morning of October 23, 2015, SS-25 started injecting gas between 3 and 4 AM, and the pressure slowly climbed as gas was being injected. The injection pressure at the wellhead was around 2,700 psi. Sometime after the injection had started, the 7 in. casing bulged and then ruptured axially. The grooves within the corrosion patch acted as stress concentrators, resulting in the axial rupture. At this point, Blade estimates that around 160 MMscf/D gas, originating from both the injection network and the storage reservoir, was flowing through the axial rupture region. The gas flowing through the axial rupture on the 7 in. production casing caused an increase in pressure on the 11 3/4 in. surface casing. This caused several of the surface casing corroded regions to fail, creating holes and thus providing a pathway for gas to escape. Over 50 such holes provided a pathway for the gas to surface.

As the gas continued to expand through the axial rupture, the temperature continued to decrease locally, reducing the casing material toughness. Within hours of the axial rupture, the 7 in. casing circumferentially cracked adjacent to the axial rupture region, which then connected with the axial rupture and then parted. This circumferential parting likely occurred between 7 and 8 AM on October 23, 2015, when the injection gas temperature was the coldest that day. The leak was detected at 3:15 PM of the same day, October 23, 2015.

SS-25 was shut in at 3:30 PM, and it was realized that the well was still flowing gas. Using the immediately available production and surface casing annuli and tubing pressure measurements, Blade estimated the flow rate to be at 91 MMscf/D at the time. Subsequently, Blade used a more sophisticated model to estimate the flow rate from the historical SS-25 flow test data, and arrived at 93 MMscf/D.

On October 24, 2015, the first kill attempt (kill attempt #1) was performed by pumping down the tubing but was unsuccessful. SoCalGas contracted a well-control company to provide technical and operational support for the subsequent six kill attempts in November and December, 2015, which were also unsuccessful.

Based on the data reviewed by Blade, the well-control company appeared to have designed the kill attempts solely by calculating a kill fluid density that was higher than the static bottom hole pressure

[3]. Kill operations where a fluid is being pumped into a well while the gas is escaping at a high rate requires a detailed transient model to define the operational parameters.

Blade conducted detailed modeling and used the more accurate estimate of flow rate and concluded that a fluid weight of 12 ppg or higher at pump rates of 10 bpm or higher would have successfully controlled the well as early as November 13 or 14, 2015. Instead, a variation of the same kill attempt design with the fluid densities of around 9.4 ppg and pump rates of around 5 to 13 bpm were utilized for kill attempts #2 through #6. Meanwhile, the well site deteriorated with the continued flow of gas. Blade reviewed all the available data and concluded that no transient modeling was done when designing these kill attempts, contributing to the lack of success in the kill attempts. The data indicated that the well flow rate had been significantly underestimated. Finally, for kill attempt #7, transient modeling was conducted, the density was increased to 15 ppg and the well appeared to be briefly under control. However, there were operational issues that required this kill attempt to be terminated early.

The uncontrolled release of hydrocarbon gas for 111 days resulted from many different causes. To evaluate these causes, upon completion of the technical analyses, the root cause was investigated in a structured fashion using the Apollo RCA Methodology.

Direct causes, including contributing ones, are those that, if identified and prevented, would eliminate the occurrence of an SS-25 type of incident (or similar). Root causes are those that, if identified and prevented, would avert an SS-25 type of incident and all other types of well integrity incidents through the use of procedures, best practices, design, management systems, and regulations. The investigation of the SS-25 incident identified direct causes and root causes.

The **DIRECT CAUSES** for the uncontrolled release of hydrocarbons for 111 days from SS-25 were:

- Axial rupture due to external microbial corrosion on the 7 in. casing OD caused by the groundwater.
  - Groundwater accessed the 11 3/4 in. x 7 in. annulus and provided an environment conducive to microbial corrosion.
  - Carbon dioxide, a component of natural gas, seeped through the 7 in. casing connections and was likely a nutrient for the microbes.
- Unsuccessful top-kills because of insufficient kill fluid density and pump rates.
  - Transient kill modeling was not performed for the first six kill attempts.
  - Gas flow rates from the well were not estimated or used in engineering the kill attempts.

The **ROOT CAUSES** for the uncontrolled release of hydrocarbons for 111 days from SS-25 were:

- The lack of detailed follow-up investigation, failure analyses, or RCA of casing leaks, parted casings, or other failure events in the field in the past. There had been over 60 casing leaks at Aliso Canyon before the SS-25 incident, but no failure investigations were ever conducted. Furthermore, external corrosion on production casing had been identified in several wells. Based on the data reviewed by Blade, no investigation of the causes was performed, and, therefore, the extent and consequences of the corrosion in the other wells were not understood.

- The lack of any form of risk assessment focused on wellbore integrity management. This included assessment of qualitative probability of production casing leaks or failures. By extension, the potential consequences of production casing failures or surface blowouts had not been assessed.

- The lack of a dual mechanical barrier system in the wellbore. The 7 in. OD production casing was the primary barrier to the gas.

- The lack of internal policy and regulations that required production casing wall thickness inspections. The existing regulations were inadequate at the time. Annual temperature logging and weekly pressure measurements are adequate to detect leaks and fix them only after an event has occurred. In SS-25, the corrosion patch was large (around 9.25 in. in length), and due to the microbial nature, the grooves within the corrosion patch acted as stress concentration locations. Consequently, when the corrosion region failed, it resulted in a rupture that was about 2 ft long. The trailing indicators of these failures were not adequate to manage the failures. Methodologies such as periodic wall thickness measurements were necessary.

- The lack of a well-specific, well-control plan that considered transient kill modeling or well deliverability. There was no quantitative understanding of well deliverability, although data were available, and well-established industry practices existed for such analysis.
- The lack of understanding of groundwater depths relative to the surface casing shoe and production casing, until the two groundwater wells were drilled at SS-9 in 2018.
- The lack of systematic practices of external corrosion protection for surface casing strings. The consequences of corroded surface casings and uncemented production casings were therefore not understood.
- The lack of a real-time, continuous pressure monitoring system for well surveillance. This prevented an immediate identification of the SS-25 leak and accurate estimation of the gas flow rate.

The roles of safety culture, operational and technical resources, and other organizational issues were also investigated as part of the RCA. Information about the SoCalGas's historical organizational structures and departmental and job function roles and responsibilities was limited. The lack of data and evidence prevented Blade from making any direct correlation to causes of the SS-25 incident. However, the approach to well integrity management, GRC submissions, and other information gleaned during this investigation allows one to infer a possible impact from the organizational structure and resources.

The histories of 124 gas storage wells were analyzed, and 40% of them evidenced wellbore integrity issues. The relevant operations standards related to gas storage were assessed with respect to wellbore integrity. The integrity procedures were reactive and were not updated.

Blade reviewed the 2007 testimony for SoCalGas's 2008 GRC [4]. Costs and details were outlined related to reservoir engineering studies, additional personnel, technological advances, and well expenses. SoCalGas cited that over a 15-year period, the number of gas storage specialists reduced from 10 to 4 for unspecified reasons, and the company "experienced a significant decline in its ability to assess the performance of individual wells due to the lack of recent data." In 2007, SoCalGas requested two additional specialists. Unlike robust transmission pipeline integrity and distribution pipeline integrity programs, there was no such focus on well integrity. This was also supported by the SoCalGas's GRC submission in 2012 [5]. SoCalGas was perhaps inadequately resourced to manage Aliso Canyon prior to the 2015 incident, but because detailed data on resourcing was not available, the lack of resources was not identified as a root cause.

The current SoCalGas well integrity practices and regulations from the Division of Oil, Gas, and Geothermal Resources (DOGGR) address most of the root causes identified during this investigation. SoCalGas has adopted the SIMP and operationally executed it for the Aliso Canyon field following the SS-25 incident. Further, DOGGR has adopted regulations that address many of the root causes.