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Email from Jim Mansdorfer to Bret Lane et al
re Aliso Well Mansdorfer Thoughts (Nov. 20, 2015)

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From:	Mansdorfer@aol.com
To:	JLane@semprautilities.com; rphillips@semprautilities.com; rschwecke@semprautilities.com; jcho@semprautilities.com
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Mansdorfer Thoughts on Aliso Well Subsurface Blowout

I was responsible for the storage wells for over 20 years and always was aware that a subsurface leak could occur (and have previously), and so have given it a lot of thought and studied all papers and published accounts of subsurface blowouts that I could find. I have offered my assistance to Scott Fergurson and Phil Baker to help solve this problem starting at Lee's house on that first Saturday, but they have not shown any interest. With the situation continuing and escalating I felt like I needed to get my thoughts on this out to a wider audience. Everyone copied here has worked with me and understands my seriousness about these kind of issues.

The mechanisms at work here mean that time is not on our side. The situation can deteriorate quickly and result in damage that would make the field unusable as a storage field. One of the results that will happen is that the formation sand being produced with the gas will cause a large cavity to form in the storage zone around the wellbore, and when that cavity gets large enough the caprock above the storage zone will collapse into the cavity. The good news about this is that it will dramatically reduce the flow of gas, but the bad news is that it will create a permanent gap in the integrity of the caprock that most likely cannot be repaired. The other situation that will happen if the cavity doesn't collapse first is formation of a large crater from the surface down to the depth of the leak. As the gas flow increases it will uplift the formations near surface, eventually blowing them out to form the crater.

The normal first response to a subsurface blowout is to pump the heaviest drilling mud as fast as possible down the well (preferably down tubing), and I know some pumping has been done and without more information its hard for me to comment on this. However, there are several other things that I would have thought should have been started within a week going by without gaining control of the well. The fact that these were not implemented promptly makes me think that the decision makers with Boots and Coots do not fully understand the subsurface mechanisms at work and how the situation can deteriorate quickly. These are discussed in the Solutions section below.

Also, there are multiple reasons why the interests and incentives of Boots and Coots are not aligned with those of SoCalGas and so putting complete control in their hands may not be in SoCalGas' best interest.

<u>Subsurface Mechanisms</u>

When the casing leak started and gas started flowing, there were restrictions at various points that restricted the rate of flow of gas from the reservoir to the surface. At each point of restriction there is a pressure drop and because of the Joules-Thompson effect a corresponding temperature drop. The temperature drop is highest at point restrictions. Following are the restrictions on flow:

1. Pressure drop through reservoir as gas flow converges through the sandstone reservoir to the wellbore - follows Darcy's Law.
2. Pressure drop at sand face and into liner through perforations and slots
3. Pressure drop through packer, several joints of tubing and ports into tubing-casing annulus
4. Pressure drop across possible hydrates in annulus above ports or at point of casing leak
5. Pressure drop across casing leak
6. Pressure drop through formations from casing leak to surface.

The Sesnon reservoir is an unconsolidated sandstone and when gas flows at high rates it carries formation sand with it. This sand flowing at high velocity is very erosive. Over time as gas flow is allowed to continue, the sand being produced from the reservoir will form an increasingly large cavern around the wellbore. A consequence of this is that the pressure drop through the reservoir (#1 above) will decrease and the flow rate will increase. This sand will also enlarge all of the openings from there to surface as time goes on, further increasing the flow rate. The openings in the liner will quickly become enlarged to where they are no longer a restriction. The sand will enlarge the ports from tubing to casing and eventually erode away the packer and tubing between packer and ports. The sand will also enlarge the casing leak. The sand won't effect the formations between the casing leak and the surface, but as gas flow increases it will create larger fizzures and pulverize the formation until the crater is formed down to the depth of the casing leak. At that point the formations from surface to the leak will no longer be a restriction to flow. At that point the 160 billion cubic feet of gas in the reservoir will flow quickly to atmosphere until the cavity around the wellbore collapses.

Solutions

1. Reduce reservoir pressure in vicinity of well – The field must be put on maximum possible withdrawal ASAP. The focus should be on wells around SS-25 and in the west side of the field. Fortunately the well is located in the west side of the field and historical reservoir behavior indicates that reservoir pressure there can be drawn down relatively quickly. During this warm weather this may require some drastic measures such as declaring force-majeure on pipelines so that as much of the load in the LA basin can be supplied from Aliso as the piping system allows. Someone should also work with the ISO to put as much EG load in the basin that can be supplied from Aliso online. Reducing the reservoir pressure around the well will make a significant difference in the amount of gas flowing. If the gas isn't withdrawn into a pipeline it is pretty likely it will be blown to atmosphere.

2. Start a relief well ASAP. I don't think we know the exact bottom hole location of SS-25 but that should not be a reason not to proceed with a relief well. The relief well should be designed to penetrate the Sesnon zone fairly close to SS25, but stopping drilling and setting 9-5/8" casing just above the top of the Sesnon. After cement sets it can be drilled out into the Sesnon, and water pumped as fast as possible down the 9-5/8" casing, which should be greater than 60 barrels per minute. A hydraulic fracture will be created and the large pressure drawdown at SS-25 will draw the fracture to the well, creating a conduit for the water to reach the well and reduce gas flow. This, in combination with reduced reservoir pressure from #1 above and pumping down SS-25 if it has not yet cratered out should bring the well under control.

   If we cannot run a gyro survey in SS-25 to determine bottom hole location, we need to have someone working on estimating the bottomhole location of the well. They can look at records of all wells drilled in the field during the same time frame that have directional surveys and come up with an average drift from surface. This will most likely be updip, or to the NE. The preferred direction of a hydraulic fracture propagation will be parallel to the direction of maximum horizontal stress, in the case of Aliso the maximum stress is around N-S to NE – SW and so the intersection point of the relief well should be somewhat North to Northeast of the estimated location of the bottomhole location of SS-25.

3. Pumping into SS-25 - I have heard that brine has been pumped into the well and that barite has been pumped into the well, and that pumping into the well seems to increase the flow of gas to surface. If I knew more details of what has been done and what the results were I could make better recommendations. I would think that pumping clay based drilling mud weighted with barite to the heaviest feasible density would be best. Based on my experience and studies its hard to believe that pumping 18 ppg mud at the highest rate the 5000 psi wellhead will allow would not kill the well, but maybe they have tried that. Pumping at high rate down the tubing will temporarily increase gas pressure in the well trapped in the casing between the tubing port and the surface and therefore increase the rate of flow of gas to surface. It may also cause hydrate restrictions to melt also increasing gas flow, but these effects should be temporary and may need to be tolerated in the short term in order to prevent much worse consequences later.

Based on what I know I would recommend laying high pressure large diameter frac piping from the well to a location far enough away that gas flow to surface will not endanger the pumping equipment or the personnel operating it (if not done already). There should be separate lines for tubing and casing. My initial recommendation would be to pump heavy drilling mud loaded with lost circulation material down the casing at a limited rate while pumping heavy drilling mud at maximum rate down the tubing. The lost circulation material down the casing should help restrict flow throught the casing leak and formations to surface. We should be prepared to pump 10 times well volume and have containment on adjacent drainages to capture mud that comes to surface.

I would be happy to discuss these recommendations and participate in solving the problem if it is desired by the Company. I can be reached at [redacted]

Jim Mansdorfer, PE