

Well Construction and Cementing Practices in Shale and Salt Water Disposal Wells

2017 Shale Network Workshop

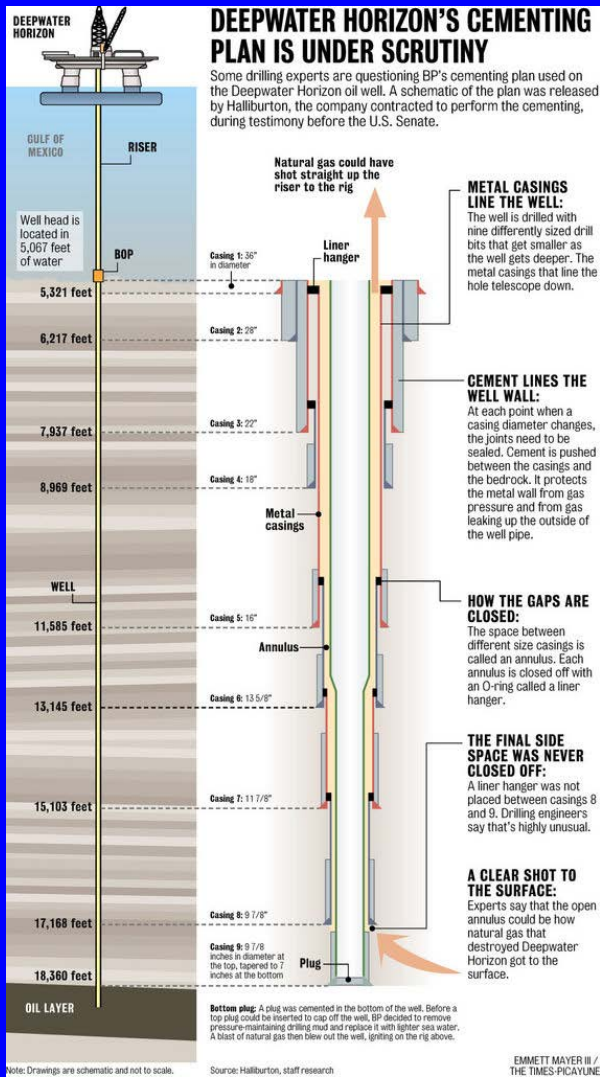
Roger Myers, President

RRM Completions, LLC

Agenda

- Well Construction – Importance and Examples
- Well Cementing – Design and Chemistry
- Summary and Q & A

Why Well Construction?



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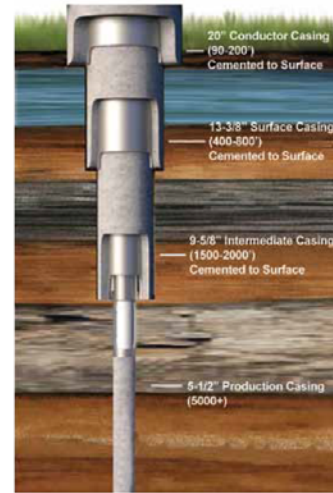
Preparing the Surface

Step 1 – Land Leasing and Surveying

The first step in the life of a well begins with acquiring the rights to drill from the landowner. After leasing these drilling rights, geological and seismic surveys determine the ideal spot for a well site – placing it a proper distance from water sources and designated environmental areas.

Step 2 – Ground Preparation

An access road is created to allow heavy equipment to reach the site. Once this is completed, we begin clearing the area where the drilling rig will sit.



Step 3 – Surface Foundation

The well site is reshaped to provide a wide, flat working area for the drilling rig. The area is then covered with crushed and compressed stone to form a sturdy and level surface that can withstand the weight of heavy equipment.

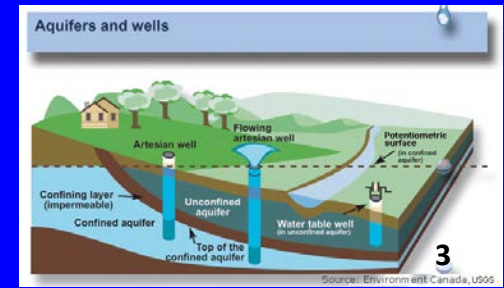
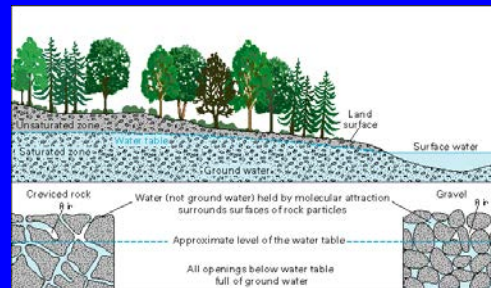
Step 4 – Protective Barrier

As part of our commitment to safeguarding the environment, we install a plastic liner over key areas to serve as a protective layer under the base of our drilling operations.

"We take the extra step of placing a plastic barrier under all our drill sites. This ensures that nothing will contact the ground to impact the environment."

George Stark
Director, External Affairs
Cabot Oil & Gas Corporation

Fact: A drill bit passes through strata containing fresh water on its way to Marcellus or Utica Shale!



Well Construction

Planning/engineering requires a drilling prognosis

- Information needed
 - Depths to all fresh water zones
 - Depth to coal
 - Depths to tops of all major formations
 - Pore pressures
 - Mud weight (or air)
 - Frac gradients
 - Geologic features – faulting, high perm matrix

Well Construction

Casing Design Considerations



- Casing Design
 - Internal (burst) yield
 - Collapse pressure
 - Joint strength
 - Axial loading
 - Connections
 - API 5T specs

Well Construction

Primary Modes of Pipe Failure

- Internal yield (burst)
 - $P_B = 0.875 (2 Y_{pt}/D)$
- Collapse pressure
 - External pressure exceeds internal pressure (radial)

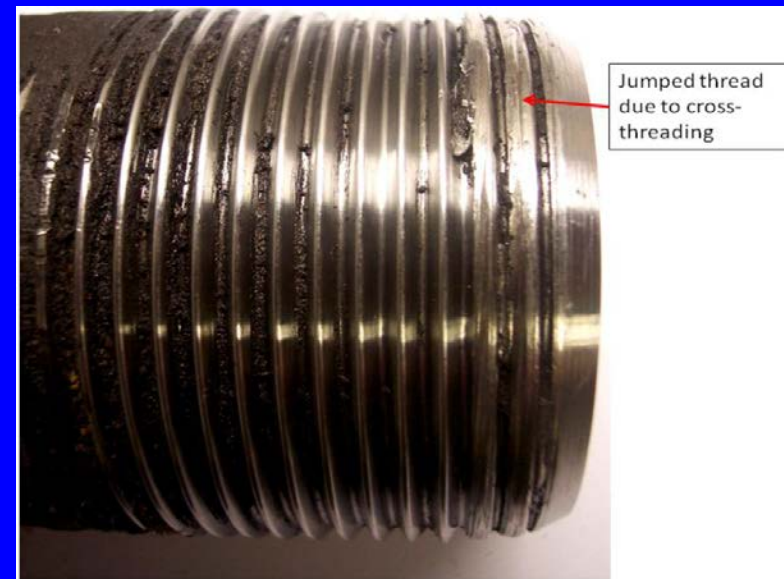
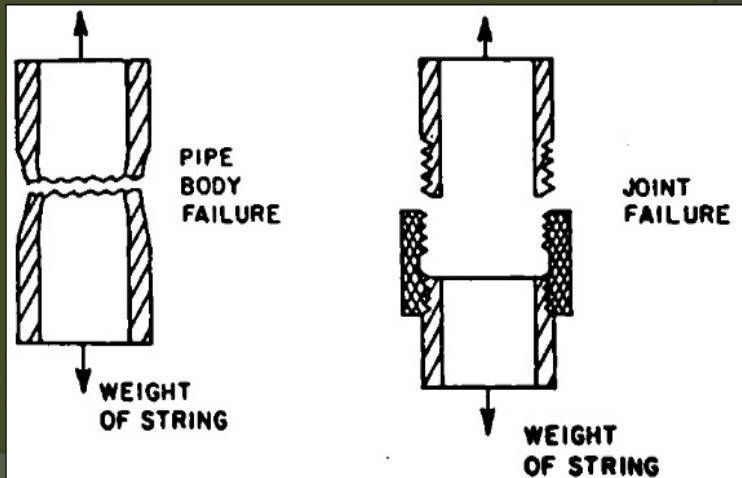


Well Construction

Primary Modes of Pipe Failure

- Joint strength – body failure
- Connection failure
 - Cross-threading
 - H₂S – rarely in NE

- ◉ The strength of the casing string is expressed as pipe body yield strength and joint strength.



Well Construction

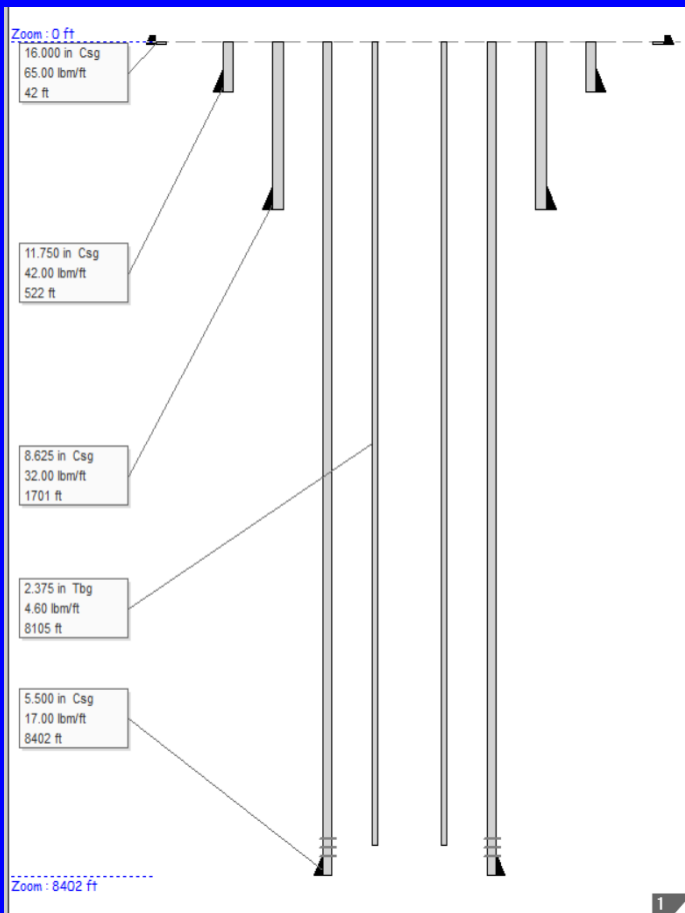
Shale Well vs. Salt Water Disposal

- **Shale Well**
 - Higher injection pressures (frac)
 - Higher pore pressures
 - Cased hole completions
 - Production casing based largely on frac pressures
- **Salt Water Disposal**
 - Lower injection pressures (MAIP)
 - Lower pore pressures (depletion)
 - Cased and **open hole completions**
 - Production casing/tubing larger to avoid friction losses

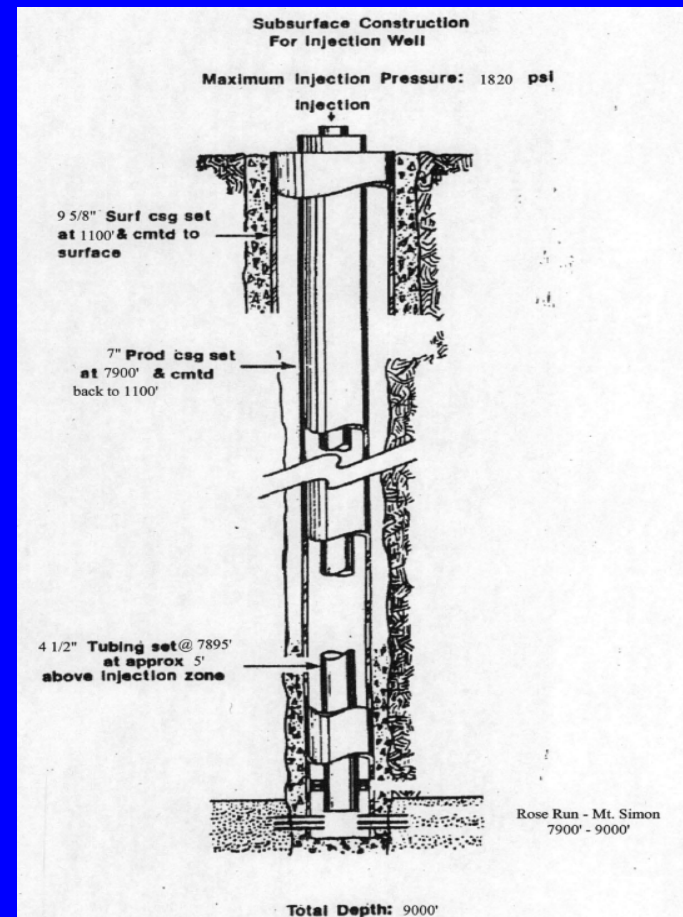
Well Construction

Shale Well vs. Salt Water Disposal

- Shale Well

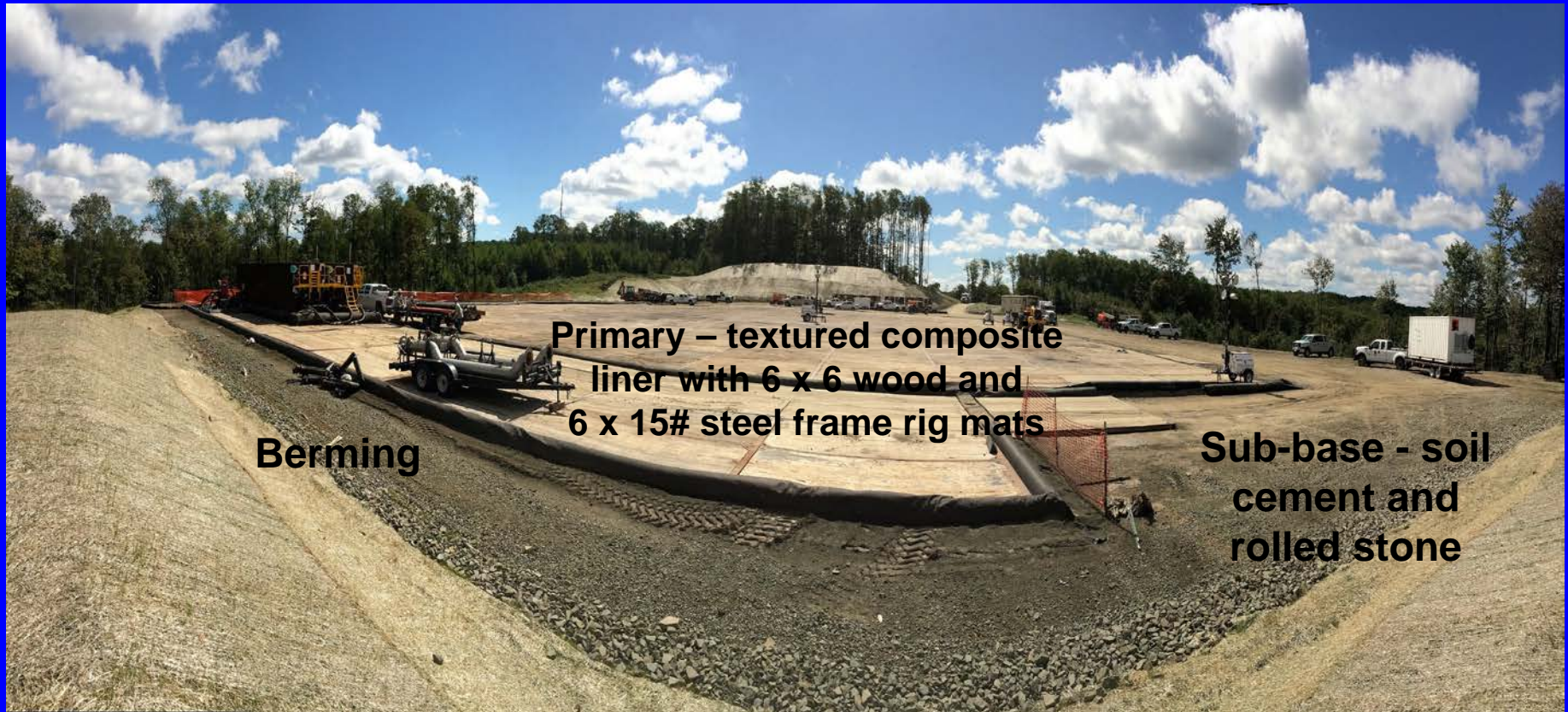


- SWD Well



Well Construction

Primary Containment



Well Construction

Secondary Containment



Well Construction

Cellars



Well Construction

Conductor Pipe – 0 – 300'

- Purpose
 - Prevent sides of hole collapsing
 - Restricts drilling returns
 - Stops artesian water flow and lost circulation



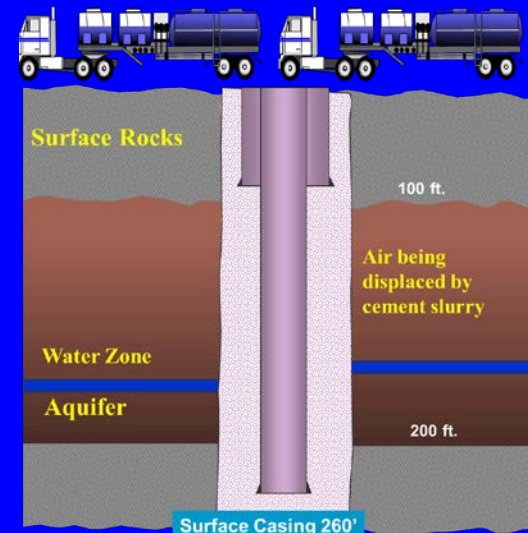
Concentric Casing Drilling Rig: inner drill pipe rotates an air percussion hammer/bit inside 94# 20" which is locked in place with a lock ring swivel and rotated independently of the inner drill pipe



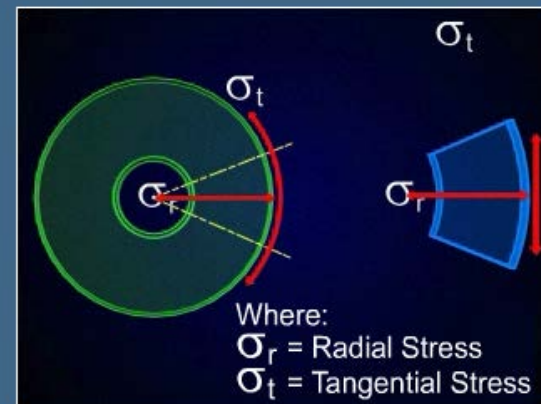
Well Construction

Surface Casing - to 800'

- Purpose
 - Prevent contamination of fresh water zones
 - Isolates coal seams
 - Supports BOPs and other casing strings



Cemented annulus



Well Construction

Intermediate Casing - to 9500'

- Purpose
 - Prevents corrosion of production casing
 - Protects against hole caving of weak zones
 - Helps resist high pressure zones below



Well Construction

Production Casing - to 20,000'+

- Purpose
 - Selectively allows for oil & gas production
 - Isolates and prevents gas and brine migration
 - Provides well control



Well Cementing

Primary Cementing Planning

- Critical Factors
 - Wellbore
 - Drilling Fluid
 - Casing
 - Rig Operations
 - Cement Properties
 - Cement Service Equipment
 - Personnel
 - Lab Testing

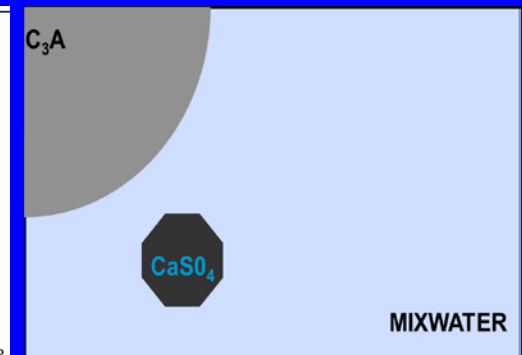
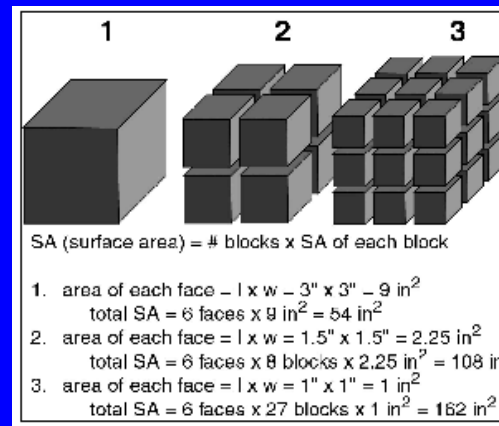


Well Cementing

Cementing Chemistry

- Hydration
 - Complex Reaction
 - Accelerators
 - Fluid Loss
 - Retarding Agents
 - Lost Circulation
 - Dispersants
 - Friction Reducers
 - Specialty Chems
 - Gas Migration
 - Zero Free Water

API Class	ASTM Type	Official Description	C ₃ S	β-C ₂ S	C ₃ A	C ₃ AF	Minimum Fineness Sq cm/g
A	I	General use	45	27	11	8	1,500
B	II	Moderate heat of hardening	44	31	5	13	1,600
C	III	High early strength	53	19	11	9	2,200
--	IV	Low heat of hydration	28	49	4	12	1,600
--	V	Sulfate resisting	38	43	4	9	1,600
G	(II)	--	50	30	5	12	1,800
H	(II)	--	50	30	5	12	1,600



Gas and Oil Well Cementing

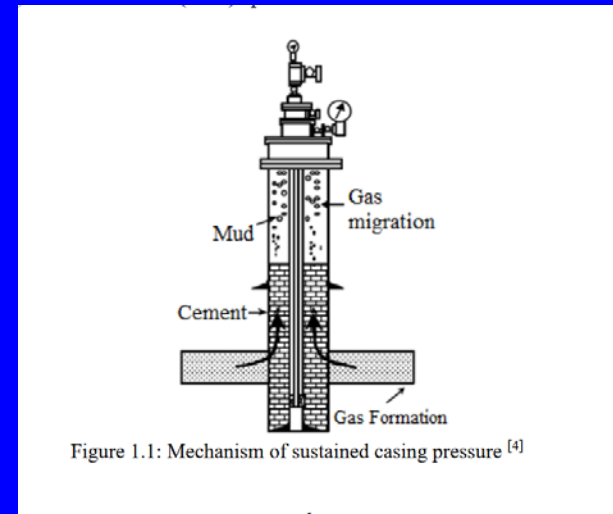
Fluid & Gas Migration/Sustained Casing Pressure

- Why?
 - Early time failures (hours/days)
 - Borehole enlargement/poor mud removal
 - Equipment failure/unplanned job shutdowns
 - Slurry design – horizontal wells – free water
 - Unknown factors – overpressured shallow rocks
 - Late time failures (weeks/months/years)
 - Bulk volume reduction of cement
 - Pressure cycling

Gas and Oil Well Cementing

Fluid & Gas Migration/Sustained Casing Pressure

- Prevention
 - Drilling practices – reduce washout hole size
 - Rethink casing program
 - Strict adherence to job standard practices
 - Lab testing with all critical test parameters
 - Gas migration additives
 - Packer collars or mechanical seals
 - Flexible cement
 - Cement expanding agents



Remediation: Tubing workovers are easy; cement sheath failure is difficult to fix and is very expensive

Gas and Oil Well Cementing

Fluid & Gas Migration/Sustained Casing Pressure

- What about backside or annular pressure?
 - Plumb annuli up with piping to ground level
 - Monitor pressure or open to stock tank
 - Poses minimal risk with a deeper intermediate casing set below properly cemented naturally fractured strata²¹



Hydraulic Fracturing

Fluid & Gas Migration/Sustained Casing Pressure

THE HYDRAULIC FRACTURING PROCESS (HF): REAL CONCERN OR MISDIRECTED FOCUS CONCERNING THREATS TO DRINKING WATER SUPPLIES (DWS)

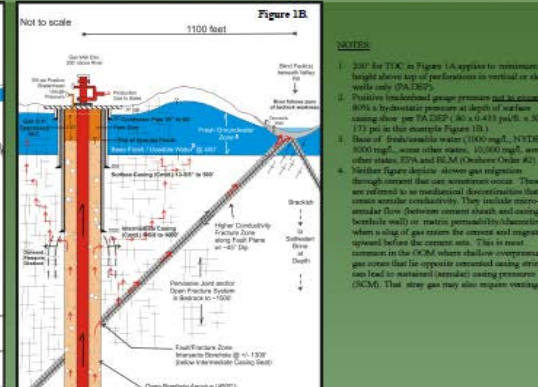
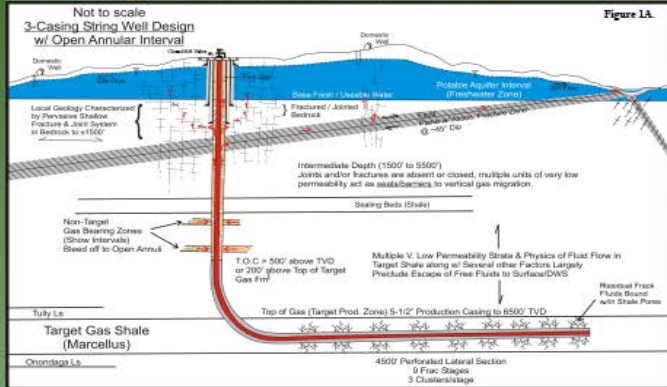
NRSS Directorate
National Park Service
U.S. Department of the Interior



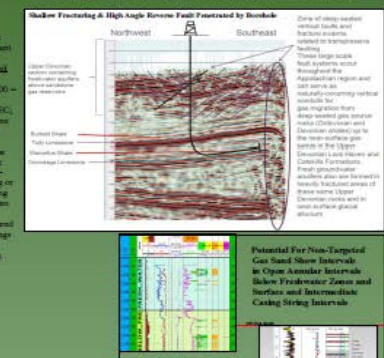
Introduction

This author's literature review, attendance at various hydraulic fracturing (HF) symposiums, forums, conferences, an EPA sponsored HF workshop on Fate & Transport and discussions with oil and gas regulatory agencies and industry representatives suggest there is a growing, if not already strong consensus among those who have performed objective analyses of the HF process, that the risk posed to potable aquifers or drinking water supplies (DWS) from the deep underground process of HF is low/negligible. Assessments of potential impacts range from "venom" (DOE 90 Day Report) to "do not present a reasonably foreseeable risk of significant adverse environmental impacts" (NYS GSEIS). Furthermore, multiple lines of evidence including theory based on the physics of fluid flow, fate and transport modeling and empirical evidence from hundreds of thousands of frac jobs performed by industry in the last 60+ years without documented impacts to DWS, indicate that further public focus on this concern is misdirected and simply unwarranted. It is often a challenge for experts to communicate complex concepts to the public to allay fears and concerns. Terms such as imbibition, imbibition water absorption, and capillary pressure effects and their underlying conceptual basis while critical to a technical understanding of any DWS to DWS, also make it difficult to convey to the public why these residual frac fluids are highly unlikely to subsequently appear in a DWS. Residual frac chemicals are most likely locked in rock pores of the target shale with no means of escape for periods possibly on a scale approaching that of geologic time. The public rarely differentiates direct impacts by methane gas to DWS which have occurred and documented pathways do exist related to gas well construction when an unintended annulus becomes overpressured. However, in most instances methane occurrence in DWS is still attributable to sources unrelated to gas development. When methane impacts from gas development do occur they are most typically related to non-routine overpressuring "events" during drilling, cementing or casing operations unrelated to the hydraulic fracturing process itself. Some well design practices can facilitate stray gas migration when site-specific geologic conditions as depicted here, are not fully understood. Specifically, should shallow fractured bedrock extend below surface (intermediate 3-string design) casing depths, higher risks for gas migration may be present.

This poster illustrates two pathways for stray gas migration that may occur independently of each other or operate in conjunction to facilitate gas migration to a DWS when a 3-string casing design with open annulus becomes overpressured. From a relative threat standpoint, a change in focus from potential hydraulic fracturing fluid impacts to DWS to the real threat of stray gas migration is long overdue. While public concerns about HF fluid impacts to DWS have brought about better regulation and many operational improvements by industry including frac chemistry disclosures (e.g. fracfocus.org), use of resin-free (green) chemical substitutes and greater transparency of overall operations, few significant additional environmental gains in this area are likely to occur that further reduce risk in any appreciable manner from its already low state. Further opponent arguments and concerns regarding impact to DWS from the hydraulic fracturing process appear increasingly without technical merit. In contrast to the fluids largely sequestered in the target formation, methane gas from non-target gas bearing zones is abundant and concentrated, can be highly mobile and migrate as a free phase in addition to dissolved phase, has a pathway that permits several thousand feet of cross-strata migration (open annulus above production casing cement) and a drive mechanism (buoyancy). Furthermore, methane from a deeper source (normal to over pressure) gas bearing geologic unit often leads to over pressuring of casing and annular intervals at shallow depths (i.e. exceed hydrostatic conditions). Overpressuring is undesirable and mitigation/remediation can be problematic and costly to rent in continuous venting of this potent GHG over a long period (e.g. yr or well). Gas build up (overpressuring) of the annulus can also create the required gradient for stray gas to penetrate fractured bedrock through the open borehole wall and move upward and around surface/intermediate casing strings of good integrity to reach a DWS. Earlier overpressure events (e.g. gas kicks) during the drilling and completion phase may also facilitate subsequent movement through shallow fractures from annular overpressuring by establishing a continuous gas phase in the fracture system.



Below Illustrations Modified From PADEP and Shell Oil



Key Questions:

- How accurate are these subsurface representations of stray gas migration relative to frac fluids; and what are the reasonable pathways (shown or not shown)?
- When an annulus becomes overpressured, can significant amounts of methane gas (enough to impact DWS) penetrate the borehole wall in the dissolved phase or only in the free gas phase (i.e. requires sufficient overpressuring to drive the water level in the annulus below the intermediate casing seat or further downward than in the case above so that free gas is opposite the borehole wall)?
- If venting is the preferred management solution to prevent borehole annuli from overpressuring, what quantity of methane is being released to the atmosphere by this standard practice?
- Given that frac fluids have not been documented to impact DWS (few pathways exist) while methane related to stray gas migration has in several cases due to a documented drive mechanism and a pathway, where are limited resources better spent?

References:
 1. EPA Office of Management, 2008. October 2010. EPA 600/R-08/001. EPA 600/R-08/001.
 2. EPA Office of Management, 2008. October 2010. EPA 600/R-08/001. EPA 600/R-08/001.
 3. EPA Office of Management, 2008. October 2010. EPA 600/R-08/001. EPA 600/R-08/001.
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 20. EPA Office of Management, 2008. October 2010. EPA 600/R-08/001. EPA 600/R-08/001.

Conclusions

Relative to HF fluids used in frac target gas shales, stray gas from non-targeted (noncommercial) gas bearing zones found above targeted gas is far more abundant, concentrated and mobile with much greater upward migration potential from the deep subsurface due to the buoyancy drive mechanism within an open borehole annulus. A several thousand foot potential cross-strata migration pathway exists to DWS via the open borehole (open annular space between top of production casing cement and surface or intermediate casing string shoe) under most current well designs accepted by states and the BLM. Should an overpressured annulus develop from these gas sources and an open fracture (or joint) condition characterize shallow bedrock that extends below surface or intermediate casing depths, this gas migration pathway to DWS is potentially complete. With the advent of unconventional shale resource plays, their expansive coverage, increased well densities and intermingling with more developed shale resource plays, the long term risks from the long term vents from intermediate annular overpressuring events or when wells exist. Mitigation of annular space methane gas build up through venting is less of an option than in the past due to concerns for GHG emissions as this methane source is poorly quantified. The complexity of the stray gas migration issue suggests further research into its component parts is warranted for a better understanding of best management practices. These include 1) Quantification of the nature of the problem or approximate amount of stray gas currently vented by the gas industry, possibly through a random/probabilistic sampling design 2) Source identification & isolation - methods of source (strata) identification (borehole logging operations), zonal isolation, cementing or limiting flowback/off to well bore/annulus 3) Annular Environment - effects of fluids present (water, mud, brine, gas), gas transport phase (free phase gas vs. dissolved), slough/cave (borehole bridging effects) and their effect on gas flow from the source to the borehole and outward to country rock from overpressuring 4) Overpressure Conditions - gas phase and entry pressure requirements for rock matrix vs. fracture (pore & aperture) intervals, setting phase of infrastructure faces, residual effects from a non-routine overpressure "event" that would facilitate gas connectance in fractures and subsequent stray gas migration 5) Monitoring - casing annular pressure correlation with annular fluid levels, freshwater zero energy (stratigraphic) and appropriate freshwater intervals or aquifer horizons for early detection of methane migration to DWS. There are many trade-offs in selecting management strategies and well designs to minimize stray gas. Further analysis of the components is warranted to better assess cost/benefit relationships and ensure GHG emissions and potential impacts to DWS are minimized.

Summary

- Water wells and oil & gas wells drill into strata containing fresh drinking water
- Well construction planning is critical to success of both shale and salt water disposal wells
- Well cementing is of primary importance but doesn't get the attention it deserves
- Long term zonal isolation and prevention of fluid and gas movement

Bibliography - References

- Slide 3
 - John Turley, An Engineering Look at the 2010 Cause of Macondo Blowout, AADE, Butte, MN, 4-24-14
 - Cabot Oil & Gas, Life of a Natural Gas Well, 2010?
 - <https://water.usgs.gov/edu/earthgwaquifer.html>
- Slide 5 – personal photo

Bibliography - References

- Slide 6
 - http://gekengineering.com/Downloads/Free_Downloads/Casing_Design_Hand_Calculati_on_Design_Example.pdf
- Slide 6 - <http://casingcollapse.com/>
- Slide 7 - <https://www.slideshare.net/akinrcraig/petroleum-engineering-drilling-engineering-casing-design>

Bibliography - References

- Slide 9 – Schematics property of Seahorse Oilfield Services, LLC
- Slide 6 - <http://casingcollapse.com/>
- Slide 7 - <https://www.slideshare.net/akinrcraig/petroleum-engineering-drilling-engineering-casing-design>
- Slides 8 – 19 – Personal photos and slides from personal archives

Bibliography - References

- Slide 20 – Removal of Sustained Casing Pressure by Gravity Displacement, E. Demirci, LSU, 2014, Master's Thesis
- Slide 21,22 – http://efdsystems.org/pdf/Stray_Gas_Migration_-_National_Park_Service_-_Peter_Penoyer.pdf; Peter Penoyer, US Department of Interior, National Park Service, Water Services Group, “Stray Gas Migration Issues in Well Design and Construction; Considerations in Avoiding Methane Impacts to Drinking Water Aquifers and/or Air Emissions”, private communication