Strategies for Cost-Effective, Reliable Long-Term Well Abandonment Barriers

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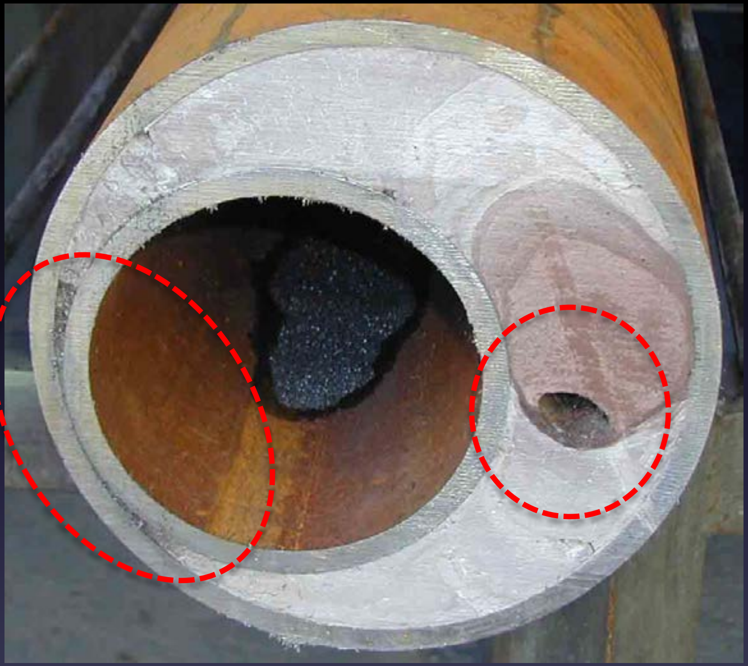
Challenges

- Design and installation of effective long-term barriers is complex
  - *Lack full understanding of how barriers and well systems work*
  - *Loss of competency within industry*
  - *Regulations/policies treat symptoms and restrict application of technologies to solve the problems*



- The best currently available evaluation and diagnostic methods are inadequate and unreliable for:

  (1) barrier evaluation and verification
  (2) well abandonment planning

10 Things to Do That Improve Long-Term Reliability and Effectiveness of Barrier Systems

(With Examples)

There are known technologies and proven strategies for creating effective long-term barriers – even with the uncertainties and challenges around diagnostics and verification.

10 Things To Do That Improve Barriers - 1

1. Design and install multi-component barriers
   - Cement alone, especially neat cement, is NOT a reliable barrier
   - Combine cement plugs with mechanical barriers and alternate materials
2. Install multiple barriers
   - Understand why and when multiple barriers should be used – *even if they are not required by regulations*
3. Remove all components in the interval where a barrier is installed
   - No ‘foreign’ materials/components imbedded in the barrier ‘matrix’
   - Seal, cut-off and remove control lines, tubulars, cables, etc
4. Include Alternative Materials for Barriers Inside Tubulars
   - Part of a multicomponent barrier system
   - Barite plugs
   - Combine barite plugs and resins/in-situ reaction materials to reduce cost and increase effectiveness

10 Things To Do That Improve Barriers -2

5. Use an Injectivity Test for <u>every</u> squeeze operation
   – Material and Placement Technique Selection
6. Use ‘In-Situ Reaction’ Materials for Annular Barriers
   – Perforate-and-Squeeze and/or Section-Milled intervals
   – Resins or Inorganic Reactive Materials Ahead of Cement
   – Consolidate materials in the annulus – penetrate formation to create internal barrier
5. Use cement formulations that meet functional concepts and property specifications for improved long-term bonding and interfacial sealing
   – Standardize minimum performance specifications for well abandonment sealants
8. Apply Industry State-of-the-Art Best Practices
   – Plug cementing
   – Quality control
   – Job Monitoring and recording
   – Post-job operations – waiting-on-cement time, etc
   – These are well known and documented (for over 50 yrs)

Material Selection for Remedial Treatments Based Upon Injection Test Data

INJECTIVITY FACTOR, psi-min/bbl = $\frac{\text{Injection Pressure, psi}}{\text{Injection Rate, bbl/min}}$

Higher Number = Smaller leak path

<2000	2000-4000	4000-6000	< 6000
API Cements *Class C cement is typically the finest particle size of normal API cements*	API Cement – Micro fine Cement Blend 50-80% API Class C, G or H cement + 20-50% Micro fine Cement	Micro fine Cements Solids-free materials like resins/monomer	Solids-free monomer or resin sealant (low viscosity materials generally preferred) Water-based Monomer Blend

Increasing sensitivity to material placement technique and methods for success

Objective is to use material with highest potential for sealing leak path on first attempt

SPOT MATERIAL OPTIONAL	MUST SPOT MATERIAL BEFORE SQUEEZE

Placement Technique is CRITICAL for Success: Requires Expert-Level Squeeze 'Cement' Advice

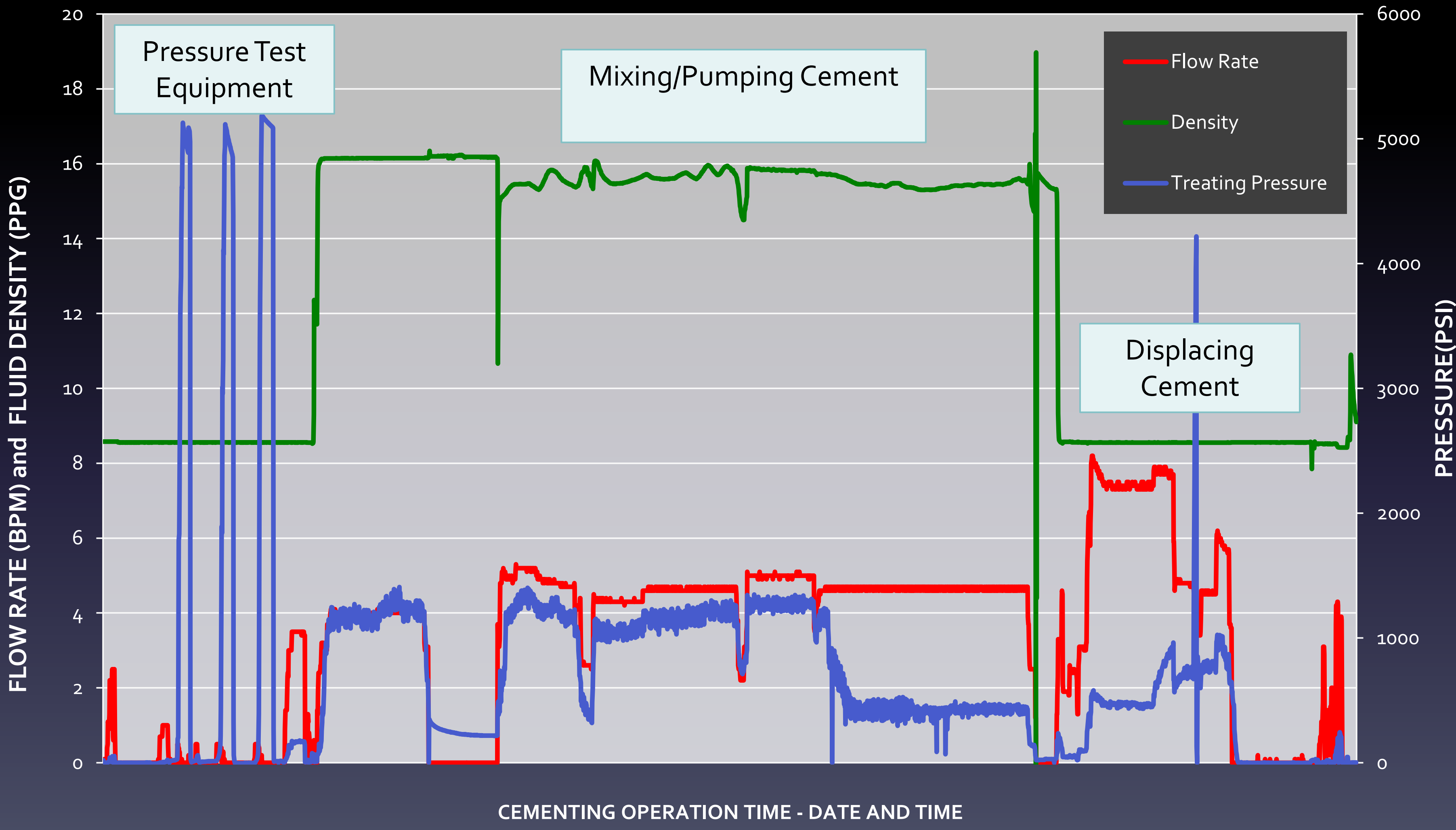
Proven Concepts for Improving Hydraulic Isolation Performance of Portland Cements

- Cement formulations with improved hydraulic isolation have the following characteristics:
- Reduced bulk and chemical shrinkage of cement
  - During and after setting of the cement
  - (Optionally) Post-set or plastic state expansion additives
- Increased compressibility of slurry
- No free water
- Low matrix permeability (OVER SERVICE LIFE UNDER CONDITIONS AT LOCATION)
- Increased ductility and elasticity
- *Anti-gas migration formulations required for gas wells – recommended for all applications*

Job Monitoring and Data Recording

Example of Data Monitored and Recorded During Cementing Operations

The ONLY way to verify execution process and fundamental data needed for evaluation.



10 Things To Do That Improve Barriers - 3

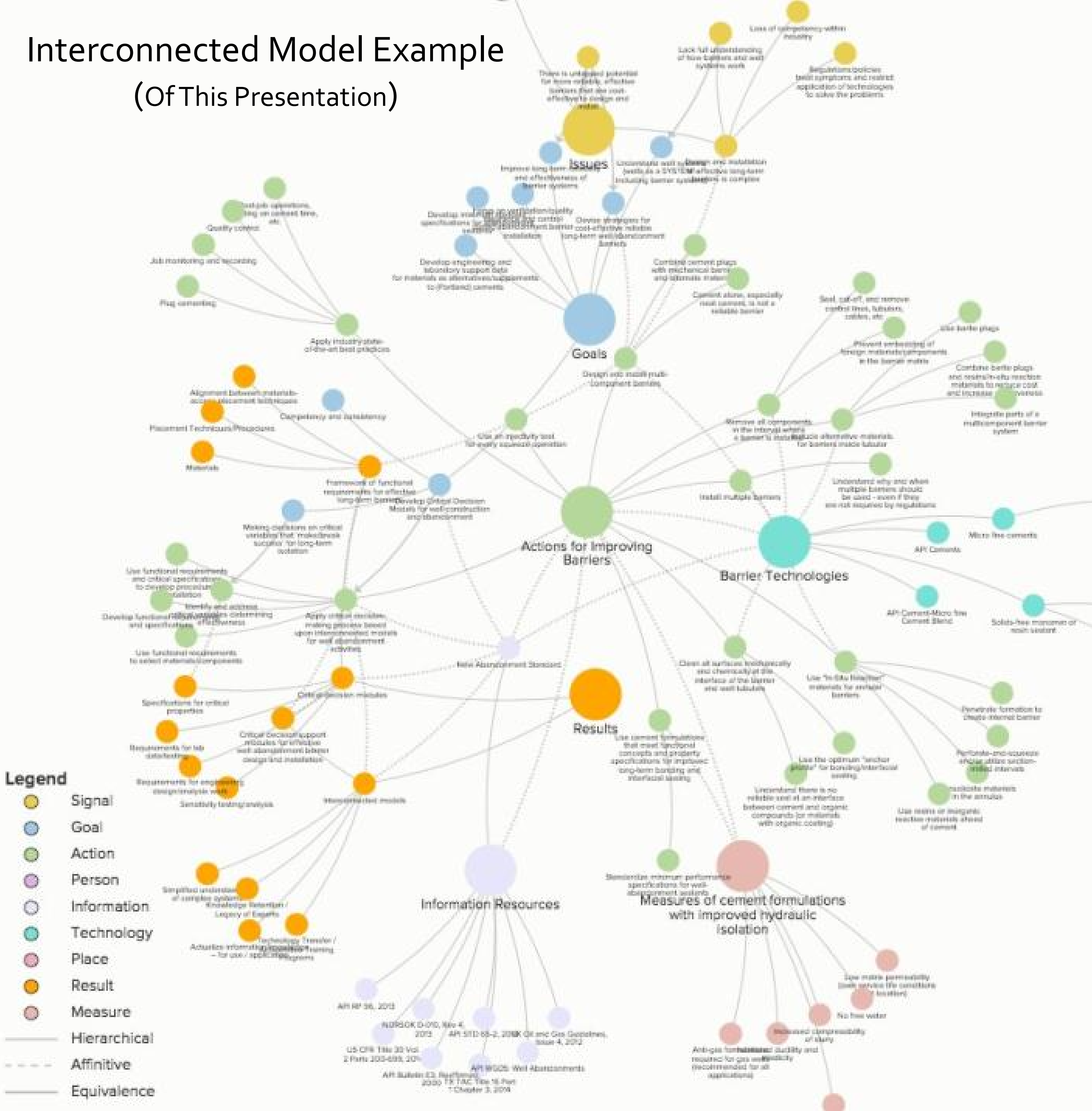
9. Mechanically and chemically clean all surfaces at the interface of the barrier and well tubulars
   – There is NO reliable seal at an interface between cement and organic compounds (or materials with an organic coating)
   – There is an optimum ‘anchor profile’ for bonding/interfacial sealing
10. Apply Critical Decision-Making Process based upon accurate Interconnected Models for Well Abandonment Activities
   – Identify and address critical variables determining effectiveness
   – Develop functional requirements and specifications
   – Use functional requirements to select materials/component
   – Use functional requirements and critical specifications to develop procedures for installation

Purpose of Interconnected Critical Decision Models

- The ‘outputs’ of interconnected models are:
  - Knowledge Retention / Legacy of Experts
  - Technology Transfer /Accelerated Training Programs
  - Actualize information/knowledge – for use/application
  - Simplified understanding of complex systems
  - Critical decision support modules for effective well abandonment barrier design and installation

- The ‘output’ of a Critical Decision Module is:
  - Framework of functional requirements for effective long-term barriers
    - Materials
    - Placement Techniques/Procedures
    - Alignment between materials-access-placement techniques
  - Specifications for critical properties
  - Requirements for engineering design/analysis work
  - Requirements for lab data/testing
  - Sensitivity testing/analysis

Interconnected Model Example
(Of This Presentation)



Summary

- What it takes to achieve effective long-term isolation and integrity is known.
- There is untapped potential for more reliable, effective barriers that are cost-effective to design and install
  - *The industry has (barely) scratched the surface of what is possible!*
- Five things that would make a positive difference:
  - Understand well systems (wells as a SYSTEM – including barrier systems)
  - Develop Critical Decision Models for well construction and abandonment
    - Making decisions on critical variables that 'make/break success' for long-term isolation
    - Competency and consistency
  - Develop minimum standard specifications for abandonment sealants
  - Develop engineering and laboratory support data for materials as alternatives/supplements to (Portland) cements
  - Focus on verification/quality assurance and control during abandonment barrier installation

API WG05: Well Abandonments

- *Work Group Charge: "Identify literature and gaps associated with well plugging and abandonment for both offshore and onshore environments. Present findings to serve as foundation to develop a Recommended Practice (RP)"*

- Members
  - Joe Shine – Chair
    (Joe.ShineJr@gmail.com and/or Joseph.ShineJr@Aramco.com
  - Jerry Calvert – Advisor

- Forward Plans:
  - Complete identified literature review
  - Evaluate categories
  - Document development

RESOURCE SLIDES

THESE SLIDES WILL NOT BE SHOWN DURING THE PRESENTATION.

MAY BE SHOWN DURING DISCUSSION, IF APPROPRIATE.

RUN IN ‘SLIDE SHOW’ MODE TO VIEW ANIMATIONS

Categories of Variables Affecting Long-Term Barrier Effectiveness and Well Integrity

Wells are mechanical systems imbedded in a complex, highly variable geosystem.
What happens in one affects the other…with different orders of response time and magnitudes of effects.

WELL CONDITION:

SCP, corrosion, scale, casing condition, operating parameters, etc

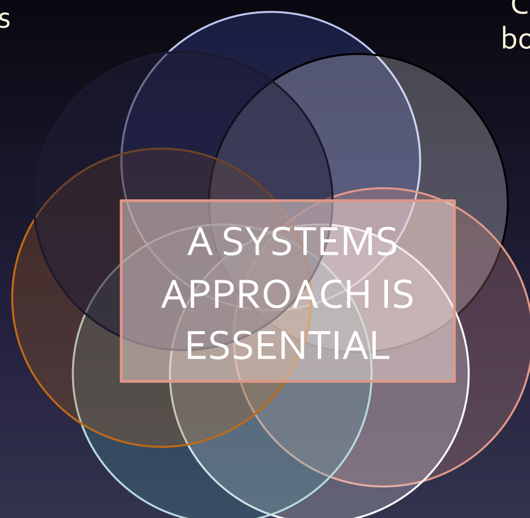
GEOMECHANICS:

In-situ stresses, change in stresses along borehole, change in stresses in cement and pipe, field effects

WELL DESIGN AND QUALITY OF CONSTRUCTION:

Casing program, annular barrier design, borehole stability and integrity, well path and tortuosity, drilling practices, completion type, etc.

CHEMISTRY:
Corrosion and chemical resistance of casing and annular barrier materials



CEMENTING PROCESS

Cementing is 80-90% Placement + 10-20% Materials

GEOLOGY/GEOCHEMISTRY:

Formation type, structure, chemical composition, formation fluid chemistry, porosity, permeability, etc.

MATERIAL PROPERTIES:

Cement, Relationships between Pipe-Cement-Formation

PRESSURE AND TEMPERATURE CHANGES/CYCLING

(Over the life of the well)

There is a complex relationship and interaction between variables within each of these categories that <u>directly</u> effects long-term integrity of both the well and geosystem.

BARRIER BASICS

- How Most Well Barriers Work:

In the absence of adhesive bonding, barriers rely on low matrix and interface permeability, length/surface area and an effective radial stress to maintain a seal at any interface in a well system.

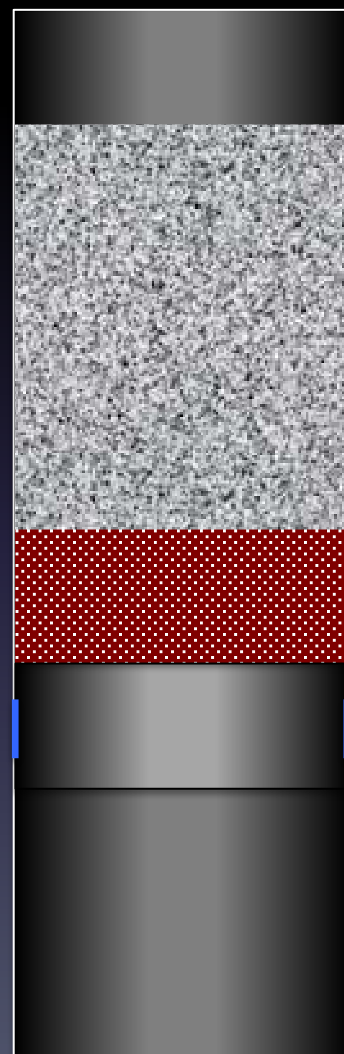
Currently, the industry has no tools to directly measure (sealing) stress along a well.

- Pressure Testing is the ONLY measure of barrier effectiveness
  - NEGATIVE and POSITIVE TESTS – *IN THAT ORDER*
  - The smaller the leak – the longer the duration of the test required to identify it
  - IF IT CANNOT BE PRESSURE TESTED…ITS EFFECTIVENESS IS UNDETERMINED
  - Testing after installation does not insure long-term effectiveness
- There is only one chance to 'get it right' for each barrier
  - IT IS NEARLY IMPOSSIBLE TO REMEDIATE A LEAKING BARRIER

Multiple, Multi-Component Barriers Example

Concepts and
Example Configuration 1

Inside Tubular Example



EXAMPLE MATERIALS

Cement Plug

Portland or other inorganic cement with long-term structural/matrix durability

Chemical Resistant Resin

(Furan, MF, Epoxy, etc. or Polymer Concrete)

Mechanical Isolation Tool

(Packer, Bridge Plug, Retainer, etc.)

COMPONENTS AND FUNCTION

1 - Long-Term Durability Component

- (Often) Required by regulations

2 - Secondary/Resilient Seal Component

- Resin based sealant. Place and apply pressure to squeeze. Penetrates and seals matrix of mechanical isolation tool.
- Can be solids-filled with no filtration control (high fluid loss) to reduce cost and increase durability
- Chemical adhesion to casing/surfaces (even oil wet). Resilient. Material properties maintain seal under changing stresses.
- Secondary seal

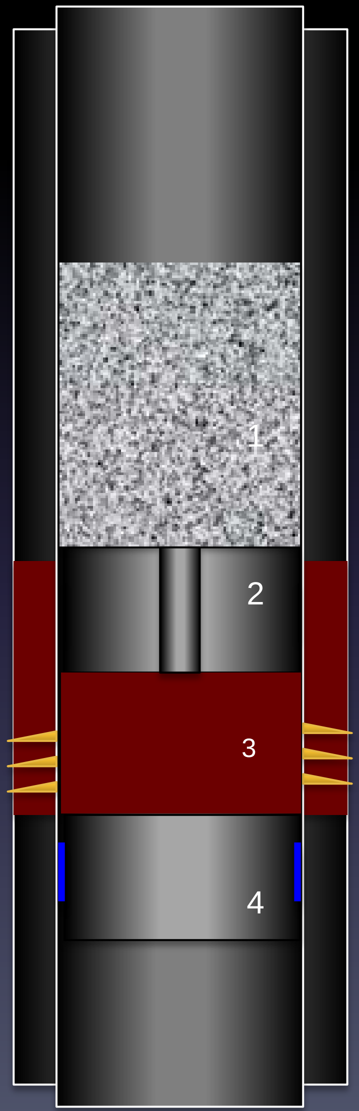
3 - Initial Isolation Component

- Initial primary seal
- Serves as base for location and placement of other components
- Location, integrity and sealing can be verified prior to installation of other components

Multi-Component Annular Barriers:
Perf-and-Squeeze Case with Without Circulation Up Annulus

Concept and
Example Configuration 3

Squeeze Below Retainer



EXAMPLE MATERIALS

Cement Plug
Portland or other inorganic cement with long-term structural/matrix durability

Mechanical Isolation Tool
(Packer, Retainer, etc.)

Chemical Resistant Resin
(Furan, MF, Epoxy, etc. or Polymer Concrete)

Mechanical Isolation Tool
(Packer, Bridge Plug, Retainer, etc.)

COMPONENTS AND FUNCTION

1 - Long-Term Durability Component
- (Often) Required by regulations

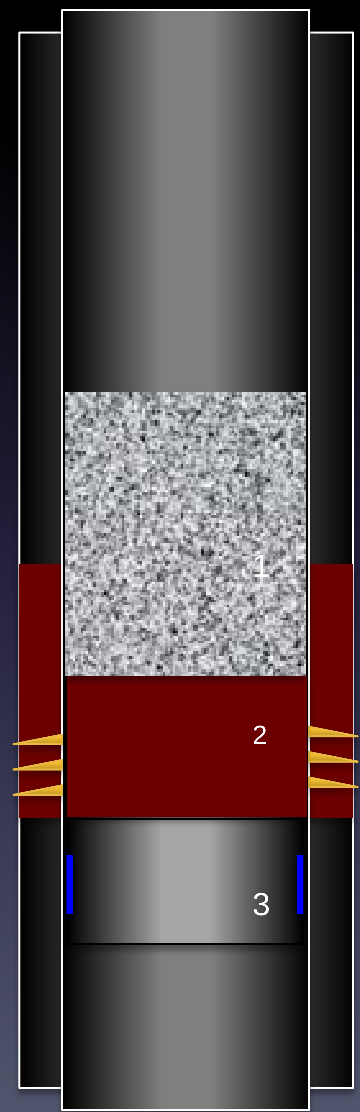
2 - Isolation/Material Placement Component

3 - Secondary/Resilient Seal Component
- Resin based sealant. Place and apply pressure to squeeze. Penetrates and seals matrix of annular materials/formations
- Chemical adhesion to casing/surfaces (even oil wet). Resilient. Material properties maintain seal under changing stresses.
- Secondary seal

4 - Initial Isolation Component
- Initial primary seal
- Serves as base for location and placement of other components
- Location, integrity and sealing can be verified prior to installation of other components

Multi-Component Annular Barriers:
Perf-and-Squeeze Case with Without Circulation Up Annulus

Concept and
Example Configuration 2



Spot Resin Material
Prior to Squeezing

Optionally, use retainer
depending upon injectivity

EXAMPLE MATERIALS

Cement Plug
Portland or other inorganic cement with long-term structural/matrix durability

Chemical Resistant Resin
(Furan, MF, Epoxy, etc. or Polymer Concrete)

Mechanical Isolation Tool
(Packer, Bridge Plug, Retainer, etc.)

COMPONENTS AND FUNCTION

1 - Long-Term Durability Component
- (Often) Required by regulations

2 - Secondary/Resilient Seal Component
- Resin based sealant. Place and apply pressure to squeeze. Penetrates and seals matrix of annular materials/formations
- Chemical adhesion to casing/surfaces (even oil wet). Resilient. Material properties maintain seal under changing stresses.
- Secondary seal

3 - Initial Isolation Component
- Initial primary seal
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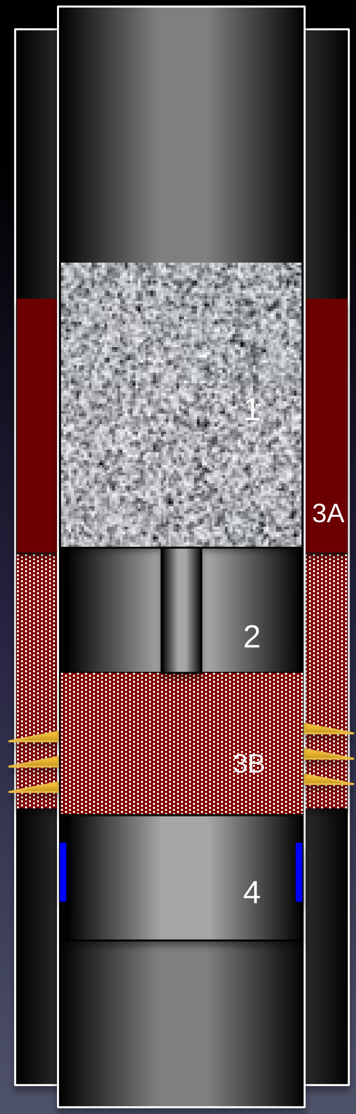
Multiple, Multi-Component Annular Barriers:
Perf-and-Squeeze Case with With/Without Circulation Up Annulus

Concept and
Example Configuration 4

Squeeze Below Retainer



EXAMPLE MATERIALS

Cement Plug
Portland or other inorganic cement with long-term structural/matrix durability

Mechanical Isolation Tool
(Packer, Retainer, etc.)

Chemical Resistant Resin
(Furan, MF, Epoxy, etc. or Polymer Concrete)

Mechanical Isolation Tool
(Packer, Bridge Plug, Retainer, etc.)

COMPONENTS AND FUNCTION

1 - Long-Term Durability Component
- (Often) Required by regulations

2 - Isolation/Material Placement Component

3 - Secondary/Resilient Seal Component
- 3A = Neat Resin 3B = Solids-filled resin
- Resin based sealant. Place and apply pressure to squeeze. Penetrates and seals matrix of annular materials/formations
- Chemical adhesion to casing/surfaces (even oil wet). Resilient. Material properties maintain seal under changing stresses.
- Secondary seal

4 - Initial Isolation Component
- Initial primary seal
- Serves as base for location and placement of other components
- Location, integrity and sealing can be verified prior to installation of other components

Situations Where Multiple Barriers Are Needed

Concepts and
Example Configuration 5

Example where MULTIPLE BARRIERS are (also) required

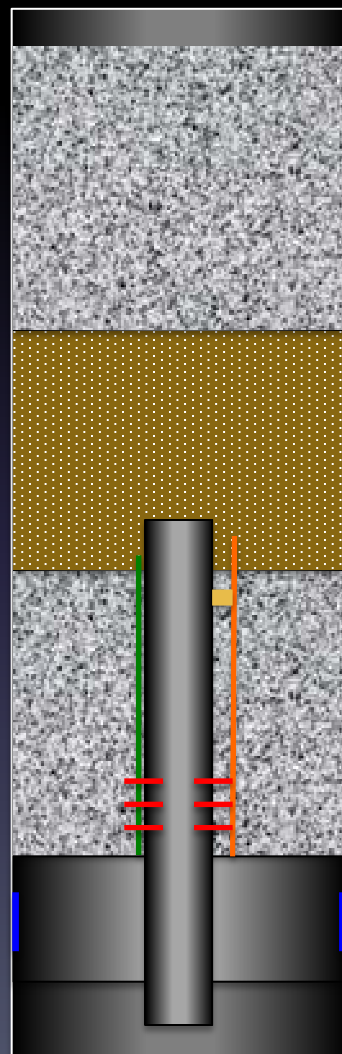
EXAMPLE MATERIALS

Cement Plug
Portland or other inorganic cement with long-term structural/matrix durability

Barite Plug / Drilling Fluid
- Modified or unmodified carrier fluid
- Modifications include in-situ reaction chemistries (Resins, etc)

Cement Plug
Portland or other inorganic cement with long-term structural/matrix durability

Mechanical Isolation Tool
(Packer, Retainer, etc.)



COMPONENTS AND FUNCTION

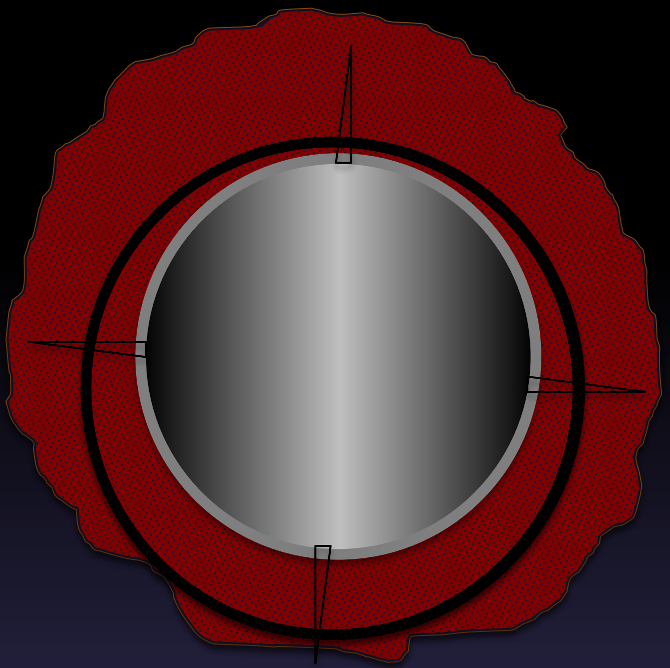
1 - Long-Term Durability Component
(Often) Required by regulations

2 - Secondary/Resilient Seal Component
- Resilient. Material properties maintain seal under changing stresses.
- Secondary seal.

3 - Long-Term Durability Component
- Control lines should be sealed prior to cutting
- This seal cannot be considered reliable since there are components imbedded into the matrix of the barrier.
- Another set of barriers above this is required for long-term reliability

4 - Production Packer, Tubing, Control Lines
- Serves as base for location and placement of other components
- Location, integrity and sealing can be verified prior to installation of other components

Benefits of Monomer/Resin/In-Situ Reaction Technologies



Penetrates material in annuli

- Consolidates material into cohesive mass
- Good adhesion to rock/steel surfaces
- Low (no) permeability
- Resilient material – good material properties
- Material properties better for long-term sealing of perforations.

Penetrates small openings/leak paths

Variety of techniques can be used for effective placement

- Some materials are self-consolidating – can be dropped through fluid in well and form a solid sealant

Many set quickly – ‘right angle set’

- Beneficial to stop/control flows (gas)
- Reduce WOC/Waiting Time

Much higher material cost than cements, but cost effective in complex, high cost well operations

Poor/limited industry support/expertise for their application

P&A Cement Formulation Example

- Total Shrinkage < 2% (as low as possible)
- API Fluid Loss: < 50 mL/30 minute (at 300 F, 1000 psi)
- Free water: Zero
- Permeability*:
- Elastic Modulus*:   Poisson Ratio*:
- Silica content: 35-50% by weight of cement
- 0.05 to 0.1 gal/sk surfactant compatible with all additives and cement
  - Addition of surfactants requires operational planning and may require additional metering and injection equipment
  - Latex emulsions contain surfactants and may provide beneficial effects of these concentrations
- Optional additives
  - Post-set expansion agents – shallow plugs (< 200 F BHST approx.)
  - Gas-generating agent – severe gas migration control

WG05: Well Abandonments

CSOEM – SC 10 – Subcommittee on Well Cements

2015 Exploration & Production Winter Standards Meeting

Joe Shine – Chair

28 January 2015

Outline

- Charge
- Introduction
- Update
- Forward Plans
- Discussion

WG Charge

- *"Identify literature and gaps associated with well plugging and abandonment for both offshore and onshore environments. Present findings to serve as foundation to develop a RP"*

Introduction

- Members
  - Joe Shine - Chair
  - Jerry Calvert – Advisor
- Contact information
  - Joe.ShineJr@gmail.com
  - Joseph.ShineJr@Aramco.com

Update

- Documents identified for literature review
  - API Bulletin E3, Reaffirmed, 2000
  - API STD 65-2, Dec. 2010
  - API RP 96, March 2013
  - US CFR Title 30 Vol. 2 Parts 200 to 699, Rev. July 2014
  - TX TAC Title 16 Part 1 Chapter 3, Rev. March 2014
  - UK Oil & Gas Guidelines, Issue 4, July 2012
  - NORSOK D-010, Rev 4, June 2013

Update

	BARRIERS															WELL STATUS		
	Requirement									Placement Methods	Quantity No.	Materials Types	Verification Methods			Drilling Active	Re-Entry Workover	Fluid Migr. Risk Cat.
	TPA	PA	CC	Position	Length	HCs	AQ	OH	CH				Cement	Mech.	Combo			
API E3																		
UK																		
CFR																		
TRRC																		
API STD 65-2																		
API RP 96																		
NOR																		

	SPECIAL CONSIDERATIONS																	
	ST	RA	AF	Hi Angle	Multi-Lat	PFZs		CS	OS	Liner Laps	HP-HT	Corrosive	Thru Tub	DHE	Geological	*Well Design*	Decom.	Monitoring
API E3																		
UK																		
CFR																		
TRRC																		
API STD 65-2																		
API RP 96																		
NOR																		

TPA = temporary abandonment
PA = permanent abandonment
CC = circumferential coverage
HCs = hydrocarbon bearing zones
AQ = aquifers
OH = open hole including completions
CH = cased hole including completions

ST = side tracking
RA = radioactive
AF = annular fluids
PFZs = potential flow zones
CS = casing stubs
OS = offshore
DHE = downhole equipment

Forward Plans

- Complete identified literature review
  - ➢ API RP 96
  - ➢ NORSOK D-010, Rev 4, June 2013
- Evaluate categories
  - ➢ White spaces
  - ➢ Similarities, differences, potential cost implications
- Document development
  - ➢ Review outlines of similar documents
  - ➢ Minimum requirements for categories
  - ➢ Alignment with applicable documents and/or workgroups