TECHNOLOGY ASSESSMENT FOR

SUPERCEMENT FOR ANNULAR SEAL
AND
LONG-TERM INTEGRITY IN DEEP- HOT WELLS

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Introduction – Current State of Technology

As the worldwide demand for energy continues to grow, the oil and gas industry continues to drill deeper wells in order to find and produce new assets. As shallow onshore and shallow-water offshore wells become depleted, the industry is forced to explore in more hostile environments to supply the world's energy requirements. Deep wells have associated with them higher pressures and temperatures, which induce more stresses on the downhole equipment and materials, including the cement sheath.

Since the 1920s, Portland cement has been used as the preferred bonding and sealing material in oil and gas wells. Portland cement is readily available, easy to form into a pumpable slurry, achieves adequate strength in the well, and is relatively inexpensive. Additionally, extensive expertise has been developed over the years in the development and application of additives to modify the kinetics of the Portland cement hydration process, and to a lesser degree the strength of the material after hydration. Inherent limitations of Portland cement include its relatively low tensile strength and lack of ductility in its set form. Increasingly, the stresses encountered in deep, hot wells demand higher tensile strengths and resiliency than is found in conventional Portland cements.

The primary apparent benefits of using Portland cement in deep, hot environments are the low cost and industry expertise in modifying the kinetic properties. However, long-term sealing integrity in these environments is low because of the material limitations discussed earlier. Cement failure is generally delayed in time as stresses encountered in production of the well break down the cement sheath over time. Failure of the cement sheath can results in fluid migration between zones, which can potentially contaminate potable water zones. Additionally, pressure behind casing can result in catastrophic failure of the well, eventual abandonment, and a risk to life and property. Solving these cement sheath failures require extensive (and expensive) remedial operations, and are not always successful. Remedial costs required to repair failed cement sheath can be many multiples of the initial cost of the cement job. Additionally, the only material available in most cases is again formulations of Portland cement, which means remedial repair will not be long-lived in deep, hot wells.

This project seeks to not only reduce catastrophic well failures and damage to the ecology due to failure of cement, but to substantially improve the economics of cementing wells. These benefits are to be realized through the development of a new "Supercement" that will exhibit long-term integrity in high pressure and temperature environments. In terms of well economics, some increase in material cost is acceptable if long-term integrity can be improved so that remedial work is reduced or eliminated through the superior performance of supercement.

Discussion: Development Strategies

Development in this area is required in order to either find a new sealing material to replace Portland cement in high pressure and temperature wells, or to substantially modify the properties of Portland cements to achieve acceptable levels of casing support, sealing effectiveness, and long-term integrity in hostile environments. There are no known materials that adequately modify the performance of Portland cement in high pressure and temperature environments available to the industry today. The consequences of cement failure include the economic considerations already discussed, as well as the adverse environmental consequences of fluid migration between formations. The requirements imposed on the sealing material are not only the set properties, but the fluid properties that allow the material to be placed in the well. Considerations during this pumpable fluid stage include the following characteristics, and the key is that these must be alterable to match the requirements of the well.

- Rheology – The fluid must be thin enough to be pumpable, but thick enough such that any entrained solids remain in suspension.
- Pump time – The length of time the material remains pumpable, so that it can be placed in the annulus properly. Normally, higher downhole temperatures make conventional cementitous materials set quicker than at lower temperatures, aggravating the pump time problem.
- Transition time – When cementing across high-pressure gas zones, it is desirable for the transition from slurry to solid occur rapidly, in order to minimize the time between loss of hydrostatic head and the development of strength. During this period of time between the cessation of hydrostatic head transmission and the development of set strength, high-pressure gas can invade the cement column, resulting in loss of sealing integrity.
- Fluid loss – This is a measure of a slurried material's ability to retain it's liquid phase during the placement process. Excessive fluid loss to the formations through which the slurry is pumped results in dehydration of the slurry and loss of pumpability.
- Density – The density of the fluid must be alterable in order to control downhole fluids. If the density is too low, the pressures in the well annulus can fall below the pressure of the fluids contained in the formation, allowing the well to flow prematurely and result in loss of control of the well.
- Compatibility with other fluids in the wellbore – incompatibility may result in lack of attainment of desirable properties, or the inability to properly place the cement.

In addition to the properties required while the material is a liquid or slurry, other properties are required after the material has hardened in the wellbore. As with fluid properties, desirable after the material attains strength must be alterable within certain ranges in order to maximize performance in the well.

- Compressive strength – Historically this was the primary aspect of strength that was considered in the design of cement slurries. Recent studies have shown that compressive strength, while important, is only one of several important characteristics of the solid material.
- Tensile strength – Increasingly, it is being recognized that cement fails in tension in the wellbore, resulting in cracking and the generation of fluid migration channels. Tensile strength in Portland cement is notoriously low, and the construction industry compensates for lack of tensile strength with steel reinforcing rods or other tension-carrying ductile members. In oil and gas wells, reinforcement options are limited, so the new material must have high levels of tensile strength.
- Resiliency – This is a measure of the cement material to absorb stresses without failure. Again, Portland cement is notoriously brittle, so it's ability to deform without failure is low. The ideal well cementing material would be sufficiently ductile to deform under load without failing.
- Shear Bond – Well cementing materials must bond not only to steel pipe but to a variety of formations encountered in the well. This bonding behavior is the primary mechanism by which the cementing material seals the wellbore fluids in place.

Project Structure:

The Supercement project is broken into three one year-long phases, with specific tasks within each phase. The first phase (to be complete by Dec 31, 2004) was designed to identify and evaluate candidate materials that may ultimately result in a replacement for Portland Cement in high pressure and temperature environments. Tasks accomplished included literature search, low temperature laboratory screening tests, high temperature laboratory testing, and non-traditional testing designed to determine characteristics other than strength attainment. The deliverables of Phase I are to have approximately six candidate systems to take into the Phase II.

The purpose of Phase II is to determine if the materials identified as candidates can be manufactured in quantity and can be mixed and pumped with field-scale equipment. Additional large-scale testing includes quality control of the field-scale mixed product, and placement and evaluation in a test well.

Phase III concentrates on commercialization and technology transfer, in which field trials are completed, cost/benefit analyses are done, and the work is published for the purpose of developing interest in the oil and gas market.

Conclusion: The Future

Phase III constitutes the primary project commercialization and technology transfer activities. It is estimated that the annual cost of Portland cementing materials used in high pressure and temperature wells in the United States is approximately $125 million. This is based on the consumption of 50 million sacks of cement annually by the oil and gas industry, with approximately 5% of that figure applied to the subject deep, hot wells. Assuming that nearly all of these wells require remediation at some point during the life of the well due to failure of the cement sheath, remediation costs can conservatively be estimated at $50 million per year. This means that the break-even point of "Supercement" is terms of economics is approximately 100% increase in the cost of the material. Any cost less than that 2X multiple results in savings to the oil and gas operators, as well as significantly reducing the risk of catastrophic well failure, ecological damage, and the risk to property and life.

All scenarios are to be evaluated throughout the course of this project, including "hybrid" solutions that might include "Supercement" application only in the parts of the well that require superior properties and Portland systems in the less hostile portions of the wells. Additionally, at this point in the project, non-Portland systems as well as hybrid Portland systems that utilize non-traditional additives that substantially improve Portland cement properties are being evaluated. The ultimate solution may be a suite of materials tailored to the requirements of the well and the anticipated life cycle stresses imposed on the cement sheath.