

CURISTEC Helping Cementing Companies Create Value By Developing New Cementing Technologies

In a world where cost reduction is at the heart of the business and where technology is mandatory to prevent cement job failure, a complete mind shift has to take place when working on high tech projects.

Today, with the heightened focus on cost, the industry expects pinpoint technologies and well specific products be used on their wells to help minimize the risk of cement failure, increase primary cement job success, and reduce non-productive time (NPT), thus reducing the time and cost of production.

This demand requires development of new cementing technologies to meet this need. Each well has specific technical needs, and no longer can one-size fit all solutions be used and meet today's demanding economics.

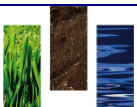
CURISTEC has and will continue to develop industry-leading cementing technologies and sciences. Partnering with CURISTEC can help cementing companies increase their technology image, reduce the time required to develop and commercialize new cementing technologies, and reduce their overall technology expenses.

A mind shift is needed to meet operators' objectives and expectations.

Well integrity is the main objective for oil well cementing. The 12th edition of the IADC Drilling Manual states, "The principles and processes for establishing and maintaining cement as a barrier are central to providing well integrity".

Over the last ten years, the industry has increased its focus on achieving cement integrity for the life of the well. The predominate drivers for this are new governmental legislations, an increase in the complexity of wells being drilled, an updating of industry standards and recommended practices, and a higher order of industry focus on quality control/assurance. (Figure 1).

Due to the recent unprecedented rate of decline in the price of oil and gas, operators are shifting their corporate strategies to reduce their well construction and operating cost in an effort to maximize Return on Investment (ROI). The industry's shift to a more "cost based" structure has resulted in operators delaying or reducing the implementation of new cementing technologies and the substantial reduction of Research and Development (R&D) funding for new cementing technology development by cementing companies. Additionally this "cost based" strategy has resulted in a shift in the industry cementing technology leadership. Today, many of the legacy cementing technology leaders are not keeping pace with the industry's demand for new cementing sciences and solutions due to substantially reduced technology budgets.



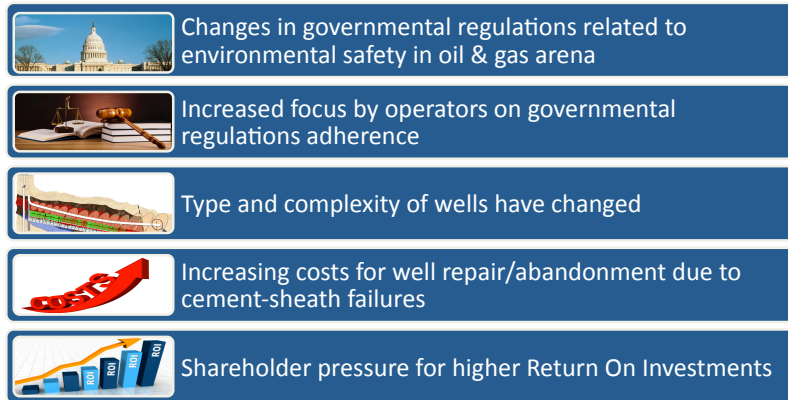


Figure 1. Key drivers that increase the demand for cement integrity

The industry is in a state of change and is experiencing a paradigm shift due to the industry's constant need for new technologies and the financial market's demand for an acceptable ROI. With the reduction in available research technology funds and the tremendous retirement of experienced scientists and engineers, the next generation of industry technical technology leaders will partner with "Boutique" companies that specialize in one or two technologies to help them develop and maintain an industry-leading portfolio.

This white paper outlines several key activities required to achieve cementing success and demonstrates how CURISTEC is ideally positioned to meet the current and future cement integrity technology needs of oilwell cementing companies.

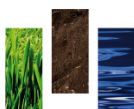
Zonal isolation for the life of the well requires advanced engineering tools and technical excellence.

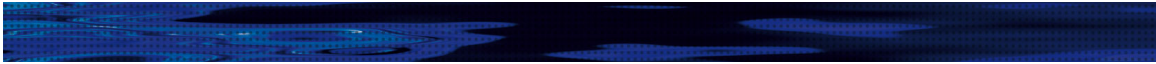
Today more than ever, the old phrase of "You only have one chance to cement a well correctly" has never been more true. A successful cement job can reduce well's CAPEX and OPEX costs, conversely a failed primary cementing job results in not only NPT, but can also result in higher operating expenses and possible lost of production.

Obtaining a successful cement job is hard and achieving complete zonal isolation for the life of the well is even harder. In order to establish and maintain a successful cement barrier for the life of a well, there are four key areas that should be mastered in the cement sheath/plug design process.

Cement slurry design and placement in the wellbore (Figure 2)

It is essential that the designed cement slurry be safely placed into the wellbore, obtain complete radial coverage and create a barrier. To meet these objectives, the cement design engineer uses a cement job simulator that may include dynamic temperature models, casing centralization models, and 3D hydraulic simulators based on Computational Fluid Dynamics (CFD). These tools are targeted at achieving a higher order of cement placement in the hole and preventing cement channels caused by poor cement placement. To ensure that the cement design can be safely placed in the well, conventional cement laboratory testing is performed. These tests typically include total thickening time, rheology, free fluid, fluid loss, and well fluid compatibility.





Today, classical cement laboratory testing methods and practices are fairly well defined by API. However in the past fifteen years new discoveries in cementing mechanics, cementing chemistry, and effect of long term thermal expose, are driving the development of new advanced cement testing processes and methods. Additionally in the past ten years, the industry has seen advancements in cement job simulators, which have led to an increase in cementing success.

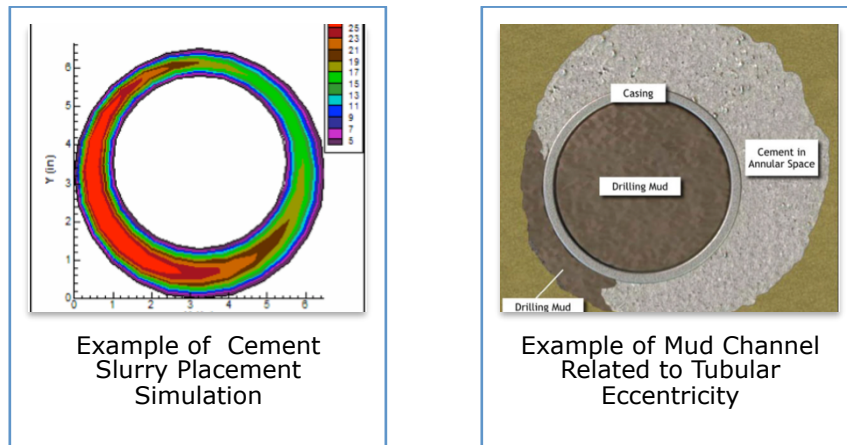
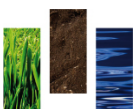


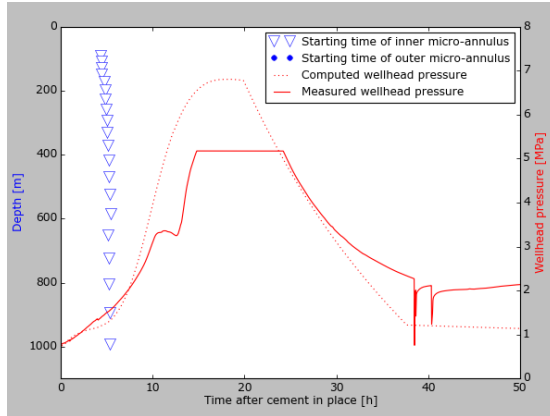
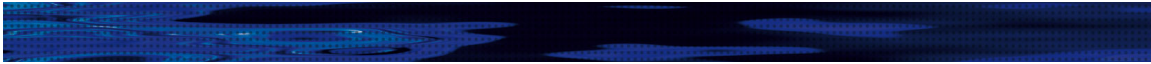
Figure 2. Use of CFD modeling and example of the consequence of poor displacement of mud from the annulus

Fluid migration prevention after placement (Figure 3)

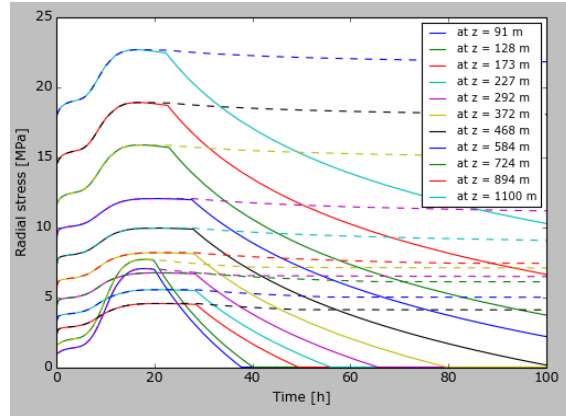
The cement must be designed to prevent any fluid flow through the cement slurry during setting, as this can have dramatic consequences: environmental issues, expensive workovers, and well safety issues. Today most fluid migration simulators are limited to a numerical check of equations developed in the mid 1980's. These models are predominately written from a strictly fluid mechanics standpoint and do not take in account the porous nature of cement during hydration. To ensure the cement design can prevent fluid migration, advanced cement laboratory testing should be performed. These tests typically include, gel strength development, cement shrinkage, and potential leakage measurements. They give only a portion of the information needed for proper design.

The R&D work that CURISTEC has completed indicates that a failure to include the porous nature of the cement during hydration and accurate cement shrinkage predictions can result in cementing system that may not prevent fluid flow after cementing.





Simulation of micro-annulus formation and wellhead pressure, with comparison with measured wellhead pressure



Simulation of radial stress at cement sheath inner and outer interfaces versus time and depth to check for micro-annulus opening

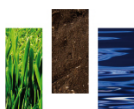
Figure 3. Evaluation of the risk of gas migration during cement hydration

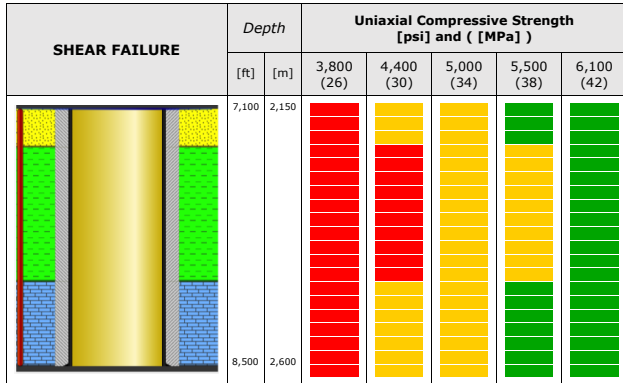
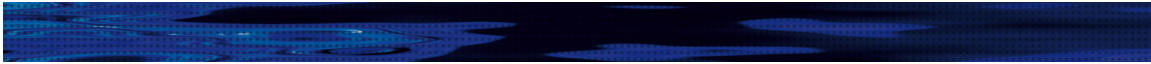
Loss of zonal isolation due to mechanical property failure (Figure 4)

The cement must be designed to withstand the anticipated stresses it will be subjected to during the life of the well. In the past fifteen years, new cementing design tools such as Cement Mechanical Integrity (CMI) models and triaxial load cell testing have been incorporated into the cement designing process.

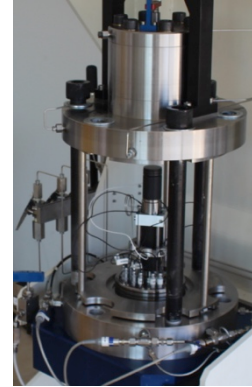
Experienced cement design engineers use CMI models to study how changes in wellbore pressures, temperatures, and reservoir compaction, affect the cement sheath/plug, and analyze if the cement design can successfully withstand these events. Many times the engineers use CMI models to identify the required cement mechanical properties before beginning to design the cement slurry. Once the CMI modeling is completed and the cement barrier is designed, triaxial load cell testing is performed to ensure that the cement design can mechanically perform as required. In addition to the standard mechanical testing for Young’s modulus and Poisson’s ratio, advanced mechanical testing (cement hydration, cement shrinkage/expansion, cohesion, and friction angle) should be performed to assure a fit for purpose design.

Today, each of the major service companies has a CMI simulator. These simulators were developed early 2000’s and typically take a very conservative approach to CMI modeling, especially in the area of calculating the “initial state of stress of the cement”. CURISTEC has done extensive R&D in how cement systems mechanically perform under various well conditions and has developed proprietary algorithms in the areas of cement hydration behavior, calculating the “initial state of stress” and cement shrinkage. The results of these R&D efforts have resulted in a reduction of cement sheath/plug failure and in lowered-cost cementing systems.





CMI modeling to evaluate the impact of uniaxial compressive strength on cement sheath integrity



Triaxial load cell to evaluate cement mechanical properties

Figure 4. Use of CMI modeling and triaxial mechanical testing to ensure cement-sheath integrity

Cement chemical degradation when in contact with corrosive well fluids

A cement sheath/plug should be designed to withstand the anticipated geochemical exposure it will be subjected to during the life of the well. In the past fifteen years, there has been an industry focus in the development of Carbon Capture and Storage (CCS) projects, and have resulted in the demand for new cement compositions to withstand both CO₂ and H₂S environments. Additionally, new cement testing protocols are being developed to measure how a cement system behaves when exposed to corrosive fluids under actual well temperatures and pressures.

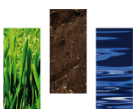
Today, API has a limited set of standardized testing protocols for corrosive environments, additionally there are a very limited number of simulation tools available to evaluate how a cement performs under long-term exposure to CO₂, H₂S, or a combination of the two. CURISTEC has ongoing R&D efforts in these two areas.

Use of Cement Mechanical Integrity to improve the tendering process

The main objective of the tendering process is to ensure the best-fit supplier is selected to supply goods and/or services to the customer, i.e., the supplier that offers best value for money. Such a supplier is likely to be commercially sound, technically competent, financially strong and perceived as best for the task.

The specification is a most important section of the invitation-to-tender documentation, both for the purchasing organization and for potential suppliers, since it is the specification that sets out precisely what characteristics are required of the products or services sought.

There are two main types of specification – the “functional” specification, which sets out the functions that the goods and/or services are expected to fulfill, including the performance to be achieved, and the “technical” specification, which stipulates the technical characteristics of the goods or services, usually designated in accordance with accepted national or international technical standards.





As a general rule, the specification should include expected performance or output, but should not necessarily define how this should be achieved. To do so may lead to more costly solutions to the purchasing organization's requirements than might be proposed by potential suppliers. **There is little point in specifying a Rolls Royce if a family car will do the job to the satisfaction of the customer.**

In terms of Cement Mechanical Integrity, the evaluation of the risk cement sheath integrity fails requires the knowledge of:

- The state of stress and pore pressure all along the well life, i.e., during cement hydration, after cement has set, and during all the loading stages the cement will be submitted to (casing tests, leakoff test, change of mud density, heating, cooling, stimulation, production...);
- The type of failure that could occur: compressive failure, tensile failure, casing/cement debonding, formation/cement debonding;
- In case of compressive failure: Cement elastic properties (Young's modulus and Poisson's ratio) and failure properties (Unconfined compressive strength and friction angle) properties;
- In case of tensile failure: Cement elastic properties (Young's modulus and Poisson's ratio) and failure properties (tensile strength) properties;
- In case of debonding: Cement elastic properties (Young's modulus and Poisson's ratio) and failure (bond strength) properties;
- In case of heating or cooling: Cement thermal properties (Coefficient of thermal dilation, thermal conductivity, specific heat).

Therefore, it is highly recommended to perform CMI modeling to evaluate:

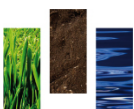
- The type of failure that may occur;
- The type of cement mechanical properties that should be specified;
- The properties specification.

For example, if the risk of losing cement integrity is under the compressive mode, at least four independent properties will have to be measured:

- Young's modulus;
- Poisson's ratio;
- Unconfined compressive strength;
- Friction angle.

These four parameters are not independent and CMI modeling should be used to precise which combinations are acceptable, and which are not. This comment is also valid if the risk of losing cement integrity is under the tensile mode, where at least three independent properties will have to be measured:

- Young's modulus;
- Poisson's ratio;
- Tensile strength.





The value of CMI modeling is thus to:

- Check if there is a need to specify some requirements in terms of cement mechanical properties. Indeed, some integrity issues that occurred in the past could have been misunderstood as of mechanical origin;
- If there is a need, ensure that the specifications are complete. For example, only specifying Young's modulus and Poisson's ratio is never sufficient;
- If there is a need, offer a range of mechanical properties and not a single value, in order to the vendors to propose their best solution.

This value directly translates into reduced cost, savings, reduced number of incidents, and, as a consequence, improved ROI.

Why CURISTEC?

CURISTEC is a privately owned industry recognized technology-company, specializing in oil & gas geomechanics, wellbore integrity, cement integrity, materials testing, engineering software, and consulting services. With engineers in France, Vietnam, North America, and Abu Dhabi (CurisCotta), CURISTEC is globally positioned to deliver solutions based on an integration of science, engineering and field experience for your projects. **The quality of the service is the same independently from where it is provided.**

CURISTEC's business model is very simple:

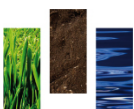
- CURISTEC works with operators and service companies to develop the best cementing solution to achieve a project's objectives.
- CURISTEC solutions are based on a combination of the latest cementing sciences, technologies and extensive operational experience.
- CURISTEC DOES NOT sell cementing chemicals, cementing equipment or cementing pumping services.

CURISTEC's cementing portfolio

As a recognized industry technology leader in oilwell cementing design, CURISTEC has developed and maintains a complete line of oilwell cementing technologies, engineering services, materials testing, and data management tools. Listed below is a short summary of CURISTEC's cementing portfolio.

Engineering and consulting services

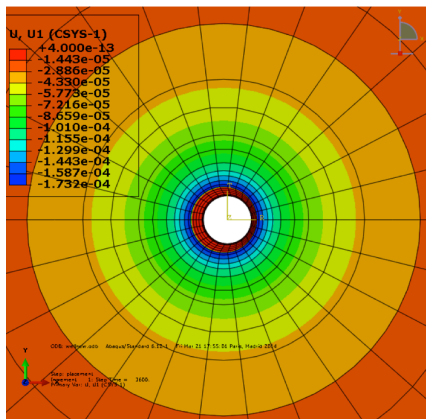
- CURISTEC cementing engineers combine the latest sciences, technologies and extensive operational experiences to proactively identify well events that can damage the cement. Our engineers assist you in designing the best cementing solution for the life of your well.
- CURISTEC's engineers, are uniquely positioned to provide support for your entire project; beginning with pre-project planning, through discrete job planning/execution and including post job analysis and diagnostics.



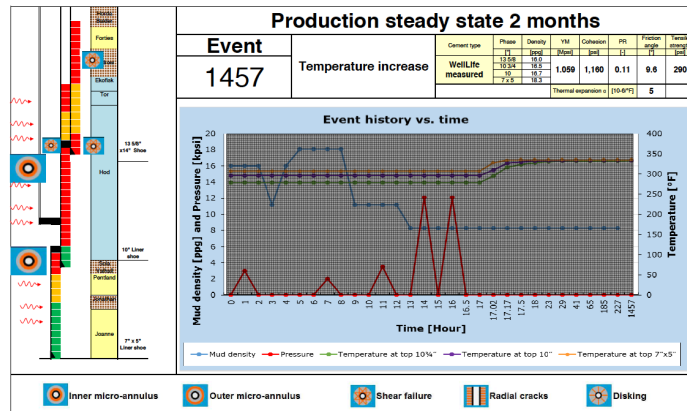
CURISTEC technology Can Help Cementing Companies Create Value by
Designing Cement Integrity for the Life of the Well

Cementing mechanical integrity modeling (Figure 5)

- **CurisIntegrity CI-A0** is a cement integrity quick look simulator that enables engineers to quickly determine the risk of cement sheath failure for conventional and advanced cement designs.
- **CurisIntegrity CI-A1 and A2** enable engineers to quickly and easily evaluate five modes of cement sheath failure using multiple loadings from temperature, pressure and cement hydration. They can also determine the cement sheath’s mechanical properties required to prevent cement damage throughout the life of the well.
- **CurisIntegrity CI-A3** enables engineers to quickly and easily evaluate four modes of cement plug failure using multiple loadings from temperature, pressure and cement hydration. It can also determine the cement plug’s mechanical properties required to prevent cement damage throughout the life of the well, including during pressure testing the plug.
- **CurisIntegrity CI-N** enables engineers to evaluate in depth five modes of cement sheath failure using multiple loadings from temperature, pressure, compaction and cement hydration. Based on the finite element method, it can be used to simulate any values of casing standoff, and any formation behavior, such as plasticity and creep, as it is encountered in salt formations.
- **CurisIntegrity CI-GM** enables to evaluate three modes of fluid migration during the hydration of a cement sheath/plug, and not only fluid migration through the cement matrix. Based on an entire-well simulation process, it can be used to simulate the risk of fluid migration at the cement sheath/plug interfaces.

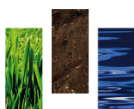


CurisIntegrity CI-N numerical simulator



CurisIntegrity CI-A1 analytical simulator – Risk of losing integrity versus depth

Figure 5. CurisIntegrity CI-N and CI-A1 outputs





Laboratory testing (Figure 6)

- **CurisLab** is a full function materials testing and R&D laboratory, located in Pau, France. CurisLab performs cementing, formation, rock, drilling and stimulation fluids testing according to API/ISO methods and maintains an ISO 9001 certification.
- **CurisLab** works with operators and service providers to deliver a complete suite of conventional and specialized cement testing services to support their projects. In addition CurisLab engineers' extensive experience enable them to provide advanced data analysis, laboratory training and audits.



HTHP cement consistometers



CURISTEC Triaxial load cell

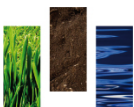
Figure 6. Two of CURISTEC's cement testing equipment

Cementing data quality management and storage

Today all companies have legacy enterprise systems, (data management, services tendering, quality assurance, etc.) in place. The direct cost to maintain and support these systems is increasing yearly. However are these systems being used? Are these systems providing value for the company? Are these systems being updated to meet the company's strategies for cost management, technical expertise and quality management?

CurisData helps engineers to efficiently and effectively manage all phases of cementing data and reduce the time and cost associated with data capture, data mining and data analysis. CurisData is CURISTEC's web-compliant Quality Data Management System. It includes modules for cementing laboratory operations, job designs, lab equipment calibration and maintenance, standards and processes, chemical inventory, onsite execution and post job evaluation. Additionally CURISTEC has ongoing development projects targeted to include capital equipment, cementing support equipment such as plug containers and service iron and bulk plant operations.

Below is an example of how ready access to quality data can lower your total yearly cementing cost and increase primary cementing success.





The five stations of the cement job cycle

Data management and analysis drive increased cementing success and higher ROI. Companies that adopt and utilize a quality management process have realized an increase in cement job success, a reduction in cementing costs, a reduction in non-productive time, and an increase in project ROI. Below is an example of CURISTEC'S quality management system and how data management is a key component (Figure 7).

Station one: Plan – Cement job design

During a project's planning stage, design engineers use cementing tools such as quick look simulators to easily and quickly identify various conditions that may increase the risk of a cement job failure. Additionally quick look simulators enable the entire project planning team to easily identify how project changes affect zonal isolation during the life the well.

During well construction stage, cement design engineers use advanced cement simulators to design cementing systems, centralizer placement, and job parameters to safely place the cement into the wellbore. Additionally cement design engineers use new cementing mechanical integrity simulators to identify the required cement mechanical properties that are required to ensure cement integrity during the life of the well.

Station two: DO – On site execution

During the job execution stage, a cementing service provider should mix, pump and place the cement as per design. Today all facets of the job execution data (densities, rates, pressure, etc.) are electronically collected and stored.

A holistic quality control review should be conducted after each cementing job to help identify anomalies between execution and design, and catalog (document) the results of these anomalies.

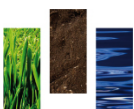
Station three: CHECK – Post job evaluation and analysis

Historically, the industry has predominately used post cement job execution evaluation and analytical logging tools to determine the quality of the cement job. On-site monitoring is limited to values measured at the surface. These methods provide a "point of time" reference and may drive small modifications to cement designs. However, each year, the industry spends millions of dollars repairing primary cement job failures.

In order to ensure that the best cementing system is constantly being designed for each well and reduce the total yearly cementing cost, the operator and service provider should routinely analyze the recent job execution data, previous jobs data, and how the previous cementing designs are performing, to identify opportunities to optimize the cement design. This holistic analysis enables operators and service providers to identify areas of cementing success, the drivers for the success, and process modifications required to enhance cementing performance.

Station four: ACT – Cement design changes

Acting means performing a Return on Experience (REX) to diagnose, assess, and improve the cementing process. This REX allows adapting the quick look, testing and simulation tools/procedures of station one (PLAN), operations of station two (DO), and QA/QC, monitoring, logging, and auditing of station three (CHECK).



Station five: Quality Data Management System – Access to quality data

The four station workflow is successful only if a quality data management system (QDMS) is easily accessible, maintained, mined, and constantly updated, where all four station processes, inputs, outputs, decisions, know-how, and decision making are captured and analyzed.

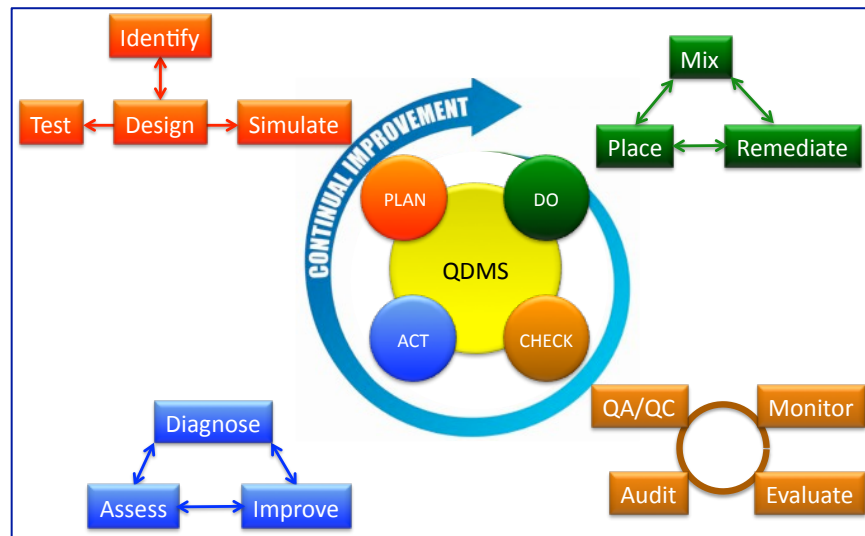


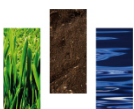
Figure 7. The cement job cycle

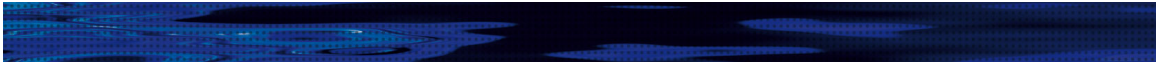
CURISTEC's maintains an aggressive cementing R&D program.

Since 2014, CURISTEC has applied for patents and has published several industry publications in the fields of oilwell cementing and geomechanics. Currently CURISTEC has ongoing, cementing R&D projects focused on increased understanding of cement volume changes during hydration, pseudo real-time monitoring of cement integrity during the life of the well and effects of high temperature and corrosive fluid exposure over time. Additionally, CURISTEC has R&D projects focused on new cement testing methods and software systems to measure and analyze these new cementing discoveries. Therefore, CURISTEC's software engineers are developing new cementing simulators and software systems incorporating new cementing sciences: improved gas migration models, cement hydration mechanics, CMI modeling for plugs, advanced hydraulic simulators, improved 3-D reporting and estimation of cement mechanical properties to fully address the unique requirements of the well.

Patent Applications

- Two new measuring cells have been designed to measure the complete set of mechanical properties of cement systems during their hydration.
- CurisIntegrity CI-A3 sciences, and algorithms





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IADC Drilling Contractor (November/December 2015) 82-87.
- Matteo Loizzo, Axel-Pierre Bois, Pantxika Etcheverry, Matthew G Lunn (2015)
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"Modeling of fluid flow through fractured porous media by a single boundary integral equation"
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"Toward an objective method of determining in situ stress from wellbore features"
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