Preface

Sand control is vital to reliable production in many sandstone reservoirs where sand can present a major obstacle to well production. The petroleum industry spends millions of dollars each year to prevent and repair sand control problems including:

- Reduced production rates
- Sand bridging in tubing and casing
- Erosion of downhole and surface equipment
- Disposal and removal of sand
- Casing damage from compressive loading caused by subsidence

Halliburton Sand Control Services

Halliburton provides a single source of solutions to these and other sand control problems. Halliburton offers dedicated equipment and total services for gravel packing, high-rate water packs, frac pack treatments, horizontal screen-only completions, and horizontal gravel packs as well as a variety of formation stabilization systems—all of which can be supported with computer simulated designs.

Halliburton believes proper well candidate selection and treatment designs, excellence in onsite delivery, safe execution, and post-treatment reporting and analysis are the keys to a successful sand control program.

Halliburton Sand Control Services start with an in-depth analysis of the reservoir and well conditions. Once a sand control method has been chosen, the design of the related fluid systems and downhole equipment can begin. Halliburton provides specialized surface and downhole equipment including gravel pack packers, inflow control technology, and screens to inhibit movement of formation sand into the wellbore, surface pumping equipment, fluid systems, and filtration systems. Sand Control Completion Services are customized to suit individual well and reservoir requirements designed to capture the best value from the asset.
Qualified Personnel

Halliburton Sand Control personnel have the expertise and experience to understand the special concerns of operators with sand production problems. Dedicated, highly qualified Halliburton engineers and technicians conduct developmental projects with a variety of downhole completion tools and systems. With ongoing fluids research, our professional personnel provide expertise in developing fluids, acid formulations, gelling agents, formation stabilizers, and processes that enhance the productivity of wells with the potential for sanding problems.

Halliburton service specialists and other field technical support personnel are among the most experienced in the industry, learning from knowledgeable veterans and receiving extensive training on the job and in the classroom. For customers, we offer special training seminars to familiarize them with Halliburton equipment and operations.

Training Centers

Training provided by Halliburton is designed to match or exceed that of any other service company. Major training centers are found in the following locations although much of the education is conducted in the individual locations around the world through home study courses and on-the-job training.

- Sandersville, Mississippi
- Carrollton, Texas
- Duncan, Oklahoma
- Houston, Texas
- Montrose, Scotland
- Ipoh, Malaysia
- Cairo, Egypt
- Villahermosa, Mexico

Quality, Health, Safety, and Environment Program

Rather than focusing only on a quality system such as ISO-9001, Halliburton has chosen to develop a business system which incorporates quality, health, safety, and environmental requirements in one single management system. The Halliburton Management System (HMS) defines our processes and includes quality, safety, environmental, and occupational health check points.

Health, Safety, and Environmental Policy

Halliburton recognizes the importance of meeting society's needs for health, safety, and protection of the environment. We work proactively with employees, customers, the public, governments, and others to use natural resources in an environmentally sound manner, emphasizing the safety of employees and the public as well as the needs of future generations. We are dedicated to continuous improvement of our global health, safety, and environmental processes while we supply high-quality products and services to customers. To meet these responsibilities, we manage our business according to the Health, Safety, and Environmental (HSE) principles.

Research and Development

With Halliburton's extensive sand control experience, customers are provided with advanced technology and outstanding personnel to solve problems efficiently and effectively. Halliburton research and development efforts are carried out in various locations:

- Carrollton Technology Center – Carrollton, Texas
- Houston Technology Center – Houston, Texas
- Pune Technology Center – Pune, India
- Aberdeen Technology Center – Aberdeen, Scotland
Singapore Technology and Manufacturing Center

The Completion Technology and Manufacturing Center in Singapore significantly expands Halliburton Completion Tools technology and manufacturing capacity. Complementing our Carrollton, Texas facility in the Western Hemisphere, the Completion Technology and Manufacturing Center serves as the new global headquarters for Completion Tools, allowing for the delivery of high-quality products to a broad and growing customer base in the Eastern Hemisphere.

This vast state-of-the-art facility includes manufacturing, technology, and administrative space. Technology laboratories and test facilities house complex processes such as high-alloy material precision machining, electrode discharge machines, and small deep-hole gun drilling. In addition, deep well simulators, high-pressure/high-temperature testing facilities and a deep horizontal well enable all aspects of engineering testing and simulated systems integration testing.

Carrollton Technology Center

Halliburton Research and Development for Sand Control Tools at the Carrollton Technology Center features an 11,000 ft² (310 m²) laboratory and testing complex. The center’s engineering test facilities provide engineering analysis and support, high-temperature/high-pressure testing, and tool prequalification to API and ISO requirements. The center also includes two working test wells with rig accessories, slickline, and electric-line operations as well as flow testing capabilities which allow Halliburton to simulate actual well environments before running new tools in a customer’s well.

Rheology Laboratory

Rheology research includes use of flow loops in various applications. Medium-scale loops test fluids developed in the research centers, while large-scale flow loops obtain full characterization of the rheology of fluids for gravel and frac packing.

Other rheology laboratory analysis studies the effects of high-pressure gases and liquids on materials at elevated pressures and temperatures. A slow-strain rate tester tests the cracking resistance of nickel alloys and other high-alloy metals.

Polymer Laboratory

A polymer laboratory tests and evaluates the latest polymeric materials for both surface and downhole applications. Equipment includes test cells capable of testing seal materials up to 500°F (260°C) and pressures of up to 30,000 psi (2067 bar). In addition, extensive studies are conducted on the effects of organic amine corrosion inhibitors on elastomers. Halliburton’s research in seal materials has yielded elastomer compounds unrivaled in the industry.

Metallurgical Laboratory

Mechanical testing and certification performed in the metallurgical laboratory provide analysis and daily support for manufacturing. An important function of the metallurgical lab is supplying materials recommendations to customers based on individual well data. Heat treatment tests determine if alloys will function downhole as needed. A scanning electron microscope can examine the surface of a failure to determine the cause, whether it be environmental embrittlement, incorrect chemistry, or overstress.
Deep Well Simulator
A unique deep well simulator at the Halliburton facilities in Carrollton, Texas tests full-size, downhole tools in hostile environments. For example, high-temperature/high-pressure packers may be tested in simulated conditions up to 1,000°F (537°C) and 30,000 psi (2067 bar) hydrostatic pressure. Other testing uses two rig-equipped test wells, also located onsite, to confirm tool compatibility, operating sequences, and service techniques.

Mike Adams Test Well Facility
As the demand for energy increases, the drilling and completion of wells continues to forge new boundaries. Higher pressures, hotter wells, and tool complexities require state-of-the-art facilities. Named in memory of one our most respected Test Department leaders, the “Mike Adams” test well is designed to be safe, operationally efficient, and best in class for downhole testing of tools for both vertical and horizontal applications.

The Mike Adams facility is a modern drilling rig running on clean, quiet electric power with SCR controls. This big bore well has a cased hole configured with 20-in. × 13 3/8-in. × 10 3/4-in. × 9 5/8-in. casing. The 9 5/8-in. casing kicks off the vertical bore through a 16° per 100-ft radius in a horizontal section. The facility features a doghouse with a safe viewing room for customers, modern data acquisition system, dressing facilities, and office area.

The Carrollton facility also includes a second test well used primarily as backup during peak periods of use of the Mike Adams test facility. This backup test well can be used for full scale testing of packer, safety valves, Sliding Side-Door® devices, wireline tools, coiled tubing units, snubbing units, and pumpdown installations. The facility is equipped with a variety of popular casing and tubing sizes to allow installation and testing of well completion tools and service equipment.

High-Temperature Test Facility
The high-temperature test facility (HTTF) is used to test experimental designs for use in high-temperature/high-pressure wells. The HTTF has five below-ground heated test cells and one rapid cool down cell. The HTTF is ideally suited for testing packers per ISO 14310/API 11D for all “V” class ratings. Each test cell is designed to accommodate assemblies up to 30-ft (9.14-m) and 30-in. (762-mm) diameter and has a temperature range up to 700°F (371°C). The device undergoing testing receives uniformly heated air to simulate severe temperatures down hole. The rapid cool down test cell employs a self-contained chiller unit capable of cooling to 32°F (0°C).
The HTTF control room contains Allen-Bradley touch screen controllers and a PC-based data acquisition (DAQ) system, which uses software to store information in a format that can be analyzed or charted. Information can be printed directly from the DAQ system in a line chart format for immediate review. Cameras safely monitor the test cell area for potential problems without exposing technicians to high pressure or temperature. A gantry crane above the simulator facilitates safe handling of long, heavy assemblies.

A special inert gas system makes the cell’s sealed/contained atmosphere nonflammable. An oxygen analyzer and alarm system monitors cell atmosphere, and controls are provided to maintain inert mixtures for lower explosion limit control. The only system pressure limitations are imposed by the physical parameters of the test fixture and casing joints. Through this system, Halliburton can accelerate development of new equipment technology already in demand by the petroleum industry.

The North Belt Campus in Houston, Texas is home to Halliburton’s largest technology center—the Houston Technology Center. At 215,000 ft², it is the largest Halliburton facility globally. The primary sand control focus is fluid development and field support, Geomechanics testing, analytical testing, and core flow testing.

Halliburton’s Fluids Center of Excellence for the Eastern Hemisphere, the Pune Technology Center in Pune, India, supports the key technology areas of Fluids Chemistry and Engineering, Fluids Delivery Systems, and Reservoir Knowledge. The engineers and scientists at the center are dedicated to finding innovative solutions for the ever-evolving energy industry.

Housed in the 66,000 ft² Pune facility is a broad range of research, development, and support activity, including teams and laboratories dedicated to Cementing, Production Enhancement, Baroid Drilling Fluid Systems, and Sperry Drilling. The Pune team is committed to delivering consistent quality service in accordance with ISO 9001:2008 requirements. Working in collaboration with other Halliburton Technology Centers, further expands our capabilities to open virtually unlimited problem-solving possibilities.

The labs in Houston and Pune provide sand control support from a production enhancement fluids/analytical/Geomechanics perspective for both new product development and technical service/field support.

Houston Technology Center and Pune Technology Center

Formation evaluation is one of the first steps in a successful sand control job. Since no two wells are exactly alike, careful analysis of formation sand samples and fluids is critical to every Halliburton sand control design. This is true whether the technique is chemical consolidation, combination systems, mechanical gravel packing, or running a premium screen, prepacked screen, wire-wrapped screen, or slotted liner.

Evaluation includes analysis of samples of formation sand, produced crude oil, and formation brine. Extensive knowledge of pretreatments and gravel pack procedures helps ensure fluids will be compatible with each other and with the formation.
Production Enhancement Division

The Production Enhancement Division helps customers manage and improve well production for new or already-producing wells and includes acidizing, fracturing, sand control, conformance technology, and coiled tubing technologies. Our capabilities make use of equipment, facilities, telecommunications systems, and a global network of real-time applications, combined with our extensive knowledge and experience.

Sand Control product development personnel work on a variety of systems that will aid in the sand control completion. These systems include carrier fluids for fracturing/gravel packing, formation stabilization products, fluid loss products, etc.

The field support or Technical Service group tests the wide range of Halliburton products used in sand control completions. Testing includes:

- Regain permeability testing of cores following treatment fluids such as formation stabilization systems, carrier fluids, fluid loss control materials
- Sieve analysis
- Large scale testing of products (typically in Halliburton’s Duncan, Oklahoma test site)

Analytical Chemistry

Analytical Chemistry laboratories in Houston and Pune house the electron microscopes, Nuclear Magnetic Resonance, and X-Ray diffraction tools as well as other high-tech equipment used to investigate samples from the field. Halliburton’s experienced scientists use these tools to perform time-sensitive tests on samples, cores, and fluids to find answers for clients. Depending on the nature of the sample material, testing might require use of multiple instruments to paint a complete picture of the situation. Some of the tests include:

- Inductively Coupled Argon Plasma Spectrometry (ICP) to identify concentrations of metals in brines, clays, and soil samples
- FTIR microscopy to obtain an infrared spectrum of data like absorption, emission, and photoconductivity from a specific region of a sample
- Thermal Gravimetric Analysis (TGA) to analyze the decomposition of a sample material
- Loss on ignition
- Particle size analysis
- Scanning Electron Microscope (SEM)
- X-Ray diffraction

Other tests such as testing of corrosion inhibitors and formulations, dynamic fluid loss testing, and conductivity testing are performed at the Duncan Technology Center.

Geomechanics

The Halliburton Geomechanics laboratory is one of only a few labs capable of performing a digital core analysis. Other capabilities include:

- Complicated mechanical fracture-type studies of loosely consolidated sandstone
- Specialized tests and fracture studies on actual field cores
- Simulated downhole conditions while studying fractures of those cores

The Geomechanics lab provides fast, cost-effective tests under pressures and temperatures found in the reservoir, including:

- Numerous mechanical properties under both confined and unconfined conditions
- PolyaXial, triaxial, and uniaxial testing for Young’s Modulus, Poisson’s Ratio, and compressive strength
- Ultrasonic velocities
- Brinell hardness test
- Brazilian tensile strength
- Mohr failure envelopes
- Fracture toughness
- Thick-wall cylinder strength
- Proppant embedment
- Fracture stimulation
- Fluid compatibility
The Geomechanics laboratory’s sophisticated machinery can examine samples larger than most other labs in the world with the ability to exert more than a half-million pounds of force on samples.

Besides physical testing, sophisticated numerical simulation capabilities with supercomputer computation power enhance understanding of Geomechanics to help design creative Geomechanics tests. The data collected can be used for sanding studies in concert with Halliburton’s Consulting & Project Management Group.

All oilfield disciplines come together in Geomechanics. The insights developed here have helped Halliburton become one of the world’s most efficient oilfield service companies.

**Field Support Laboratories**

In addition to the facilities in Houston and Pune, Halliburton has field support laboratories in various locations around the world. These laboratories can provide localized support and also conduct quality control of the chemicals to be used on the job.

**Manufacturing Facilities**

Manufacturing facilities for downhole sand control equipment are found at the following locations:

- Carrollton, Texas
- New Iberia, Louisiana
- Lafayette, Louisiana
- Arbroath, Scotland
- Jurong, Singapore
- Johor, Malaysia

The following Halliburton locations manufacture surface sand control equipment:

- Duncan, Oklahoma
- Arbroath, Scotland
System Design Capabilities

Halliburton offers an extensive array of software packages that support job design for sand control completions. These include (but are not limited to):

Reservoir Modeling

- **QuikLook® service** – Numerical simulator primarily intended for reservoir fluid management. It is the first simulator designed specifically for use by practicing engineers. QuikLook service is a 3D, three-phase, four-component, non-isothermal reservoir simulator that numerically solves the differential equations for multi-dimensional fluid and heat flow through a porous medium. The QuikLook simulator is used to design various completion and exploitation strategies. It may also be used to optimize design and evaluate various reservoir treatments such as conformance and fracturing.

- **NETool™ simulator** – Steady-state, network-based simulator used for calculating multiphase fluid flow through a well completion and near-wellbore region. Once the reservoir description is obtained, it can be imported directly from the reservoir software without modification or simplification.

- **Landmark Graphics PRIZM™ well log analysis package** – A well log analysis program developed by GeoGraphix.

- **StiMRIL™ integrated stimulation process** – Integrates magnetic-resonance imaging (MRI) analysis and reservoir simulation into a stimulation treatment design for creating an accurate reservoir model.

Completion Design Modeling

- **P-MAX™ program** – Predicts maximum pressure where a premature sandout occurs during pumping (the mixed fluid suddenly stops moving into reservoir during sand-control operation). The P-MAX program is capable of modeling multiple pumping schedules as well as taking into account the ballooning and water hammer effect.

- **WEM™ system analysis program** (PE Moseley and Associates, Inc.) – Used to evaluate/optimize sand control completions in the design phase and performance evaluation. It is a reservoir inflow, wellbore surface flow simulator used to model multiphase flow, reservoir performance, and tubing performance characteristics of the well.

- **Landmark Graphics’ PROFILE™ system** – Enables any engineer—from rig supervisor to completions engineer to business analyst—to quickly visualize currently installed and historical wellbore information and downhole equipment in the form of wellbore schematics and reports.

- **Cyberstring® program** – Advanced tubing movement program that calculates the movements, forces, temperatures, and stresses occurring in the tubing string and downhole tools during well operations, including major well operations—setting packers, pressure testing, injecting, producing, circulating, and shutting in.

- **CyberWell™ electronics system integration test** – Allows for integration of multiple tool systems together to maximize operations on each trip in the well. Its broad capabilities also help quicken turnaround time without sacrificing crucial job planning.

- **WELLCAT™ program** – Primarily used for modeling thermal effects during production operations although it has multiple other capabilities.

- **ShockPro™ service** – Used to evaluate mechanical risk factors of all well components to help ensure all aspects of Health, Safety, and Environment (HSE) and Service Quality are covered. This information helps determine the peak pressure applied to a packer. Once dynamic failure criteria have been established, the software can be used to examine whether potential problems may occur with a given perforating assembly.

- **SurgePro™ service** – Helps design perforating assemblies and procedures to achieve optimum well productivity. It can be used to predict wellbore and gun pressurizations, wave propagation, perforation damage, determines the maximum dynamic pressure and load that can be safely applied to packers, plugs, tubulars, and casing.

- **PerfPro® perforating service solutions** – A systematic approach to delivering engineered perforating systems. The process includes perforation flow modeling and damage assessment performed with a fully 3D finite-element model.

- **Completion fluids graphics (CFG)** – Proprietary software tool from Baroid determines optimal displacement fluids based on actual wellsite specifications.

- **3L Communications / Jaycor GPS2001 gravel pack simulator** – A pseudo 3D model of flow of gravel and fluids in deviated wells and perforations for the design and evaluation of gravel pack treatments. The GPS can handle both vertical and horizontal gravel packs.

- **Force (filtercake erodibility)** – Hole displacement solids and excess wall cake removal are critical to the ultimate productivity of horizontal completions. This tool incorporates the findings of Halliburton’s extensive research of this process.
Stimulation Modeling

• Stim2001™ software package – Proprietary software package for selection of potential candidates for many types of stimulation including acidizing, fracturing, and reperforating.

• Material Library – Calculates and displays the engineering properties of Halliburton materials.

• SS-MAP™ program – Organizes the critical reservoir/formation mineralogy/treatment fluid interrelations into one comprehensive, user-friendly program to optimize treatment fluid design and improve sandstone acidizing success.

• FracproPT® program – Principal software tool for design and modeling of hydraulic fracturing treatments. It is the Gas Research Institute (GRI) fracture-stimulation engineering software supported by Pinnacle Technologies.

• StimPlan™ program (developed by NSI Fracturing Technologies, Inc.) – A fracture design simulator with special modifications for tip screenout designs. At tip-screenout initiation, fracture extension is stopped, and the program calculates a width increase based on the increase in net treating pressure. This program will analyze complex formations composed of multiple productive layers with varying fluid-loss coefficients.

• GOHFER® grid oriented hydraulic fracture extension replicator (Barree & Associates) – Easy to use, realistic 3D fracturing design simulator that uses a finite difference method to compute the fracture growth, fluid leakoff, proppant transport, and acid reactivity, which sets it apart from other such simulators on the market.

• HzGPSim™ program – Predicts and models horizontal gravel packing in open and cased holes. It models the alpha/beta wave mechanism for horizontal gravel packing and calculates required injection and return rates, expected bottomhole treating pressures, alpha/beta wave heights, predicted time for end of alpha/beta waves, and minimal rate below which premature screenout occurs.

• Sieve™ Plus program – PC-based program calculates and plots sieve analysis results.

• AcidCalc™ program – PC-based program calculates acid and brine mixes.

• Darcy, Forchheimer, Ergun programs – Darcy calculates pressure, flow rate, and viscosity relationships using Darcy’s linear flow equation. It can be used to estimate the gravel height above the gravel pack screen using sandout conditions conforming to Darcy flow through the pack in the blank annulus above the top of the screen.

The Forchheimer program calculates pressure, flow rate, and viscosity relationships using non-laminar linear flow equation. This program estimates the height of gravel above the gravel pack screen at sandout conforming to non-laminar flow through the pack in the blank annulus above the top of the screen. The Ergun program calculates pressure, flow rate, and viscosity relationships using the Ergun program linear flow equation for a bed of spherical particles. It can estimate height of gravel above the gravel pack screen at sandout conforming to laminar or non-laminar flow through the pack in the blank annulus above the top of the screen.

• Max Rate-Max Pressure™ calculator – Calculates rate, surface pressure, bottomhole pressure, and skin relations. It is used to simplify planning and monitoring of matrix acid treatments using high matrix rates to improve the uniformity of zonal treatment distribution. This concept is described in SPE17154, SPE20623, and SPE24781 by Paccaloni, et al.

• K-Max™ calculator – Calculates the components volumes of a K-Max™ or Z-Max™ pill in various fluid weights.

• Sand Transport – Various sand transport data exists, including slip velocity calculations, terminal particle settling velocity, Gibbs critical transport velocity, single particle settling velocity Newtonian fluids, Stokes’s Law, fall rate in water, single particle settling in non-Newtonian fluids (Moore correlation), etc.

• Sand/Screen Sizing – Takes the data from Sieve™ Plus program or other means of determining $D_5$, $D_{10}$, $D_{50}$, $D_{40}$, $D_{90}$, $D_{95}$, fines content, etc. and uses it to determine a gravel or proppant mesh for gravel packs or FracPac™ treatments.

• FracPac-N™ fracture design service – A fracturing treatment normally includes a minifrac and step-rate test with results from the procedures used to calibrate the frac model. Although extremely valuable in low permeability (hard rock) formations, field data has shown that data obtained from a minifrac treatment and step-rate test are not always accurate enough to provide optimized frac geometry in high permeability (hard rock) frac pack treatments. FracPac-N™ service replaces these steps with a process that helps optimize frac pack treatments, saving rig time and fluid costs.
Real-Time Monitoring

- Real-Time Visualization Service (RTVS) software package – Developed to assist Halliburton completion teams in planning and monitoring complex completions. During pre-job planning, a simulator is available to validate the expected interaction between the service tool and the sandface completion string based on the proposed completion plan.

During the job, a 2D/3D visualizer provides the capability to monitor real-time downhole tool positions and movements (squeezing, circulating, and reversing) as each interval is treated. RTVS is strictly a passive system using surface data sources.

After the job, recorded tool movement data can be replayed for post-job reviews. The RTVS system assists in ensuring no unexpected component interaction occurs as the service tool traverses the sandface assemblies.

Since late 2007, RTVS has been used to support all Halliburton ESTMZ™ tool installations to date; including system integration tests, field trials, and commercial installations in the US, Gulf of Mexico, and Asia Pacific. The service is described in technical paper OTC 23626 “Sand-face Completions Enter the Real Time Age with a One-of-a-Kind Downhole Visualization Tool.”