Well Stimulation Treatments

2nd Edition

THE UNIVERSITY OF TEXAS AT AUSTIN
PETROLEUM EXTENSION SERVICE

Well Servicing and Workover, Lesson 11

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About the Author

A. Richard Sinclair, an Oklahoma native, has over 30 years of experience in well stimulation. An engineering graduate and postgraduate of the University of Oklahoma, Sinclair has authored numerous technical papers and reports focused on well stimulation and other oilfield solutions and obtained approximately 30 patents.

Sinclair began his career with Exxon Research in production engineering, well stimulation, and research. He later worked for Maurer Engineering as a Petroleum Engineering Consultant where he started and ran several different companies. In 1976, Sinclair helped start Santrol Proppants and became President until the company was sold in 1990 and again in 1992. He then became a consultant for Santrol, during which time he started Well Stimulation, Inc., and served as President. For years, Sinclair has provided petroleum engineering instruction for oil and gas companies and for Halliburton's Energy Institute, specializing in areas of well stimulation and production engineering.

Today, Sinclair's Santrol startup has evolved into one of the largest oilfield supply companies, providing proppants, such as Ottawa sands, resin-coated sands and ceramics, and other oilfield products.

Units of Measurement

Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is one of only a few countries that employ the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Systeme International (SI) d'Unites. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The Rotary Drilling Series gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is metre, not meter. (Note, however, that the unit of weight is gram, not gramme.)

To aid U.S. readers in making and understanding the conversion system, we include the table on the next page.

English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet ($lb/100\ ft^2$)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet ($lb/100\ ft^2$)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.75	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

Courtesy of Baker Hughes Incorporated

A large frac job

Well Stimulation Overview

In this chapter:

- Why well stimulation is necessary
- Stimulation techniques used today
- Shale play fracturing
- New developments underway

Today, *well stimulation* is required for most newly drilled oil and gas wells and many older wells where production has been blocked or is diminished. It is also needed in *injection wells*, *coalbed methane wells*, *heavy oil wells*, and *geothermal wells*.

Well stimulation has been described as the best way to achieve optimum production from oil and gas formations (fig. 1). From an economic standpoint, most wells require some type of well stimulation to maximize the economic return. *Payout* on most wells is rapid, but the exact payout time depends on the well's production capacity. Other techniques have been unable to extend the life of the well and improve its economic health.

Well stimulation techniques include several different types that are used effectively according to the type of well:

- Hydraulic fracturing
- Acidizing
- Frac packs
- Explosive fracturing
- Steam treatments

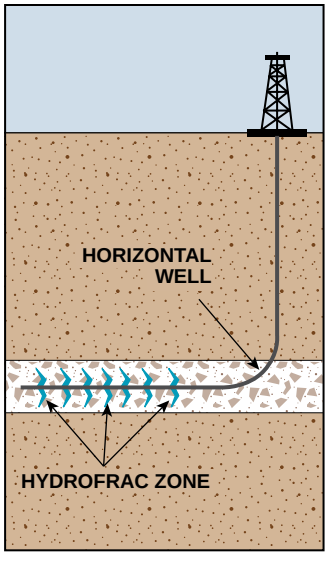

Figure 1. Basic view of fracturing

Hydraulic Fracturing

In this chapter:

- Development of hydraulic fracturing
- Cost considerations
- Hydraulic fracturing design
- Materials and equipment
- Job planning and execution

History of Hydraulic Fracturing

Hydraulic fracturing started in 1947 in the Hugoton gas field in Grant County, Kansas. The Klepper Well No.1 was a limestone formation that fractured using napalm-thickened gasoline as the fracturing fluid. The first commercial fracturing of wells was carried out by Halliburton in 1949. Two wells were fractured simultaneously—one in Archer County, Texas, and one in Stephens County, Oklahoma. Prior to these wells, AMOCO or Stanolind Oil and Gas had been studying hydraulic fracturing for several years in the laboratory and field. They found that oil or water could be used as *frac fluids* and that sand proppants were needed to keep the fractured formation propped open.

Over the following 10 years, fracturing, or *fracking*, became an accepted stimulation treatment in the oilfield. It is calculated that over 1.2 billion pounds of sand were used during this time. The treatment was found to be the most economic way to stimulate the oil and gas formation. According to the following method, this process showed that hydraulic pressure overcomes the stresses in the formation and causes it to fracture. Fluid is pumped into the formation to open the fracture wider and longer. Proppants or particles are added to keep the fracture

Acidizing

In this chapter:

- Types of acid treatments
- Additives and retarders
- Matrix acidizing treatments
- Acid fracturing design
- Treatment costs and considerations

History of Acidizing

The first patents on acidizing were published by Herman Frasch in 1896. They revealed that hydrochloric acid (HCL) would react with limestone to produce soluble products like carbon dioxide and calcium chloride. The first test recorded was in Lima, Ohio—the center of oilfields at that time. Acidizing obtained much better results than explosives in the wells. However, after only a few years of use, acidizing treatments fell out of favor.

About 30 years later, the use of hydrochloric acid was revived and used as a scale removal treatment for Gulf Oil Company in Oklahoma. The modern era of acidizing began in 1932 when Pure Oil and the Dow Chemical Company teamed up to look at the possibility of using HCL along with an inhibitor to protect pipe from corrosion and for stimulation. A dead well responded with 16 barrels per day (bpd) after the acid treatment. Other wells began to be acidized after that, and some responded better than the first one did. In 1932, Dowell, Inc., was formed by Dow Chemicals to use this acidizing process and perform other well services. By 1935, the Williams Brothers and Halliburton began acidizing oilwells commercially.

Frac Packs

In this chapter:

- Impact of frac packs
- Use of water-based fluids and proppants
- Frac pack design

Frac packs were invented during the 1990s to increase production from offshore wells when the results from gravel packs were disappointing. *Gravel packs* are used in soft or unconsolidated sands to form a filter that allow fine particles to pass through but block most of the medium and larger particles that might plug the formation. Although gravel packs work and are still used, skin factor(s) calculations (see Appendix B) show that there is still damage around the near-wellbore area. Frac packs increase the length of the fracture and provide a wide propped fracture in soft sands. This brings the skin factor down to a negative value and is considered a stimulation treatment.

The width of hydraulic fractures in hard sandstone formations averages about 0.2 inches, while a frac pack width can average about 0.5 inches. This can be measured by the calculation of *Young's Modulus (E)*. This measurement of elasticity in the formation determines the width of the fracture. The *E* values on soft or unconsolidated formations range from near zero to 2,000,000 psi (3,579,098 kg/metres). Regular sandstone values average an *E* of 5,000,000 psi (8,947,785 kg/metres). Limestone and dolomite formation can have much larger *E* values and narrower fractures.

Other Well Stimulation Techniques

In this chapter:

- Types of wells
- Fracturing techniques
- Highly viscous oils

Horizontal versus Vertically Drilled Wells

With today's wide variety and types of formations, drilling has gone from all vertically drilled wells to a mix of vertical and horizontal wells. Past drilling was conducted into sandstone and limestone formations with low to moderate permeability. Adequate production could be gained naturally or with hydraulic fracturing. In the past 20 years, many offshore wells required horizontal drilling to reach the formations in all directions from the offshore platform. While fracturing is still used, production from a prolific well is such that fracturing is not always needed. When hydraulic fracturing is used, many fractures can be required for each horizontal well. The created fractures are usually vertical fractures and are spaced widely to cover most of the producing sections of each well drilled.

In the last several years, many shale plays (for example, Barnett, Woodford, and Haynesville) have started to be drilled and fractured. Shale is found in many areas of the United States. Most of these shales contain natural gas and oil but have very low permeability. Natural fractures occur in many of the shales, but newer hydraulic fracturing practices have been used to increase production. Sometimes, two horizontal wells are drilled almost parallel to one another and fractured at the same time (fig. 31). This opens more natural fractures and exposes more area, creating higher production rates.

In Review

Well stimulation is performed when production of a well has been blocked or diminished. The goal is to restore optimum production of the oil and gas formation.

There are four known systems of well stimulation including hydraulic fracturing, acidizing, frac packs, and explosive fracturing. The type of treatment selected is determined according to the type of well. Although new stimulation treatments are invented and tested each year, economic and practical issues often inhibit further use. For a hydraulic treatment to succeed, the job size must correlate with fracture length and cost. A typical hydraulic fracturing job balances the cost of proppants, frac fluids, horsepower, and manpower. The costs are estimated prior to the job and are subject to change throughout.

When a well is selected for treatment, a service company is hired to schedule, plan, design, and implement the treatment. Hydraulic fracturing and frac packs are the method most commonly used, though matrix acidizing and acid washing provide an alternate treatment. Hydraulic fracturing factors rock fracture mechanics with fluid flow and leak off, assuming the rock is elastic. There are over twenty variables to consider before designing and implementing the treatment. Two and three-dimensional models provide structured measurement of these variables and aid in the selection and design of the treatment.

Advancements in technology have evolved the effectiveness of fracturing fluids; the first fluids being gelled gasoline, whereas modern frac fluids use systems that combine only water and proppants. Deeper wells require stronger proppants and pressure to drive fluid through the system. The amount of horsepower needed for a job depends on the flow rate and pressure that can be applied to a formation. Flow rate must exceed the leak-off rate to lengthen the fracture, and the maximum flow rate is determined by the diameter of the pipe itself.

Appendix A

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Appendix B

Calculations

Equations for Well Stimulation Treatments

Some of the equations and calculations used in the text were mentioned but not shown. The equations can be complex, but the end result knows how the equation is used and if it will show how the well is performing after the hydraulic or acid fracturing jobs.

The skin factor(s) is the first calculation that shows if a near-wellbore area is damaged or stimulated. A positive number from zero to infinity shows a damaged area, while the negative number shows the stimulation achieved by well stimulation.

The equation is shown below:

$$s = 1.151[(p_{1hr} - p_{ws} / m) \log (k/\phi\mu c_t r_w^2) + 3.23] \qquad \text{Eq. 1}$$

where

s = skin factor
p_{1hr} = pressure at 1 hour, psi
p_{ws} = pressure at shut-in bottomhole, psi
m = 162.6 $QB\mu/kh$ the slope of the Horner plot
k = permeability, md
ϕ = porosity
μ = viscosity, cp
c_t = total compressibility, 1/psi
r_w = wellbore radius, ft
Q = cumulative production, STB

Appendix C

Checklists to Optimize Well Stimulation Treatments

Good communication between the service company and the operator is a necessity. To help in this matter, use of checklists are suggested so the best job can be completed without difficulty. Any well stimulation treatment is complex and there are many considerations and decisions to be made or approved. Whether a service company or operator, checklists help get the most out of each treatment.

Planning checklist:

1. Abide by rules set forth by the operator.
2. Read service company recommendations.
3. Check number and location of perforations and zone to be treated.
4. Number of frac tanks for the job and layout for all equipment.
5. Strap tanks for volumes.
6. Obtain copy of service company reference tables.
7. Have sample containers and bags for treatment.
8. Safety equipment required: hard hats and steel-toed boots.
9. Fluid van or equipment for measuring frac fluids.
10. Water test equipment to determine water quality.
11. Number of workers and guests to have onsite.

Job planning:

1. Ascertain the total water volume needed in the frac tanks.
2. Were frac tanks cleaned before the job?
3. Is the correct amount of potassium chloride and other chemicals on hand?
4. Check for leaks out of frac tanks.
5. Pre-gel fluid quality control is approved.
6. Check proppant tanks for volume and normal appearance.
7. Check proppant for fines or dust: use sieves.
8. Ascertain that the proppant is the correct mesh size and type.

Appendix D

Figure Credits

Figure		Owner	Web site
Cover		Copyright © Santrol Proppants. All rights reserved.	www.santrolproppants.com
Inside	A large frac job	Copyright © Baker Hughes Incorporated. All rights reserved.	www.bakerhughes.com
1	Basic view of fracturing	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
2	Several powerful truck-mounted pumps are arranged at the well site to perform fracturing.	Photo by Bret Boteler. Copyright © EnerMax, Inc. All rights reserved.	www.enermaxinc.com
3	Sand is one proppant used to hold fractures open (magnified view).	Copyright © Santrol Proppants. All rights reserved.	www.santrolproppants.com
4	Reservoir fluids flow into the fracture of the well.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
5	Acid enlarges existing channels or makes new ones.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
6	Hydraulic fracturing of shale formations.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
7	Current active shale plays in the United States	Public Domain. Source: U. S. Energy Information Administration (EIA)	www.eia.gov
8	Oil and gas flow more easily through fractured formations.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex

Glossary

A

acid *n*: 1. any chemical compound, one element of which is hydrogen, that dissociates in solution to produce free hydrogen ions. For example, hydrochloric acid, HCl, dissociates in water to produce hydrogen ions, H^+, and chloride ions, Cl^-. This reaction is expressed chemically as $HCl + H^+ + Cl^-$. 2. a liquid solution having a pH of less than 7; a liquid acid solution turns blue litmus paper red.

acidizing *n*: the use of low pH fluids to dissolve limestone and dolomite formations.

acid fracture *v*: to part or open fractures in productive hard limestone formations by using a combination of oil and acid or water and acid under high pressure. See *formation fracturing*.

acid fracturing *n*: see *acid fracture*.

acid treatments *n pl*: matrix acidizing cleans up near wellbore damage and acid fracturing opens and etches the formation to improve production. Usually hydrochloric, hydrofluoric, acetic or formic acid is used.

acid washing *n*: an acidizing treatment using low or no pressure to remove scale inside the tubing or casing.

additives *n pl*: chemicals and/or minerals used to enhance the frac or acid fluids.

alkali *n*: a substance having marked basic (alkaline) properties, such as a hydroxide of an alkali metal.

annulus *n*: spacing between the tubing and the casing.

API *abbr*: American Petroleum Institute.

API gravity *n*: the measure of the density or gravity of liquid petroleum products on the North American continent, derived from relative density in accordance with the following equation:

$$\text{API gravity at } 60°F = 141.5/\text{specific density} - 131.5$$

API gravity is expressed in degrees, a specific gravity of 1.0 being equivalent to 10° API.

API units *n pl*: degrees. See *API gravity*.

aquifer *n*: a body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

arsenic (As) *n*: a chemical element that occurs as a brittle, steel-gray hexagonal mineral and that is added as an impurity to semiconductors to give them a negative charge.

arsenic inhibitor *n*: a chemical formerly used to coat tubing and prevent tubing erosion during acid treatments. Arsenic inhibitors have been replaced by other organic inhibitors.

As *abbr*: arsenic.

Review Questions

WELL SERVICING AND WORKOVER

Lesson 11: Well Stimulation Treatments

Multiple Choice

Pick the *best* answer from the choices and place the letter of that answer in the blank provided.

_____ 1. Which of the following materials are required for frac treatments?

A. Frac fluids
B. Proppants
C. Horsepower
D. Manpower and equipment
E. All of the above

_____ 2. Why are large-horsepower pump trucks needed for the treatments?

A. To prevent plugging in the perforations
B. To allow the treatment schedule to be completed
C. To maximize the costs of the job
D. To keep the temperature down

_____ 3. Why are computers used to design the hydraulic frac treatment?

A. So the engineer can observe the treatment in progress
B. So the alarm system will be automatic
C. So the twenty variables of the formation and stimulation treatment can be processed
D. So the engineer has a printout when the job is completed

_____ 4. Which are used to stimulate limestone formations?

A. Steam and hot water
B. Inorganic and organic acids
C. Mud chemicals and high pH
D. Oil-based surfactants

Fill in the Blanks

5. Name the most practical stimulation technique used in the oil and gas industry today.

_____

6. Name the types of costs involved in carrying out a hydraulic frac treatment.

_____

Index

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