Fracture Design and Stimulation – Monitoring
Well Construction & Operations technical workshop
In support of the EPA Hydraulic Fracturing Study
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Agenda

- Well Construction
- Before the Treatment
- Well Site Rig-up
- Monitoring the Treatment
- After the Frac

July, 1947 - Stanolind Oil and Gas 1st Job: Klepper No. 1
Well Construction

- Protect shallow formations
- Protect producing formations
- Withstand treating pressures
Before the Treatment

- Treating rate and pressure
- Equipment and materials
Well Site Rig-up

- Safety meetings
Well Site Rig-up

- Safety meetings
- High pressure and low pressure
- Pressure testing
- Protection systems tested
- Flowmeter calibration
- Data acquisition computers
Simplified Location Schematic

1 – Annulus pressure gauge
2 – Surface treating pressure gauge
3 – Downhole densometer
4 – Slurry flow meter
5 – Clean flow meter
6 – Gel flow meter
7 – Liquid additive flow meters

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Monitoring Equipment
Blender Photos
Pressure Control and QC
Monitoring the Treatment

- Rate is brought up slowly
- Several people involved
- Treatment parameters
  - Rate, pressure, density
- Material parameters

\[ WHTP = BHTP + P_{pipe} + P_{perf} - P_{hyd} \]
Treatment Chart
Additives Chart
Additional Real-time Information
After the Frac

- Safety meeting
- Post treatment inventory
- Post treatment report
Questions

- Well Construction
- Before the Treatment
- Well Site Rig-up
- Monitoring the Treatment
- After the Frac
Fracture Design and Stimulation – Monitoring

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As the previous sections have shown there is considerable work that goes on before a fracture treatment is pumped. Two points that bear repeating concern (1) the importance of proper well construction and (2) the availability of information about conditions to be expected during the treatment. It is through the well construction process that drinking water aquifers are protected, producing formations are isolated, casing is protected from corrosive fluids, etc. In addition, since the fracture treatment is carefully designed beforehand and expected pressures and other parameters are established, the casing and tubulars will have been designed to handle the treatment and subsequent well production without compromising the integrity of the well.

There has also been discussion about what goes into the design of a hydraulic fracture treatment, i.e., knowledge of the mechanical rock properties of the formation to be treated as well as adjacent bounding layers, reservoir properties of the target formation, information about the fluid systems to be used and how the formation will interact with these fluids. From this information the operator and pumping service company can set up the hydraulic fracture treatment and know what will be pumped, what equipment will be required, and what is to be expected during the actual treatment.

What Do You Need to Know before Showing up on Location

The first step in setting up a fracture treatment job is to know the expected treatment rate and pressures. These two parameters are based on several factors discussed more thoroughly within this workshop, but for this section it is important to note that they are calculable. For a given formation there is a pressure which when applied will cause the rock to fracture. This pressure is often referred to in terms of a gradient (fracture gradient - fg). Knowing the fracture gradient, the actual bottom hole treating pressure (BHTP) required to fracture the rock can be calculated for a given depth:

\[ \text{BHTP} = \text{fg} \times \text{depth} + \text{excess pressure} \]

......................................................................................................................... (1)
In this equation excess pressure is the additional pressure required to extend a hydraulic fracture; i.e., net extension pressure, process zones stress, etc. These excess pressures are typically significantly lower than the pressure required to fracture the rock.

Once the BHTP is known then an expected wellhead treating pressure (WHTP) can be calculated by accounting for additional pressures that occur while treating a well:

\[
\text{WHTP} = \text{BHTP} + P_{\text{pipe}} + P_{\text{perf}} - P_{\text{hyd}}
\]

In this equation \( P_{\text{pipe}} \) is the friction pressure resistant to flow down the wellbore during pumping operations and is fluid and rate dependent; \( P_{\text{perf}} \) is the pressure drop across the perforations; and \( P_{\text{hyd}} \) is the hydrostatic pressure of the fluid in the wellbore and is also fluid dependent.

Once the expected BHTP and WHTP are determined, the proper casing string or tubular configuration can be designed to handle the pressures experienced while treating the formation. The WHTP is also used to calculate the hydraulic horsepower (number of trucks; HHP) required to pump the job at the desired treatment rate from the following equation:

\[
\text{HHP} = (\text{WHTP} \times \text{Rate}) / 40.8
\]

The next step in setting up a job is to know what will be pumped, e.g., the additives required and the rates at which the additives are to be used, proppant type and volume, etc. For some jobs this requires pre-job testing to determine whether the fluid system intended for use in the fracture treatment is compatible with the base fluid being supplied on location. This is an important step since it also establishes what will be required for the fluid system to perform as desired. Once this information is known then a final treatment design is determined and communicated to the field location for execution. This information is then put together in tabular form, giving the operator and service company a ready guide for setting up the job. An example of a typical pump schedule is included in the appendix.

**Rigging Up the Pumping and Monitoring Equipment**

The care that is taken in designing a fracture treatment job carries over to the implementation of the job, beginning with the set-up for the job. After the equipment, personnel, and materials are on location a safety meeting is held. During this safety meeting items such as well site concerns, proper PPE, rig-up concerns, etc. are reviewed to ensure that appropriate steps are being taken to ensure safety on the job site. The time it takes to rig up the pumping equipment and surface treating lines can vary from a couple of hours to a couple of days depending on the treatment. During this time there is also quality control work going on to ensure that the fracturing fluid will perform as expected and that the correct materials are on location in the appropriate quantities.

After all the surface equipment has been rigged up there is another safety meeting. During this safety meeting details of the job are reviewed, including the maximum WHTP, expected WHTP,
pump rate, overall job schedule, who is responsible for what, etc. After the safety meeting all
surface piping is pressure tested to a predetermined maximum pressure. At this time the pop-
off valves on the surface lines are tested to make sure they work at the desired pressure and
the pressure kick-outs on the high-pressure pumps are also tested to insure they work properly.
In addition, the pumps used for liquid additives are bucket tested to ensure that they are
functional and are calibrated properly. The proposed pumping schedule is loaded into the on-
site computer system to assist the fracturing treatment operator in running the job as close to
design as possible. While computers are capable of actually running the treatment, at this time
most service companies still rely on a team in the treatment van to control the actual fracturing
treatment with the assistance of the computers.

**Pumping the Treatment**

Once everything has been calibrated and pressure tested there is generally one last review
between the operator’s representative and service company representative to go over the
treatment parameters. Once everyone is in agreement, the wellhead is opened up and the high
pressure pumps are brought on line. At this time fluid is being pumped down the wellbore at a
slow rate as pressure starts to increase. The rate and pressure are increased to the anticipated
WHTP where the formation should fracture (breakdown). This is one of the first points where
the actual treatment can be calibrated to the job design. If breakdown does not occur within a
reasonable pressure compared to what is expected then the treatment is shut down and
possible causes are investigated.

There are several points on the surface where rates, pressures, and densities are monitored
and recorded during a treatment. (A simplified location schematic showing where the different
treatment monitoring occurs is provided in the appendix.) For example, highly accurate
transducers are placed at several different locations in the surface lines and equipment to
monitor real-time pressure data, a variety of different flowmeters are used (depending on the
material being metered) to record treatment rates and additive rates, and densometers are
used to measure the density of the fluid being pumped downhole. Examples of some of the
data being monitored and recorded include: WHTP, annular pressure, downhole slurry pump
rate, clean fluid rate, wellhead proppant concentration, and individual additive rates, along
with an extensive amount of mechanical information about the equipment on location. All the
information from these multiple sources is collected and displayed by state-of-the-art computer
systems located in treatment control vans. Most of the time, these data are transmitted using
hard wires connecting the computer to the monitoring device.

It is also important to note that in addition to monitoring there are also mechanical devices
which are used during a fracture treatment to provide additional safety for the wellhead. Two
of these devices are pressure pop-off valves on surface lines and pressure kick-outs on the high
pressure pumps.

While pumping the treatment both the operator and service company continually monitor the
computer screens displaying information about the treatment as it is being pumped. The main
concern is pressure. Both the operator and the service company want to make sure the
maximum WHTP is not exceeded to protect the wellbore from any possible damage. (It is important to understand that it is inefficient to have to repair wellbores so every effort is made to prevent them from being damaged.) Some variations in pressure are normally seen during a fracture treatment. These variations are interpreted to determine their causes and significance; there are constant decisions being made about what the status of the treatment is and what to do as the treatment proceeds. An example of a treatment chart can be found in the appendix of this abstract.

Close attention is also paid to the annulus. In many cases the annulus is monitored with a gauge for any pressure increase in excess of normal fluid cool-down and heat-up, in other cases the annular valve is open and any fluid flow up the annulus can be seen at the wellhead and appropriate steps can be taken to address the fluid flow in the annulus.

Since any additive used in a hydraulic fracturing treatment serves a specific purpose, it is important that these additives are run at their designed concentrations. As mentioned earlier all additive rates are monitored during the treatment to insure they are run correctly. (An example of an additive rate chart is shown in the appendix.) In addition, overall job treatment information is displayed in the treatment control van in real-time to assist the operator and service company in understanding how the treatment is progressing. This allows for spot checks throughout the treatment process to compare the physical inventories of volumes of additives pumped with those calculated to again insure the treatment is being pumped as planned.

In addition, during the pumping operation there is continual monitoring of the surface lines, equipment, and wellhead to make sure there are no leaks. If a leak does develop, it is either isolated if possible or the treatment is shut down and the leak fixed before pumping is resumed.

The majority of hydraulic fracture treatments are pumped as planned or with changes that are based on the way the treatment is proceeding. On occasion, the formation may be difficult to fracture stimulate, resulting in a rapid pressure increase while pumping; this is called a screen-out. Even if there is a rapid increase in pressure relative to normal increases in pressure due to pumping, the system is still compressible so there is still time to react. As the pressure increases, the fracture treatment operator will start bringing pumps off-line to counteract the rapid pressure increase. In a worst case scenario, if the pressure increases too fast then the pump kick-out will activate and shut down the treatment.

After the Fracture Treatment

After the well has been treated the equipment used in the fracture treatment is rigged back down. At this time there is another safety meeting to discuss any possible issues that may be associated with this rig down. A final physical inventory of materials still on location is conducted to determine the actual volume of materials that was pumped during the treatment. During the rig-down of the pumping equipment steps are taken to prevent any spills and surface contamination. Finally, the operator is provided with a post job report that provides
details of the treatment, a summary of what occurred during the time on location, and what was pumped into the well.

Appendix

Nomenclature and Terminology

Treatment Rate (bpm) – the downhole rate that fluid is entering the formation
Hydraulic Horsepower (hhp) – horsepower being applied to the formation while pumping
Wellhead Treating Pressure (psi) – the surface pressure at the wellhead during pumping
Max Pressure (psi) – the maximum WHTP that will be allowed
Bottom Hole Treating Pressure (psi) – pressure being applied to the formation including net pressure
Frac Gradient (psi/ft) – pressure at which fluid will cause the formation rock to part
Pipe Friction Pressure (psi) – friction pressure of the fluid being pumped down the wellbore
Perf Friction Pressure (psi) – pressure drop across the perforations
Hydrostatic Pressure (psi) – pressure the fluid column exerts on the formation
Net Pressure (psi) – excess pressure over frac pressure required to extend the fracture
Instantaneous Shut-in Pressure (psi) – a pressure used to calibrate the frac gradient
Clean Volume (gal or bbl) – volume of fluid pumped without proppant
Dirty Volume (gal or bbl) – volume of fluid pumped with proppant
Proppant Concentration (lb/gal) – the amount of proppant added to one gal of fluid
Proppant – small diameter material used to keep the fracture open
Solid Additive (lb/Mgal) – a solid chemical added to the fluid system for a specific purpose
Liquid Additive (gal/Mgal) – any liquid chemical added to the fluid system for a specific purpose
Pop-off – a mechanical device activates at a preset pressure to prevent damage to surface and downhole tubular
Kick-outs – mechanical or electrical devices that activate at a preset pressure to disengage high pressure pumps
High Pressure Pumps – Positive displacement pumps used for pumping downhole
Centrifugal Pumps – used on the low pressure equipment to mix and move fluid
Additive Pumps – used to inject liquid additives; different types based on the additive type and additive rate
Pressure Transducer – device used to measure and transmit pressure data
Flowmeter – used to measure and transmit fluid flow rates; different types depending on application
Annulus – Area between two concentric casing strings or tubular strings
Figure 6. Simplified Location Schematic

Figure 7. Inside the treatment monitoring van
Figure 8 Treatment Chart -- Pressure, Rate and Prop Concentration

Figure 9. Additive Chart
Figure 10. Fluid Tracking, Numeric Value, and Stage Summary Screen

Figure 11. Blender schedule