Tubing specifications selection and its effect on the results of hydraulic fracturing treatment in oil formations

ASTHANA, Abhishek, ABUHATIRA, A. and ALBOUESHI, A.

Published version

ASTHANA, Abhishek, ABUHATIRA, A. and ALBOUESHI, A. (2016). Tubing specifications selection and its effect on the results of hydraulic fracturing treatment in oil formations. In: 6th World PetroCoal Congress, New Delhi, India, 15-17 Feb 2016. (Unpublished)

Tubing Specifications Selection And Its Effect On The Results Of Hydraulic Fracturing Treatment In Oil Formations

Ahmed Abuhatira[1], Abhishek Asthana[1,*], Alaa Alboueshi[2], Sanjay Mukherjee[1]
[1]Sheffield Hallam University, Sheffield, S1 1WB, United Kingdom
Tel. +44 114 225 3261, **Email**: a.asthana@shu.ac.uk
[2]NOC-Halliburton Fracturing Team, 4.5 km Airport Road, Tripoli, Libya, PO Box 395

Abstract

Equipment specification, data collection and design process are critical factors for any hydraulic fracturing treatment success. This paper investigates tubing specifications selection and its effect on the results of hydraulic fracturing treatment in oil formations.

Simulations were carried out on well E-45 owned by National Oil Corporation (NOC) of Libya using two main tools - Pumping Diagnostic Analysis Toolkit (PDAT) and Halliburton proprietary software package (FracPro) for analysing Mini-Frac pumping data. The initial modelling results using 3.5 inch tubing were compared with the experimental results obtained from the actual hydraulic fracturing tests carried out at the E-45 by Halliburton as a sub-contractor for NOC. The simulation results showed good agreement with the experiments, validating the model.

The model was then extended to explore alternate tubing diameters. This was implemented by introducing the relationship between the tub friction pressures and pumping rate (Friction Pressure vs. Pumping Rate) with the mentioned tube sizes. The results showed that in high stress rock formations, it is worthwhile to minimise the pipe friction by using higher tubing grade (4.5 inches) and burst pressure. A bigger tubing inner diameter can increase the allowable surface pumping rate and pressure.

1. Introduction

Hydraulic fracturing or fracking Fracking is the process of drilling down into the earth before a high-pressure water mixture is directed at the rock to release the gas inside. Water, sand and chemicals are injected into the rock at high pressure which allows the gas to flow out to the head of the well.

During the implementation of hydraulic fracturing treatment by the Halliburton team for the well E-45 in the 103 Oil Field, which is owned by the National Oil Corporation (NOC) of Libya, there were some pressure control difficulties. The pressure relief valve (PRV) of the pumps (surface pressure) had been set at 9,000 psi due to the tubing specifications by NOC for safety purpose. Nevertheless, while pumping a fluid from the surface for fracturing, the friction pressure was increasing and the formation could no longer take higher proppant concentrations. Furthermore, at some points the surface pressure started increasing significantly and was approaching the maximum allowable pressure (9,000 psi) and there was no possibility of increasing the pressure above this limit.

2. Literature Review

Obtaining the understanding of rock mechanics and stress analysis in hydraulic fracturing treatment are two of the most difficult issues that need to be considered (Schlumberger, 2012). Having the right stress analysis means having a perfect hydraulic fracturing treatment job taking into consideration time and cost-effectiveness (Hartley & Holden, 2013).

This work investigates the effect of tubing specifications selection on the results of hydraulic fracturing treatment in oil formations. It also gives recommendations for any further hydraulic fracturing treatment in the areas where the rock formations have high stresses.

3. Methodology

The procedures employed for the Main-Frac design are shown in the flowchart below (figure 1).

3.1 Design Process and Simulation

After collecting site data and designing the hydraulic fracturing process, appropriate equipment is selected to carry out the mini frac. Mini frac involves pumping the fluid for fraturing the rock formations without using proppants. If the mini frac is successful, it is followed by main frac. In the main frac stage, the fluid is pumped along with the proppants which keeps the induced fractures open.

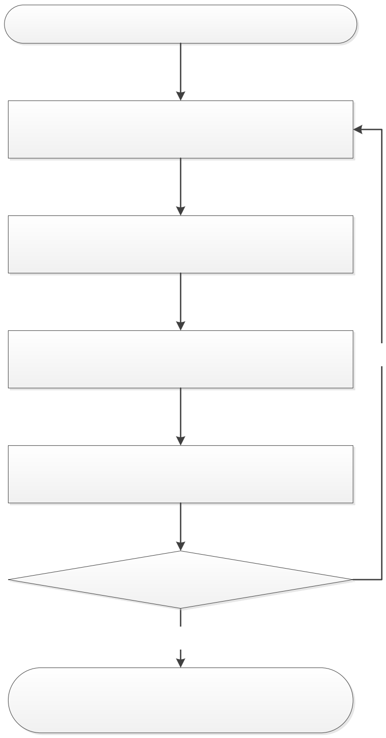

Figure 1: Process design and simulation flow-chart

Accurate data collection is the most important step in the process which usually takes time in order to be a reliable input for the design (Mala & Yogi, 2011). The data obtained from various methods and sources depends upon the type of data as well as the situation of the well. For instance, well productivity data is obtained from the operations department (Petroleum Engineers) at NOC, whereas others such as rock behaviour are determined by the geologists. The well information from various sources for E-45 is summarised in table 1 below.

However, Well E-45 has been completed as L. Gir water injector (i.e. the treatment is just only water without adding any substances such as chemicals), The target formations for the treatment are M2, M1, L, J, I, H, and G. The well in question was completed with fifteen set of perforations in 7’’ casing.

Table 1: Well information (A. Albooueshi, pers. comm. 10-Jun 2015)

Well Name:	E-45
Well Type:	Water Injector
Total Depth	9,300 ft
Frac Tubing :	3.5” tubing +/-7,550 ft to surface
Production Casing:	7”, 26 lbs/ft, L-80
Formation Temperature:	+/- 224°F
Formation Pressure:	+/- 2,100 psi
Formation Permeability:	+/- 0.01-10 mD
Fracture Gradient:	+/- 0.75 ~ 0.85 psi/ft
Closure Gradient:	+/- 0.6 ~ 0.7 psi/ft
Formation Type:	Limestone
Porosity:	12%
Formation Press:	2,100 psi
Tubing Burst Press:	10,000 psi

The fracturing fluid system selected for this proposal was Halliburton’s delayed borate crosslinked system Hybor (a system used for increasing the viscosity of the fluid before pumping it when required). The system has been used successfully around the globe over the last 15 years. The main reason for the global use is that Hybor system can be prepared from nearly any type of source water. The Hybor system is used on nearly all treatments in reservoirs with BHST (the temperature of the undisturbed formation at the final depth in a well) above 200° F in Algeria, Egypt, Europe, Oman, Russia, and Saudi.

Proppant selection is one of the most challenging stages within any fracturing job. Halliburton frac engineers selected the proppant based on the fracture gradient. The figure (2) below illustrates the conductivity of Intermediate strength 16/30.

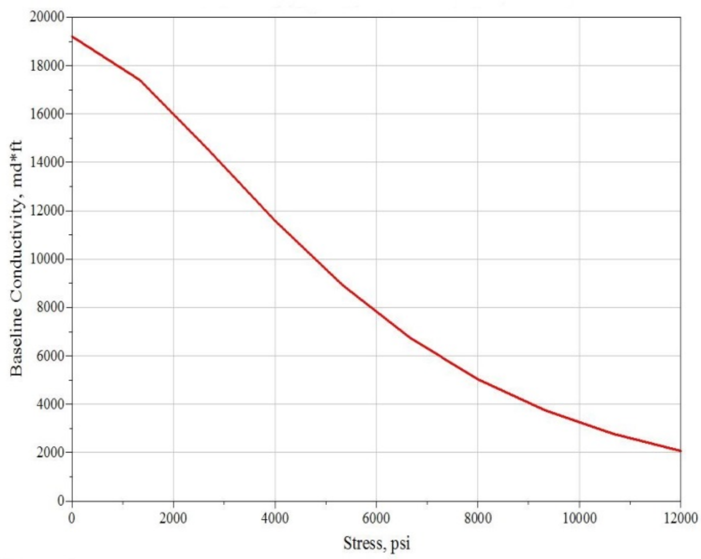

Figure 2: Conductivity of Intermediate Strength 16/30 Proppant under different Stress (A. Albooueshi, pers. comm. 10-Jun 2015).

The minimum horizontal stress along the fracture can be as high as 6,500 psi. As this well is an injector, the design effective stress on the proppant is of the order of 5,000 to 6,000 psi based on preliminary interpretation and log analysis. Frac Engineers have selected the 16/30 mesh size intermediate strength prop as it is readily available and will provide sufficient conductivity contrast between the formation and the fracture.

Equipment specifications selection is an essential factor which should be deeply considered for any process design and simulation. There was several equipment with different specification used for the hydraulic fracturing treatment of the Well E-45 as following:

- Pumping Equipment (Halliburton, 2012).
- Blending Equipment (Halliburton, 2015).

- ❖ Proppant Handing (Halliburton, 2015).
- ❖ Data Acquisition (Brookfield, 2015).
- ❖ Support Equipment (CATPUMPS, 2015).
- ❖ Design modelling software (FRACPRO, 2015).

The equipment specification is differing from fracturing job to other. "In some cases, the equipment selected does not suit the purpose and in others the equipment specifications result in unintended consequences that were not apparent to the designer"(Fulton, 2003). There are many essential issues that should be considered such as wellbore site and location, working environment and time and cost effectiveness. However, the above mentioned equipment specification are all used with accordance to the health safety environment regulations and standards within Halliburton and NOC.

3.2 Mini-Frac execution, analysis and observation

In the stage of Mini-Frac execution, the proposed treatment starts with filling the well with Linear Gel to minimize friction pressures during the breakdown followed by pumping a Mini-Frac followed by a Step down test. The Step down test is used to quantify perforation and near wellbore friction (tortuosity) which will help to determine whether fracture entrance problems are present. Based on this test, proppant slugs may be incorporated into the Main Frac to decrease the amount of tortuosity.

By using Pumping Diagnostic Analysis Toolkit (PDAT), there are several required parameters obtained and monitored in order to perform the fracturing treatment. For instance, the G-function shown in figure (17) below is a dimensionless time function relating shut-in time (t) to total pumping time (tp) (at an assumed constant rate). The G-function is calculated by the FracPro. Both the increasing slope of the superposition curve and the increasing magnitude of the derivative indicate an apparent increasing leak-off coefficient. This is consistent with the total fracture surface area approaching the permeable (leak-off) area, and the decreasing fracture compliance associated with the receding height. The superposition derivative (GdP/dG), the magnitude of this slope is proportional to total leak-off as shown in Figure 3.

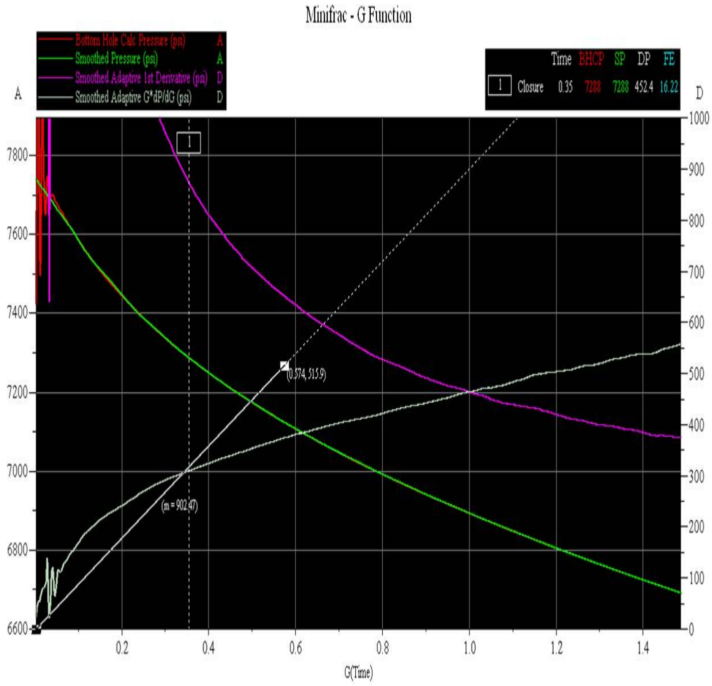

Figure 3: Mini-Frac G-Function curve and pressure

This indicates that the fracture has occurred because of the leak off. The pumping pressure suddenly dropped which means the fracture was successful and the fluid leaked trough the rocks. The result shows significantly high leak-off which confirms the occurrence of fracture.

The pressure vs G-function curve shows a significant high leak-off which approves the occurrence of fracture. This is illustrated by the increasing magnitude of dP/dG. The numerical data shown here are obscured by bumps or steps caused the numerical model. Real field data show smooth curves with pressure concave down and dP/dG and GdP/dG both concave up. Height recession occurs when fracture tips which extend into high-stress boundaries are forced to close first. Both the increasing slope of the superposition curve and the increasing magnitude of the derivative indicate an apparent increasing leak-off coefficient. This is consistent with the total fracture surface area approaching the permeable (leak-off) area, and the decreasing fracture compliance associated with the receding height.

Step rate test is another technique which is carried out in this fracturing job. It used to approximate the change from matrix flow to fracture-dominated injection in accordance with the change in slope of a plot of pressure against rate (SRT, 2015).

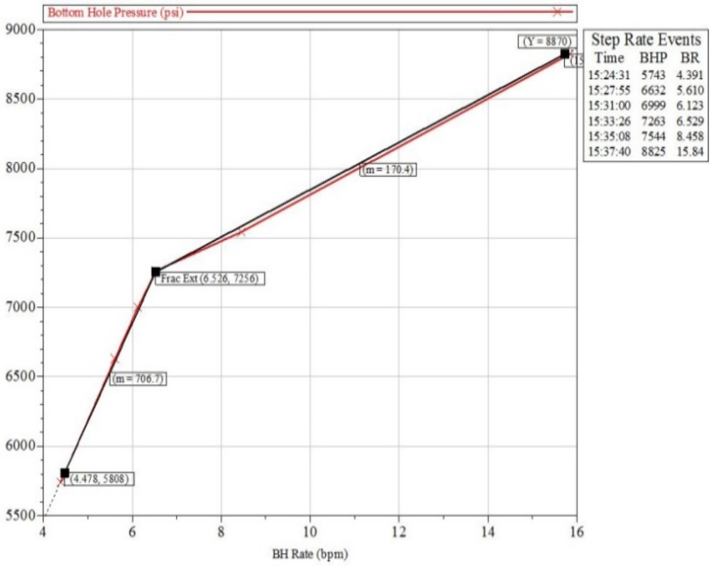

Figure 4: Step Up Rate Test

The red line indicates the Bottom Hole Pressure (BHP). X-axis represents the bottom hole rat (BH rate) whereas Y-axis the treatment pressure. It can be summarized that the frac extension pressure is 7256 psi and frac extension rate is 6.5 bpm.

In a nut shell, a complete PDAT analysis was done after performing the Mini-Frac and the results obtained from the analyzing the real time surface pressure such as closure pressure, closure gradient, Fluid efficiency, BH ISIP and Fracture Gradient are listed in the table (2) below.

Table 2: PDAT analysis

Surface instantaneous shut-in pressure (ISIP)	**3877 Psi**
Bottom Hole instantaneous shut-in pressure (BH ISIP)	7740 Psi
Fracture Gradient	0.91 Psi/ft
Closure Pressure	7245 Psi
Closure Gradient	0.86 psi/ft
Perforation Friction Pressure	659 Psi
Near Wellbore Friction Pressure	422 Psi
Fluid Efficiency	16.33 %

From the figures and table presented previously the following can be observed.

- ❖ High formation stresses were observed (7245 psi).
- ❖ High Frac Gradient 0.91 psi/ft
- ❖ Low Fluid Efficiency of 16 %
- ❖ PDAT analysis (G-Function) indicates Multiple Fractures created.
- ❖ 1 ppg prop slug pumped into formation with no indication of formation resistance.
- ❖ Perforations and near well bore Frictions were identified and didn't seem to be a problem.

Summing up, the bottom hole treatment pressure (BHTP) analysis shows that the fracture occur as explained below.

$$BHTP = P_{surf} + P_{hyd} - P_{fric} \quad \text{(Kim, 2010)}$$

$$BHTP = 8018 + 3797 - 4060 = 7755 \text{ psi}$$

BHTP is greater than Frac extension pressure. This confirms the occurrence of fracture. However, it will be much better if the BHTP is much higher.

Note: BHTP will be higher at higher proppant concentration. This can be applied by whether increasing the surface pressure or reducing friction pressure.

3.3 Redesign of Main-Frac

The following changes were made to the original design based on the Mini-Frac results:

- ❖ To compensate for the low fluid efficiency and to help get enough fracture opening width, fracturing fluid viscosity was increased from 17 cp to 25 cp by adding more gel loading.
- ❖ Fracturing Fluids were tested and checked on location to get a crosslink time of about 1 minute to help reduce the pipe friction. This is the time taken for increasing the viscosity of the fluid as required, e.g. the viscosity of a fluid can be increased straight away or after a few mintues.
- ❖ As there were multiple fractures indicated, Pad volume percentage was increased to 37%.
- ❖ Pumping rate was increased to maximum possible rate of 25 bpm (average) based on the maximum allowable surface pressure.

4. Results and Discussion

Due to the tubing specifications (burst pressure, etc…) National Oil Corporation (NOC) representatives in Libya set the pressure relief valve (PRV) and the pumps automated kick out system at 9,000 psi surface pumping pressure. This pressure limitation eliminates the option of pumping at higher rate than the 24 bpm, and reduced the pressure room to only 1000 psi. Therefore, the maximum allowable working pressure was 9000 psi.

During the main-frac being pumped, the pumping surface pressure was approximately 8000 psi to be the Pad stage. At the time when the 1 ppg prop stage started, the hydraulic pressures increased and simultaneously lead to surface pressure decrease but didn't produce much friction when it hit the formation. However, at the end of the above mentioned stage (1 ppg prop stage) and with the beginning of the 2 ppg prop stage, the friction was increasing and it didn't seem that the formation can take high prop concentration. In addition, as soon as the 2 ppg prop hit the formation, the surface pressure started increasing rapidly approached the max allowable pressure (1000 psi). There was no pressure room to play with so a real time decision to cut proppant and go to flush was taken and a screen out occurred.

All things considered, the pressure limitations for a well can dictate the surface and BH treatment pressure and therefore affecting the pumping rate and proppant concentration, and because of this formation nature, having enough BHTP and enough pressure room on surface was crucial.

Tube selection and its effect on the hydraulic fracturing treatment

In this stage there were scenarios presented which is the real tube used for this fracturing treatment (3.5 inch) and, a tube of size 4.5 inch for comparison in order to find out the impact of tube selection. This will be implemented by introducing the relationship between the tub friction pressures and pumping rate (Friction Pressure vs. Pumping Rate) with the mentioned tube sizes. However, the lowest friction pressure obtained was the best for bottom hole treatment pressure because it provided better chance for proppants concentration and surface pressure control (hydraulic fracturing pumping). This is shown in figure 5 (a) and (b) below.

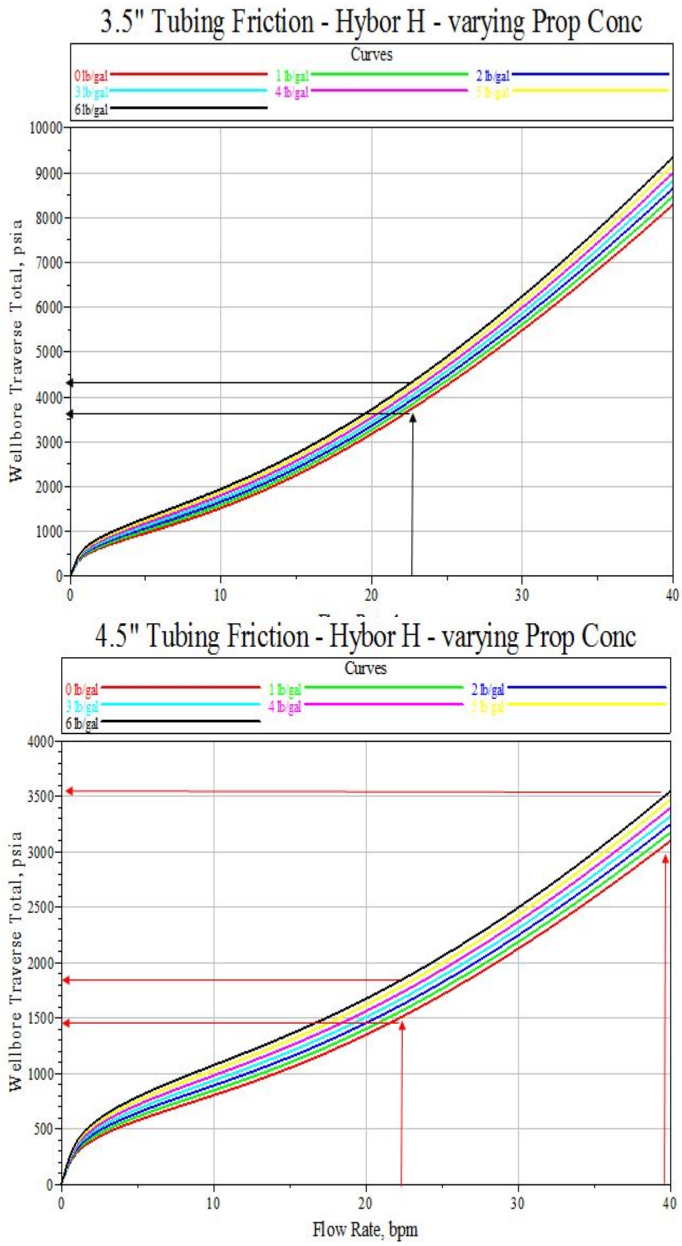

Figure 5: Friction Pressure vs. Pumping Rate in the case of (a) 3.5 inch tube size and (b) 4.5 inch tube size

The graphs 5 (a) and (b) illustrate the tube friction pressure on the Y axis and the pumping rate on the X axis. From the graphs the friction pressure is approximately 4000 psi at 22 bpm in the case of 3.5 inch tube size and its only 1500 approximately at 22 bmp in the case of 4.5 inch tube size. All in all, it's worthwhile to minimize the pipe friction by having higher tubing grade and burst pressure, bigger tubing ID's to be able to increase the allowable surface pumping rate and pressure.

Conclusion

This paper has addressed a complete hydraulic fracturing treatment for the well E 45. This job was carried out by Halliburton fracturing engineers in cooperation with National Oil Corporation (NOC) representatives. It has also investigated tubing specifications selection and its effect on the results of hydraulic fracturing treatment in oil formations.

The main tools used in this hydraulic fracturing treatment are Pumping Diagnostic Analysis Toolkit (PDAT) and Halliburton proprietary software package (FracPro) for analyzing Mini-Frac pumping data. After the completion of the Mini-Frac execution it is observed that the formation stress and the Frac Gradient are both high. They were (7245 psi) and (0.91 psi/ft) respectively. However, the fluid efficiency was low (16 %) and thePDAT analysis (G-Function) indicates multiple fractures created and 1 ppg prop slug pumped into formation with no indication of formation resistance. Furthermore, perforations and near well bore Frictions were identified and didn't seem to be a problem.

The decision of redesign the Main-Frac was based on the results obtained from the Mini-Frac analysis. There were some changes implemented. Fracturing fluid viscosity was increased from 17 cp to 25 cp by adding more gel loading to help get enough fracture opening. Moreover, crosslink time set to be 1 minute to help reduce the pipe friction. Furthermore, Pad volume percentage was increased to 37% as there were multiple fractures observed. Pumping rate was also increased to maximum possible rate of 25 bpm.

The pressure limitations for a well can dictate the surface and BH treatment pressure and therefore affecting the pumping rate and proppant concentration, and because of this formation nature, having enough BHTP and enough pressure room on surface was crucial. So for future jobs in the same area and for similar reservoirs and well conditions, the followings are recommended:

- ❖ Minimize the pipe friction by having higher tubing grade and burst pressure, bigger tubing ID's to be able to increase the allowable surface pumping rate and pressure
- ❖ It is recommended to treat each zone / unit separately in a single stage by planning small focusing fracturing treatments in short perforation schemes, to get enough bottom hole treating pressure and rate for each zone.
- ❖ When sonic logs data are available, calculating rock properties are more accurate and trustworthy than other logs and give a very good idea about the formation properties since the design stage.
- ❖ Incorporating this knowledge gained from this job into future Jobs in the same reservoir / area is recommended.

References

American Petroleum Institute. (2009). Hydraulic Fracturing Operations — Well Construction and Integrity Guidelines. *API*, 23(October), 1–36.

Brookfield. (2015). The Global Leader In Viscosity. Retrieved August 1, 2015, from http://www.brookfieldengineering.com/products/rheometers/laboratory-pvs.asp

CATPUMPS. (2015). Industrial Duty Relief & Pop-Off Valves for Reliable Secondary Pressure Relief. Retrieved August 1, 2015, from http://www.catpumps.co.uk/products/relief-pop-off-valves.asp

FRACPRO. (2015). Frac Pro Software Manual. Retrieved August 1, 2015, from http://www.michaelackermanphotography.com/manuals/f/frac-pro-software-manual.pdf

Fulton, S. W. and S. (2003). Specifications – Importance of Getting Them Right. Retrieved August 1, 2015, from http://www.digitalrefining.com/article/1000320,Specifications_____importance_of_getting_them_right.html#.VcNb_E3JBaQ

Halliburton. (2012). Sales of Halliburton Products and Services. Retrieved August 1, 2015, from http://www.halliburton.com/public/pe/contents/Data_Sheets/web/H/H09146 HQ-2000 Pump Trailer SDS.pdf

Halliburton. (2015). Stimulation Equipment and Services. , 1–6. Retrieved July 1, 2015, from http://www.halliburton.com/public/cps/contents/books_and_catalogs/web/sandcontrol/section6_stimulation_equipment.pdf

Hartley, J. & Holden, D. (2013). SPE 163902 Evolution of a Pinpoint Stimulation Technology and the Benefits Thereafter. *SPE*, (March), 26–27.

Kim, G.-H. (2010). Interpretation Of Hydraulic Fracturing Pressure In Low-Permeability Gas Reservoirs, MS Thesis, Pennsylvania State University.

Mala, V. P. & Yogi, A. M. N. (2011). Importance of Data Collection and Validation for Systematic Software. *International Journal of Computer Science & Information Technology (IJCSIT)*, 3(2), 260–278.

Schlumberger. (2012). Assess Rock Mechanics to Optimize Drilling in Real Time SonicScope 475 Service Improves Understanding of Drilling Mechanics to Maximize ROP. Retrieved August 1, 2015, from http://www.slb.com/~/media/Files/drilling/case_studies/sonicscope475_rock_mechanics_cs.pdf

SRT. (2015). Guidelines for Step Rate Testing. Retrieved August 1, 2015, from http://www.advntk.com/pwrijip2003/pwri/final_reports/task_1/srt/srt_final.htm