Open hole completions: case histories and technical studies with formation micro imaging (FMI)

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Historically, propellants were used mostly in open holes. There continues to be interest in the StimGun™ assembly and other related technologies in open hole applications to overcome near-wellbore damage and as a pre-treatment to enhance additional stimulations. These products initiate and propagate fractures over very long intervals (considerably longer than the interval stimulated). A number of open hole wells have been successfully treated using this approach, primarily using the Well Stimulation Tool (WST). This fracturing mechanism has been documented by formation micro imaging (FMI) and video logs, and is discussed below.

From an operational standpoint open hole stimulations with propellants require some additional planning. One early concern is the possibility of open hole collapse due to the high-pressure gas surge. Over a many year period, no known open-hole collapses have been associated with the use of StimGun products, even though they have been used in a variety of formation types. Nevertheless, care must be taken not to overpressure holes; anecdotal evidence obtained from others indicates that hole collapse is not impossible.

The Well Stimulation Tool (WST), a cylindrical, solid configuration, is most commonly run in open-hole applications. The WST is conveyed inside a vented carrier to protect the tool and to allow the combustion gases to readily escape to the wellbore.

Case histories

The following case histories have been selected for review:

- In Oklahoma, the Propellant Technology Development Group made six runs with 6 ft (1.8 m) and 12 ft (3.6 m) WST's in an open hole filled with drilling mud. No hole collapse was indicated. Formation stimulated varied from sands to shales to carbonates at well depths no greater than 3500 ft (1067 m). Of special significance is that FMI fracture identification logs were run both before and after the propellant jobs. The logs clearly show fairly intense multiple fracturing in the stimulated interval and then bi-winged fracturing up to 100 ft (30.5 m) upwards and downwards away from the tool. Calculations (Figure 3) show that open hole fractures at the tool can extend deeply into the formation. Away from the tool, although fractures are created, they are much less deep. This is because fractures are gas/liquid-driven near to the tool and only liquid driven away from the tool.

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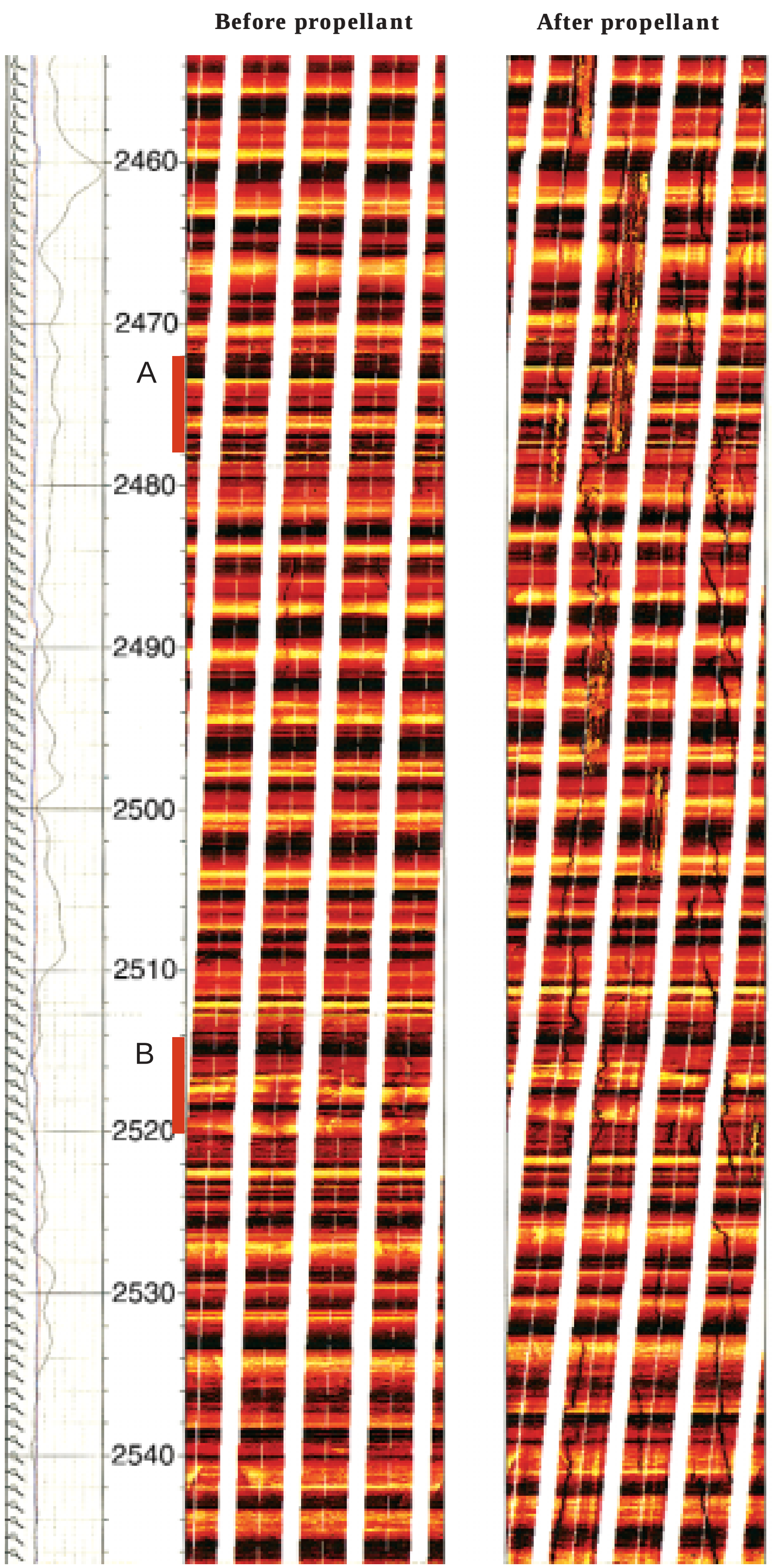
- An operator in the Odessa, Texas area stimulated one of the first open hole horizontal wells where a long interval was treated with the WST. The well was in the San Andres Dolomite formation (2 md permeability estimate, 4500 ft (1372 m) TVD, 8 in. (203 mm) open hole.) Two runs were made, one 200 ft (61 m) in length and the other 880 ft (268 m) in length, both with 3 in. (76.2 mm) diameter WST. Subsequent to the stimulations, there was no additional tool drag after either run; although there were large increases in incremental production, it was mostly water. The operator acidized the well one year later. The hole was still open and acid injection pressures indicated the fractures from the propellant stimulation were still effective.

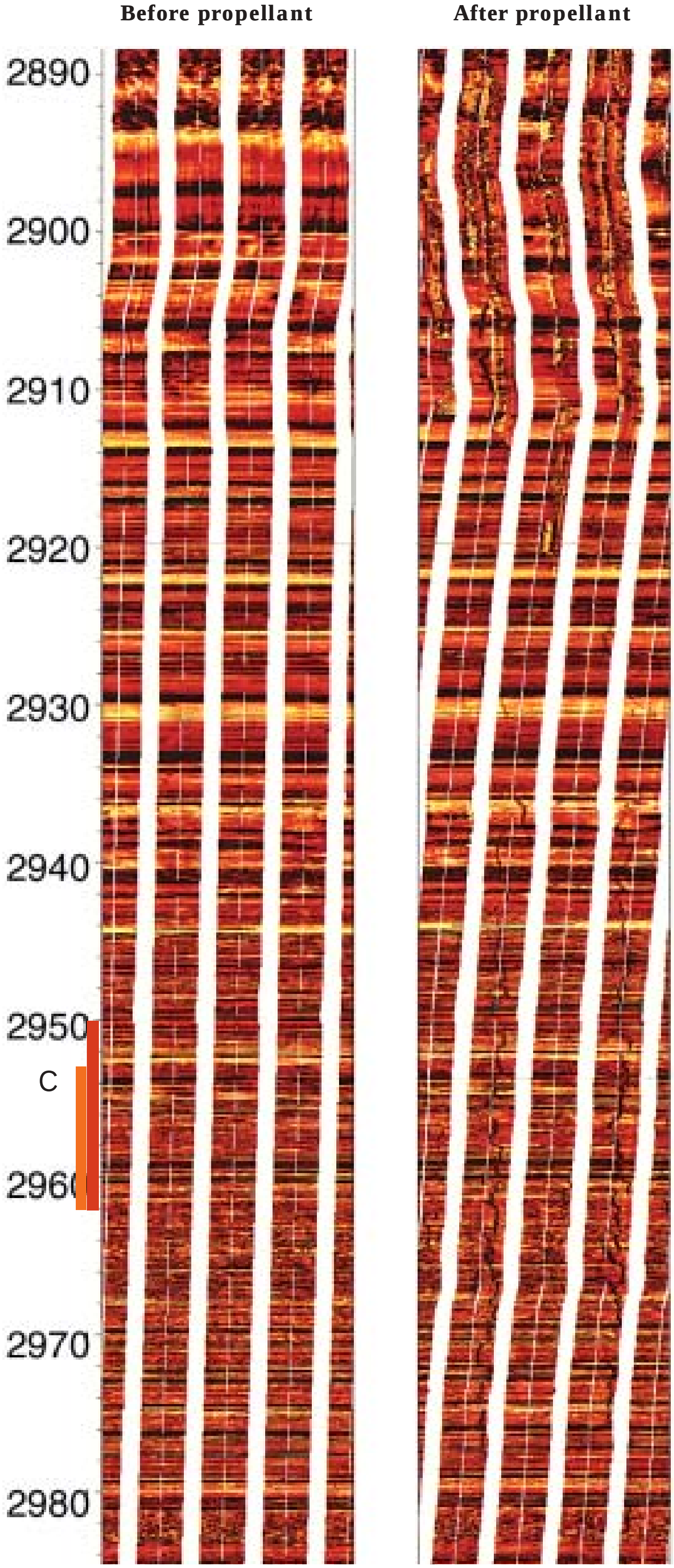
Formation micro logs of a Oklahoma test well showing fracture length profile where FMI logs were run before and after shooting propellant



A. 6 ft x 2 in. WST Tool was shot at 2472 - 2478 ft in a limey shale section. Please note the created fractures on the "After propellant" logs that extend vertically up and down the open hole wellbore.

B. A 6 ft x 2 in. WST tool was shot at 2514 - 2520 ft in a limestone formation.

Figure 1 – *FMI Log 1*



C. Two WST tools (one 6 ft and one 12 ft) were shot at 2954 - 2960 ft and 2950 - 2962 ft respectively in this shale formation.

Figure 2 – *FMI Log 2*

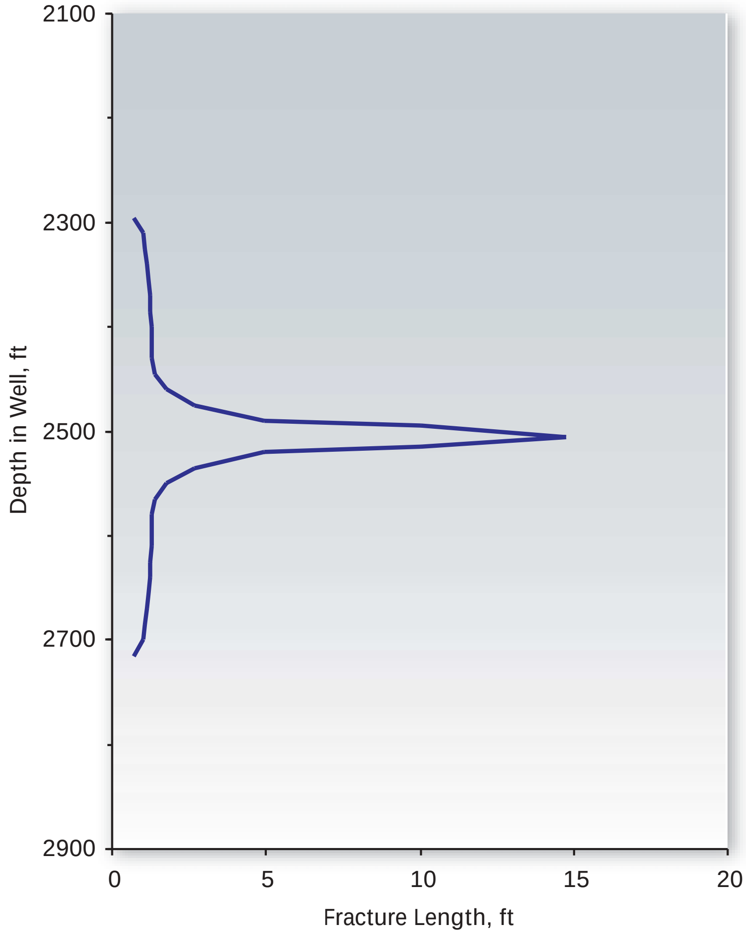


Figure 3 – *Typical calculated maximum fracture length profile near and away from tool (2 in. (50.8 mm) diameter by 12 ft long WST at 2500 ft in 8 in. open hole). At tool – 6 fractures. Away from tool – 2 fractures.*

- An operator in western Canada stimulated the Alida Beds (1 md carbonate at 4200 ft (1280 m) TVD, 6 in. (152.4 mm) hole) with 160 ft (49 m) of 2.5 in. (63.5 mm) WST, and the stimulation assembly was pulled with minimal to no drag. Incremental oil production was approximately 100 bopd (16 m^3/d), which decreased to an incremental 25 bopd (4 m^3/d) during the following one year period.
- An operator in the Hobbs, New Mexico area stimulated the Delaware sand, which is soft and loosely consolidated (50 md to 100 md, 6 in. (152.4 mm) open hole) with 2 in. (50.8 mm) and 2.5 in. (63.5 mm) WST in 80 ft (24 m) and 220 ft (67 m) runs, respectively. There were no problems getting in or out of the hole on either run. The more interesting facet of this job was that it was the first horizontal well in which the downhole pressure gauges were used to verify the model; the data gave strong indications (later substantiated by the operators) that the toe of the well, where the 80 ft (24 m) of propellant was ignited, was out of zone and in a carbonate formation. Both the pre-and post-job modeling are available, as well as the fast pressure gauge data from the job. No production results are available, as this job was primarily a test case in soft sandstones before conducting a planned North Sea application.
- A Canadian operator stimulated the Halfway Sand in a British Columbia horizontal well (15 md permeability, 8200 ft (2500 m) TVD, 6 in. (152.4 mm) open hole). Two 7 ft (177.8 mm) runs with 2 in. (50.8 mm) diameter WST were used to successfully initiate fractures for subsequent stimulation. This was a pre-frac application and was successful. No open hole collapse was noted in this higher stress environment at increased depth.
- In North Dakota, an operator stimulated a Bakken 2000 ft TVD horizontal well with 500 ft (152.4 mm) of 2.5 in. (63.5 mm) diameter WST. This was a high bottom hole temperature application. The tools sat on bottom overnight and the WST was successful ignited. Production increased from 30 bfpd (4.8 m^3/d) to greater than 300 bfpd (48 m^3/d), but due to mechanical problems not related to the stimulation the well was killed by pumping water. The equipment was retrieved without any indications of hole collapse. Production was re-established at 70 bfpd (11.2 m^3/d) and increased to 120 bfpd (19 m^3/d) before slowly declining to 60 bfpd (9.5 m^3/d) one year later.
- A Canadian operator stimulated an Alberta open hole Leduc D3 Dolomitic limestone well in three wireline runs with 2.5 in. (63.5 mm) diameter 13 ft (4 m) WST. This well is at 8200 ft (2500 m), had 50 md to 150 md permeability and a 6 in. (152.4 mm) open hole. After all three runs, no fill was tagged on bottom, and the operator subsequently pumped a small acid job after the propellant breakdown/stimulation. Production

went from 200 bopd (32 m^3/d) and 4800 bwpd (763 m^3/d) to 800 bopd (127 m^3/d) and 4200 bwpd (668 m^3/d). After one year, production was 600 bopd (16 m^3/d), 4400 bwpd (700 m^3/d). After three years, the well was still producing 400 bopd (64 m^3/d) and 4600 bwpd (731 m^3/d). High-speed pressure data are available from all three runs.

- In Australia, an operator successfully stimulated a coalbed methane extraction well (650 ft (198 mm), 5.0 in. (127 mm) hole, .4 md permeability). The well was stimulated in five runs with 2.0 in. (50.8 mm) and 2.5 in. (63.5 mm) diameter WST. There was some tool drag after the first run, but after successfully making all five runs, the operator had to

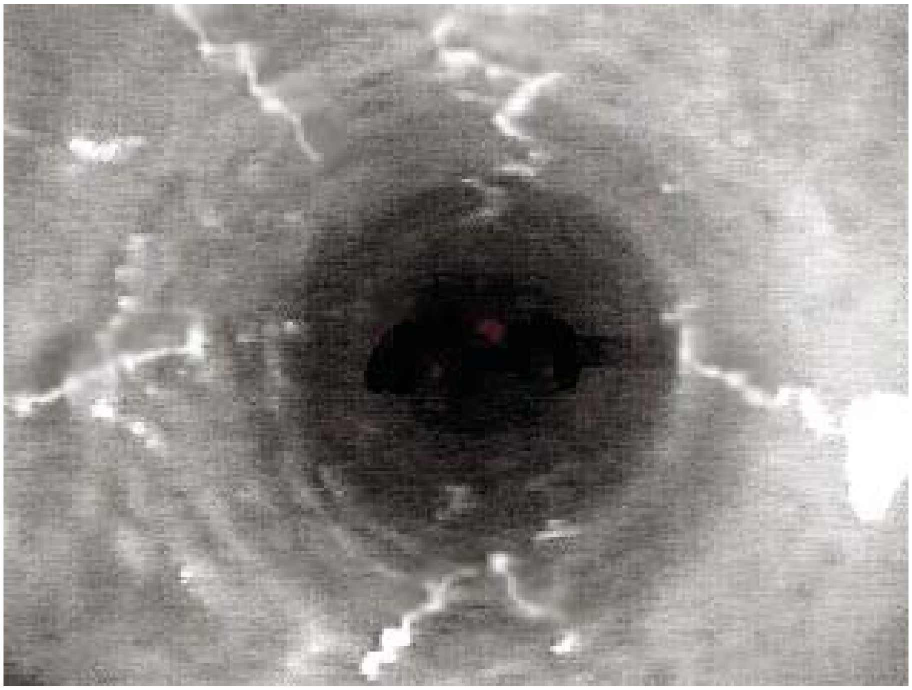


Figure 4 – *Video log frame from section at tool showing 6 fractures (contrast-enhanced).*

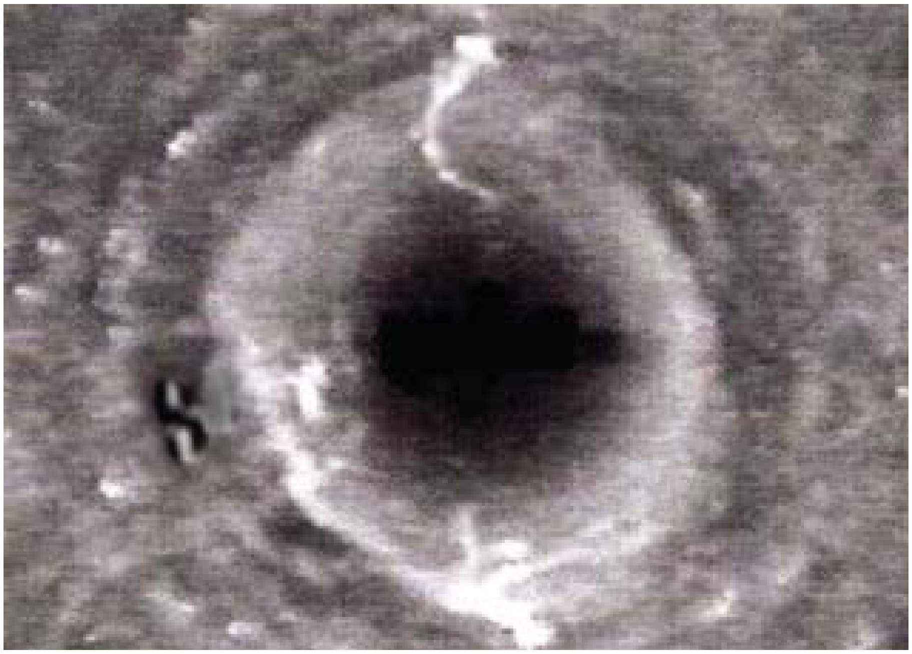


Figure 5 – *Video log frame from section away from tool showing 2 fractures (contrast-enhanced).*

circulate out only some coal fines from the well. The well was successfully taking fluid and then producing gas, but the other information from the well was held confidential. Fast pressure gauge data from the WST stimulations and model data are available.

- An operator in Wyoming made eight runs with propellant in open hole Dolomite formations with no hole collapse problems. These eight runs were on wireline with 2.0 in. (50.8 mm), 2.5 in. (63.5 mm), and 3.0 in. (76.2 mm) diameter WST tools. Some increases in injection rates were noticed and pressure data is available from this 4700 ft (1433 m) well.
- The same Wyoming operator as listed above stimulated a 3200 ft (975 m) deep Wyoming dolomite formation with tubing conveyed systems consisting of 1.5 in. (38.1 mm), 2.0 in. (50.8 mm) and 2.5 in. (63.5 mm) diameter WST. No open hole collapse was noted and some increases in well injectivity were noted.
- A Canadian operator stimulated a northern Alberta Belloy Sandstone open hole well to establish injectivity (5 md, 7900 ft (2407.9 m) TVD, (83 mm) open hole). There were no hole collapse issues in four wireline runs of 2.5 in. (63.5 mm) and 3.0 in. (76.2 mm) diameter WST covering 52 ft (15.8 m) overall. Although the well could not be broken down prior to the propellant stimulation, acid was subsequently utilized thereafter. High-speed pressure data for three of the four propellant runs is available.
- In Texas, an operator shot 10 ft (3 m) of 2.0 in. (50.8 mm) diameter WST to restore production after a cross-link polymer job. This job was successful in restoring production in this 10 md Grayberg dolomite open hole producer (2600 ft (792.5 m) TVD, 7.5 in. (190.5 mm) open hole).
- In Michigan, an operator ran three 12 ft (3.6 m) WST jobs in open hole sections of sandstone at about 1500 ft (457.2 m) in an attempt to restore deliverability to gas storage wells. Video logs were run subsequent to the jobs. No hole collapse occurred and the observed fracture patterns were similar to the ones described in the first case study above. That is, there were four to six fractures near the tool and long, running bi-winged fractures away from the tool as shown in Figures 4 and 5. The WSTs were run in water, and the water injected to the formation probably created water blockage problems, so the jobs did not improve the gas deliverability of these wells. Reservoir pressure was not high enough to generate significant clean-up. Presently strongly recommend the use of non-damaging fluids when stimulating injection wells.