WELLHEAD ISOLATION IMPROVES SAFETY AND PROTECTS EQUIPMENT

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INTRODUCTION

Wellhead isolation tools can help operators control the high pressures often associated with well stimulation techniques. Fracturing requires the use of very corrosive and abrasive fluids under high pressure which can result in wellhead and tubing erosion. For safe well operation and other safety reasons, operators were usually forced to either change wellhead equipment for a fracturing job or to limit fracturing job design to the capabilities of their wellhead equipment. A wellhead isolation tool provides a means of isolating wellhead equipment from the high pressures and harmful fluids used in fracturing.

This paper reviews the different wellhead isolation tools available and the advantages and disadvantages of each design. Suggestions to help ensure good fracturing job design are presented, and fluid flow through a wellhead isolation tool is reviewed and discussed. A discussion of the effects of fluid type on the wellhead isolation tool and tubing follows, and finally, some case histories help illustrate the use of this tool.

DIFFERENT WIT DESIGNS: ADVANTAGES AND DISADVANTAGES

There are a few different tool designs used to isolate the wellhead. This paper describes three different designs in use and discusses the advantages and disadvantages of each design.

All current wellhead isolation tools (WITs) share some basic design features. Each WIT has a mandrel inserted through the vertical passage in the wellhead. The lower end of the mandrel is sealed or packed off in the production tubing or casing. Each design has a high pressure valve attached to the top of the mandrel to control pressure while the mandrel is seated and packed off in well tubing or casing. Differences in the three WIT designs are found in the way the mandrel is inserted through the wellhead.

The first WIT has a mandrel which passes longitudinally through both ends of a hydraulic cylinder and is coupled to a power piston in the cylinder. The mandrel can be moved up and down through the vertical passage in the wellhead by piston action. Hydraulic fluid from a special pump is used to extract the mandrel from the well. With a single hydraulic cylinder centered over the wellhead, the mandrel aligns vertically with the wellbore. This simplifies insertion and removal of the mandrel from the wellhead. Mandrel movement, however, is limited to the stroke of the piston within the hydraulic cylinder.

If a long wellhead must be isolated using this equipment, the packoff nipple assembly must be extended on the end of the mandrel. Mandrel extensions are usually added on site just before WIT installation. Since the mandrel extends above the top of the WIT hydraulic cylinder, the valve on top of the mandrel is approximately 6 ft above the wellhead. This arrangement may require a remote-actuated valve for emergency shutdown.

Also, because the mandrel pierces the hydraulic piston and reduces piston surface area, the size of the piston as well as the hydraulic cylinder must be large enough to provide adequate hydraulic force for inserting and removing the mandrel and packoff nipple assembly in wells with high wellhead pressures. These requirements increase WIT size and weight.

One of the safety features of this design is that the mandrels containing stimulation fluids are fully enclosed during the job, either by the hydraulic chamber or the wellhead. If mandrel erosion occurs, pressure gauges monitoring the hydraulic chamber or wellhead indicate that stimulation pressure is in these areas. This allows operators time to make needed corrections without exposing personnel on location to stimulation fluids.

A second wellhead isolation tool design features a mandrel harnessed to at least two hydraulic cylinders or mechanical jack assemblies. These cylinders or jack assemblies are offset from the vertical passage in the wellhead. The hydraulic cylinders or mechanical jacks together insert or remove the mandrel through a wellhead. Once the mandrel is set with these tools, the valve is immediately over the top of the wellhead. Such an arrangement allows easy access to the valve. In this tool also, the mandrel length is limited to the length of the hydraulic cylinder or mechanical jack stroke which prevents this style WIT from entering certain long wellheads. Again, mandrel extensions may be used to compensate for the short reach in some cases.

One important consideration with this type of tool is maintaining the synchronization of the two or more hydraulic cylinders or mechanical jacks when inserting a mandrel. If the cylinders lose synchronization, they may work against each other.

A third WIT design is made up of a mandrel attached to the bottom of a piston in a hydraulic cylinder. Stimulation fluids are pumped through the hydraulic cylinder upper chamber, piston, and mandrel into the well. A series of valves which control differential pressure moves the double-acting piston. Wellbore pressure is used to stroke the mandrel into the well, and independent hydraulics to extract the mandrel from the well. Like the first example above, this style WIT has the advantage of a single hydraulic cylinder to permit good alignment with the wellbore to simplify mandrel insertion and removal.

This tool shares the disadvantages of a limited reach like the other WITs and therefore requires mandrel extensions to isolate long wellheads. Because the mandrel is integral with the hydraulic cylinder, access to the high pressure valve is approximately 3 to 6 ft above the wellhead equipment and may require remote-actuated valves for emergency shutdown. Also, sand or aggregate may become lodged in the hydraulic cylinder upper chamber and hamper removal of the mandrel from the well. Lastly, it is important that sufficient wellhead pressure be available to set this tool.

JOB PLANNING

The importance of pre-job planning can hardly be overestimated. Thorough records of activity and equipment provide the accurate information needed by the service company when performing a fracturing job. Good records and close cooperation can result in a successful job for both the customer and the service company.

It is important to know the type and dimensions of the tubing in the hole and the wellhead being used.

Tubing Dimensions and Type

Accurate ID information on tubing is essential when using premium grade tubing in the well. The strength of premium tubing comes from a reduction in the tubing ID. Even though premium tubing manufacturers usually assign standard names and sizes to their tubing, actual tubing ID could be smaller than the stated size. For example, 2 7/8 in. 6.5 lb/ft premium tubing may really have an ID smaller than the expected 2.441 in.

It is important that service companies know actual tubing ID rather than just size and weight range.

Tubing with Internal Upset

It is also important to know if tubing with an internal upset is in the well. Here again the strength of tubing with internal upset requires a reduced ID around threaded tubing connections. The WIT has to pass through these reduced ID threads, so careful job planning and accurate ID measurements are essential to successfully completing the job. Use of a WIT in internally upset tubing may not be possible at all.

Precautions

If stimulation operations are likely in the future but premium or internal upset tubing is needed in the well, an operator can plan ahead by using either a blast joint or extra standard diameter tubing at the top of the tubing string.

The simplest solution is to use a 3 to 4 ft long blast joint with a known ID to give the WIT safe entry into the tubing string. Another solution is to top off the tubing string with 3 to 4 ft of a known diameter tubing to provide entry to the tubing string. It is important not to set the tool in the internal upset connection.

Wellhead Information

If a wellhead with internal upsets is used, the service company must be informed. It is important to check the wellhead for an ID smaller than the tubing ID because even if the tool fits in the tubing ID, it must get through the wellhead ID first. Other required wellhead information includes the wellhead seal type, flange, and connection type. It is important to know what is between the top flange and the top of the tubing.

If a nonstandard wellhead is being used, the operator should notify the service company before the stimulation job to give them time to make an appropriate adapter.

WIT FLUID FLOW

This section includes a general discussion of the mechanics of high speed fluid flow through the WIT and an explanation of why this is a concern in the WIT even more than in tubing.

Velocity through the WIT is an average of two to three times faster in the WIT than in the tubing. Because the WIT mandrel has to be small enough to fit into the tubing, the available flow area through the WIT mandrel is less than that of the tubing. Reduced available flow area results in increased fluid velocity. Velocity is the most critical measurement to consider when determining which tool to use.

Another factor to consider in using a WIT is the tradeoff between pressure and fluid rate. Since there is an inherent tubing ID restriction on all tools, wall thickness is the only variable available for increasing strength and pressure rating. The only way to get greater wall thickness is to reduce the internal ID. Therefore, a high pressure rating requires a decrease in flow rate; a high flow rate requires a decreased pressure rating.

The mechanics of fluid flow through the system, from the pump to the tool to the tubing, are such that it is possible to (1) run large ID tubing and use high flow rates to the wellhead, (2) then reduce the ID, (3) accelerate fluid through the tool, (4) then expand and decelerate through tubing. This system has two main critical areas: the acceleration at the top of the tool and the deceleration at the bottom of the tool. When the specifics of the job are known, the acceleration can be controlled to help prevent induced turbulence due to sharp edges or quick ID reductions. The intent is to prevent flow separation from the wellhead isolation tool ID during acceleration.

Fluid separation at any point will cause very high localized rapid velocities as the fluid expands back to fill voids at the separation point. Fluid separation induces swirl in the fluid which extends 10 to 20 times the diameter of the tubing before working itself out. In trying to work itself out, fluid flows perpendicular to the wall, creating severe erosion (Figure 1). Such effects are normally limited only to the tool, but the consequences could result in job termination and well shutdown.

Flow separation can be easily avoided, however, because service companies are aware of these fluid flow properties, and they are careful in designing the job. Erosion is not so severe in tubing because velocity decreases as fluid expands in the larger ID tubing.

Tubing erosion as a result of fluid velocity occurs mainly as the fluid exits the tool. The fluid passes through the reduced tool ID and must be expanded at the bottom of the tool. This expansion creates radial velocity which must be expended on the tubing or the WIT. In some cases, tubing has actually been cut at the bottom of the WIT due to high fluid velocity. In all cases, most erosion caused by the high velocity of the fluid exiting the tool occurs within 50 diameters of the exit point. A patented diffuser has been developed to help minimize the effects of exit fluid velocities.

This patented diffuser contains and redirects the radial velocity of the fluid before it enters the tubing. This allows velocities to be expended in the diffuser rather than in the tubing. Comparison testing shows a tubing erosion rate with a diffuser 70 to 90% lower than without a diffuser. The diffuser can help curb the erosive effects of a fracturing job (Figure 2). Different fluid systems have different erosive effects on the WIT and tubing.

EFFECT OF FLUID TYPE ON WIT AND TUBING

Different stimulation fluids have different effects on WITs and on tubing. This section discusses the effects of clean fluids, acids, sand-laden fluids, fluids with high-strength proppant, foamed fluids with sand, and foamed fluids with high-strength proppant through the WIT and tubing.

Erosion occurs when solid material is actually removed from the tool or tubing itself. Corrosion occurs when the tool or tubing is eaten away, dissolved, or oxidized.

Clean Fluids

Clean fluids are fluids without any solids such as sand or high-strength proppants. Clean fluids usually cause little erosion. They are not abrasive by nature, but at high velocities, fluid cutting is possible. Fluid cutting may be especially pronounced on the tubing at the point where fluid exits the WIT, unless the diffuser is used. Clean fluids are usually pumped at very high velocities, but without the proppants in the system, these fluids are safe at higher velocities. Clean fluids, even acids, contrast with foamed fluids which can be erosive at high velocities.

Acids

Even highly corrosive acids cause little erosion in WITs in most cases. In fact, acid can usually be called a "clean fluid." Some acids are incompatible with rubber sealing elements in the wellhead isolation tool.

Hydrofloric acid (HF), for example, can quickly destroy rubber goods. However, tools can usually be tailored to resist particular acids.

Sand-Laden Fluids

In this paper, sand-laden fluid refers to any type of fluid with normal-size sand, usually 20/40 Ottawa. The erosive effects of sand-laden fluids vary depending on fluid velocity, sand concentration, carrier fluid viscosity, and total quantity of sand pumped. In estimating possible erosion rates, fluid velocity is the most critical factor. Sand concentration is the second most critical factor, and carrier fluid viscosity is the least critical factor. These three factors, plus the total quantity of sand pumped, can give an indication of the total potential erosion. These observations are based on experience and are intended to be used as guidelines only. They are not intended to be used as rules or standards.

Experience in pumping sand-laden fluids seems to indicate that there are threshold values based on fluid velocity, sand concentration, and flowline/tool geometry. For example, a multiple well stimulation program with large quantity sand fracs using equipment dedicated to that program was underway. Periodic equipment inspection revealed no detectable erosion. Toward the end of the program, however, the pumping rate was increased by approximately 5%; subsequent erosion required the replacement of two tool parts.

Investigation into the cause of the erosion revealed that the increased velocity created flow separation from the wall of the mandrel. A low pressure zone, created at the point of separation, induced localized high velocity swirls in the fluid. Rather than flowing parallel to the mandrel wall, the fluid flowed perpendicular to the mandrel wall until it hit the wall and "bounced" off. Effects of the swirling were limited to a length of the mandrel approximately 20 times the mandrel diameter. Knowing this allowed the point of separation to be established and the geometry to be corrected to prevent a recurrence.

Fluids with High-Strength Proppants

In general, the erosive effects of high-strength proppants in fluids are the same as the sand-laden fluids, except more pronounced. Most high-strength proppants are substances with sharp edges and are usually harder than most sands, so this proppant type causes more severe erosion than sand. Fortunately, in most cases where high-strength proppant is used, the concentrations and quantities are less than when using sand. However, since fluid velocity is the most critical factor in erosion, maximum pumping rates should be reduced by approximately 20% of similar sand-laden fluid systems.

Foamed Fluids

Foamed fluids used to enhance well stimulation multiply the effects of erosion. Foamed fluid creates a situation similar to what occurs in flow separation. Gas in the fluid system creates bubbles or "voids" in that system. The significance of these voids is discussed in the next section covering foamed fluids with proppant. The difference between foamed fluids and actual flow separation is that with foamed fluids there is no low-pressure zone to create localized high-velocity profiles. Because voids already exist in the fluid system, flow separation is much easier to initiate. For this reason, maximum recommended velocities are lower for foamed fluids as compared to similar nonfoamed fluids. The appropriate percentage reductions for foamed fluids as compared to sand-laden fluids will be stated in the following sections.

The two most common foaming agents are CO_2 and N_2. One difference between CO_2 and N_2 is that CO_2 can mix with stimulation fluids and form an acidic solution. This results in both erosion and corrosion.

Foamed Fluid With Sand or High-Strength Proppant

Sand-laden fluids and fluids with high-strength proppant cause erosion normally, but the erosive effects of the proppant are magnified in a foamed fluid. In particular, high-strength proppant in a foamed fluid produces a very erosive system. Foam quality is a factor in determining the magnitude of erosion. Experience and tests show 70% quality foam to be a threshold value; that is not to say that foam of less than 70% quality has minimal erosive effects.

The mechanics of erosion are functions of particle strength, particle mass, and radial velocity. This relationship is true in all instances, but its effect is so pronounced in a foamed fluid that it requires extra caution when designing the fracturing job. Again, proppant concentration, proppant quantity, and fluid velocity are the determining factors in estimating erosion; however, the critical velocity values are 65-80% of nonfoamed fluids. Operators need to remember that the fluid velocity will significantly decrease in the workstring as compared to the velocity through the wellhead isolation tool.

CASE HISTORIES

Two case histories from field operations illustrate how a wellhead isolation tool helps minimize erosion. Relevant data is noted and followed by a brief explanation of the situation in each case.

Case 1

Casing: 4 1/2 in. 10.5 lb/ft
Maximum Treating Pressure: 2970 psi
Proppant Type: 20/40 sand
Amount of Proppant: 234,000 lb

Fluid Type: 70% foam with 45% CO_2 and 25% N_2
Sand Concentration: 3 lb/gal
Pump Rate: 30 bbl/min (101 ft/sec through WIT)

Comments:

This job is an interesting study in the tradeoffs which are possible in order to perform high velocity foam fracs. The velocity through the tool approaches the maximum recommended value for a 70% foam fluid with proppant. However, the other three factors are favorable: the proppant is sand, and the quantity and concentration of sand are about half the recommended maximums. No detectable erosion was reported as a consequence of running this job.

Case 2

Casing: 5 1/2 in. 23 lb/ft
Maximum Treating Pressure: 6580 psi
Proppant Type: 20/40 sand
Amount of Proppant: 2,216,000 lb
Fluid Type: Gel
Sand Concentration: Ramp from 2 lb/gal to 8 lb/gal (6 lb/gal for 80% of the job)
Pump Rate: 61 bbl/min (116 ft/sec through WIT)

Comments:

This job approaches the maximum in velocity and concentration for a gelled fluid frac job. The volume of sand pumped on this job is equal to that of four or five normal jobs, so the potential for severe erosion was present. Erosion from this job was detected but was not significant. A uniform amount of erosion was found for the entire length of the tool. This is expected and represents normal service for the tool.

CONCLUSIONS

The wellhead isolation tool helps minimize wellhead erosion and corrosion resulting from the high pressures and high fluid velocities used in performing fracturing stimulation jobs. Knowing the different WITs available and the relative advantages and disadvantages of each WIT can help operators make better equipment decisions. Understanding the basics of fluid flow through the WIT and the varying effects of different fluids can also help ensure a profitable stimulation job.

ACKNOWLEDGEMENTS

The author would like to thank the management of Halliburton Services for permission to present this paper.

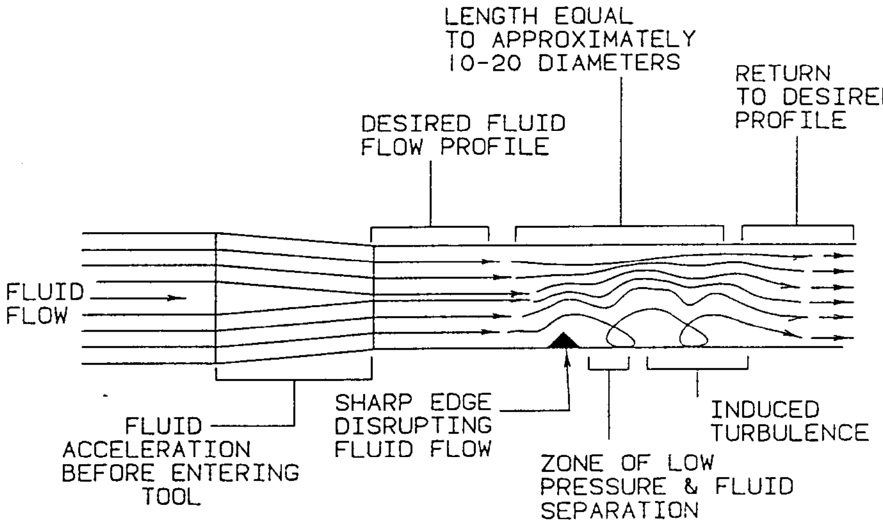

Figure 1 - Fluid acceleration into tool with sharp edge creating flow separation from wall

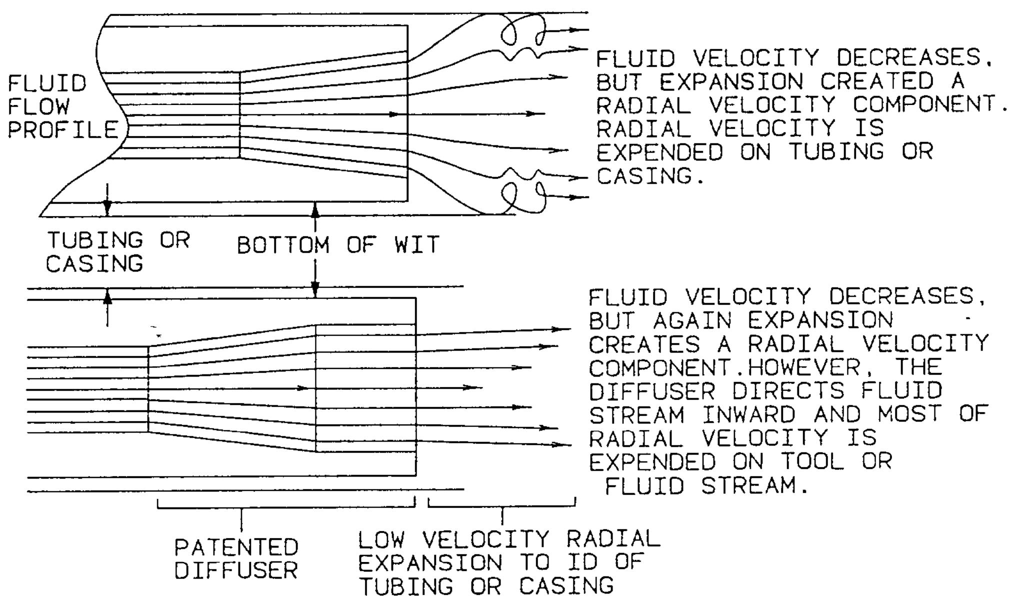

Figure 2 - Comparison of methods of decelerating fluid before exiting tool