Perforating for Heavy Oil Cold Production In North West Saskatchewan and North East Alberta, Canada

by Kirby Hayes

Abstract: An overview of the variables involved in heavy oil well completion, perforating products and techniques and their impact on cold production is presented. After a detailed examination of a range of variables, the author presents conclusions which will assist producers to minimize problems and maximize production in heavy oil formations.

Introduction: Cold production is: enhanced oil production created by a zone of increased permeability established around the well bore by the initiation of aggressive sand inflow. Perforating products and techniques, to assist the initiation of sand in flow and sustain production, are a key component of this process.

The demand for the ideal perforating product for cold production (CP) is a vigorous quest. Numerous products have been introduced into this market. The success of these products, though, has been poorly tracked. The suggested practices contained herein are the summation of (and perhaps an extrapolation of) the most popular practices of a wide range heavy oil producers, operating in a large geographical area. Admittedly, the assumption that heavy oil is one great big homogeneous reservoir and should be subjected to all the same completion techniques (including perforating products and perforating techniques) is without merit. Given the limited data and actual science we have to work with, when choosing those techniques, that is precisely the assumption made. Even with what might be described as poor science and bad engineering,[1] the success of CP (in which aggressive perforating is a key component) is indisputable. The techniques and products used in CP are constantly evolving and as a result are slowly being experimented with in other types of reservoirs.

Sometime in the early 1950's a field trial was attempted using plastic coated walnut shells dump bailed into an open hole completion in hopes of controlling sand inflow. The trial failed. So did many other similar trials and experiments (including but not limited to sand screens, fire flooding and sonic pumps). The pioneering spirit/attitude/practice of working with what you have and try, try, try-fail, fail, fail is still the state of the art in heavy oil production. In fact without it, cold production would not now be acceptable practice. The attitude of the production and service sector staff is as much as a key component to CP as the right type of completion, the right PCP pump or the right perforating product.[i] The committed cold producer therefore is continually learning (i.e. failing).

Perforating charges

The modern jet charge came from the same technologies used in the development of armor piercing ammunition between the First and Second World Wars. To perforate casing the charge forms a jet of particles traveling at a velocity which enables it to pierce the casing, cement and the formation. Figure 1 illustrates the sequence of forming a jet and lists the components of the charge. Figure 2 demonstrates the effects of the geometric variables. It is easy to see the limitations of this technology when placed in the confines of a conveyance system inside the confines of a well bore.

Perforating charge design innovations for cold production

As sand production became more and more desirable, the demand for larger and larger entrance hole diameter (EHD) became greater. When big hole (BH) charges were being introduced in the early 1980's, the commonly used charges at the time had an EHD of 0.4" with a penetration (PEN) of 23". These BH charges typically had a maximum of .75" EHD and 14" PEN. A survey of heavy oil producers conducted in the early 1990's asked how much penetration would they sacrifice in order to achieve a bigger EHD. The results of the survey was an acceptable minimum penetration of 12". An extra big hole (EBH) charge was developed that boasted of quality control (QC) specifications of 1" EHD and 10" PEN. It rapidly became the preferred charge for large numbers of heavy oil producers. This inspired the rest of the charge manufactures to follow suit. Figure 3 is a comparison table[2] of current heavy oil perforating products.

The pursuit of large and larger EHD is an attempt to prevent perforation plugging. Perforation plugging was, is and will be a major problem plaguing CP. The complex phase flow is very difficult to understand. Oil, sand, water and gas flow is complicated further with the presence of sand consolidation, ½" nodules, silt, clay, shale, scale and the ex-solution of gas. Perforation plugging therefore can not be predicted with simply sand to EHD ratios, or viscous drag and flow velocity.[3] [ii] Further complications come when the blockage occurs in the formation.[iii]

The nature of the jet charge design for larger EHD is very sensitive to the clearance between the casing wall and the carrier. Figure 4 shows this relationship. Casing size and weight, carrier size type and condition, the utilization of scallops and centralization; all have an effect on EHD. Even in more controlled conditions (i.e. API testing) there is quite a range of EHD. Figure 5. Each charge design has an unique character (i.e. jet shape or the distance from the apex of the charge that the jet is fully formed) causing various effects to different charges. This also makes the modeling of EHD from one manufacture’s software to another manufacture’s charge impossible.

Debris

The achievement of large EHD has not been without detrimental side effects. In order to achieve a large EHD in the casing a larger exit hole in the carrier is produced. This allowed substantially more shrapnel (mostly case material approximately ½" square pieces from the spent explosives) to exit the carrier than was previously experienced with smaller EHD producing charges. This was lessened by different means by different manufactures. One method was to design a charge with a case (zinc) that would powder after the jet was formed. Another utilized a jet that would develop after exiting the carrier resulting in a small exit hole (limiting the debris entering the well bore) while still achieving a large EHD in the casing wall. Still another applied a stronger material that would leave the case relatively intact preventing it from exiting the carrier through the exit hole.

The other cause of debris is carrots. The last particles of the liner forming the tail of the jet, travel at a lower velocity. This lower velocity allows these particles to fuse, forming what is referred to as a carrot. In smaller EHD charges, carrots are virtually eliminated by use of disintegrating metal liners (DML) and powdered metal liners (PML). The parabolic shape of BH & EBH liners makes the use of PMLs difficult to manufacture. The use of PML material in BH type charges also have reduced EHD because of the way that that liner breaks down during detonation and the speed of the resulting jet. By using a solid liner material like copper brass or pfinodal with its high yield strength, a higher mass is induced into the jet stream which tends to produce a larger EHD. The parabolic shape on the liner also controls the speeds of the jet stream which in turn controls the shape of the jet. Although the use of brass liners has greatly reduced the number and size of carrots experienced, they have not completely eliminated the problem. Recently there has been discussions/inquiries into the extremely unconsolidated nature of the reservoir partly being the cause of forming more carrots. In more consolidated conditions, the liner material is deposited along the circumference and length of the perforation. In extremely unconsolidated conditions, the liner material has more opportunity to collide and fuse into carrots. Clearly more documented study is needed to understand this phenomena.

Penetration

The effects of extremely unconsolidated formations on entrance holes and the formation of carrots is not understood. The effects of these formations on penetration is equally a mystery. The lower the compressive strength of a target, the farther the penetration; is an accepted fact up to the point where that compressive strength fails to maintain the shape of the jet. At this point the jet starts to disperse. To illustrate this effect, refer to the exit hole of the target in figure 6. The recent introduction of some perforating products with PEN of a mere 5.9" proves that far less penetrations is needed than was once thought (i.e. PEN 12"). The presence of drilling damage might be reason to consider products with further penetration (DP charges). There is no evidence, except open hole caliper logs, though, of what that penetration has to be (drilling fluids have been discovered as far off as offset wells). Charge performance modeling indicates the probable penetration through most well bore wash outs. The argument that a larger volume of disturbed area will aid initial sand production might be a further reason for using DP charges. When considering the use of DP charges or the highly technically termed practice of "salt and peppering"[4] consider the resultant decrease of flow area.

Shot Density and Phasing

It is extremely logical that if solids are produced and those solids have a high tendency to plug perforations, we should therefore create more perforations to sustain production longer. If there is a quality control issue with perforating products, higher shot densities will increase the odds of effective perforations.[iv] Heavy oil reservoirs are not homogeneous, therefore, to enhance the number of worm holes that propagate from perforations and to increase the odds of accessing the preferential direction of propagation, higher densities and close phasing are recommended.[v vi i] Higher shot densities and close phasing aid sand flow initiation by a creating a geometrically thorough disturbed zone around the well bore[vii viii] (Refer to figures 7 and 8).

Conveyance

Hollow steel carriers[5] (HSC) both re-useable and expendable retrievable (ERHSC) are utilized in this area. Rigidity, robustness, and weight all aid in conveyance through highly viscous fluids. HSC minimize casing damage by containing most of the concussion. Perforating in a true under balanced condition,[6] avoiding problems caused by severe and immediate sand inflow suspended in high viscous fluids (getting down with subsequent runs and getting stuck), perforating longer intervals (i.e. the entire zone[7] [8] and safety (in very active areas etc.) are factors contributing to the growth of pressure activated (PA) TCP operations. The use of mechanical collar locators (currently an under utilized method) when PA TCP perforating large intervals >6m in wells <600m is an economical option[9] where accurate depth control is not imperative (i.e. +-1m).

Logistics and economics

Constantly complicating field operations, are the choices of completion products and techniques. These decisions are based primarily on logistics and economics. The low margins experienced in heavy oil and the high efficiencies of field operations demanded by tight margins dictate the prioritizing of logistics and economics. They should not , however, overlook the long term effect they may have on production. It should be the objective of a completion strategy to ensure continuous and sustained production. The prevention of work over operations not only has favorable implications on economics, but it might make sustaining production possible. It has been widely experienced that cold production, once interrupted, is difficult and sometimes impossible to re-establish.

The products and techniques that have idiosyncratic effects on economics, logistics and possibly production are: HSC vs. ERHSC, TCP vs. wire line, higher shot densities, MCL, clean out techniques, completion fluid and multiple well completion (the performance of a single service on multiple wells enabling reductions on mobilization charges). The effects of these variables on long term production has not been rigorously tracked. The magnitude of these effects may vary from well to well, field to field and area to area.

Casing Integrity

There is no way to put numerous large diameter holes into casing without lowering its strength. As an example, 69 shots per meter (SPM) .8" at 120 by 60 degree phased holes reduces the casing’s strength by approximately 20 %. Casing strength is decreased the closer holes are on the same plane.[ix x] Suggestions to minimize casing strength loss are: perforate less, re-perforate cautiously with a different phased product (the re-perforated shots will not be oriented relative to the existing perforations),[10] or use much stronger casing. If shooting casing collars is to be avoided, (a possible logistical complication), try not to place them in the perforating interval when setting casing (another possible logistical complication). If it is, as suspected, that casing damage is a result of subsidence of the overburden caused by producing large quantities of sand, there is not much that can be done when the earth starts to move.[11] If, in fact, these phenomena are determined to exist in a large number of cold produced fields, it will have enormous negative implications for heavy oil. After such aggressive perforating practices are carried out - 26 SPM of 1" holes - the area of the perforations only represents approximately 2.3% of the original casing area. Casing that is not sufficiently supported can experience moderate to severe damage when perforated.[xi] Figure 9 is an example of this damage.

Cement Integrity

The cement sheath through the perforated interval will be damaged (having been shot full of holes). Figures 10 to 13 illustrate the damage is contained primarily to the perforating interval. Some of the differences in the cement bond logs is due to the difference in fluid level from the before to the after perforating passes. Severe damage to cement has been experienced in previously steamed and then aggressively re-perfed situations. Severe casing damage will occur when the cement sheath is not supported by the well bore or formation.

Re-perforating

Re-perforating is an accepted, widely used and, as demonstrated in figure 14, highly successful work over technique. In situations where existing perforations are deemed inadequate for CP (i.e. .5"EHD at 13 SPM) it may be imperative to re-perforate. In situations where casing integrity is in question[12] it might be more prudent to perforation wash, chemical stimulate[xii] (figure 15 is an example), use sand acids, sand bail, pump to surface, use fluid flushes, super flushes (fluid stimulation), use stable foam clean outs or utilize propellants[xiii] to unplug perforations. The problem could conceivably be out in the formation and not in the perforation. In this case, re-perforating, although it may stimulate the well back into production, will further decrease casing strength.

Case studies

Variables such as production philosophies, production techniques, economics (wells being shut in), geology, geography, geometry, completion practices, drilling practices, drainage geometry and other such things that may or may not be apparent make product comparisons cumbersomely difficult.

The 69 SPM vs. 26 SPM study results in Figure 16 and 17 demonstrate that a significant increase in flow area did not produce a positive impact on production volumes. The results from this test should not be interpreted to exclude the 69 SPM product from use in heavy oil. The thin pay of some Colony zones showed dramatic results from utilizing this product (Figure 18). The greater flow area’s effect of less pressure draw down on the production of water needs more experimentation. The study, because of it’s relative short time span, was not able to conclude whether there was a reduction in work over frequency. There was no difference in work over frequency in the short term after the wells were completed.

The results from the study done in Figure 19[13]demonstrate that the 39 SPM had a positive effect on production. Though the brief time span of the data (two months) and did not hold true for cubic meters of production per meter of perforations (figure 20), makes this conclusion very dubious. The fact that these two studies contradict each other (i.e. one indicates more perforations and flow area did not effect production and the other indicated it did) proves: 1) that more variables need to be eliminated 2) obviously further study is needed and 3) that products should not be evaluated on such a limited basis.

Conclusions

When perforating a heavy oil well that is going to be subjected to common cold production practices the following is recommended:

Closely review all pertinent data, sources of information and considerations such as open hole logs, cores (of the well/s in question or cores from the area), area geology, area geophysics, economics, logistics and most importantly (if available) past production experience to ensure the development of a congruent exploitation, drilling, completion and production strategy.[14]

Choose perforating products and perforating and completion techniques congruent to the strategy and consider the implications to production, logistics and economics.

Large diameter, high density, closely phased perforations be utilized, shot under balanced and covering the entire zone to provide a geometrically thorough disturbed zone, minimize plugging, enhance initial sanding and sustain production.

Use compatible fluids that do not promote sand fall out.

Clean out possible perforation, formation and drilling solids debris.

Pump to surface or put on pump to ensure sand movement is continuous.

Track and document the results.

In the spirit of the example in the introduction, encouragement of new and different products, techniques, technologies and business practices is crucial to the full exploitation of heavy oil cold production. Participation in and support of forums to introduce, exchange and evaluate new innovations will greatly expedite the quest.