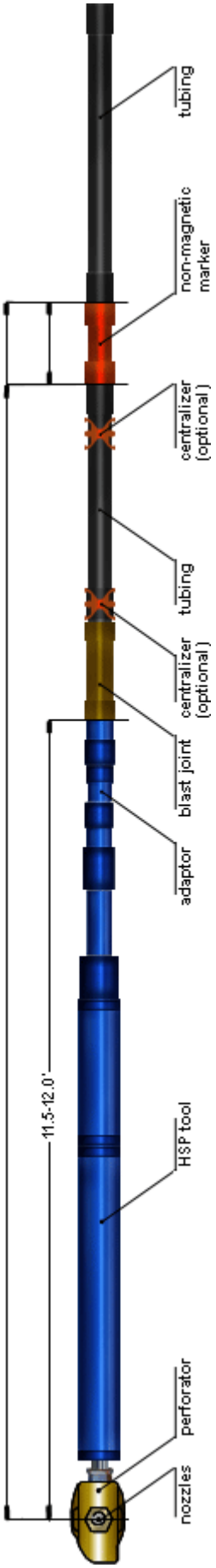


Hydro-slotting perforation procedure

Hydro-slotting perforation (HSP) tool

Underground hydro-slotting perforation tool for vertical wells (Patent US 8863823) is consists of perforator with jet's nozzles, return block, hydraulic block, shank, and adaptor (picture on the left).

Operating principle

When pressure (working fluid: water with abrasive filler) is applied, perforator with jet's nozzles starts to perform a rectilinear movement with a constant velocity down, enough to cut of casing, cement, into the productive formation. Usual operating pressure is 4500-5500 psi. When a pressure accidently jumps more 6500 psi tool stops (perforator with jet's nozzles no longer moves along the borehole), and cutting of slots no longer produced (it is possible only point perforation (abrasive jet perforation with a maximum depth of 1'). At reducing working pressure 800 psi (or cut the pressure) perforator with jet's nozzles automatically returns into the initial position. The depth of the cutting slots reaches 3-5' (for unloading circular stress conditions in the near wellbore zone enough 3'). Number of simultaneously cutting slots depends on the number of jet's nozzles in the perforator (2, 3, or 4). The length of the cutting slots depends on the length of the working rod (in this particular model is 1.64').

In HSP tool is provides a number of safety protections for perforator (ergonomic form, does not jams and does not scratch the casing, ability to direct and backwash bypassing the nozzles, possibility of reverse circulation even when accidently landing on the ground), return block (ability to return the perforator into the initial position even in case of breakage of the return spring), hydraulic unit (ability for automatically change the internal volume depending on the external hydrostatic pressure, to prevent an explosion closed hermetic oil unit at a depth), etc.

Ground equipment and piping

For HSP it uses a closed circular scheme for water, and open scheme for abrasive filler (sand is separated in a special "cutting", "vibration" tank (look "surface equipment"). Water tank → abrasive filler → pump → manifold block → high pressure line → wellhead → tubing → casing → wellhead with preventer → low pressure line → cutting tank.

Length and diameter of low pressure line should be sufficiently for not to create backpressure in the casing. Backpressure is worsening the cutting process, and maximum back pressure for old casing 500-700 psi.

Should be provided for quick switching from direct to backwash in the case of accidently stop the pump (in some cases, using an intermediate pump).

Connection the hydro-slotting perforation (HSP) tool

HSP tool → adapter (for connection to a standard tubing 2 ⅜, 2 ⅞) → blast joint (or one tubing section) → non-magnetic marker (visible when logging) → tubing → additional pipe joints (for easy and quick change of sections when lifting the HSP tool to the next cutting interval, also it depends on the maximum lifting height of the high pressure line).

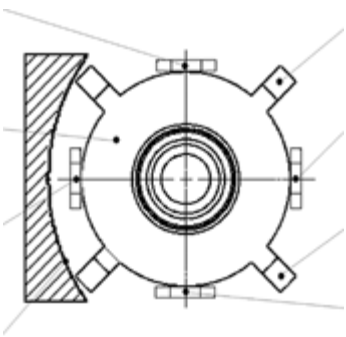
External diameter of HSP body tool is 3.5', inner diameter of the borehole (ID casing) is ~ 4.0" (for casing 4.5") and ~ 4.8" (for casing 5.5") (wall thickness depends on the weight of the linear ft.). The distance between the HSP body tool and the borehole wall in the first case only 0.25", in the second case 0.65". Through this distance must pass the waste sand and rock with reverse fluid flow on the surface.

Therefore, the use of any centralizers (especially in wells with a small casing's diameter (4.5') should to do very carefully, and perhaps even abandon this.

Rig

Surface equipment: Rig, tubing (2 ⅞ or 2 ⅜), wellhead with BOP, scraper and caliber for the inner diameter of casing, well piping, low pressure line, intermediate rig's pump, additional intermediate's pipe joints, nonmagnetic marker or pipe joint (visible on logging), water tank(s), cutting tank (vibrating tank for the separation of waste sand and slag), in some cases it is required water heating. For work at night lighting is required.

Underground hydro-slotting perforation tool is a high fairly accurate instrument, assembled and tested in special laboratories, under special conditions, temperatures and pressures. Some internal parts (hydraulic block, for example) have a sizes 0.03", and are sensitive to temperature, shock and vibration. Normal operation of the instrument depends on careful handling.



Do not hit and do not throw on the ground HSP equipment, it is not just a piece of pipe. Do not knock on the tool with a hammer.

Reinforcement ribs of perforator are protecting the jet's nozzles from contact with the walls of the well (picture on the left). but if casing have any crumples, unevenness, protuberances (especially after repair of casing), when lowering the HSP tool in the well, violation (or even damage) of one of the nozzles may occur. Nozzles will run unevenly.

Before lowering the HSP tool in the well must be sure to run scraper and calibration with the caliber for corresponding well's diameter.

Before lowering the HSP tool into the well is necessary to measure and calculate the exact distance from the jet's nozzles to the top and bottom of non-magnetic marker.

If exist a map of most fractures directions for deposit-field, is possible to use only two nozzles in the perforator (this will reduce the amount of abrasive quartz sand). Perforator oriented on the surface and further labels each tubing's section, lowered into the well.

Lowering the tool into the well must be carried out carefully and with a sufficiently low speed.

Lower tool into the well at high speed can result in slip-off nozzles under the influence of rapidly increasing hydrostatic pressure (especially if the valve metal ball is already in the perforator).

Lower HSP tool into the well must be carried out under the constant supervision of the total weight of the column (tubing + HSP tool). At depths approaching to planned cutting intervals reduce speed of lowering and take extra care (possible sand).

Unacceptable lowering of the HSP tool on the ground at high speed (at any stage of the process, including the final flushing).

When lowering the HSP tool on the ground at high speed (or any other obstacle, including unevenness of casing), under the multi-ton tubing's weight, perforator with the working rod are pressed into the tool (from the return block's side) (in normal condition the end of the working rod protrudes from the return unit on 7.68"), at the same time pressing in the main piston moves, occurs damage of main piston with control flow device, upper sealing cap of the hydraulic block is pressing in the shank, rods of the hydraulic and return blocks are bending, and a tool to be completely replaced (cannot be restored even in the factory).

Example:

The photos below show: Two left photos - normal (working) HSP tool condition before cutting, and after cutting process. Visible rod between the return block's body and perforator. The normal distance is 7.68". The right photo shows the tool after improper use (violation of lowering-lifting operations). It can be seen, that the rod with perforator recessed into the return unit (no distance). It had been a clear hit HSP tool on the ground (sand) at a high speed during the lowering into the well. After that functions of perforator's movement (cutting slots) has been lost. In addition, on the perforator clearly seen uneven eroded of nozzles (one nozzle is completely washed out together with nozzle-holders, but the other three nozzles remained in the almost normal conditions). This indicates, that one nozzle with nozzle-holder was damaged even during lowering and lifting operations (so one nozzle eroded more than others from the very beginning). In normal use, reinforcement ribs of perforator close the nozzle and nozzle holder from contact with the casing's surface. In this particular case one nozzle with nozzle-holder was damaged by asperity (or ridge) on the casing (perhaps, after repair operations with cement or casing), after which the well elementary was not passed with scraper and caliber. As a result of this negligence of working rig's team whole HSP operation has been ruined.

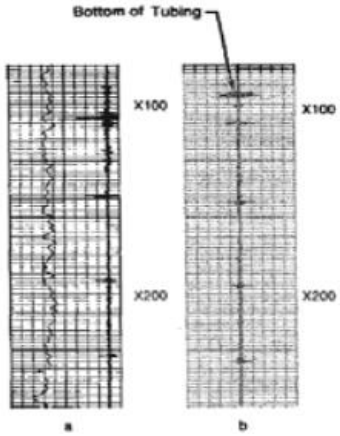
The HSP tool is lowered into the well to a depth of approximately selected first cutting interval.

Log

The inner diameter of the adapter smaller than the diameter of the log's probe.

The log's probe must be lowered above the HSP tool (at least higher than nozzles level, and accordingly first cutting interval, for 12'.

Absolutely enough just to see on the log top and bottom of non-magnetic marker (because the distance from the nozzle to the marker is already known) (drawing on the right).



After logging is necessary to compare (correlate) two logs (an old original electric / induction and received new gamma-ray / neutron) by the most striking peak / points of chart.

If the peaks of the new logging below the original, necessary to subtract the difference. If the peaks of the new logging above the original, necessary to add the difference. Knowing the exact required distance from the jet's nozzles to the top and bottom of non-magnetic marker, and knowing the exact depth of the first cutting interval, as well as knowing the exact difference between the first and second logging, is possible to calculate the exact distance for lifting or lowering the tubing, for jet's nozzles will stay exactly opposite the first cutting interval.

When the final installation should be considered the column's stretching under the work pressure at a given depth (take away from the value of the result).

Pump

Pump, frack-van (for monitoring HSP process) with the sensors for pressure and concentration, blender (mixer), manifold block for two lines: direct and reverse flushing, high pressure line.

As abrasive filler commonly used abrasive quartz sand 20/40, sometimes possible 10/20 (in truck).

If necessary, test the tubing (all connections at once) (unless of course the metal ball of the valve is not in the perforator, otherwise it is necessary to wash out on the surface with the reverse flushing, and catch the metal ball).

Should be provided for quick switching from direct to backwash in the case of accidently stop the pump (in some cases, using an intermediate pump).

It must be possible to switch the manifold unit on the backwash. It must be able to catch the balls on the surface.

The pump and pipes must be clean and not contain proppant (adhesive's sand) which is used at hydraulic fracturing. Leftovers of proppant (adhesive's sand) in the pump/pipes instantly clog HSP tool/equipment, which requires lifting the tool to the surface for full replacement.

Tubing's test (all connections at once): Drop the sintered metal ball 1.5" into the tubing, wait 10-15 min, possible carefully run the ball with supply low pressure up to 500 psi until the ball does not sit in a special ball's seat in the adapter (before HSP tool). Make sure that the ball is sitting in the saddle, increasing the pressure up to 2000-3000 psi. Give the pressure into the tubing 7000 psi for 1-2 min. If the pressure does not drop, it means all the connections of tubing OK. Wash out test ball on the surface by reverse circulation.

Poor connection can lead to leaks working fluid (water with abrasive quartz sand) anywhere in the well. The stream of the working fluid will cut a hole in the casing, cement and make a cavern in completely unexpected place (layer), possibly watered. This is especially dangerous for the oil and gas wells.

Drop the metal valve ball 1.0" into the tubing, wait 10-15 min, possible carefully run the ball with supply low pressure up to 500 psi until the ball does not sit in a special ball's seat in the perforator. Make sure that the ball is sitting in the perforator's saddle, increasing the pressure up to 1000-2000 psi.

Supply pressure should be smooth, without sharp jumps. Pressure jumps higher than 6500 psi are not permitted; this leads to stopping HSP tool (and respectively to the lifting HSP tool on the surface for replacement).

The cutting process starts with continuous pressure supply up to 4500-5000 psi. That is the working pressure during the whole HSP process.

As soon as the pressure becomes higher 1000-1500 psi perforator starts to perform a rectilinear movement with a constant velocity down. This is the start of readout time. Please note that in the present model total length of the working rod (and correspondingly maximum length of full perforator's movement and the cutting slots) equals 1.64'.

Even if the sand is not being supplied yet, at an operating pressure 4500-5000 psi it starts cutting the casing (with water only).

The pressure must not jump. The pressure should be kept at the same position. Jumping pressure accelerates erosion of the nozzles, nozzle-holders and perforator.

If pressure is normal, is possible to begin give the sand. Supply sand usually starts with a low concentration 0.2 pound/gal and subsequently can reach 0.35 pound/gal. That is the working concentration of abrasive during the whole HSP process.

Sand's supply should be smooth, without jumps. The sand concentration must not jump and should be kept at the same position.

Jumping of sand supply accelerates erosion of the nozzles, nozzle-holders and perforator. Supply batches of sand or excess concentrations of sand above 0.5 pound per gallon leads to damage of perforator with jet's nozzles (and respectively to the lifting HSP tool on the surface for replacement).

In some cases, supply of sand in batches with the high jumping concentration can lead to tear off perforator from working rod. Consequences: jamming of perforator with nozzles in the borehole, where it is not possible to drill out with the standard methods (and without damage of casing).

If the pump's company fails to maintain a constant pressure or a constant concentration of sand, HSP process must be canceled.

Please keep in mind, that the time of reach the first batch of sand to the cutting nozzles is several minutes (calculated by a special program).

At reducing working pressure 800 psi (or cut the pressure) perforator with jet's nozzles automatically returns into the initial position.

Please keep in mind, that the time of reach the last batch of sand to the cutting nozzles and back to the surface is several tens of minutes (calculated by a special program).

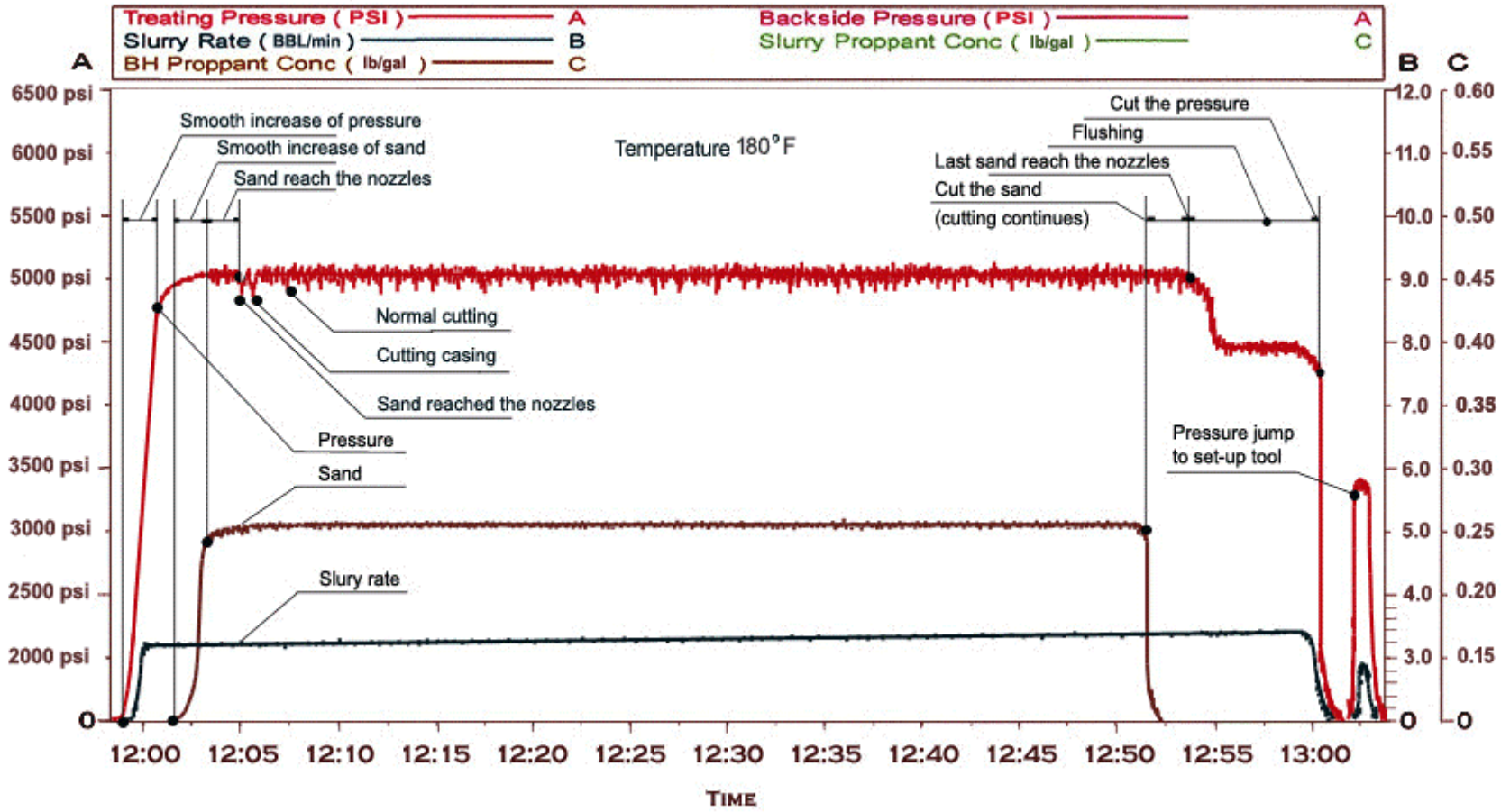
Time of reach the last batch of sand to the surface is not equal the travel time of water in the amount volume of the well to the surface.

Cut the send does not stop cutting process immediately, keep in mind the time of reach the last batch of sand to the cutting nozzles.

At accidently stop pump during cutting process, a large amount of sand and slag located in the casing, starts to crumble down to the HSP tool. Only Immediate switching-on of additional pump for circulate the water can save the well from the loss.

After cut the sand and at the end of each cutting interval is recommended to make a "jump" with pressure from 4500-5000 psi to 500 psi for 2-4 sec (it is not necessary to wait for the command for increase the pressure, during this time the perforator will already back into initial position) and back to 4500-5000 psi for fit the perforator in the middle position in the slots. After this, the slots are flushing during 30 min. After that cut the pressure and lift the tubing to the next cutting interval. The operation is repeated.

On the next page you can see a standard chart for HSP slotting-perforation process:


Treating Pressure (PSI) A
Slurry Rate (BBL/min) B
BH Proppant Conc (lb/gal) C
Backside Pressure (PSI) A
Slurry Proppant Conc (lb/gal) C
A
B
C
6500 psi
6000 psi
5500 psi
5000 psi
4500 psi
4000 psi
3500 psi
3000 psi
2500 psi
2000 psi
0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
0
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0
Temperature 180°F
Smooth increase of pressure
Smooth increase of sand
Sand reach the nozzles
Cut the pressure
Flushing
Last sand reach the nozzles
Cut the sand
(cutting continues)
Normal cutting
Cutting casing
Sand reached the nozzles
Pressure
Sand
Slury rate
Pressure jump
to set-up tool
12:00
12:05
12:10
12:15
12:20
12:25
12:30
12:35
12:40
12:45
12:50
12:55
13:00
TIME

Technical parameters of HSP process:

working pressure		sand concentration	
min	max	min	max
4000 psi	5500 psi	0.2 pound/gal	0.35 pound/gal

Taking into account the loss in pipes. Cutting takes place at a pressure on the nozzles not less 3500 psi.

ID nozzle's diameters (initial and final)

	Initial diameter		Final diameter	
number of nozzles	1 nozzle	all nozzles	1 nozzle	all nozzles
2	5.1 mm (0.2 inches)	10.2 mm (0.4 inches)	8.9 mm (0.35 inches)	17.8 mm (0.7 inches)
3	5.1 mm (0.2 inches)	15.3 mm (0.6 inches)	8.9 mm (0.35 inches)	26.7 mm (1.1 inches)
4	5.1 mm (0.2 inches)	20.4 mm (0.8 inches)	8.9 mm (0.35 inches)	35.6 mm (1.4 inches)

Approximate erosion of nozzles by cutting intervals:

2 nozzles

Start	end of 1 interval	end of 2 interval	end of 3 interval	end of 4 interval	end of 5 interval
10.2 mm	11.8 mm	13.2 mm	14.8 mm	16.2 mm	17.8 mm
0.4 inches	0.46 inches	0.52 inches	0.58 inches	0.64 inches	0.7 inches

3 nozzles

Start	end of 1 interval	end of 2 interval	end of 3 interval	end of 4 interval	end of 5 interval
15.3 mm	17.7 mm	19.8 mm	22.2 mm	24.3 mm	26.7 mm
0.6 inches	0.7 inches	0.65 inches	0.81 inches	0.96 inches	1.05 inches

4 nozzles

Start	end of 1 interval	end of 2 interval	end of 3 interval	end of 4 interval	end of 5 interval
20.4 mm	23.6 mm	26.4 mm	29.6 mm	32.4 mm	35.6 mm
0.8 inches	0.93 inches	0.78 inches	1.04 inches	1.28 inches	1.4 inches

The main parameters for HSP are pressure and concentration. Pump's rate is only an indirect parameter, that allows determine the status of nozzles.

Approximate rate can show the following table:

Approximate pump rate by cutting intervals

2 nozzles

Start	end of 1 interval	end of 2 interval	end of 3 interval	end of 4 interval	end of 5 interval
4.25 bbl./min	4.85 bbl./min	5.45 bbl./min	6.05 bbl./min	6.65 bbl./min	7.25 bbl./min

3 nozzles

Start	end of 1 interval	end of 2 interval	end of 3 interval	end of 4 interval	end of 5 interval
5.25 bbl./min	6.01 bbl./min	6.77 bbl./min	7.53 bbl./min	8.29 bbl./min	9.05 bbl./min

4 nozzles

Start	end of 1 interval	end of 2 interval	end of 3 interval	end of 4 interval	end of 5 interval
6.25 bbl./min	7.17 bbl./min	8.09 bbl./min	9.01 bbl./min	9.93 bbl./min	10.85 bbl./min

Violation of the technical conditions of HSP process leads to changes in the above parameters, and vice versa, inconsistency of the above parameters should doubt the correctness of HSP process.

Chemical additives

During slotting perforation process is possible to use any chemical additives to the working solution, favorably influencing present productive formation (HCL, nitrogen, for example). Nitrogen, for example, also reduces the density of the solution, which increases the kinetic energy of the abrasive particles and contributes to greater cutting depth.

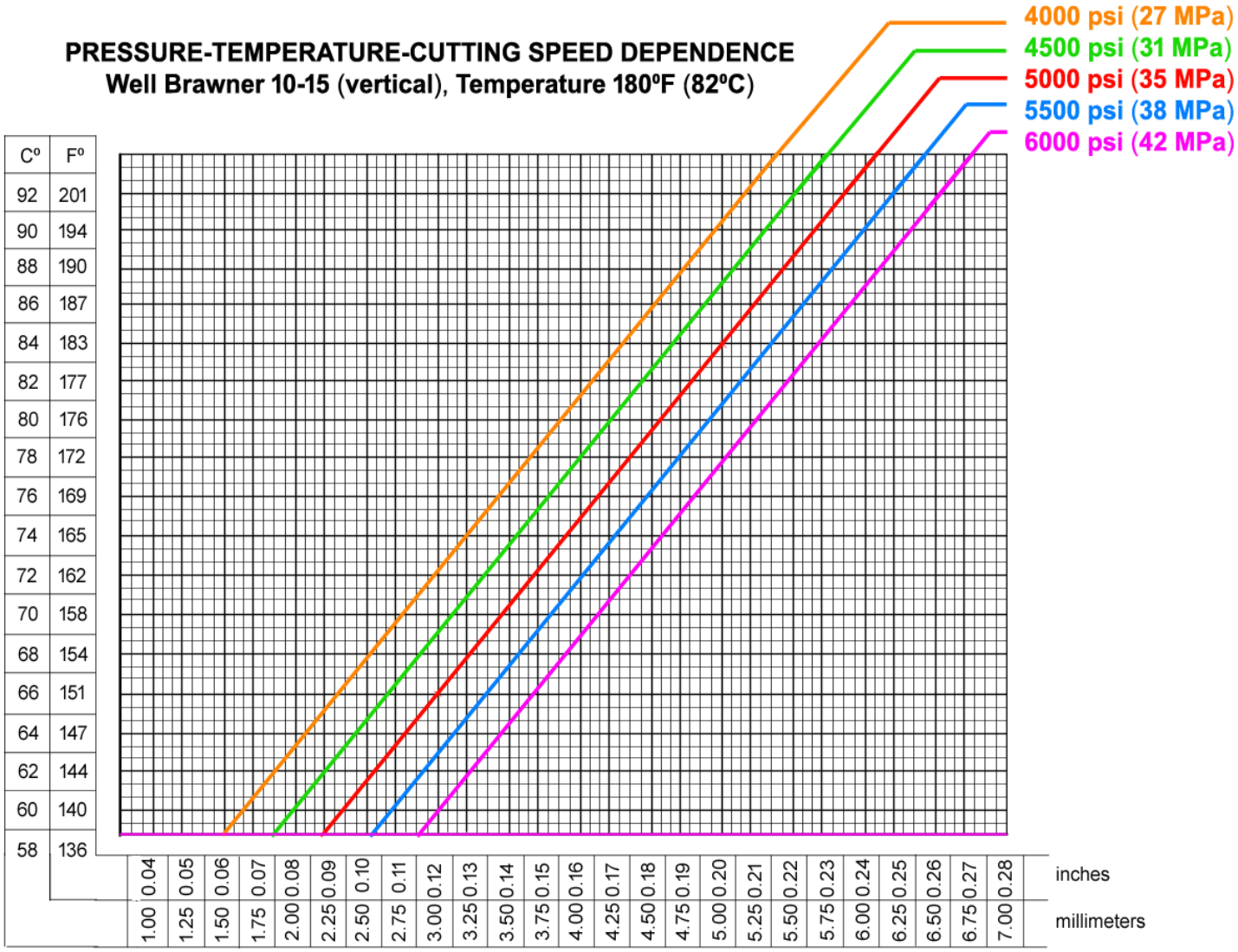
Absolutely unacceptable to use additives, that form foam (soap foam), this prevents the cutting process and kill it.

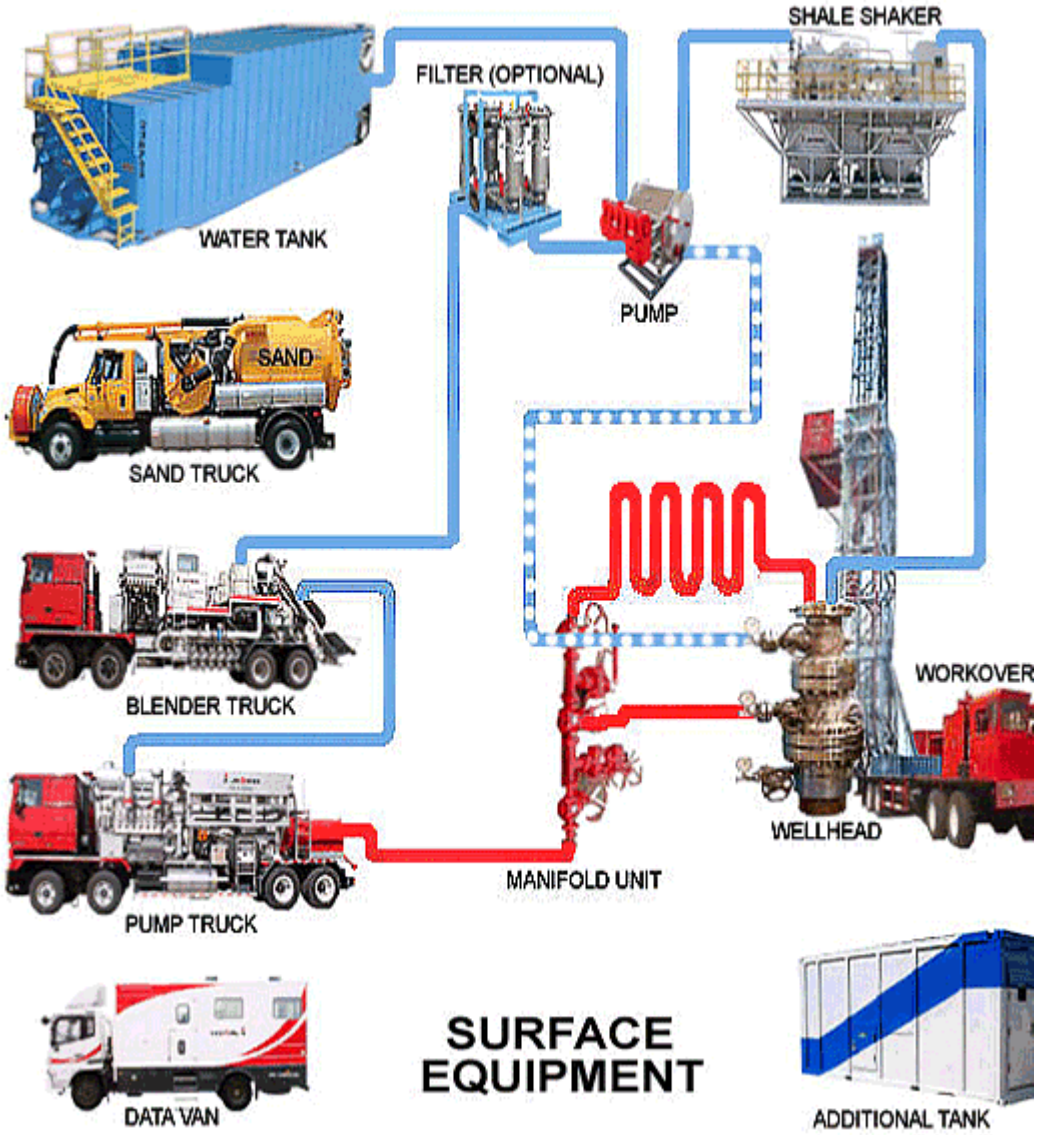
Additions

Underground hydraulic slotting perforation tool/equipment, like any other hydraulic equipment, contains oil. Throughput capacity of oil and viscosity (and accordingly speed of rectilinear forward movement of the working rod with perforator and cutting nozzles, and accordingly cutting speed) is sensitive to changes in temperature.

Each HSP tool is installed and tested (under different pressures and at different temperatures) in a special laboratory. Each HSP tool is prepared for use in a next well with predetermined parameters of temperature. Sometimes the temperature data in the well does not correspond to reality, then the cutting speed is either too fast or too slow. In this case HSP specialists trying to adjust the optimum cutting speed by the change pressure, concentration or heat water. Also rating of cut determined by the emerging rock (sludge) and its size.

Sample of temperature-speed graphic for HSP tool, obtained in the laboratory:




SHALE SHAKER
FILTER (OPTIONAL)
WATER TANK
PUMP
SAND
SAND TRUCK
BLENDER TRUCK
WORKOVER
WELLHEAD
MANIFOLD UNIT
PUMP TRUCK
DATA VAN
SURFACE EQUIPMENT
ADDITIONAL TANK