What is Happening When a Pump Cavitates?

Anyone on a location when it is happening knows for certain what is happening when a positive displacement or triplex pump starts to cavitate. The characteristic knocking starts up, sometimes barely noticeable and sometimes rising to a deafening hammering sound. On some occasions it will sound like a thump like a badly balanced washing machine, and on others it will sound like someone inside the pump banging on it randomly with a sledgehammer. But what is going on INSIDE the pump when you hear this outside the pump? (note – if you aren't familiar with the operation of triplex pumps and other positive displacement pumps you can go here for a great basic tutorial: http://www.drillingformulas.com/basic-understanding-about-positive-displacement-in-drilling-industry/ or here for just a video: https://youtu.be/M9Vt-GpK3_Q

Air in the System

The short answer to what's going on is that somewhere there is air inside the pump. Let's take the example of a triplex pump circulating at 3,000 psi (207 bars) Lets suppose that some air gets in from outside the pump at the inlet conditions of the pump – usually somewhere around 50 psi (3 bars).

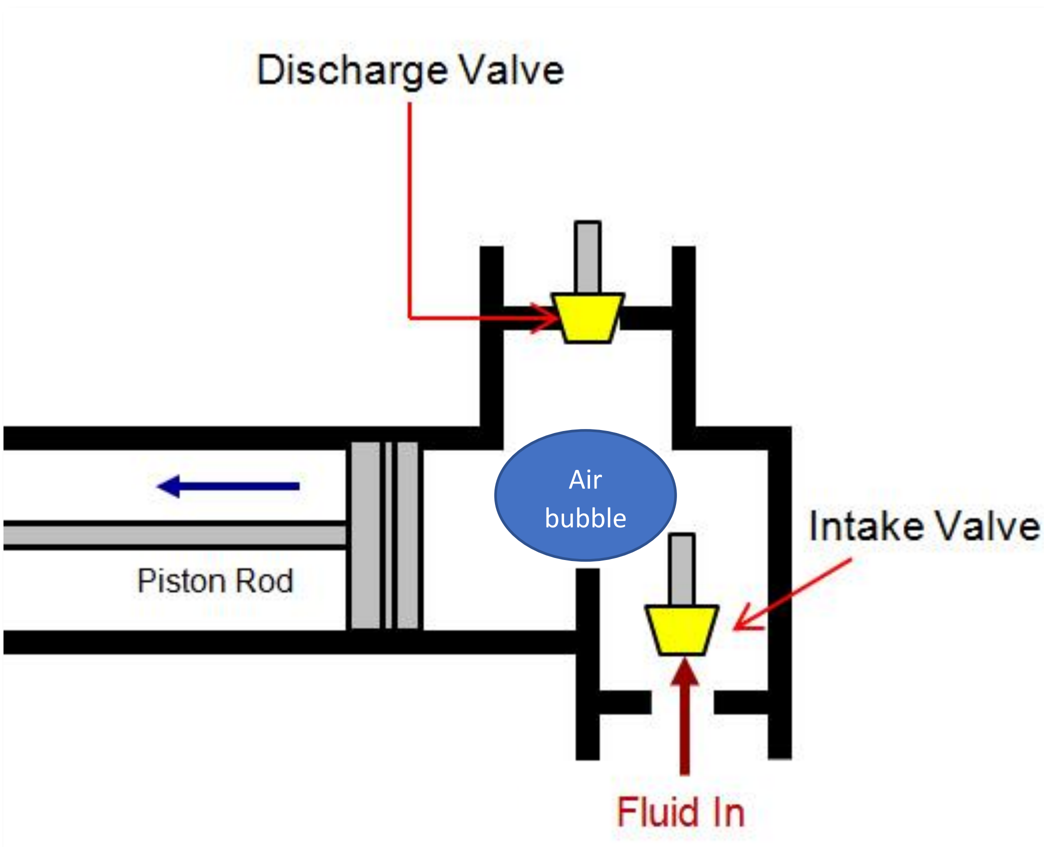

Figure 1 Air entering cylinder on intake stroke adapted from drillingformulas.com

When the cylinder starts to push forward on the power/discharge part of the cycle, the discharge valve opens, and it is exposed to the 3,000 psi (207 bars) in the outflow side of the pump system. This is 70 times higher than our inlet pressure was. Suddenly the air in the pump has been compressed a size about 70 times smaller than it was before the piston began the discharge part of the cycle. The air bubbles collapse and the work that was being done in the pump to push the otherwise relatively uncompressible liquid out of the pump by the drive rod on the piston suddenly drops nearly to zero for as long as it takes for the piston to 'catch up' and compress the air to the new equilibrium volume.

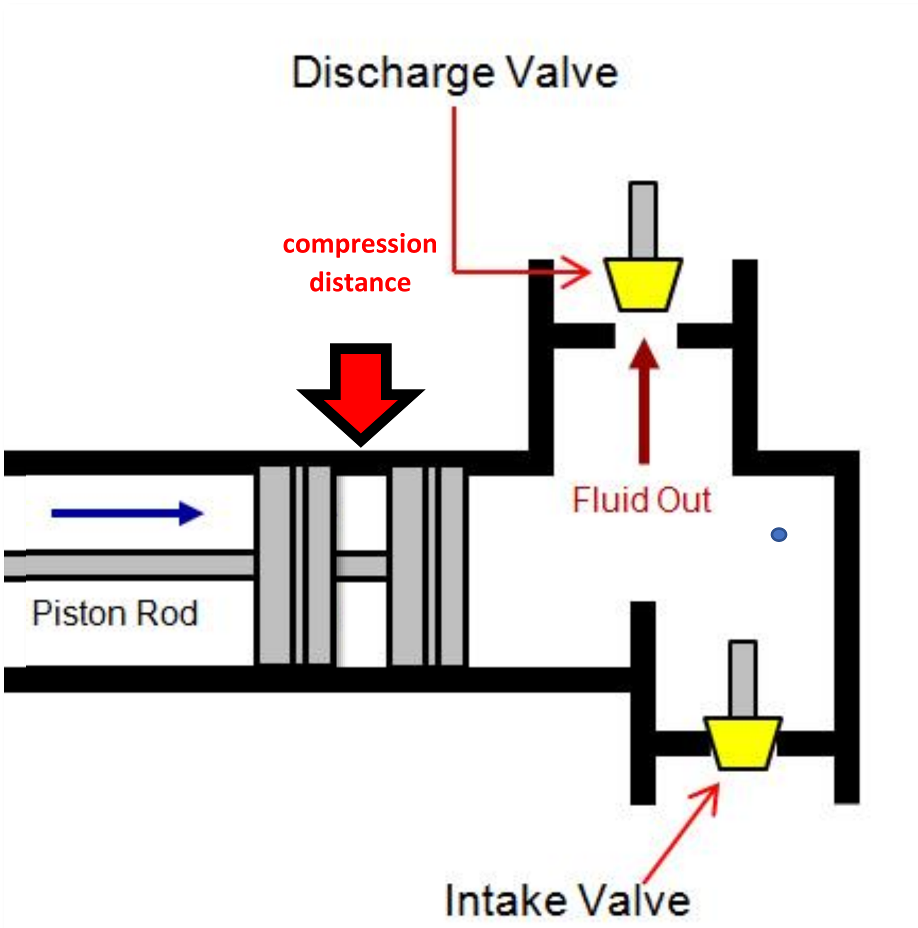

Figure 2 air bubble compressed, and 'free' piston motion adapted from drillingformulas.com

In a triplex pump, only one cylinder is in the compression/discharge stage at any given time, so when there is no constant discharge of fluid taking place while the air is getting compressed, suddenly the load on the driveshaft, engine and power end of the pump is close to zero briefly then shoots back up to normal as the air is compressed to 3,000 psi (207 bars) This causes the knocking and banging sounds as the different parts of the engine and power end rapidly change speeds, move from tension to compression, hit bearings, etc. So how did the air get in the system?

Improper Priming

The simplest answer is that it was already there. A positive displacement pump will not draw or pull fluid into it. There must be some other type of pump or pressure or gravity forcing fluid into the pump for it to operate. If that process, called priming was not done correctly it may have left some air in the piping that is in between the source of the fluid and the pump. It only takes a small amount of air trapped somewhere in the intake system to create knocking and cavitation. If this is the source of the problem, it will tend to go away after a short period of use. If the fluid source is changed, the lines and piping for the inlet system altered or the pump is started or stopped briefly it can come back again. This is especially the case if the properties of the fluids being pumped change – for example switching from a low viscosity fluid to cement is notorious for causing issues in systems where the intake system is not properly purged and prepared. Sometimes these issues are so bad that it becomes difficult to conduct a good cement job because the volume of fluids being pumped cannot be rapidly and accurately measured with common equipment.

Leaking intake lines

It can be the case that the intake lines instead of leaking fluid out (which might be obvious) there is a place where air is leaking IN. this is almost always between the fluid source and the centrifugal charge pump for the triplex. Between the charge pump and the positive displacement pump, the fluid usually has enough pressure that it leaks out, but sometimes between these two points the pressure is low enough for air to leak in. If general checking for tight connections and good seals does not solve the problem these problems can be hard to track down. In some cases it may be necessary to stop pumping and turn the centrifugal pump off in order to be able to look for the source of the pumping fluid which can now leak outwards under gravity from the fluid source without the suction from the centrifugal charge pump on the system. This is obviously a sort of problem you want to discover and resolve before getting into a critical situation. These problems tend to occur in temporary lines, in systems which have been used to pump solvents or acids which destroy seals in the suction system, in systems which are used to pump cement or other abrasives which damage the lines, and in systems which are permanent but which have not been maintained and checked on a regular basis. One final area which is often overlooked is to watch for leakage on/in the seals of the central shaft of the centrifugal pump itself.

Low Charge pressure

So your system is properly primed up, and you checked your suction system for leaks but the pump is STILL having issues. No idea where the air is getting in. In fact, there might not be any leaks or residual air in the system. This leads to one final potential problem and that is low charge pressure. Typical inlet pressure for a positive displacement pump is somewhere around 50 psi (3 bars) but this number is usually measured at the charge pump itself. Between the charge pump and the positive displacement pump there is inevitably some piping, and of course there are the valves on the triplex pump itself which are usually spring loaded to ensure they close properly and must be pushed open by the charge pressure for the pump. If the pressure and associated feed rate of the system gets too low by the time it reaches the positive displacement pump, then some odd non-intuitive things occur.

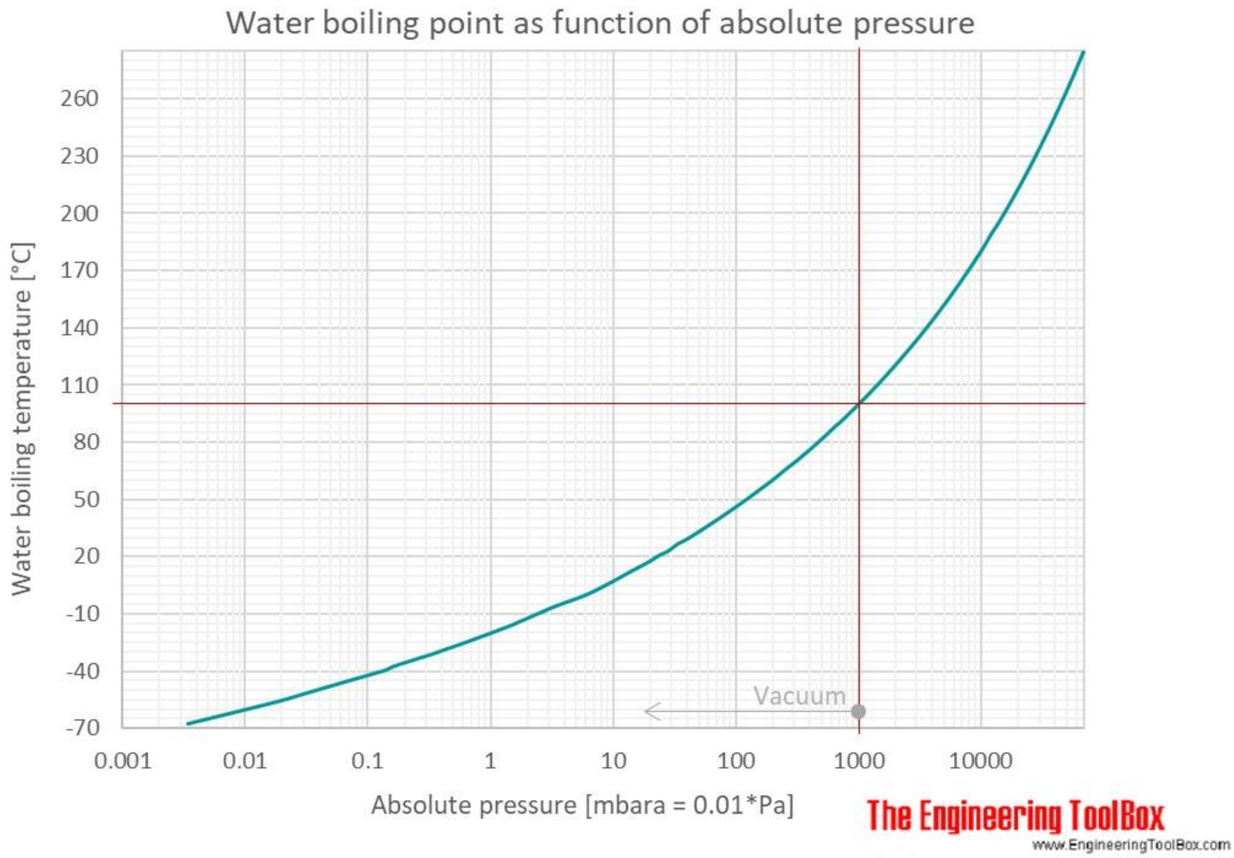

Figure 3 water boiling temperature versus pressure

At one atmosphere/1 bar water boils at 100 degrees Celsius (212 F) but what if the inlet pressure to the pump is lower than this? When the piston on the pump begins to pull back *something* must come in through the inlet valve and fill the space being made in there. If fluid is not coming in fast enough to fill up the space with liquid, then some of the liquid will begin to boil off at room temperature to make up the difference. At ~ 0.15 bars (2 psi) water boils at room temperature. The resulting steam (steam at room temperature!) then fills the space in the piston. Now that it is a gas, it acts exactly like our air did when we looked at what causes cavitation in the first place. When the piston starts the discharge stroke it compresses, and in addition unlike air it recondenses into liquid and in both cases causing all that knocking and equipment damage.

How do we diagnose and resolve this? Usually if the problem is a lack of charge pressure it will not be present at low discharge rates (because the charge system can keep up) but it will begin and worsen as discharge rates increase. It will also get worse with thick viscous fluids like cement or heavy pills because they have more friction in the piping between the charge pump and the positive displacement pump, making it harder for the charge rate to keep up. This can occur suddenly and unexpectedly when switching from a relatively low viscosity working fluid to a higher viscosity one. It will also get worse if materials with a low vapor pressure like xylene, toluene or other flammable and combustible solvents. This is because they already boil at a low temperature and have a high vapor pressure – it does not take a lot of loss of inlet pressure before a lot of vapor is developed by these fluids. The solutions are in two parts: increasing the charge pressure and decreasing the losses between the charge point and the positive displacement pump. Sometimes this means using a 'boost' charging pump closer to the positive displacement pump than the normal one – other times it means bypassing the normal charging pump in favor of a larger temporary one. Decreasing pressure losses between the charging point and the pump can be done if piping and lines can be shortened, straightened made larger diameter or if excessive valves and junctions can be avoided. Another way to reduce pressure losses in some cases is by selecting valves and seats on the pump which have a larger inlet area and/or a weaker return spring.

Conclusions

Cavitation and pump knocking are often created by complicated problems, but usually have simple solutions. In situations where there are consistently issues, a careful consideration of the causes and ways to prevent them will usually resolve the issues. For any given type of pump system and installation experienced crews and operators will learn to recognize the limitations of the systems and how to resolve them. It is good practice to write these things down and ensure they do not get 'lost' because the wrong person is on vacation or retires! Having a quick reference of best practices and issues for the systems and fluids commonly used can avoid major difficulties with 'known problems' and can also predict the sorts of problems and solutions for fluid systems and combinations which aren't as well understood through experience.