UNDERSTANDING CAVITATION IN HYDRAULIC JET PUMPS, A SOLID AND EASY TO IMPLEMENT GUIDELINE TO AVOID AND MITIGATE CAVITATION DAMAGE

Osman A. Nunez-Pino

Liberty Lift Solutions, LLC.

ABSTRACT

Hydraulic jets are classified as hydro-dynamics devices, where the Venturi effect is used to reduce a fluid stream local pressure, by flowing it through a constricted section of a passage. In a jet pump, a stream of primary fluid with high potential energy is flowed through a conduit which cross-sectional area is gradually reduced. Once the primary fluid stream has exited the nozzle, a substantial portion of the potential energy has been converted into kinetic energy. This controlled localized pressure depletion induces the flow of reservoir fluids from the wellbore to the jet pump admission passages. After exiting the nozzle, the jet core drags reservoir fluids into the mixing tube and then initiates the transferring of hydraulic momentum. It is indeed around this energy interchange process where cavitation might take place, if operating conditions are inappropriately managed.

Jet Pump performance can be affected by two types of cavitation: Production Cavitation and Power Fluid Cavitation. On both cases cavitation can create a physical damage that are similar in appearance, but different on their origination cause and location in the mixing tube. Production cavitation happens when large flow rates are “forced” to flow through a relatively reduced annular area. The mean flow velocity of the secondary stream is increased to values where the correspondent local pressure drops below that fluid vapor pressure; consequentially, bubbles are formed along the stream of fluid. In the other hand, power fluid cavitation takes place when the jet pump is working to pump very low reservoir fluid rates at a considerably low intake pressure. Because of the enormous difference of velocity between the two streams, small vortices (like mini-tornados) are created at the interphase between both streams, to then give inception of bubbles. On both cavitation modalities, the induced low local pressure causes the appearance of bubbles or voids which will eventually implode at some position across the throat.

The cavitation phenomenon has been extensively studied for many years, however, guidelines on how to implement this existing knowledge to the actual operation of the jet pumping systems in the oilfield are not abundant and, as per the author can see it, not yet being presented in such way that the people that operate these systems in the oilfield could implement on a straight forward way. It has been proven that using a scientific/easy to follow methodology, it is possible to prevent jet pump operating problems related to cavitation, during the early, middle and late term of the well production life. Preventative and Corrective methodologies are based on: Measured production rates, power fluid rate and pressure, gas to liquid ratio, jet pump seating depth and jet pump nozzle/throat combination.

This paper presents a straight forward discussion on the jet pump cavitation, its hydrodynamics, causes, identification, potential damage, consequences on the jet pump performance and methods to predict it and avoid it.

INTRODUCTION

With the introduction of the directional drilling, extended reach horizontal sections and other highly complex well geometry elements in modern petroleum production engineering, considerable technical challenges are imposed not only on the process to construct oil and gas producer wells; but also, to the subsequent hydrocarbon production process. High dogleg severities, high hole deviation angles, presence of fracturing sand (proppant) along the well's produced fluids, high gas rates; are some of the challenges that modern production engineering imposes on the artificial lift systems that are currently used to produce these wells, especially when the production operation is carried on unconventional reservoirs.

To overcome unconventional well challenges mentioned in the previous paragraph, oil & gas equipment providers are making gargantuan efforts to create shorter pumps, so they can pass through high dogleg severity angles and be installed at depths where deviations are considerably high. Internal mechanical/moving parts are made from abrasion-resistant materials or covered with wear-resistant coatings, so they can give a longer run-life when producing fluids with high sand content. These pump improvements are made to meet and succeed on difficult well production operation are already existing attributes of one of the long ago existing, but not well-known artificial lift methods, the hydraulic jet pump.

Jet pumping systems were for first time used for commercial hydrocarbon production back on the 70's, with the main intention of handling applications that the already well-known hydraulic piston pump could not handle because of its limitations. Since then, the installation of jet pumps has been associated with producing "problem wells'', very often on wells were the other better-known lifting technologies were tried, but the level of success was not that satisfactory. The author of this paper has often heard from production engineers that, jet lift is the only artificial lift system that will let them produce problem wells economically, i.e. profitably. That said, the cause for the considerably lower number of jet pumping systems installed around the world, compared to the rest of artificial lift systems, can be credited to the fact that the jet pump is considered as a system for difficult well production, or as some production engineers often say, "the last frontier of ALSs".

Being hydrodynamic devices, jet pumps brings several desirable and useful characteristics, however it also brings a few disadvantages and issues that have been clearly identified and addressed. The objective of this paper is to discuss one of the more relevant issues that jet pumps can present, i.e. Cavitation, so we are focusing on this specific topic. There are plenty of available information that discusses jet pump advantages and benefits, please look at this paper references for more details about this topic.

In general terms, when a jet pump is operating within cavitation region, it's overall performance might decline to levels that are not technically or economically reasonable. If the jet pump is kept working beyond the cavitation boundaries, it's performance result temporarily compromised because of the energy losses along the cavitating stream of fluid(s), but also because of permanent physical damage infringed to the jet pump internal components, mainly to the mixing tube (typically called throat). In oilwell production using jet pumps, operating within cavitation will typically mean producing rates below than expected, and if the jet is operating in severe cavitation, a permanent and widespread damage to the throat will greatly affect even more the jet overall performance, to the point where the production rate approaches to zero.

In this paper, the cavitation phenomenon is discussed from the practical jet pump operation standpoint. This study also analyzes on detail the two types of cavitation that might take place during jet pump operations: Production Cavitation and Power Fluid Cavitation. A special section of this work will be dedicated to go over the causes, cavitation damage location, prediction and prevention of both types of cavitation.

Vapor Pressure – The Jet Pump Case

A simple definition of the term vapor pressure could be expressed as follow: Vapor Pressure of a pure liquid is that local pressure that at a certain temperature will cause the first bubble of vapor of the fluid to be formed. In an environment at a specific temperature, the local pressure will determine in what phase (or phases) that mass of fluid will exist.

When a jet pump operates, a stream of fluid flows from the wellbore through the casing, packer, jet pump cavity, standing valve and jet pump intake passages. For technical analysis purposes, if we consider constant temperature across this path (for simplification of calculation), vapor pressure can be reached if the flow mean velocity at any of the mentioned flow paths reaches such values that can induce significant pressure drops that will make local pressure to be equal or lower than vapor pressure.

Let's see an example of vapor pressure calculation, with a single-phase fluid (water) which average environment temperature is 220 °F. We will use the Antoine Equations to determine vapor pressure:

$$\mathbf{Pv = 10^{A-\frac{B}{C+T}}}$$

Equation # 1

Where:

Pv: Vapor pressure [mmHg].

T: Temperature [Celsius].

A: 8.07131 for temperatures between 1 through 100 Celsius, and 8.14019 for temperatures between 101 through 374 Celsius.

B: 1730.63 for temperatures between 1 through 100 Celsius, and 1810.94 for temperatures between 101 through 374 Celsius.

C: 233.426 for temperatures between 1 through 100 Celsius, and 244.485 for temperatures between 101 through 374 Celsius.

For 220 °F = 104.4 °C

$$\mathbf{Pv = 10^{\left(8.14019-\frac{1810.94}{244.485+104.4}\right)}}$$

Equation # 2

$$\boldsymbol{Pv = 891.53\ mmHg} = \textbf{17.24 psia}$$

This calculation results on the following estimation: At an environment temperature of 220 °F, pure water (no impurities, i.e. salts, solids and any other estrange particle) will start evaporating (first bubble is formed) at an environment pressure of 17.24 psia.

For those familiar with jet pumps operation in the oilfield, it is clear that is practically impossible to operate (and make it work properly) a jet pump at an intake pressure (total pressure from the wellbore that feeds the jet pump) of around 17 psia (~2.3 psig). We know that cavitation is going to show at an intake pressure considerably higher than 17 psia. There is a reason for it, and its related to the terms "share flow" and "separated flow". As mentioned before, cavitation in jet pump operation is caused by dynamic flow conditions; the mechanism of cavitation in a jet pump is closely related to the turbulent mixing process. In a jet pump, secondary fluid stream molecules are dragged to the mixing tube entrance by the molecules (at higher speed than the secondary fluid molecules) of the primary fluid (jet core). In the same context, we can say that flow in a jet pump is of the shear type. The primary and secondary fluids are separated by a shear or mixing layer, at which many small turbulent eddies are formed.

In a jet pump, the interaction between the power fluid and produced fluids is of the shear flow type. The primary and secondary flows are separated by a mixing layer composed of many small turbulent eddies. It is important to keep in mind that the total local pressure inside the mixing layer region is considerably lower than that inside the primary fluid stream or the secondary flow stream. The bottom line is: Vapor pressure can be reached inside the mixing layer way before in the primary or secondary fluid main streams.

PRODUCTION CAVITATION

The term "Production Cavitation" was assigned to that type of cavitation that is caused by the reduction of total local pressure of a stream of fluid, because of the high flow velocity of the jet pump secondary stream when this is moving through a reduced cross-sectional area path (throat entrance). Talking in "jet pump practical language"; production cavitation happens when a jet pump, equipped with a specific nozzle and throat, is driven to produce a flow rate that is larger than the maximum flow rate that its throat – nozzle suction area can handle. It is important to know that once the cavitation rate limit is reached, the production rate will not increase any more, even if power fluid pressure is increased; actually, production rate might decrease because of the intensification of the cavitation.

The jet Pump Area of Suction (As) is determined by the annular cross-sectional area that results from subtracting the nozzle area from the throat area. This is the area that is available for the produced fluids (oil, gas and water) to flow through the jet pump. Typically, when specified and operated correctly, a jet pump can flow through its suction area a finite rate of flow at a determined velocity and without cavitation. If an increment of production rate is made, using the same nozzle/throat combination, the flow velocity raises, and local pressure decreases. If power fluid pressure is increased further, hence the jet core velocity, the mixing layer between primary and secondary fluid will reach, eventually, the fluid's vapor pressure. When vapor pressure is achieved, bubbles are formed before and/or at the entrance of the mixing tube. Please look at figure # 1.

Production Cavitation – Step by Step

With a jet pump in operation and producing reservoir fluids (oil, water and gas), the jet core molecules (power fluid stream exiting the nozzle), at a predetermined certain pressure, drags the secondary stream fluid molecules (flow entering the annular area in the throat) at a certain pressure as well. This pressure, which is commonly named suction pressure or intake pressure, is relatively close in magnitude to the jet core pressure. Now, lets assume that the pump intake pressure has achieved values that are equal or lower than the fluid's vapor pressure at downhole pressure-volume-temperature conditions. On this scenario, bubbles will likely form within the secondary fluid stream (produced fluids). These bubbles are basically void of vapor that travel within the secondary fluid stream, towards the mixing tube (throat) inlet. Subjected to slight pressure increments at the throat entrance, a fraction of these bubbles might implode inside this throat region; some of them within the secondary fluids stream, while other bubbles will implode at the vicinities of the throat's wall.

Those bubbles that implode within the stream of fluids and relatively distant from the throat wall, do not cause any physical damage to the jet pump mixing tube. However, bubbles that collapse close enough from the mixing tube wall can produce significant damage. When a vapor bubble collapses, its volume is progressively reduced, but it does not happen homogenously in terms of bubble diameter, it happens on an asymmetrical shape, where the section of the bubble that is not adjacent to the throat wall, takes a concave shape. Please figure # 3.

At the end of the implosion process, the asymmetrical collapse of the bubble produces a microjet that can strike the throat internal surface at a very small area. Pressure is defined as force per surface area, so when the force exerted by the microjet impinges at very reduced area of the throat surface; extraordinary pressures can be developed, causing important physical damage to the impacted surface. The consequence of microjets striking the throat internal surface, is a lost of material that transform an originally smooth surface of tungsten carbide, or sometimes ceramics, to a very irregular and rough surface that negatively affects the flow of fluids through the throat entrance. Please see figure XX that illustrates a case of production cavitation.

<u>Procedure to Select and Operate the First Nozzle/Throat Combination to Be Installed to the Jet Pump</u>

Production Cavitation is more likely to happening during the well early production stage, where the well deliverability is at relatively high levels. That said, it is of capital importance to take the following considerations and principles to be applied during the first-to-be-installed nozzle/throat combination:

a. Based on recent well production data, calculate average flowing bottom-hole pressure for the calculated average production rate.
b. If a static bottom-hole pressure has been measured during a well shut-in or a pressure build-up test; use this to estimate the productivity index and/or inflow performance relationship of the subject well, for that specific time frame. On unconventional well production, it is important to bear in mind that the inflow performance has a transient behavior, as consequence, a calculated PI-IPR might be useful for few days.
c. If a static bottom-hole pressure value is not available, one can proceed to estimate an approximated producing operating point down the PI-IPR curve. To do this, it is necessary to assume a PI which can be an average of recorded value for close by wells, at approximately the same production elapsed time (i.e. hours of production since the wells started production).
d. Once the inflow performance of the well is estimated, it is time to define the target operating point, i.e. target production rate at the correspondent producing pressure. The maximum achievable production rate will be typically limited by the installed maximum horsepower available, i.e. maximum injection rate and pressure.
e. New wells and wells that have been closed for some time, usually have high bottom-hole pressures. When a jet pump is installed and started, the producing bottom-hole pressure might be considerably higher than the calculated stabilized value, then if the injection pressure is set to the final value, the rate of reservoir fluids entering the jet pump intake might be higher than the maximum rate that the nozzle/throat suction area (As) can handle without cavitating. To prevent production cavitation to happen during a well startup, it is recommended to start powering the jet using injection pressure that is around 75 percent of the final injection pressure target.
f. When injection pressure is at a stable 75% value, and reservoir fluids production is confirmed at the surface, it is suggested to maintain the same injection pressure for at 48 to 73 hours, or until the well producing pressure is stabilized. The stabilization of the well inflow is observed on the injection rate of power fluid. If at constant injection pressure, the injection rate is approximately constant, then the bottom-hole producing pressure should also be relatively constant.
g. At this point it is recommended to re-analyze the jet pumped well performance, using any of the computer programs that are available. By running the program at this point of the operation, there is a prime objective: Knowing where the production cavitation zone is from the current producing point. The idea is to find out is it is prudent yet to increase injection pressure, so the system can produce higher rates, and making sure that the jet pump is going to work properly, without cavitating.
h. Then, if it is safe to do so, the injection pressure is increased to around 90% of the final target. Once this step is completed, the considerations explained at steps f and need to be repeated.
i. Injection pressure is increased to 100%, if it is convenient to do so. Finally, steps f and g are again implemented, to verify that the producing point is at a prudent separation away from production cavitation.
j. Please see figure # 4 for an illustration of production cavitation though a jet pumped well IPR – VLP graph.

Production Cavitation Limit Rate Estimation

Nowadays there are several computer programs that using complex algorithms, can calculate the maximum production rate that a specific nozzle/throat combination can pump, without presenting production cavitation. Notice that the cavitation phenomenon has been studied for many years, by many scientists, and as consequence, the correlation that nowadays are used to estimate cavitation on-set can produce accurate results.

An equation that can be used to estimate the maximum allowable reservoir fluid flow rate that a certain nozzle/throat combination can properly handle, without cavitating is:

$$Qs \le \frac{As}{\left[\left(\frac{1}{691} \times \sqrt{\frac{GradSuc}{Pps}}\right) + \left(\frac{(1-WC) \times GOR}{24650 \times Pps}\right)\right]}$$

Equation # 3

Where:

Qs: Maximum production rate, [blpd].

As: Nozzle/Throat suction area (Asuction = Athroat -Anozzle), [in^2].

GradSuc: Produced Fluid Gradient, [psi/ft].

Pps: Jet Pump Suction Pressure (also called pump intake pressure or PIP), [psig].

WC: Water percentage in produced fluid, [fraction].

GOR: Producing gas/oil ratio [scf/stb].

The author recommends following the below listed steps to calculate the production cavitation maximum rate:

- Obtain recorded pump intake pressure (using memory gauges or real time gauges), or calculate it using available jet pump performance program.
- Estimate the produced fluid gradient, at the jet pump installation depth. This can be calculated vertical gradient charts, or better and easier, using a gradient calculator computer program.
- Estimate the percentage of water in produced fluids.
- Calculate gas/oil ratio, using the gas rate and produced net oil, both measured at the location separator (at s.c.p.t).
- Calculate Maximum Allowable Production Rate (Qsmax), using equation # 3.
- calculated maximum allowable rate, the jet pump should be working within proper parameters, no worries about production cavitation should exist.
- If measured production rate is greater than the calculated maximum allowable rate, then the jet pump is likely cavitating. Corrective actions have to be taken quickly in order to avoid damage of the throat, if this is not already damaged.

Corrective Actions to Apply when a Jet Pump is Working Under Production Cavitation Conditions

Production Cavitation can typically cause two main detrimental effects, that can be clearly identified: Operating performance decline and physical damage to the mixing tube.

When the jet pump intake pressure is driven to levels beyond the cavitation pressure onset, as previously explained, bubbles are formed around the throat entry vicinities. The formation, grow and implosion of a considerable large number of bubbles along the secondary fluid stream, does negatively affect the energy transfer process (momentum transfer) from the jet core to the secondary fluid stream. When cavitating, the higher the injection pressure, the larger is the quantity of cavitation bubbles, and consequently, the lower the energy efficiency of the jet pump at the current conditions. Production Cavitation might take place, be identified and remediated as explained below:

- A jet pump is equipped with a specific nozzle/throat combination, which has a definite suction area to handle a limited flow rate of production fluids. Also, this combination is supposed to work at a certain maximum injection pressure, that should not be exceeded in order to avoid production cavitation.
- When the jet pump is powered by power fluid at the design injection pressure, and the well inflow performance behaves approximately as expected, the jet pumping performance will also be as expected, without cavitation.
- Either of these two circumstances can lead to production cavitation: A higher well inflow performance that the one taken into account for the analysis to select the nozzle/throat combination, and an injection pressure higher than the maximum allowed.
- Assuming that production cavitation is already happening, there are two corrective actions that can be taken in order to mitigate it:
  - Reduce injection pressure in order to shift the jet pump operating move up to a point in the PI-IPR curve where pump intake pressure is higher that the onset cavitation pressure. By applying this cavitation mitigating action, some production rate is sacrificed for the sake of the throat integrity.
  - Re-sizing the jet pump with a larger suction area combination. By resolving the cavitation problem on this way (preferred option), higher production rates can typically be produced without the risk of production cavitation. Usually, this is the favorite production cavitation mitigating measure, that is most accepted by jet pump users.
- Depending on the extent of the cavitation regime, the damage to the throat can happen within minutes or days. For any of the cavitation intensity case that a specific jet pump is suffering from, it is suggested to apply corrective actions as soon as possible. The more the extent of the damaged caused by cavitation, the higher the detriment on the throat discharge coefficient, and consequently, the lower the pumping performance will be.

Physical Location of the Damage caused by Production Cavitation

Production cavitation damage typically is located at the entrance of the throat. Since drawdown is decreased by the local pressure environment that the jet core creates, vapor bubbles (voids) form right before entering the throat and implode around the throat entrance.

POWER FLUID CAVITATION

The term “power fluid cavitation” was adopted by the jet pump industry from long time ago, however it might cause confusion because power fluid does not cavitate. The author prefers to name this type of cavitation “low intake pressure cavitation”, this is because this hydrodynamic phenomenon takes place when the bottomhole producing pressure is relatively low, compared to the minimum required levels that a jet pump working at specific conditions needs.

Low Intake Pressure Cavitation typically happens when a jet pump is operated to produce relatively low flow rates at a very low intake (“suction”) pressure. In unconventional oilwell production, this scenario might take place during the late production stage, where the well deliverability is being depleted, and the production operating point is pushed down the IPR curve in order to achieve a flow rate that is close to the AOF (absolute open flow), where the correspondent production pressure is usually below the pressure limit that a jet pump needs to don't fall into low intake pressure cavitation.

When a low inflow well is produced with a jet pump, the magnitude of energy that needs to be provided to the jet pump, by means of the power fluid, is usually high. In more practical words; to produce a deep well with low intake pressures, the injection pressure and rate to power the jet pump are considerably high. That said, when the large potential energy supplied to the nozzle entrance, and the energy transformation takes place from potential to kinetic energy, that results on a jet core which mean flow velocity is substantially greater than the mean flow velocity of the produced fluids entering the suction area between throat and nozzle. As previously indicated, the molecules of produced fluids are "dragged" into the throat by the power fluid jet core molecules. When high injection pressures are required for the jet pump to lift depleted wells, where both production rates and pump intake pressure are low, the difference of velocities between jet core and produced flow can be very large. Along the mixing layer, where high velocity molecules (jet core driving molecules) collide with low velocity molecules (dragged molecules), a sort of vortices or "mini-tornados" are formed. The center portion of these vortices present a total pressure, low enough to initiate the inception of bubbles. As in the production cavitation, the recently formed bubbles grow, shrink, collapse, and if located around the throat inner surface vicinities, impact and cause damaged to the throat.

<u>Low Intake Pressure Cavitation – Predictive Analysis.</u>

This type of jet pump cavitation hasn't been studied as much as production cavitation has. According to this author, the most relevant literature related to low intake pressure cavitation is a paper titled: "Obtaining Low Bottomhole Pressures in Deep Wells with Hydraulic Jet Pumps", by F.C. Christ and H.L Petrie. Christ and Petrie derived a theoretical equation to estimate the minimum required submergence that a jet pump needed to operate without low intake pressure cavitation, the expression is:

$$S = \frac{1}{1 + \left[\frac{N}{(1+N)}\right] * \left\{\left[\frac{[0.831] * \left(\frac{1-R}{R}\right)}{M}\right]\right\}^2}$$

Equation # 4

Where:

S: Minimum Required Submergence (S = Pump Intake Pressure / Pump Discharge Pressure).

N: Jet Pump Pressure Ratio = (Discharge Pressure – Intake Pressure) / (Injection Pressure – Discharge Pressure).

R: Area Ratio = An/At.

M: Flow ratio = Qproduction / Qpowerfluid.

The calculated actual submergence (Scalc) can be estimated using the following equation:

$$Scalc = \frac{Pps}{(gs \times D + Pwh)}$$

Equation # 5

With gs = go(1-Wc) + (gw*Wc) – Note that this is a simplified equation to calculate suction gradient.

Where:

D: Well depth [ft].

gs: Gradient of suction fluid [psi/ft].

Pps: Jet pump suction (intake) pressure [psi].

Pwh: Wellhead flowline pressure [psi].

Wc: Water Cut [fraction].

So, in order to determine the minimum required Bottomhole pressure to avoid cavitation, before the jet pump is operated, equation # 4 will give us a good idea of this pump intake pressure lower limit. On the side, if we need to estimate the current submergence of the jet pump, it is recommended to use the equation 5 and compare it with the minimum required submergence calculated with equation 4.

The pump intake pressure at equation # 5 (Pps), can be calculated using a jet pump program, or measured using a memory gauge or a real time gauge (wired to surface).

<u>Actions to be taken when a jet pump is working on Low Intake Pressure Cavitation</u>

When low intake pressure cavitation on a jet pump application has been verified, there are three options that the user can apply to mitigate this issue:

- If the same nozzle/throat combination is going to be used, low intake pressure cavitation can be avoided by shifting the production operating point up on the PI-IPR curve. The problem with operating at a higher pump intake pressure, is that the correspondent production rate is going to be lower. Resolving the cavitation issue by letting the intake pressure to be higher (above the minimum required submergence S), some production rate is sacrificed, but the throat run life will be longer.
- In a scenario where the jet pump is working under low intake pressure cavitation, we can temporarily get back to a partial percentage of the nominal performance of the jet pump, by increasing power fluid injection pressure. When injection pressure is increased, the jet core mean velocity is also increased; and as consequence, the cavitation vapor bubbles might be driven to a section of the throat located beyond the area that is being already damaged by the bubble's implosion. When this action is implemented, larger energy is supplied to the secondary stream and the negative effect created by the cavitated damaged surface, is up to some extent, offset by the increased hydraulic momentum supplied. Again, this mitigating action is temporary, and a new throat needs to be installed, as soon as possible.
- The last potential, and more permanent solution for the mitigation of low intake pressure cavitation, is to increase the suction area between nozzle and throat. By providing a larger annular passage between the throat's surface and the jet core, there will be a larger space available for the bubbles to travel further into the throat and diffuser. A bigger number of bubbles will have the chance to implode within the mixing stream, causing no damage, and fewer bubbles will implode and strike the throat's inner surface.

Physical Location of the Damage caused by Low Intake Pressure Cavitation

The process of bubbles formation when low intake pressure cavitation appears to require a longer time compared to production cavitation, mainly due to the longer process that low intake pressure cavitation needs to produce the vortices that give place to the inception of bubbles. In this scenario, bubbles are formed later, already into the throat's straight section, and they typically implode within this the straight section or at some point at the pre-diffuser or diffuser. The implosion of bubbles is most caused by the progressive collapse due to the increasingly higher-pressure environment in the throat, and due to the contact of the imploding bubble with the throat's surface. Long history short, low intake pressure cavitation damage is typically located across the throat straight section, pre-diffuser or in the diffuser. One fact to keep in mind, the closer the low intake pressure cavitation damage is from the throat entrance, the worse the cavitation problem, and the more difficult to mitigate.

RECOMMENDATIONS:

- Both production cavitation and low intake pressure cavitation boundaries can be calculated with relatively accurate precision. It is highly recommended to estimate these numerical limits, before a jet pump is operated.
- For new wells, it is of great importance to start the injection of power fluid at a pressure that is lower than the projected final injection pressure. The author suggests starting a well with 75% of the final target injection pressure; maintain the same injection pressure for 48 hours at least, or until the well shows stabilization on the producing bottomhole pressure. Then, increase injection pressure to 85% and observe again. Repeat the procedure until the final target of injection pressure is achieved.
- If after an injection pressure increment is completed, the system is expected to produce a higher production rate. If production rate rather declines, it might be a warning for cavitation (either production or low intake pressure cavitation). If this scenario takes place, set injection pressure back to its original number, and evaluate the system cavitation parameters, as suggested in this paper.
- Notice that it is recommended as well, to evaluate the system cavitation parameters after every increment of injection pressure, to make sure that there is a prudent margin of safety between the operating point and the cavitation zones (both production and low intake pressure cavitation).

REFERENCES

R.G. Cunningham. “Jet Pump Theory.” Pump Handbook, Mac Graw-Hill, third edition 2007.

T.S. Pugh. “Overview of Hydraulic Lift Systems”. Fort Worth TX, 2002.

N.L. Sanger. “Cavitating Performance of Two Low-Area-Ratio Water Jet Pumps Having Throat Lengths of 7.25 Diameters. NASA. 1968.

F.C. Christ, H.L. Petrie. “Obtaining Low Bottomhole Pressures in Deep Wells with Hydraulic Jet Pumps”. SPE-15177-PA.

R.G. Cunningham. A.G. Hansen. “Jet Pump Cavitation”. J. Basic Eng. 92(3), 482-492. 09/01/1970.

ILLUSTRATIONS

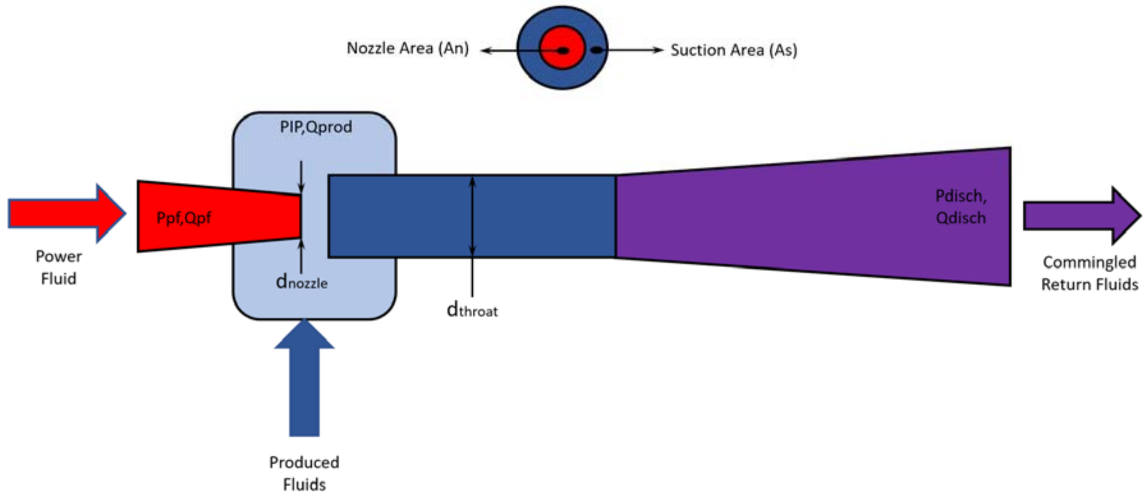

Figure # 1: Jet Pump Diagram

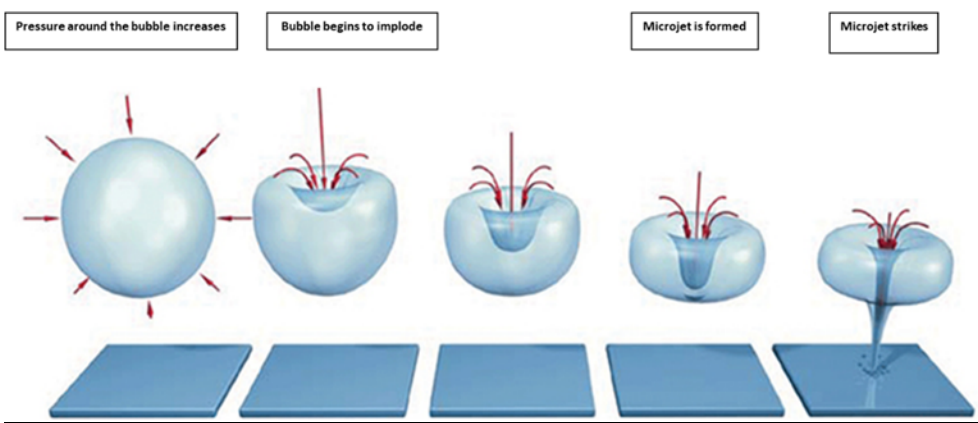

Figure # 2: Cavitation Bubble Stages

Figure # 3: Production Cavitation on Large Size Nozzles

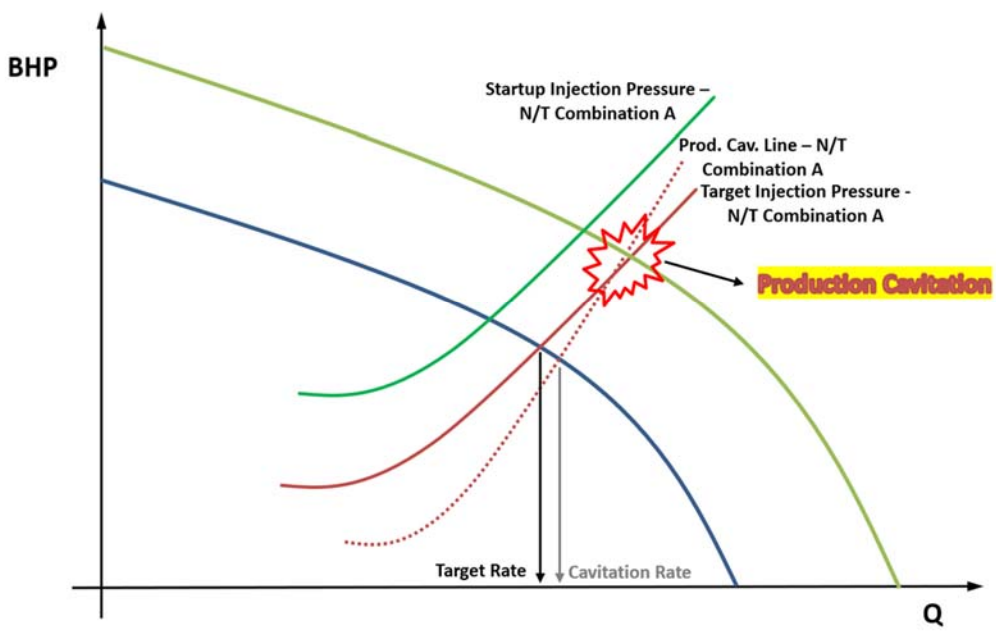

Figure # 4: Production Cavitation During a Well Start Up

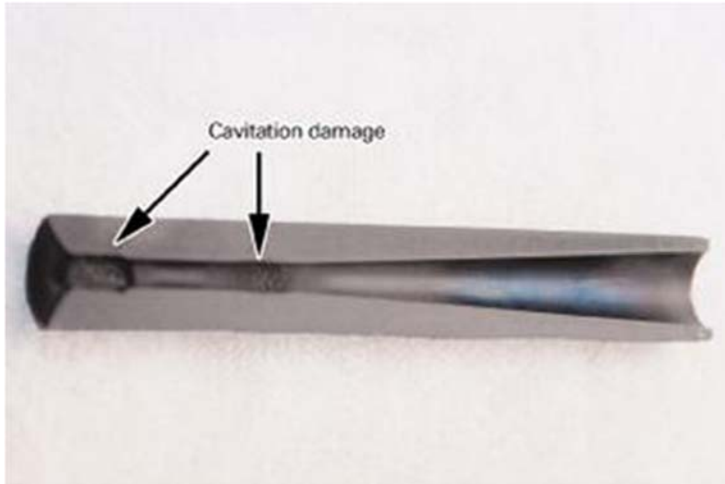

Figure # 5:   Throat Damaged by Low Intake Pressure Cavitation