Jet Pumps

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At some point during production, most wells experience a drop in reservoir pressure that hinders hydrocarbon production and requires operators to deploy an artificial lift system. Various artificial lift technologies are available to bring wells back to profitable production rates and to delay the decision to abandon an asset; no single artificial lift technique is applicable for every scenario.

For example, in deviated wells rod pumping units have limitations due to friction between the rod and the tubing wall. The efficiency and run life of electric submersible pumps (ESPs) suffer in wells that produce significant volumes of sand, gas, or both. These lift technologies also contain moving parts that inevitably wear out and have to be replaced, adding significant cost and deferred production to each well.

Because they have simple downhole architecture and no moving parts, jet pumps have become an increasingly popular artificial lift option in challenging production scenarios. The principles underlying the operation of a jet pump have been known for hundreds of years, starting in 1738 when Bernoulli's principle was introduced; the principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in its pressure.

Although the first patents for oilwell jet pumps were issued in the 1860s, jet pump technology was not applied in the oil field until the late 1960s, and only in onshore wells. Hardware improvements and the introduction of computer models enabling improved pump designs led to more widespread use of jet pumps throughout the 1970s, and their application to other production scenarios has increased steadily since then.

Architecture and Operation

Jet pumps generate high-velocity fluid jets to lower downhole pressures and increase production rates. The basic operating principles of the subsurface jet pump mimic those of the jet engine. Both the pump and engine contain a nozzle that converts pressurized, slow moving fluid into lower pressure, fast-moving fluid by adiabatic expansion. In the case of a jet engine, the fast-moving fluid—a burning mixture of air and jet fuel—generates the thrust that propels a plane forward. The thrust generated by the movement of a high-velocity jet pump fluid, on the other hand, lifts hydrocarbons to the surface.

The jet pump is deployed downhole through the casing string to a depth at which it is immersed in the production fluids in the wellbore (Figure 1). A pump at the surface moves a pressurized fluid called a power fluid—typically refined oil, water or a mixture of oil and produced water—downhole through tubing to the jet pump, where the fluid flows through a nozzle in the nose of the pump. The nozzle introduces a constriction in the power fluid's flow path that causes the fluid speed to increase through the nozzle per the Venturi effect, a corollary to Bernoulli's principle that describes the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe.

Because the power fluid exits the nozzle at a higher velocity and thus lower pressure than that of the surrounding wellbore fluid, the wellbore fluid is drawn into the low-pressure section of the pump through a production inlet chamber. The two fluid streams combine in a short mixing tube known as the pump throat, where some of the power fluid's momentum is transferred to the produced fluid. When the fluids reach the end of the throat, the streams have been thoroughly mixed, and the single mixed fluid stream contains significant kinetic energy. The fluid mixture then transfers to an expanding area diffuser that converts the kinetic energy to static pressure in the fluid. This pressure is sufficiently high enough to lift the fluid mixture to the surface through a second tubing string.

Sizing the Pump

Jet pump performance depends primarily on pump discharge pressure, which in turn is influenced by the gas/liquid ratio in the power fluid–reservoir fluid mixture returning to the surface. Optimizing this ratio to maximize lift is a complex process of fine-tuning the mixture by accounting for the gas/oil ratio in the reservoir fluid and the volume of power fluid entering the throat. The optimal volume of power fluid is dictated by the size of the nozzle and the operating pressure of the surface pump supplying the power fluid. Balancing the power fluid rate, nozzle size and pump discharge pressure is an iterative process requiring successive refined estimates.

Many jet pump suppliers have developed in-house computer programs that use these parameters to make the necessary iterative calculations for application design. The objective of the calculation sequence is to superimpose the jet pump's performance curve onto the inflow performance relationship (IPR) curve for the well, which is a graphical representation of the relationship between the flowing bottomhole pressure and liquid production rate (Figure 2). The intersection point between the two curves represent the pump's performance in that well based on the original parameters. Starting here, the supplier can make successive changes to program inputs such as nozzle size and surface pressure until arriving at a design that delivers the desired pump performance for the well.

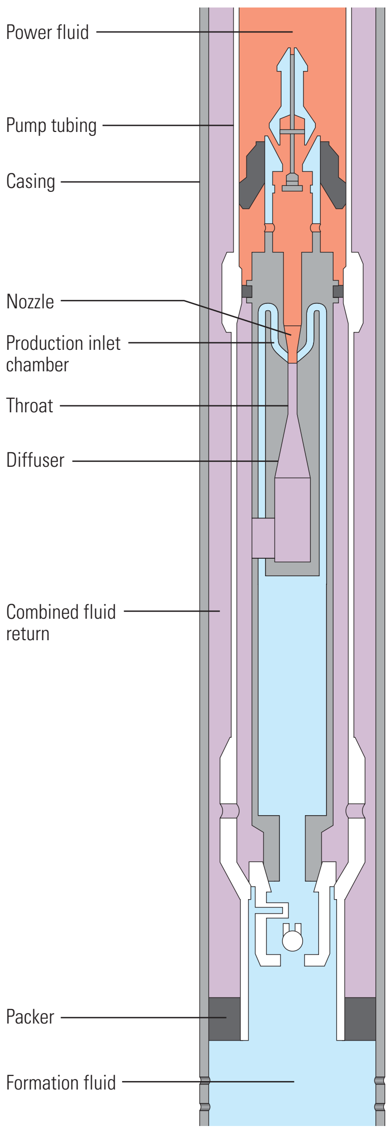

Figure 1. Typical components of a downhole jet pump. Pressurized power fluid from the surface enters the pump from the top and travels through the nozzle. The power fluid mixes in the pump throat with the reservoir fluid, which enters the jet pump from below. The fluid mixture passes through the diffuser, where it picks up sufficient velocity to travel to the surface through the combined fluid return.

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Benefits and Shortcomings

In many field applications, jet pumps provide a variety of operational advantages, including versatility, over other forms of lift. When the size of the nozzle and throat are changed, a jet pump can produce wells ranging in depth from 300 m [1,000 ft] to 5,500 m [18,000 ft] and production of less than 8 m^3/d [50 bbl/d] to more than 3,200 m^3/d [20,000 bbl/d].

Because jet pumps have no moving parts to generate mechanical wear, they can operate for several years at a low risk of failure and with minimal maintenance requirements. They also tend to be more rugged and tolerant of corrosive and abrasive well fluids than other types of downhole lift systems. As a precautionary measure, production chemicals can be mixed with the injected power fluid to help control downhole corrosion, paraffin and emulsion problems. Jet pumps can handle significant volumes of free gas in the production stream. Operators install jet pumps via wireline or by using pressurized power fluid to transport the pump downhole. By redirecting the flow of the power fluid, technicians can bring the jet pump back to the surface for repair or replacement without incurring the expense of a workover or pulling unit that is commonly required to retrieve a downhole pump. To optimize pump efficiency as well conditions change, pump nozzles and throats can be quickly changed at the rig site and the pump redeployed downhole.

Jet pumps are prone to some design drawbacks, including the risk of cavitation—the formation of vapor cavities—at the entrance of the throat section caused by the rapid acceleration of the production fluids as they enter the pump body. As the fluid's velocity increases quickly, fluid pressure can decline to its vapor pressure. Vapor cavities form at this low pressure, resulting in restricted flow into the throat. These vapor cavities may collapse as pressure rises in the pump, causing cavitation damage—erosion of internal pump parts. Field experience has shown that cavitation-induced erosion rates are low in most oil wells, but the rate could increase in high water-cut wells in which little gas is present.

The choice of oil as the power fluid can prove problematic. Not only does oil introduce a fire hazard to the well site, but the large oil inventories required for such an operation also lower the profitability of the well.

Because they are essentially high-velocity mixing devices, jet pumps are prone to significant internal turbulence and friction, which drops horsepower efficiency—the percentage of the total power supplied that goes into lifting fluids out of the well—to approximately 35%. Although this is lower than the efficiencies typically achieved by using positive displacement pumps, the operational benefits of jet pumps combine to make them a more dependable and economic solution for many wells.

Diverse Applications and Well Conditions

Jet pumps are flexible enough to boost production in a variety of scenarios but are commonly deployed in wells that are difficult to produce because of challenging geometries and fluid compositions. The pump's compact size and rig-free installation make it well suited for use in horizontal and highly deviated wells. A jet pump can be deployed through wellbore turns of up to 24° per 30 m [100 ft], and have demonstrated equally reliable operation in both deviated and straight holes.

Because the pump is able to handle high volume, high gas and high solids, it is a good fit for early well production applications. The jet pump can reliably operate in high-volume production wells by raising the horsepower of the surface pump to increase the power fluid flow rate.

Jet pumps are manufactured with high-strength, corrosion-resistant alloys for deployment in wells that have highly corrosive produced fluids and high solids production. By incorporating high-temperature elastomers for its sealing elements, a jet pump can operate reliably in high-temperature production environments. Heated power fluid can be pumped through the jet pump to dilute viscous crudes and enable consistent flow in heavy-oil production.

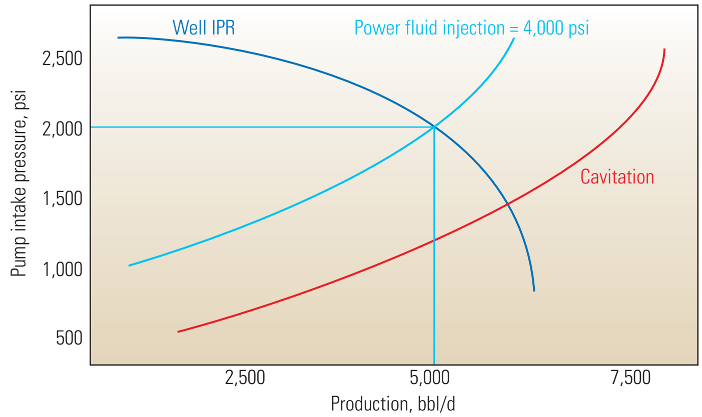

Figure 2. Performance plot for a jet pump system. In this jet pump system performance plot, the intersection of the well's inflow performance relationship (IPR) curve (dark blue) and jet pump's performance curve (light blue) represents the pump performance in the well. In this example, to achieve a targeted production rate of 5,000 bbl/d using a power fluid injected at a pressure of 4,000 psi, the pump intake pressure should be 2,000 psi. Jet pump operation should be maintained such that the IPR curve stays to the left and above the cavitation line (red).

Jet pumps have been successfully deployed in marginal offshore wells in which high intervention costs make the use of ESPs prohibitive. The pumps have also been used to dewater gas, coalbed methane and shale wells. In flowback operations following hydraulic stimulation, jet pumps deliver quick and cost-effective recovery of fluid and proppant at rates of 300 m^3/d [2,000 bbl/d] or more.

Future Developments

Jet pump suppliers continue to evolve pump designs to help oil and gas operators increase production at minimal operating expense. Current trends in well placement include positioning multiple wells on one site, which creates logistics and footprint problems for some conventional lift systems. A jet pump can be configured through a manifold system to run multiple wells, which serves to reduce lease operating expenses by limiting the amount of equipment on location.

Although earlier versions of the jet pump had a reputation for high energy consumption and raising operational costs, new technologies are allowing the surface pump to be powered with gas coming directly from the well. Integrated control systems precalibrated for the particular engine model help to optimize the engine's performance during fluctuations in gas flow rate or in BTU levels while ensuring that the field operation maintains emission compliance by flaring less gas to the atmosphere.

As design innovations continue, jet pumps seem well positioned to address the industry need for cost-effective and reliable lifting solutions for all manner of marginal production scenarios.