ESP GAS SEPARATORS DEVELOPMENT AND TESTING

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All forms of artificial lift, with the exception of gas lift will have trouble with gas. The gas increased the volume of fluid to be moved, and decreases the bulk density and lubricating properties of the fluid. The gassy fluid is less capable of dissipating heat and its tendency to separate can leave some mechanisms dry.

The general choices for producers with gas problems it to avoid the gas, handle or live with the gas or attempt to separate the gas. Pumping with electrical submersibles is no exception. The ESP has the advantage of having a high speed rotating shaft that can be used to power a separating device.
The active or rotary gas separators were introduced to the market 20-25 years ago and made a step increase in the ability of the ESP to operate in gassy wells.

THE GAS PROBLEM

It would be the rare oil well that does not produce some gas. Crude oil is a mixture of a large variety of elements and short, medium and long chain hydrocarbons. Gas, the shorter chain hydrocarbons, is an integral part of the mixture. Under sufficient pressure, the natural gas and the oil exist together in a single liquid phase. When the pressure is decreased, the mixture expands. As pressure is continued to decreased, the elemental gasses and lighter hydrocarbons chains have sufficient energy to liberate themselves from the liquid to form a separate gas phase. The point at which the gas phase first appears is the bubble point. The composition of the gas at this point is a function of the solubility of the individual constituents in the remaining liquid. The lighter gasses tend to come off first. The gas phase is in a complex equilibrium state between the evolved substances and the substances still left behind in solution. As pressure continues to decrease, the gas phase expands and the liquid phase shrinks.

The relation between the volume of the liquid phase and the gas phase is represented by the gas oil ratio (GOR). It represents the volume of liberated gas in ratio to the volume of liquid at the condition of standard temperature and pressure. This can be expressed as a direct ratio, (barrels per barrel, or cubic meter per cubic meter) or in Oil Field Units as standard cubic feet of gas per barrel of oil (SCF/BBL). GOR values of several hundred are common and values exceeding 3,000 are not unknown. The goal of artificial lift is to maximize the production of oil from a well and it is accomplished by drawing the well pressure down as far as practical. The two phase fluid pumping problems become obvious considering a crude oil with a GOR of 500 SCF/BBL at atmospheric pressure represents a fluid that is only 1.1% liquid.

THE GAS SEPARATOR

To separate the liquid and gas phase it is necessary to make use of the differences in their properties. The liquid is generally 100 to 1,000 times the density of the gas. A mixture of liquid and gas if left undisturbed for a sufficient period will readily separate. It follows that if turbulent remixing of the fluids can be avoided the problem will solve itself.

All of the passive gas separator designs are based on this gravity separation principle. The Rod pump industry has used many varied designs of passive separation in their slot/stinger/cup type gas anchors. They can do quite well at low and moderate volumes[1]. The worm and helical cup gas anchors advance a step beyond the strictly passive separators by swirling the fluid, developing a centrifugal component to add to the natural gravity separation.

ESPs have made their place in the artificial lift by efficient pumping of large volumes of fluid. Almost every variety of rod pump gas anchor has been translated into a similar design for the ESP. Again as was noted before they only work efficiently at low production volumes.

In the oil boom in the 1970s, the need for efficient higher volume separators became acute. Using the shaft rotation to power a separation device, several design of these dynamic or rotary separators were created and successfully marketed (Fig.1). These designs though differing in principle contained a number of similarities.

They all have a fluid intake section and include some mechanism (impeller, inducer or auger) to increase the pressure of the fluid and force it through the rest of the device. They all have a flow divider or skirt to segregate the higher quality fluid from the lower quality fluid and they all have a crossover to return the low quality fluid to the casing annulus and pass the high quality fluid to the pump.

These devices are distinguished by the way they induce the spinning motion into the fluid. They can be loosely describes as a paddle wheel, the rotary chamber, and the vortex.

The paddle wheel used four to eight axial positioned blades or vanes running parallel to the rotating shaft. The fluid is forced to rotate by the blades and is subjected to centrifugal forces which impel the higher density fluid to the periphery and the lower density fluid (gas) to move towards the shaft. One disadvantage, to this method is that the fluid at the ID of the housing is not moving (zero slip boundary). The vane tips moving through the slower fluid and pick up a portion of the denser fluid and circulate it back towards the shaft. This remixing of the fluids inhibit the efficiency of the device. The rotary chamber solves the remixing problem by isolating the rotating vanes from the stagnate fluid layer. This is accomplished by enclosing the vanes with a cylindrical cover. The fluid is rotated in a closed container and the centrifugal separation can be maintained. As the fluid enters the rotating chamber, it has to be accelerated up to the speed of the chamber. At high flow rates, the inertial forces involved in accelerating the fluid and the short time that the fluid resides in the chamber may inhibit it from achieving its maximum efficiency.

The vortex device separates gas by spinning the fluid with an axial flow inducer, then allowing the spinning fluid to pass into an empty chamber. In the chamber the fluid naturally tends to form a vortex with the lighter fluid near the shaft and the heavier fluid at the walls. This type does not spin the fluid at the high rotational speeds of the other types, but obtains good separation efficiency by avoiding the remixing phenomena.

GAS SEPARATOR TESTING

All of these separators can be of benefit. Which one is best is highly subjective. It should be noted that the purpose of a gas separator is not specifically to separate gas, but to provide the pump with a pumpable fluid. The fluid can be made pumpable by removing the gas but it also becomes more pumpable it the gas is broken up into very small bubbles and evenly dispersed in the liquid.

API has not developed any standards for testing the gas separators. The simple tests generally produce doubtful results. The best arrangement for testing has to mimic the position of the equipment as it would be in actual use. Attempts to do horizontal testing or testing which pipe off the fluids from the gas and liquid exits ports are usually misleading because of the critical relation that the exit pressure has on the performance of the separator.

The criticality of the facility inspired the construction of a specialized gas test facility. The gas test loop is designed to operate the equipment in a test well that can simulate the actual application. The system is a pressurized environment that recycle the liquid and gas used in the test fluids. Originally designed with parameters of 5,000 BPD liquid with 5,000 BPD gas at 450 psi. This facility has been used to test both gas separators and gas handling pumps with total fluid volumes of 10,000 BPD. For safety, the fluid was water and the gas nitrogen.

TEST RESULTS

A performance limitation that had been noted earlier in all of the devices was referred to as intake limitation or impeller over loading [2]. Simply stated, if you can not get the fluid in, then you can not properly separate it. Another way to state the same problem is if the fluid impelling device can not provide enough pressure to expel the gas, then there is no fluid moving out the gas exit ports. It is possible that fluid is being sucked in through the gas exit ports. When this occurs, there is no separation and all the gas enters the pump.

Another fact that had been observed earlier was that the head produce by the auger (Fig. 2), often used as a fluid moving device, dropped drastically with as little as 5% free gas in the fluid. This appears to be due to gas core build up in the auger. If the gas can not produce enough pressure to overcome the pressure at the auger outlet, then the gas will stay in the auger. It will build up and block the liquid.

The observations in the tests indicated that there were several areas that needed to be improved. The flow resistance through out the separator had to be minimized and a fluid moving device that was less affected by gas than the auger had to be found.

Early in the development of rotary gas separators it was realized that they were very susceptible to radial bearing wear. The easiest design for the separator had a radial bearing below the fluid entrance, and another above the crossover and exit ports. This allow for a wide open chamber in which to work on the fluid. The thrust from the pump coupled with the short length of the slim separator shaft and the imbalance of the rotating mass creates side loads on the bearings which could quickly cause failure. These were resolved by installation of an intermediate bearing, increased shaft size and balancing of the rotating masses.

The auger was selected for most gas separator designs because unlike the centrifugal pump impeller it was not thought to add a radial component to the flow. This however is not completely true. An auger’s maxim flow, zero pressure, is generally about half of what its theoretical maximum (zero rotation) flow. This indicates that the fluid will be rotating at approximately half the rotational speed of the shaft. Any pressure requirement will reduce the flow and add to the rotation of the fluid. If the gas can not easily escape from the auger it builds the gas core and increases the problem.

GAS SEPARATOR IMPROVEMENTS

All of the gas separator limitations appear to be linked to the flow that can be obtained through the separator. Improving the performance can be accomplished by reducing the flow path resistance and increasing the capability of the fluid mover. To improve the separator it is required to develop a fluid mover that will not be as susceptible to the gas core build up as the auger, and to streamline the fluid passage for minimum flow loss.

It was determined that the gas core build up in the auger can be reduced by inclining the vanes to the axis of the auger. This “High Angle Vane” auger (Fig. 3) induces a motion in the liquid towards the center which helps to flush and mix with the gas in the core to carry the gas on through the separator.

Reducing the flow resistance at the entrance is accomplished simple by enlarging the intake holes to their practical limit. The flow resistance of the radial support bearing can be reduced by minimizing the number of support vanes and inclining the vanes to more closely match the angle of the in coming fluid (Fig. 4).

The gas exit required more consideration. Along with the gas, the separator expels a considerable quantity of liquid. If the path for the exiting fluid is tight or convoluted, the resulting back pressure will reduce the performance of the separator. To make these passages as transparent as possible a CAD/CAM system was employed to aid with the conception (Fig 5>. The result was a design that incorporated low flow resistance liquid and gas exits with the upper radial support bearing in a single piece (Fig. 6).

RESULTS

With the knowledge gained from the testing a line of separators have been created that can be built either as a rotary chamber or a vortex.

These separators were designed with abrasive and corrosion resistant construction so that the standard separator could be used in the problem wells.

The creation of the low resistance flow paths allow for more efficient gas separation.

The development of the high angled vane auger allows larger volumes of fluid to be processed by the gas separator.

Future gas separator development along these paths will allow for higher volumes to be processed through smaller diameter equipment.

REFERENCES

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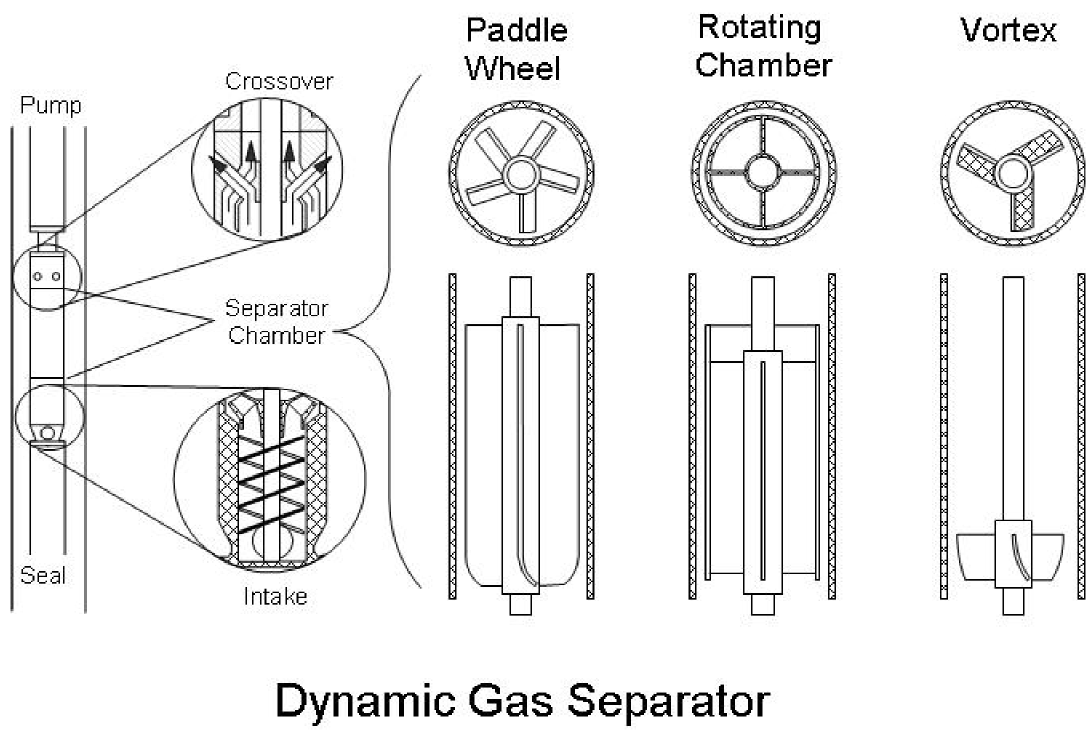

Figure 1

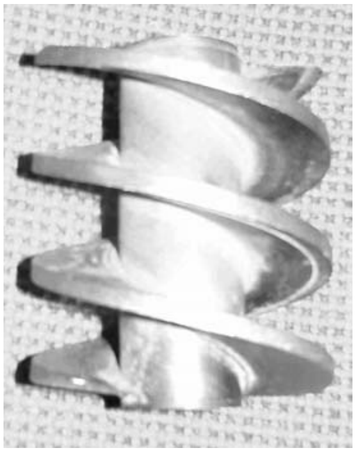

Figure 2 - Flat Vane Auger

Figure 3 - High Angle Vane Auger

Figure 4 - Low Flow Resistant Bearings

Figure 5 - CAD Design Separator Head

Figure 6 - Rapid Prototype Head Design