TANDEM GAS SEPARATOR PERFORMANCE FOR ELECTRICAL SUBMERSIBLE PUMPS

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ABSTRACT
The performance of the centrifugal pump used in Electrical Submersible Pumps (EPS) systems is significantly degraded by the presence of gas in the fluid. This reduces the applicability of the pump. Rotary separators, devices that use the pump shaft rotation to force the gas from the liquid were developed over twenty five years ago. In situations where even the rotary separator could not remove enough gas from the fluid to prevent interference, a tandem or stacked rotary separators was often used.

Improved models of rotary gas separators have recently been developed and introduced. In the development of the new separators, a large body of information was obtained on the mechanism involved in the rotary separation. Part of the lessons learned in the development of these new separators indicate that a tandem separator may be of little if any benefit to downhole gas separation.

This paper reports on gas separator testing performed in a high pressure gas test loop. This testing concentrated on the possibility of benefits from tandem configuration on the new style gas separators. It examines and reports on where the benefits of tandems may occur.

BACKGROUND

Gas in the pumped fluid is a hindrance to all types of artificial lift with the exception, of course, of gas lift. Dozens of different designs of passives gas separators or gas anchors have evolved in the rod pump industry. The basic design philosophy of passive separators involves arranging the entrance so the fluid is required to flow downward. If the buoyant forces dominate the drag forces on the bubbles, the gas will continue to move upward and the fluids will separate.

Early in the ESP history, the industry used passive separation designs similar to those that served the rod industry. They functioned well as long as the fluid velocity was low. The chief reason for selecting an ESP in the first place was to produce higher volumes. Fluid volumes in which the economics favored ESP were generally too high for the passive gas separators to do much good. The general rule of thumb (ROT) was that the ESP could function with a maximum of 10% free gas at the pump intake with little degradation. If the gas volume was significantly more, then the ESP might simply not function at all.

The jump in oil prices that began in the mid 1970’s inspired the industry to push for separators for the higher volumes. The concept of using the shaft rotation to generate the centripetal acceleration to separate the gas was not completely new but the economics of the times shifted the focus of ESP application to high volume high efficiency separators.

THE ROTARY GAS SEPARATOR

By the early 1980’s all ESP companies were marketing rotary gas separators as part of the standard product line. The expanding market and the profit margin induced operators to routinely add a gas separator to their installations whether on not they were experiencing gas problems. The philosophy seemed to be that if you weren’t having gas problems then you were not pulling the well hard enough. Often separators were added with little thought given to the possible down sides of putting more complex systems in the wells.

All these separators fit into the category of rotary separators even though the internal separating mechanics could differ markedly. They could be divided into three general types, depending on the configuration of the separating device (Fig.1). The open vane or paddle wheel, created fluid rotation in the separating chamber with a number of straight axial vanes fixed to the rotating shaft. The closed vane or rotary chamber enclosed the paddle wheel in a cylindrical container. This closed vane reduced the fluid remixing occurring in the open vane but required all the fluid to rotate at the shaft speed. The third configuration, the vortex type spun the fluid with a short inducer as the fluid entered the chamber, and let the fluid spin unimpeded and form a vortex as it proceeded through the separation chamber.

The other parts of the rotary separator are fairly similar in design (Fig.2). The intake directed the fluid from the casing annulus to an impelling device (flow inducer). The impelling device provided the pressure to move the fluid through the rest of separator. After the separating chamber, a splitter or skirt divided the fluid into two volumes, the denser fluid at the periphery and the less dense near the shaft. After the splitter the fluids proceeded to a crossover which conducted the less dense fluid through the outer wall of the separator to exit it back to the casing annulus and conducted the denser fluid to the pump intake.

Generally, the rotary chamber, which spun the entire fluid volume at the rotational speed of the shaft, produced the highest separation forces. It was therefore very good in viscous fluids. The vortex produced the least fluid rotation and consequently was not as good as the rotary chamber at higher viscosities. On the other hand, the vortex had the smallest rotation mass and put the least energy into the fluid, therefore suffering less internal erosion in sandy applications.

SEPARATOR PERFORMANCE

In the rush to develop rotary gas separators, few gave much concern to performance. The rotary separators were a huge improvement over the passive separator. It allowed the ESP to produce more fluid and that was good enough.

Testing separators presented many problems. There was no prescribed method to use or measurement to take. The University of Tulsa decided on separator efficiency described as the ratio of the volume of gas flowing up the casing after the separator, to the volume of gas flowing up to the separator. This gave a number that varied from zero, all the gas going into the pump, to one, all the gas flowing up the casing. Multiply by 100 and stick on the percent sign and you have the efficiency of the separator. This measurement did not take into account the volume of liquid. Obviously 0% efficiency was bad and 100% was good, but an efficiency value of 90% or 80% did not mean that the pump was going to be able to function.

The simplest method for the manufacturers to test a separator was to insert a liner, simulating the proper size casing, in one of their water test pits. Install the equipment, inject shop air below the ESP motor and start the tests. Unfortunately this in no way simulates the fluids, the downhole pressure nor the column of fluid over the pump. There are two separating phenomena occurring, the natural separation at the inlet and the internal separation performed by the gas separator. With this combination, most of the rotary gas separators were quite capable of high efficiency with moderate fluid volumes. The messy result was the gas expelled by the separator lifted the liquid out of the well casing, spilling on to test well floor. Closing the top of the well was not an option because it would force the gas through the separator and defeat the purpose of the test. Lowering the unit in the pit was not helpful unless the level of fluid in the pit could be similarly lowered. A taller column of fluid would required more gas to create the same percentage of gas at the intake and increased the tendency to gas lift the casing.. The test wells were shallow in the first place - 100-200 feet - and draining them down to obtain a few more test points was impractical.

The performance data gathered and presented was considered adequate for the needs even though no two manufactures used the same scales or measurements (Fig 3 & 4). The manufactures were not keen on head to head competitive testing of their product. The tests were always somewhat subjective and the downside of coming in last was obvious. The industry followed the advice given by Niccolo Macheavelli in ‘The Prince’: “never seek the truth when a supposition will do”.

ADVENT OF THE TANDEM

The separator works best if the separator chamber is made as long as practically possible without the interruption of shaft support bearings. The longer the chamber, the longer the fluid residence time and the higher the quality of the separation. The original gas separators were prone to radial wear due to its unsupported shaft and the relatively large rotating mass. Increasing the length of the separation chamber was possible but only at the cost of increased failures. If you installed a gas separator and were still having gas problems, what was there left to do? Using the cook book rule “if some is good, then more is better”, two gas separators in tandem was the only thing left.

The testing that was done indicated that the tandem separators could improve the amount of gas removed. However the increase was not great, only about 10% to 20%. In some cases this was enough to make the pump function.

Every piece of equipment added to the ESP stack is one more place to have problems. Tandem separators are no exception. The original configuration (Fig.5) was just two single separators, stacked one on top of the other. Later, to improve the shaft stability, they were built on a single shaft. This was simplified to the final configuration, the one piece tandem separator. The second fluid entrance was considered superfluous and eliminated.

CONTINUED DEVELOPMENT

With the collapse of the oil boom in the mid 80's there was scarcely time or manpower to continue the development of gas separators. The major problems presented by rotary separators, shaft vibration and abrasive fluid cutting, had been understood and addressed. The economics did not press the industry to fund significant development of new systems.

In recent years the emphasis on producing gassy wells has increased. Investments had been made in facilities and equipment to increase the knowledge base for gas handling and gas separation. This has sparked the development of a new generation of gas separators and given insight to problems of the earlier gas separators.

One phenomenon which had been identified in the late 80's was referred to as "intake limitation" or "impeller overload". The fluid traveling through the separator is obstructed by every object it encounters or turn it takes. If the flow inducer (impeller at the entrance of the separator) cannot create an internal pressure greater than the pressure in the casing annulus then it is overloaded. There is no pressure to force the fluid, liquid or gas, out the exit ports. The exit ports may then become auxiliary fluid entrances

The improvement of gas separators centered on minimizing the internal flow resistance and increasing the capacity of the flow inducer. The requirement for the flow inducer differs from the requirements of a pump impeller. A pump impeller attempts to efficiently create a flow which varies with resistance (lift). The gas separator is designed with a big hole in its side so the flow inducer labors against very little resistance. The flow inducer is designed for volume with little regard for efficiency. This flow is the total fluid, liquid plus gas and it always operates near its maximum. Figure 6 shows the inducer performance of a four inch diameter separator which has a maximum fluid rate of 5,000 BPD.

If, as in the new separators, the internal design has good separation and low flow resistance, the limit of the separator is the maximum inducer flow. Tests indicate the limit of the separator performance is linear. A straight line drawn form 100% free gas at zero flow to the maximum flow of the inducer, 5,000 BPD at zero free gas in this case, is the performance boundary for the vortex separator (Fig.7). For liquid flow and gas percent combinations above this line, the separator cannot product the internal pressure to exit the gas and its efficiency is zero. For flow and gas volumes combination below this line the efficiency is 100%.

For safety and convenience, testing of the separators was performed with nitrogen and water.
The test curve is sufficient to represent the performance for the majority of the ESP applications as the combination of downhole temperature, dissolved gas and large water cut, result in a bulk viscosity of 6 cP or less. In situations with higher viscosities, or with separators which have higher internal resistance, the separator performance does not show this sudden break from 100% to 0%, but rather a family of curves of decreasing efficiency as fluid flow or gas percentage increase (Fig.8).

EVALUATING TANDEM CONFIGURATIONS

A single piece style tandem separator adds a second separating section, that is, a flow inducer and separating chamber on top of the first. Both flow inducers are operating very close to their maximum. With them flowing approximately at the same rate, the tandem configuration adds little or nothing to the efficiency of the separator. The flow inducer in the second section robs the first section by not allowing it to exit the fluid through the gas exit ports. For the first separator to exit any fluid through the first gas exit ports, it has to be flowing at a volume significantly greater than the second.

If the first flow inducer was twice the volume of the second - that is, it could deliver 10,000 BPD - the tandem configuration would still be of little use. The upper flow inducer restricts or demands a flow of 5,000 BPD. If the lower flow inducer is flowing more than 5,000 BPD, the excess fluid goes out the gas exit ports. If it is supplying less than 5,000 BPD, the demand from the upper flow inducer will lower the pressure in the first section and reduce the separation efficiency of the lower chamber. If a higher flow inducer was available, a better solution would be to use a single separator with the higher volume flow inducer.

This is not to say that all tandem separators are useless. The indicated examples are based on the new generation vortex separators in very low viscosity fluids. These separators have low flow resistance and excellent internal separation. For older separators, or the new generation separators used in high viscosity fluids, the tandem performance can be better than the single. The existence of an area of graduated efficiencies on the separator performance curve is a good indication that a second separation section gives a second chance for the device to separate the gas and will produce a higher efficiency than the single separator of the same type acting alone.

The original version of the tandem, that is two single separators stacked, can in some cases actually perform better than the single separator. The existence of the second intake can disconnect the mutual performance dependence of the two sections in the tandem. This is on the provision that the second intake does not take its fluid directly from the gas exit ports of the first. The assumption is that the second separator has fluid available from two sources, A relatively gas free fluid from the first separator and a make up volume from the casing annulus.

CONTINUING DEVELOPMENT

The industry continues to demand more from the performance of gas separators. The 4.0 inch diameter gas separator of the 1980's had a maximum flow in the range of 3,500 BPD. The flow for the new style 4.0 inch standard separator is 5,000 BPR and is available in high volume models that approach 8,000 BPD. The residence time at 5,000 BPD in the separating chamber is 0.2 seconds. Even in the low viscosity test fluids, the performance curves of the higher volume separators are showing the "sag" that is indicative of inability of the separating scheme to keep pace with the fluid volumes. Developing efficient separators for still higher volumes will require re-examination of the tandems.

CONCLUSIONS

The tandem configuration with the older style separators showed an increase of the separation efficiency, but this was seldom more than 10% to 20%.

The new style separators provide excellent separation in low viscosity fluid, and do not receive much benefit from a single piece tandem configuration.

In higher viscosity fluids where the rotary chamber is more efficient, the tandem configuration will allow for better separation efficiency than the single.

The existence of an area of graduated efficiencies on the separator performance curve indicates a tandem configuration may achieve higher efficiencies than a single of the same type

Separating Device

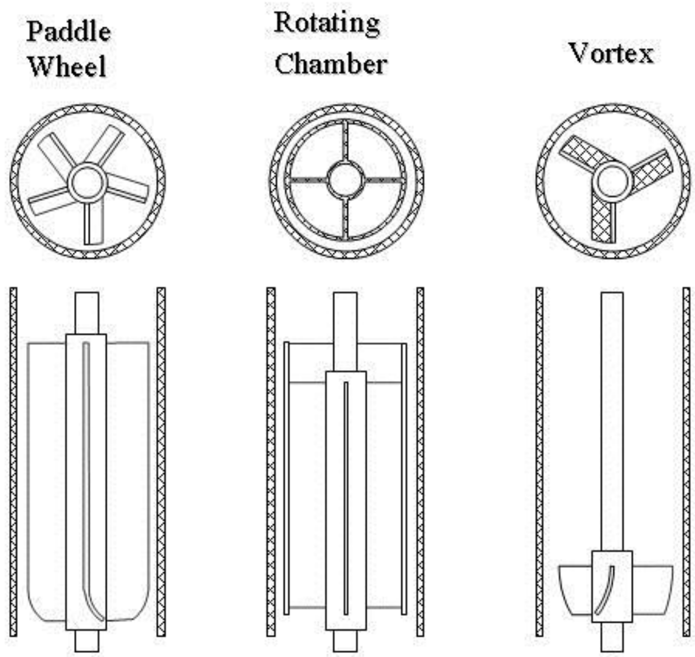
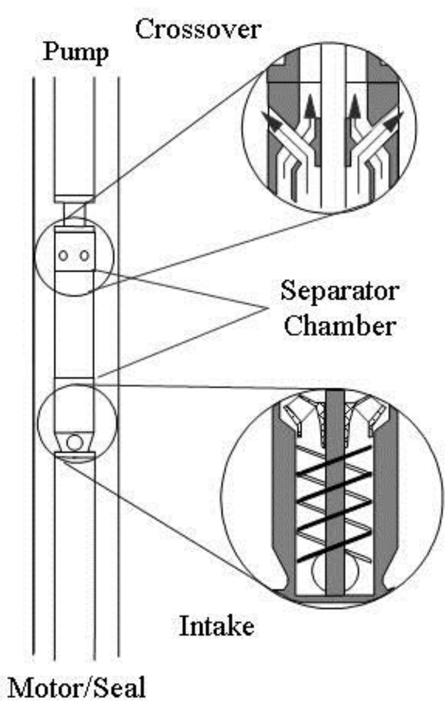


Fig. 1

Rotary Separator



Common Parts

Exit

Cross over

Splitter (skirt)

Separation Device

Fluid Mover

Intake

Fig.2

Free Gas % in Separator and Separator Efficiency

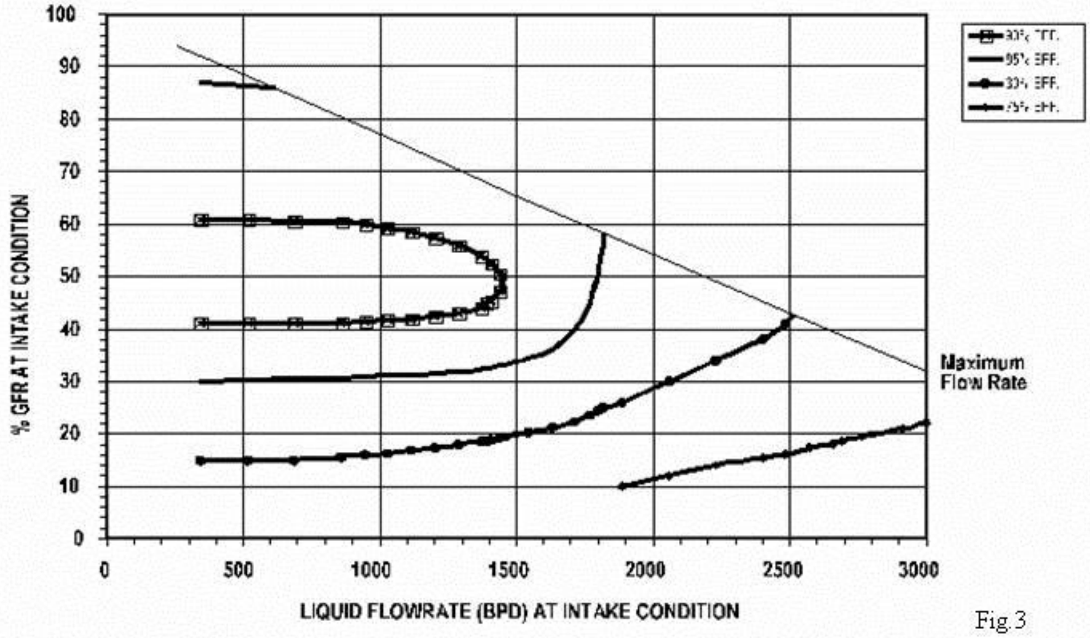


Fig.3

Free Gas % in Separator and Free Gas % in Pump

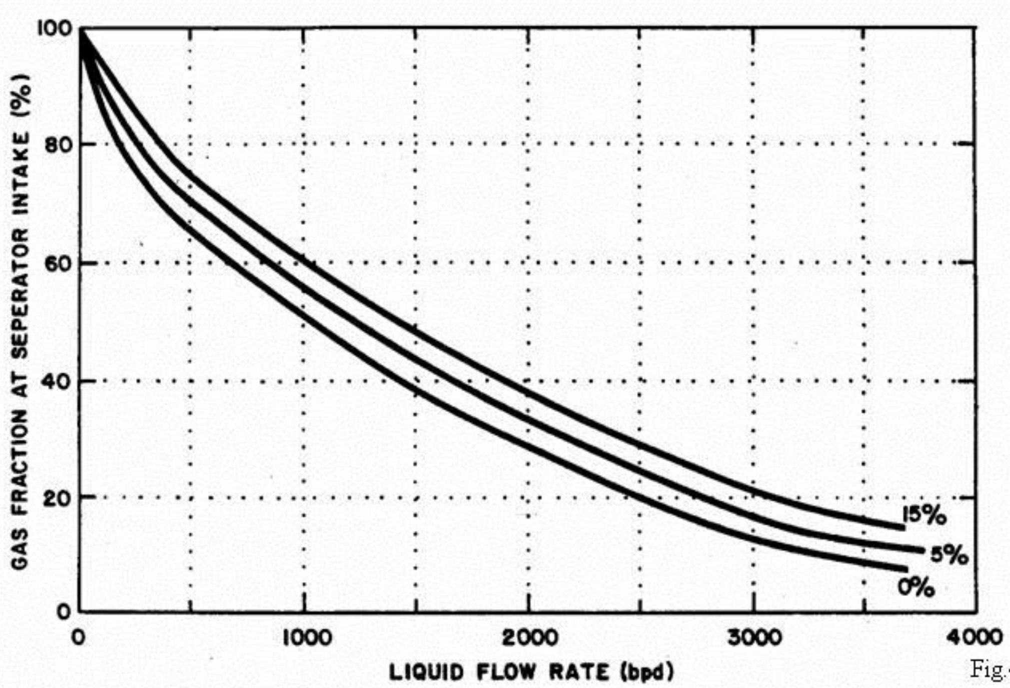


Fig.4

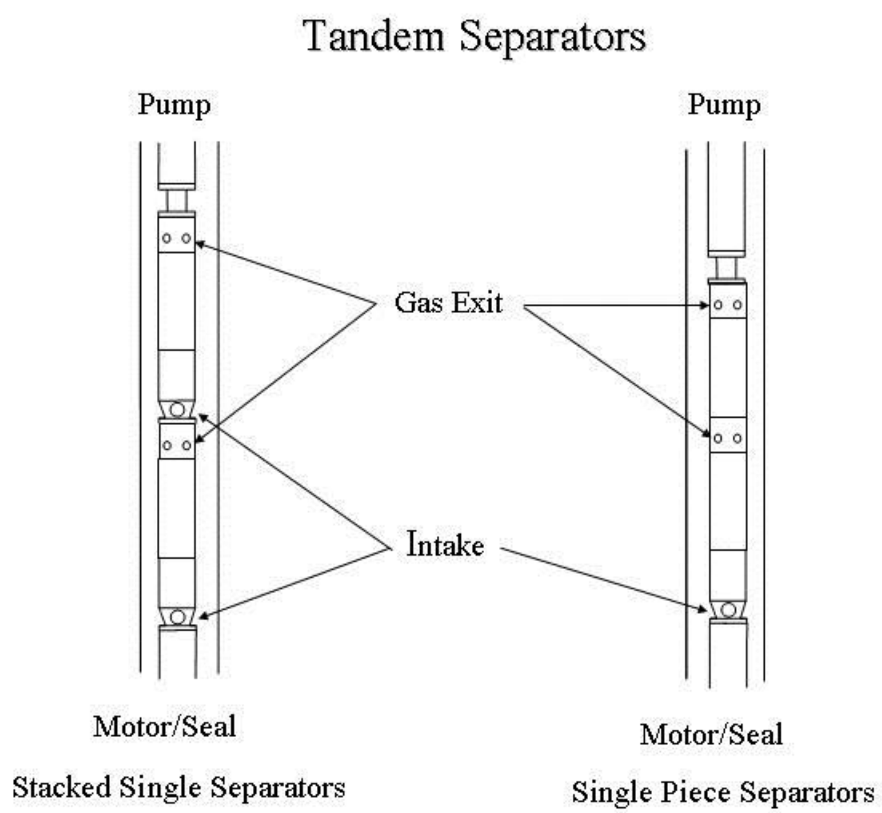

Tandem Separators
Pump
Pump
Gas Exit
Intake
Motor/Seal
Motor/Seal
Stacked Single Separators
Single Piece Separators

Fig.5

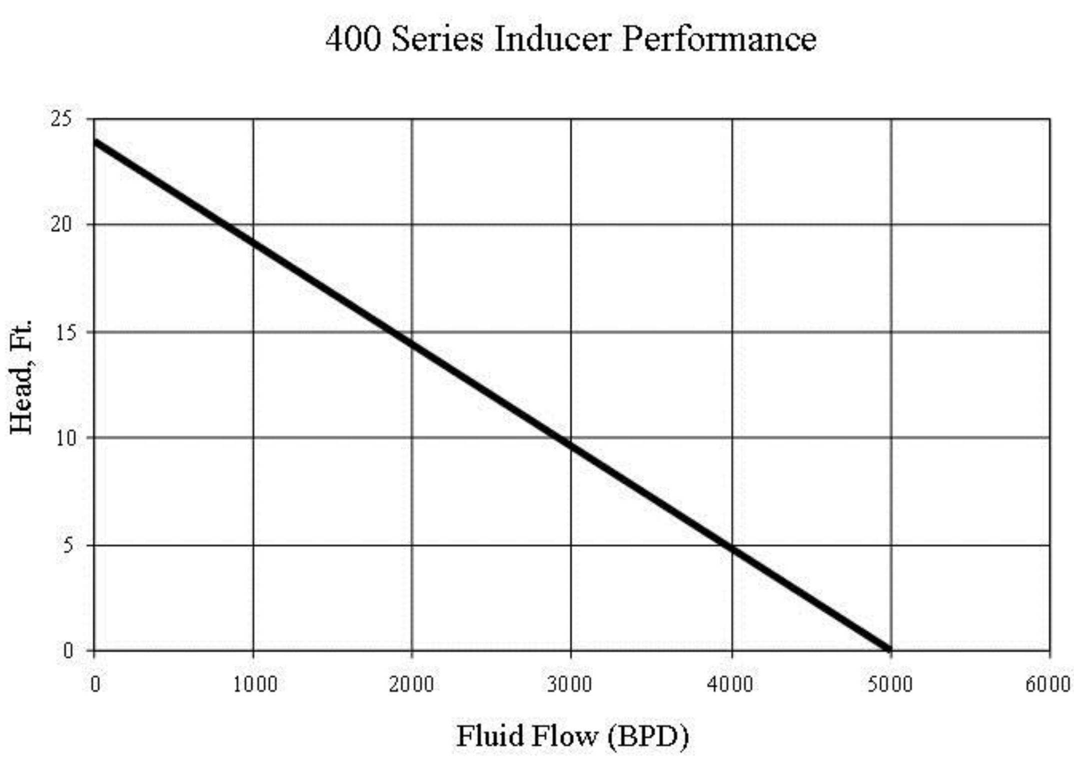

400 Series Inducer Performance
Head, Ft.
25
20
15
10
5
0
0
1000
2000
3000
4000
5000
6000
Fluid Flow (BPD)

Fig.6

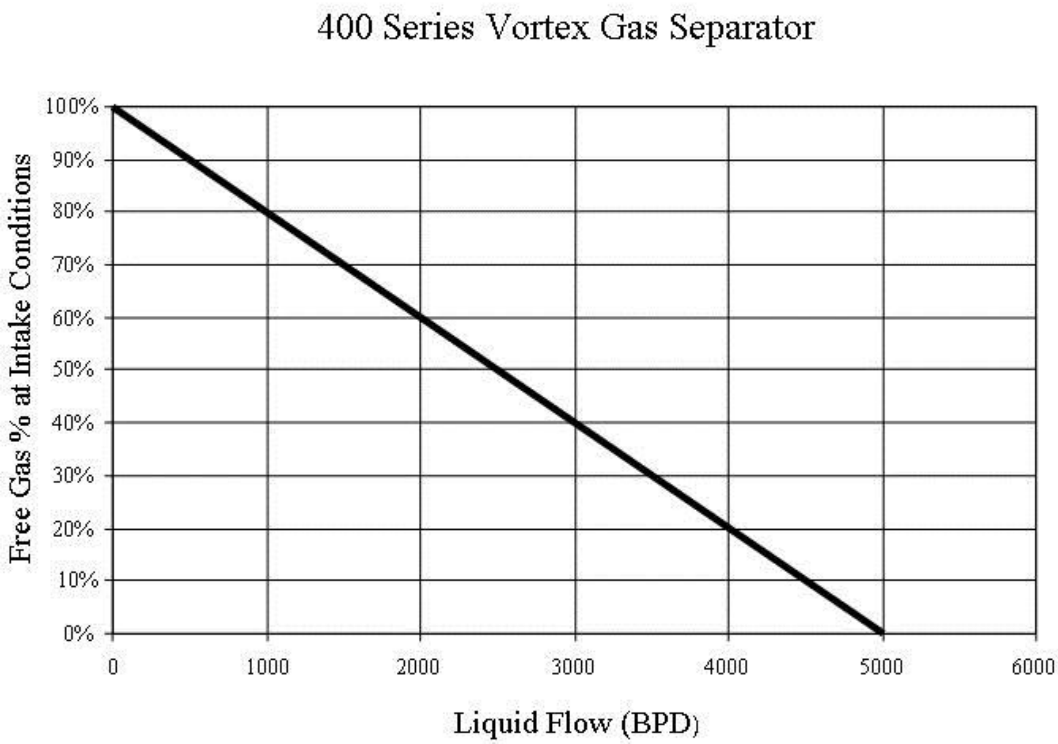

400 Series Vortex Gas Separator
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Free Gas % at Intake Conditions
0
1000
2000
3000
4000
5000
6000
Liquid Flow (BPD)

Fig.7

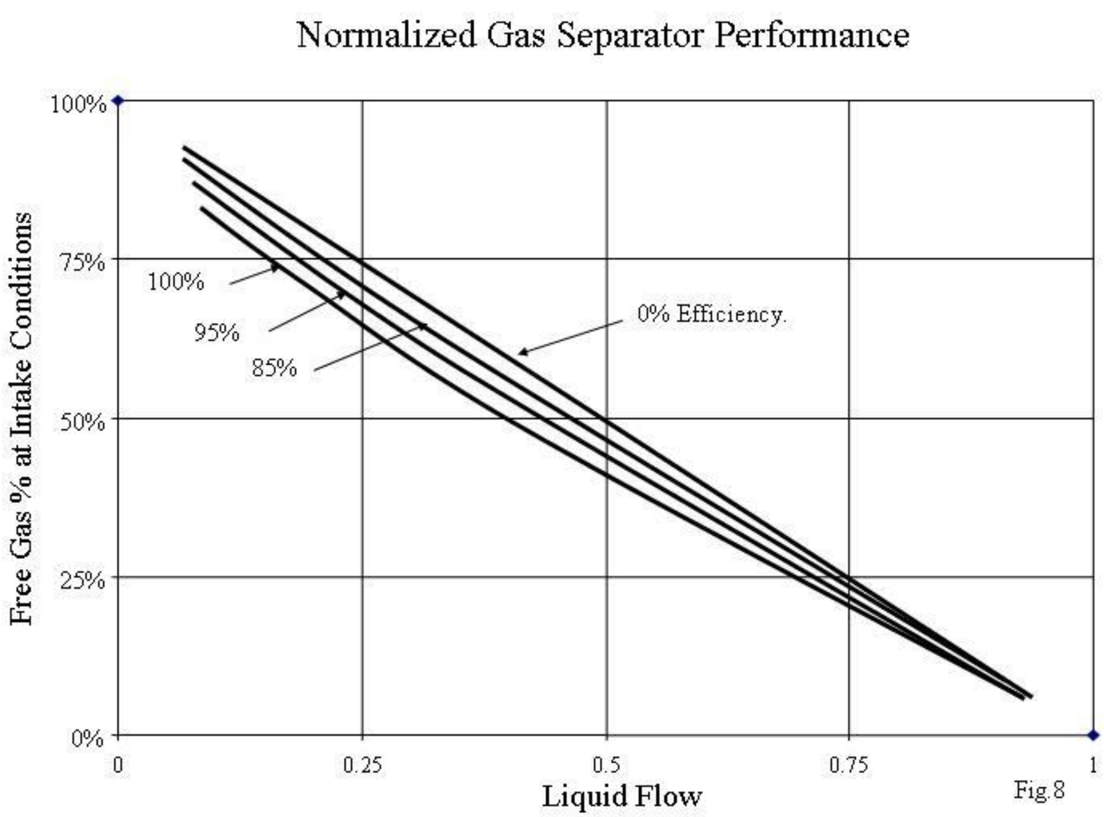

Normalized Gas Separator Performance
100%
75%
50%
25%
0%
Free Gas % at Intake Conditions
100%
95%
85%
0% Efficiency.
0
0.25
0.5
0.75
1
Liquid Flow

Fig.8