PROBLEMS AND SOLUTIONS FOR ESP'S IN GASSY ENVIRONMENTS

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Centrilift

The centrifugal pump is a dynamic pumping device. One of the limitations of centrifugal pumps is their inability to handle significant quantities of gas. Two-phase fluids with several orders of magnitude difference in the density of the phases have always been very difficult to pump.

This presentation reviews the nature of gas in its relation to well production with Electrical Submersible Pumps and examines historical methods for gas handling. It presents information on the gas handling methods and devices more recently introduced to the industry and quantifies limitations to two phase production with ESPs.

WHAT IS GAS?

Crude oil is not by nature a homogeneous substance. It is a mixture of a large variety of elements and short, medium and long chain hydrocarbons. The API gravity of an oil can be interpreted as a bulk average of the substances present at standard conditions. Under sufficient pressure, the natural gas and the oil exist together in a liquid phase. When the pressure is decreased, the mixture expands. As pressure is continued to decreased, the elemental gasses and lighter hydrocarbons molecules 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 Bubble Point is a property of the bulk solution. High bubble point crude oils may have larger volumes of gas in solution, and/or greater percentages of the light substances in the gas phase. Removing a portion of the dissolved gas changes the properties of the remaining crude. For a given sample of crude with a 5,000 psi bubble point, if the pressure is lowered to 3,000 psi and the gas cap is bled off, the remaining crude will have an increased API gravity, viscosity and a 3,000 psi bubble point.

The relation between the liquid phase and the gas phase is represented by the gas oil ratio (GOR). It represents the volume of liberated gas in contrast to the volume of liquid at standard conditions of 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 1000 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% by volume liquid.

WHERE DOES GAS COME FROM?

A simple answer is that it evolves from the liquid. Just how the gas and liquid got there in the first place is beyond the scope of this presentation. The gas is held captive in the crude by the formation pressure. With a gas cap present in a formation, the crude is at its bubble point, and attempts to remain in equilibrium with the gas cap. As oil is produced from the formation, the gas cap expands. This "solution gas drive" relies on the evolution of the gas cap to provide the pressure to force the oil into the well bore.

The concern of this paper is to examine the effect of free gas on a centrifugal pump in the well bore. Three situations will be considered:

1. The well bore pressure is at or higher than the bubble point. No gas will evolve in the well bore until the crude has risen to a point where the pressure is lower than the bubble point. This can simplify production if the pump can be set low enough that there is no free gas.

2. The well bore pressure is lower than the bubble point. Gas is evolving from the crude as it approaches the well bore and entering the well bore as free gas. Unless the gas can be avoided, the pumping system will have to be able to cope

with the two phase fluid.

3. Direct gas production can occur by coning of the gas cap down to the perforations, or gas production from another zone or formation fracture. Large quantities of gas is pulled into the well bore. This can deliver enormous volumes of gas, much larger that would be predicted by a PV analysis of the existing oil.

WHY IS GAS A PROBLEM?

The centrifugal pump is a dynamic device that uses velocity imparted to the fluid to produce the energy to lift a column of fluid a distance. This distance or "head" to which the fluid can be lifted is related to the pressure by the density of the fluid. The equations that govern a dynamic pump relate the produced head to the geometry, flow and rotational speed. The density of the fluid does not affect the head produced. This means that a dynamic pump may produce the same head without regard to the density of the fluid (Fig. 1). **A** dynamic pump design that can lift a column of water 6,000 feet could theoretically lift 6,000 feet of air at the same flow rate. However, the pressure required for water is 2,600 psi verses 3 psi for air.

The burden of the Electrical Submersible Pump is to lift the column of fluid to the required height (to the surface) at the desired flow rate. The difficulty is that this must be accomplished with equipment of small enough diameter to fit into the bore hole.
An impeller in a 4 inch diameter pump stage can impart enough velocity to the fluid to provide 25 ft of lift at 3500 RPM. To produce 6,000 feet of lift would require 240 of these 4 inch stages, or it could be done with a single stage to be rotated at 54,000 RPM. Obviously the multi stage arraignment is the practical solution.

The basis assumption in the mulit stage ESP is that every stage is seeing the same fluid properties at its intake and every stage is adding the same lift and requiring the same horsepower. ESP creates the high head necessary by stacking a large number of stages in tandem.

The presents of a compressed or dissolved gas in a vertically flowing column of liquid is not a negative. The gas lightens the fluid gradient in the tubing and reduces the pump burden with the gas lift effect. The problem is getting the gas compressed or dissolved in the liquid and into the tubing string. If the two phases are homogeneously dispersed in one another, and remained dispersed, the pump may have little trouble with the fluid other than the lost work in the gas compression.

In a centrifugal pump, multi phase fluid seldom remains homogeneous for very long. Due to the difference in density, the centrifugal force segregates the phases more quickly than the turbulence can mix them back in. The oil may have a density of. 70% of the water, the solids (sand) may be 2 to 3 times the density of the water. Natural gas, however can have a density two to three orders of magnitude less than water.

HOW DOES GAS INTERFERE WITH THE PUMP?

Separation of the phases is extremely detrimental to two phase production. Head is created by the imparted velocity and the pressure is a function of the head and density. **A** separate gas phase will not have sufficient pressure to move with the liquid into the diffuser, and therefore it will gather in the impeller and blocks the pump or is transported by some method other than velocity created pressure (Fig. 2).

Gas can affect the performance of a centrifugal pump in a variety of ways.

Gas decreases the bulk density of the fluid.

Gas increases the total volume of fluid that the pump is required to handle.

Gas causes flow anomalies in the impeller.

The density is not so much a problem as the density difference between the phases. If it were only a question of bulk density, the lift output from the pump and the lift required for the tubing could be matched and maintained. With two phase, the gas is compressible, and the flow somewhat irregular. **A** cyclic or "gassy" amp chart indicates a lack of stability in the power requirements, caused by cyclic changes in the density of the fluid and flow through the pump..

The increase in the fluid volume forces the pump to be operating further to the left on the pump curve. It may require that a larger volume stage be selected. If a pump is required to move 1200 BBD of fluid that is 30% gas, the bulk volume at the first impeller is actually 1714 BPD. The volume increase by itself would cause the head production in the frist impeller of this example to drop from 27 feet to 8.5 feet. The 27 feet of head with 100 % liquid would represent approximately 11.5 psi of pressure acting on the fluid. The 8.5 feet at 30% free gas represents only 2.5 psi acting on the fluid. The gas is compressed by pressure, not head. This is important when relying on the lower stages in the pump to compress the gas.

Flow anomaly is a term used to describe a number of phenomena that result from the chaotic and disturbed flow that are created by the fluid phases. If the different phases can stay evenly dispersed in one another, a homogeneous mixture is developed, will only suffer from the volume and head penalties stated previously. The problem is the inability to maintain homogeneous flow when gravity or centrifugal force segregates the phases more quickly than the turbulence can mix them back in.

Factors effecting phase separation:
Density Ratio
Bubble size
Viscosity
Stage geometry
Magnitude of centripetal acceleration (speed)

The density function was discussed earlier in terms of pressure creation, but it also has a very important function in establishing the ratio of the gas to the liquid density, which is responsible for the magnitude of the buoyancy forces causing the fluids to separate.

The drag forces encourage the particle to move with the fluid and the buoyant forces, encourage the particles to segregate. The drag is a function of the cross sectional area of the particle and the buoyant force is a function of the volume. As the size of the particle decreases, it is more likely to flow with the fluid than to separate. Avery finely dispersed phase can be difficult to separate and sometimes the fluid develops some unusual bulk properties. Emulsions are good examples of this.

The viscosity of the liquid is important in the creation of the drag force. The increased drag in higher viscosity liquids would not allow the phases to segregate as easily.

The specific geometry of the stage effects the creation of the centrifugal field, which separates the fluids, as well as the turbulence, which disperses the fluids.

The rotational speed has a similar dual effect, if increased, it increases the magnitude of the centrifugal force causing the fluids to segregate, and also increases the mixing and turbulence that reduce bubble size and disperse them in the liquid.

PREDICTING GAS INTERFERENCE

Of all of these items affecting the ability of a centrifugal pump to handle gas, (other that the quantity of gas) only the density ratio (pressure) has had significant analysis. Two (twenty year old) papers (Turpin and Dunbar) have been published that are specific to observations of ESPs. Both attempt to relate the performance of an ESP to the They both attempt to predict when an ESP will give satisfactory performance, considering the quantities of free gas and liquid and the pump intake pressure.

Dunbar presents graphical results based on a compilation of field data. The term VLR (Vapor Liquid Ratio) was presented by Dunbar to refer to the ratio of gas/liquid volume at downhole (pump intake) conditions, to distinguish it from the oil property, GOR.

The paper by Turpin presents an analysis of controlled laboratory test on a small variety of pump types. It attempts to relate the performance to gas volume, liquid volume (VLR) and the absolute pressure at the intake (Pa) by calculating a performance factor F:

$$F = 2000/3 \times (VLR)/ Pa$$

Turpin implies that the pump can give adequate performance if the value of F is less than or equal to 1, but adds the requirement that the pump be sized to handle the total intake volume.

On Dunbar's graph (Fig. 3), a line divides the graph into an area that is suitable for pumping, and one that is not The line represents data from many years of operating experience and the author warns that the distinction is not sharp and should be a broad band rather than the line. Lines representing the Turpin relation are shown on the same graph for F values of 1.00 and .75. At first glance the Dunbar seems to be more conservative, however it should be remembered that is field data and includes wells that maybe slugging as well as pumps that may not have been not properly sized.

The Dunbar and Turpin representations can shown in another way (Fig. 4), using the void fraction (percent of free gas) in place of VLR and the log of the density ratio of the phases instead of intake pressure. This form of the graph encloses the whole field of interest, from zero to 100% gas and all density ratios of practical value. It also begins to bound the non suitable pumping areas so that predictions for future developments can be projected.

It should be mentioned that in the past ten years, increased examination of the phenomena has resulted several in papers that better represent the performance of ESPs in two phase flow.

WHAT CAN BE DONE ABOUT GAS?

Gas interferes with the normal operation of an Electrical Submersible Pump, there are three general solutions:
Avoid the Gas, or Gas Excluding
Separate the Gas or Gas Expelling
Handle the Gas or Gas Pumping

Gas avoidance is defined as modification of the system so that the gas never enters into the fluid handling system. The classic examples is setting the unit below the perforations and devising some method to cool the motor. Some of the methods are as follows;
Passive Gas Separator
Inverted Shroud
Ratholed pump
Shrouded unit below perfs
Recirculation pump below the perfs

Gas separation is defined as performing some action on the fluid after it has entered the unit in order to expel the gas to the annulus and reduce or eliminate the amount of gas that will be passed on to the pump. There are three general types of gas expelling separator.
The Rotary Chamber
The Paddle Wheel
The Vortex

Gas Handling is defines as an arraignment that attempts to increase the ability of the pump to pump the gas. If the gas can not be avoided or expelled, then the pump must be able to compress and move the gas with the liquid. The following systems are a few that have shown some practicality in gas handling.
Overstaged Pump
Larger Pump Volume Pump
Tapered Pump
Gas Charger
Gas Mixer (Blender)
Special Stage

Overstaged Pump

The oldest and simplest is the overstaged pump. This requires the selection of a pump with additional pump stages. The over staging attempts to reduce the overall burden on the upper pump stages to make up for the reduction in pressure produced by the lower stages because of the gas interference..

Larger Volume Pump

The oversized pump is useful as a way to ingest the increased volume presented by the gassy fluid at its intake. Often though the upper stages are not operating within their operating range. The additional thrust load can shorten the life of the pump

Tapered Pump

The tapered pump attempted to solve the low flow problem in the upper stages of the pump by using progressively smaller stages as the fluid is compressed and the volume is reduced. These can be tailored to the well conditions using a mass flow design technique. Aproperly fitted tapered pump can be the most energy efficient method for standard staged ESP to handle all the gas. If however the well conditions differ from the assumptions, then the tapered pump is probably not operating at its optimum and may possible have many of the stages operating both above and below their operating range.

Gas Charger

The gas charger is very similar to the tapered pump. It is basically a short lower tandem pump with large volume stages. It will usually contain some device to protect itself from excessive down thrust so that it can operate over a large range of flow conditions. It is simpler than the tapered pump and often can be added in the field.

Gas Mixer (Blender)

The gas mixer relies on the dispersing the gas in the liquid. If the bubbles are small enough, then they will be carried with the liquid through the impeller, rather than separating and locking the impeller. The higher the liquid viscosity, the more likely that the gas will be carried with the liquid.

Special Stage

This is a stage that is specifically designed to operate with low pressure or gassy fluid.
The NPSH stage Is an example, it is sized for large volumes and designed to reduce entrance shock and phase separation. Other stages include a variety of circulating and self-flushing stages.

DESIGNING A GAS HANDLING PUMP

With the knowledge that gained by studying the effects of free gas on the pumps, criteria for performance improvement can be identified.

The density dilemma is the reason that the two fluids can not behave as one. There is not too much that can be done about it except to understand it and know the practical bounds of pumping.

Discourage separation by selecting a pump design that has radial fluid movement and reduces the low pressure pockets where gas can collect.

Encourage homogenization and ventilating or re-mixing of the liquid into the gas areas

Available pumps today:
Standard mixed flow stages
High angle mixed flow (NPSH)
Ventilated vane flushing stages
Dual vane flushing stages

FUTURE PUMPS

There are several types of pumping systems that may prove suitable as a two phase pumps The "Wet" style turbine stage offers a reduced centrifugal separation but has suffered from the large axial thrust load and high shut off horsepower that it draws.

Progressive cavity pumps have made some headway by controlling the fluid slip between the stages to make up for the compression of the fluid volume as the fluid progresses through the pump.

Twin screw pumps are being considered, however like the progressive cavity Moyneau, it will either have to rely on fluid slip or perfect a tapered pitch screw. It may also have the disadvantage of being unable to operate for even short periods at shut in with out special unloading devices.

CONCLUSION

There are many devices that can to aid an ESP in gassy situations. It is not necessary that these devices be used individually. Systems are in place that use as many as four of them. One combination uses a static separator intake, a dynamic separator which expels the gas and recirculates portions of the liquid, then passes the fluid to a oversized charging pump, then on to a standard pump.

Although the exact configuration of future gas handling pumps may not be known, the downhole environment dictates some of the requirements.

It must be able to operate in abrasive fluids.

It must be able to operate with large temperature variations.

It must be able to unload the kill fluid and mud from a well.

Many wells are now being successfully pumped that would have been uneconomic with standard equipment. The goal for the future is to continue to decrease the boundary for "Non Suitable" ESP operation (Fig. 5).

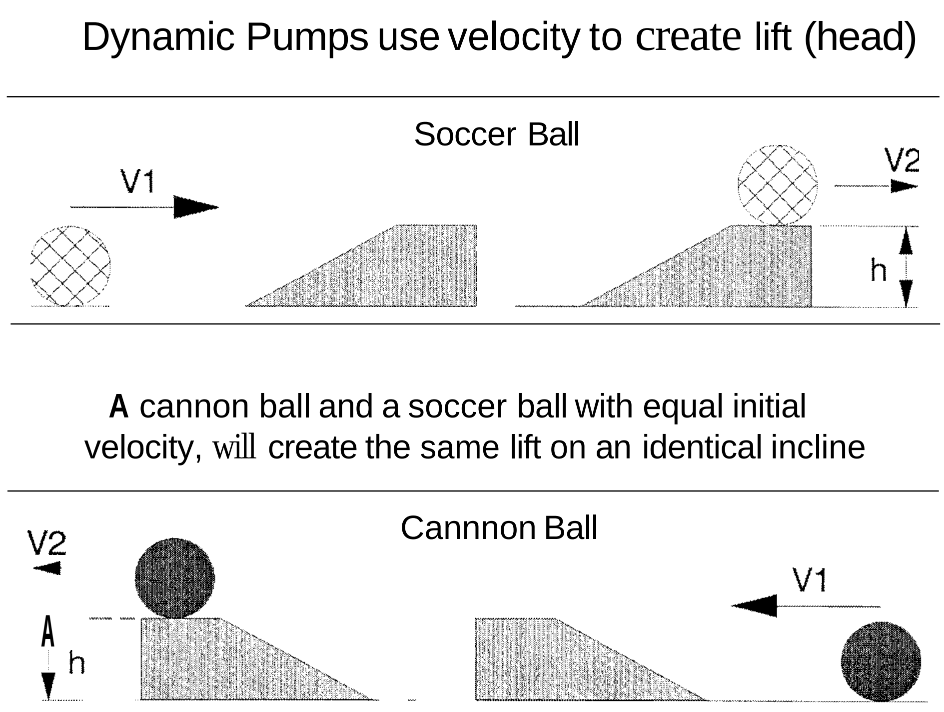

Figure 1

Dynamic Pumps use velocity to create lift (head)

The energy (pressure) of tbe cannon ball is so much larger, there is no way that the the soccer ball can displace it.

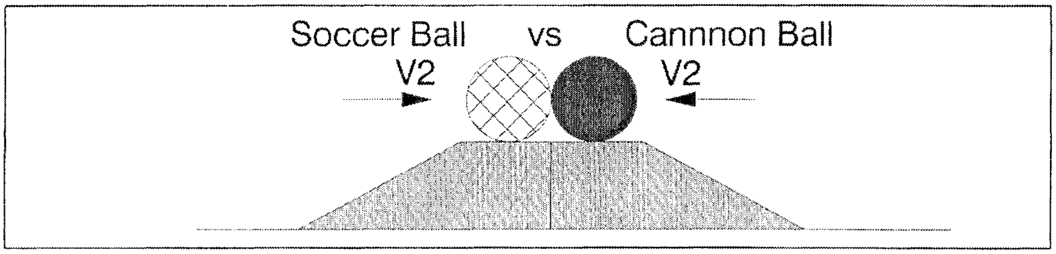

Figure 2

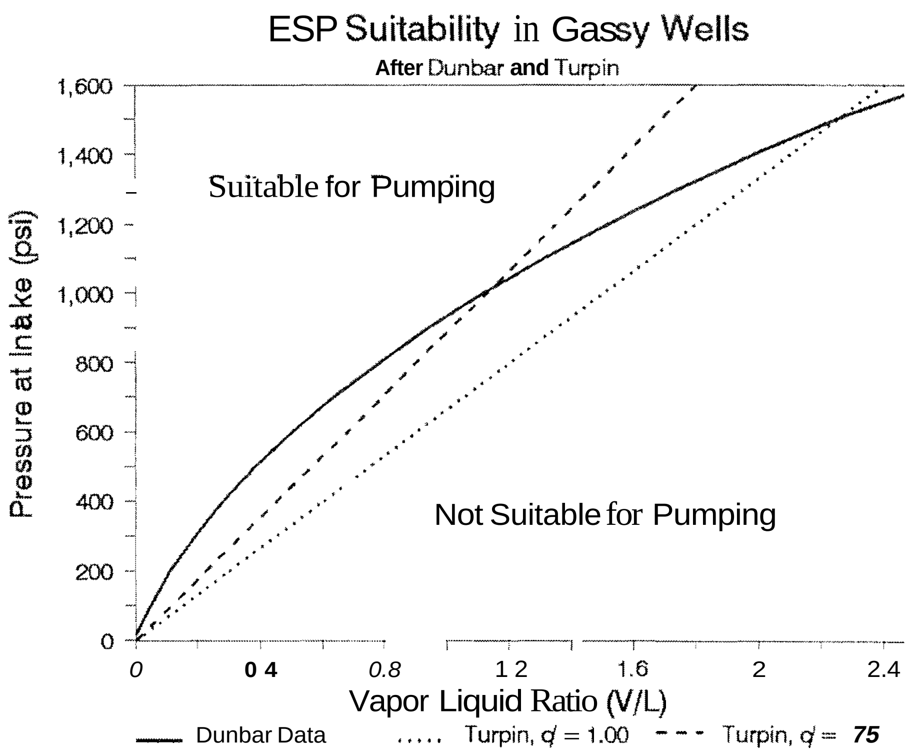

Figure 3

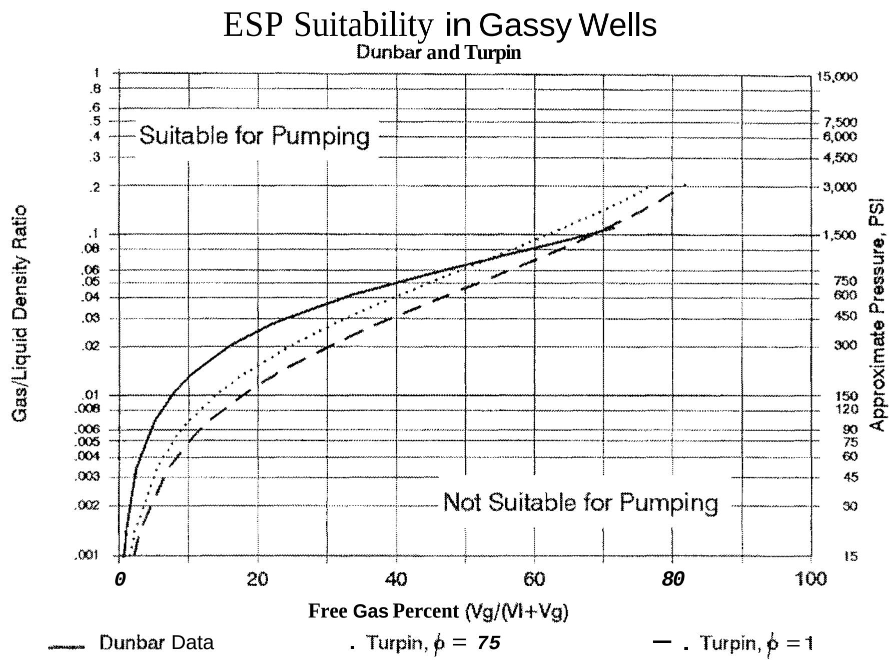

Figure 4

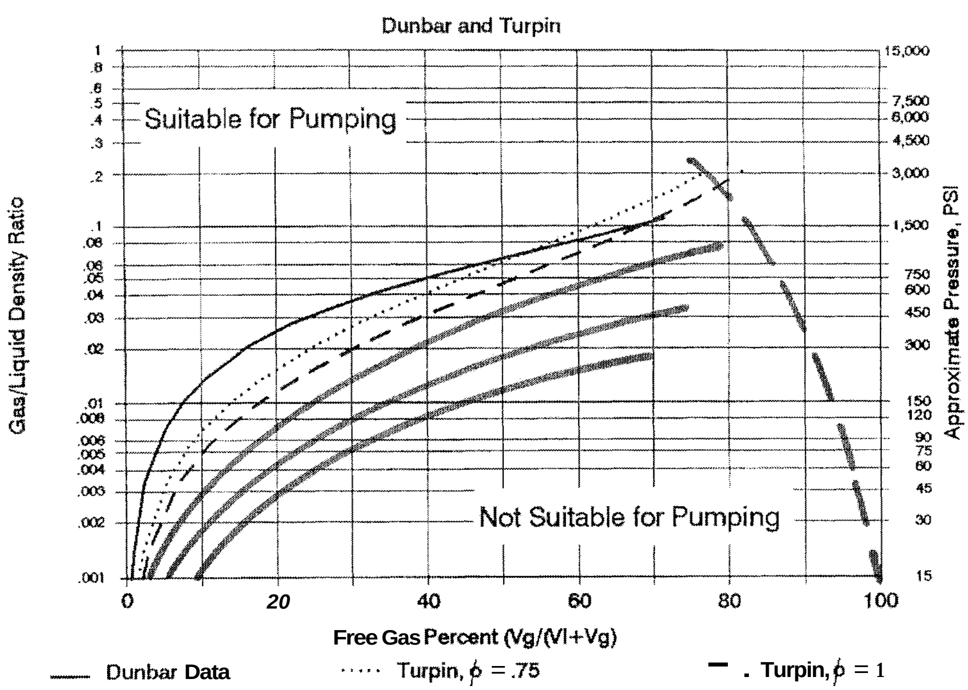

Figure 5 - EPS Production Envelope, Present and Future