# Down-Hole Gas Separator Performance Simulation Software

J. N. McCoy, Ken Skinner and O. Lynn Rowlan, Echometer Company

Kyle Marshall, Capsher Technology

Tony Podio

## Abstract

The performance of down hole gas separators is simulated in software.  Different production rates, different sizes of separators, different SPM and different gas bubble rise velocities are simulated to show the performance of different separators and different well conditions.  This simulation software is a great aid in educating personnel in the operation, performance, selection and proper design of gas separators. Knowledge and use of this software will help operators increase pump fillage and total production and also reduce operating expenses.

## Definition of Terms and Basic Operation of Down hole Gas Separators

A frequent reason for inefficient down-hole pump operation is incomplete liquid fillage caused by gas interference especially when the pump intake is set above the perforations that are producing gas and liquid. A common solution of this problem is to install, at the bottom of the tubing, a down hole gas separator (often called a "gas anchor") just below the pump intake or to configure the completion so that the pump intake is located below the gas entry point into the wellbore. These designs take advantage of natural separation due to gravity segregation of the gas and liquid phases to maximize the volume of liquid delivered to the pump intake.

**Figure 1** is a simplified schematic of what is defined as a "tubing conveyed down hole gas separator" installed above the producing formation and showing the fluids (oil, water and gas) entering from the perforations and  flowing upwards in the wellbore annulus to the separator openings. The majority of the produced gas flows past the separator inlet openings and continues up through the casing-tubing annulus to the surface[1] while the liquid and a smaller amount of gas enter the separator inner annulus. At the top of the separator outer barrel or mud anchor are several openings through which the produced liquid and some gas enter the separator and also through which the separated gas can return to the wellbore.  The dip tube is a small diameter tube inside the separator outer barrel that directs the produced fluid to the pump intake and into the pump barrel.  Inside the separator annulus there is a gas/liquid mixture with the liquid flowing down towards the dip tube suction.  The less dense fluid in the mixture, i.e. the gas, has an upward velocity relative to the denser liquid.  Depending on its size, each gas bubble in the separator annulus (annular area between the separator outer barrel and the dip tube) has an upward velocity relative to the liquid, known as the slip velocity.  The motion and position of the gas bubbles depend on the difference between the downward liquid velocity and upwards bubble slip velocity. For a given liquid flow rate and separator design, small bubbles (less than 1/16 of an inch) may be dragged by the liquid into the dip tube while larger gas bubbles (greater than 1/4 inch) may flow upwards and out through the separator ports, ultimately venting out through the casing-tubing annulus.  Therefore, the slower the liquid is moving down the smaller the volume of gas that is dragged by the liquid into the dip tube. Consequently the pump liquid fillage would be near 100%.

In this gravity separation system, the efficiency of separation of gas from liquid is controlled by the downward liquid velocity in the annulus between the separator outer barrel and the inner dip tube. The liquid velocity is controlled by two variables:

1. The actual pump displacement rate. For a rod pump this rate is determined by the plunger area, the plunger velocity and the plunger leakage.
2. The annular area between the internal diameter (ID) of the separator outer barrel and the outer diameter (OD) of the dip tube.

Field experience and laboratory studies[1-10] have shown that when the separator annular liquid velocity is less than or equal to about 6 inches per second the majority of the large (greater than1/4 inch) gas bubbles are able to overcome the drag forces caused by the liquid's downward motion and flow upwards so that mainly liquid reaches the entry to the dip tube. As the downward liquid velocity increases, above this 6 inch/second limit, a larger volume of gas is dragged down the separator annulus and into the pump. The pump's liquid fillage decreases accordingly. This concept is clearly illustrated in Figure 2 where three video snapshots are displayed for different downward liquid velocity inside the annulus of a separator (built with clear acrylic pipe 2.75 inch ID and with a 1.5 inch OD dip tube) inside clear 6 inch ID casing. When the video was taken the gas flow rate in the casing annulus was constant at about 96 MSCF/D. Liquid rate through the separator was increased gradually from zero to 420 Bbl/day. When the liquid rate is 243 Bbl/day its velocity in the separator annulus is 5 inch/second and only very small gas bubbles are seen being dragged down and into the dip tube. When the rate is increased to 275 Bbl/D the liquid velocity is about 6 inch/sec and a high concentration of bubbles has formed in the separator annuls above the entrance to the dip tube. These bubbles are in equilibrium (they do not rise or move downwards) while liquid and smaller bubbles are flowing down and into the dip tube.
 (NOTE: Copies of the original videos can be downloaded for free from the following web site: http://www.utexas.edu/ce/petex//aids/pubs/beamlift/toolbox/#downholeseparator and also will be handed out at the SWPSC with the simulation software.)

For a pumped well the downward liquid velocity in the separator annulus is determined by the ratio of the actual pump displacement rate to the separator annular area. In practical terms, a pump rate of 53.4 Bbl/day flowing in a conduit that has a cross sectional area of 1 square inch results in an average liquid velocity of 6 inches per second. For a given outer-barrel/dip-tube diameter combination, a liquid flow rate limit that results in efficient gas/liquid separation can be computed knowing the annular area. For example, a pumping well completed with 5-1/2 inch casing and 2-7/8 tubing with a separator dip tube of 1-1/4 inch outer diameter set inside a 2-7/8 perforated sub and separator outer barrel would have an annular area of approximately 3.45 square inches which would result in an efficient liquid separation capacity of 184 bbl/day. **Table 1** lists the capacities of some of the most common practical separator configurations assuming that their performance is not affected by other variables such as excessive casing gas flow rate or the installation tools causing restricted flow into the pump such as small strainer nipples or long dip tubes.

Special Pumps

Whenever the pump intake is set above the perforations in a well producing significant free gas the down hole gas separator is the principal component in determining the pump liquid fillage. For normal pump operation the percentage of liquid present in the pump barrel at the top of the upstroke cannot be larger than the percentage of liquid that the down hole gas separator delivers at the pump intake. One exception is when special pumps with a large barrel/plunger clearance or pumps with variable slippage barrels are used to fill the pump with additional liquid flowing into the barrel from the bottom of the tubing rather than from below the standing valve. Since liquid flows into the pump barrel from the tubing, the production rate from the formation is reduced. Such specialty pumps are not included in the following discussion.

Separator Pump Fillage Factor

Based on the previous description of the gravity mechanism at work in the gas separator and the operation of the pump, we can define a *Separator Pump Fillage Factor* that represents the % of liquid that a given separator with a specific design delivers to the pump intake at different displacement rates.

Given a pumping well where the casing annulus gas flow rate is significant but results in a gas superficial velocity less than 5 ft per second, then the *Separator Pump Fillage Factor* is primarily a function of only the liquid flow rate through the separator and thus of the actual pump displacement rate. For a given separator design, the pump fillage factor is a value close to 100% only for very low pumping rates where the liquid velocity is such that just very small gas bubbles reach the entrance of the dip tube. Such low rates generally are not economical and are not used in practice. As the pumping rate increases the Pump Fillage Factor decreases as shown by numerous controlled laboratory tests reported in reference 2.

The general trend of the Separator Pump Fillage Factor is illustrated in **Figure 3** for three of the separator designs listed in **Table 1**. The Pump Fillage Factor decreases slowly from 100% as the liquid rate increases. Then at some point, near the liquid rate that corresponds to the 6 inch/per second liquid velocity limit, it begins to drop rapidly .This flow rate is indicated on the horizontal axis by the colored dot markers and corresponds to the point where the Fillage Factor begins to drop below 95-97%. When the liquid flow rate exceeds this limit, the shape of the curve past this point varies slightly depending of factors such as number and shape of the openings into the separator and the flow rate of the gas flowing in the casing-tubing annulus. These effects are minor, as described in detail in Reference 2, compared to the effect of the separator annular flow area in determining the separator capacity.

For evaluation of a specific separator design or for selection of a standard off-the-shelf separator, the important quantity is the flow rate at which the separator efficiency begins to deteriorate. The actual shape of the pump fillage factor curve for rates greater than the limit does not impact on the decision about the performance of a specific separator since the objective is to design or select a separator that delivers better than 95% liquid to the pump intake.

For a given combination of plunger pump and gas separator the **net liquid pump** displacement can be computed as the product of the net plunger displacement times the Separator Pump Fillage Factor as expressed in the following relation:

$$PumpDisplacement = \frac{Separator\ Pump\ Fillage\ Factor}{100} * PlungerDisplacement$$

Where:

*PumpDisplacement* is the net pump flow rate in bbl/day.
*PlungerDisplacement* is the plunger flow rate in bbl/day, corresponding to the plunger travel, plunger diameter and pumping speed.
*Separator Pump Fillage Factor* is a number that depends on the specific separator design and the plunger flow rate.

This relation assumes that the pump-separator system does not suffer from other inefficiencies that would reduce the pump liquid fillage such as using an undersized standing valve, a small diameter strainer nipple, a screen strainer, an excessively long small diameter dip tube, or the presence of scale or paraffin that partially obstructs the intake and restricts inflow of liquid to the pump barrel.

The software described in this paper has the objective of assisting the operator in the selection of a specific down hole gas separator by computing the maximum pumping rate that keeps the pump barrel at a liquid fillage greater than 95% and displaying a quantitative animation of the operation of the separator. The best suited separator is one that results in the greatest flow rate for a fillage factor of 95%.

Simulation and Visualization of Down-Hole Gas Separator Operation

Although the basic principles of down hole gas separation described in the previous section are relatively simple, the interaction between the plunger pump operation and the separator are somewhat difficult to visualize since it involves dynamic effects of multi-phase flow. The flow of the liquid and the gas within the separator is intermittent and dependent on the motion and velocity of the pump plunger.

Referring to Figure 1, during the plunger upstroke fluid is removed from the lower portion of the gas separator through the dip tube and is delivered to the pump intake. During the same time, liquid and gas flow from the casing annulus through the separator openings into the separator annulus. Whenever the casing annular gas flow rate is significant it causes lots of turbulence and creates a mixture of liquid with gas broken up into bubbles of various sizes. The amount of gas that enters the separator with the liquid is dependent on the pumping rate and the percentage of gas and liquid that are present in the casing annulus. This percentage of gas and liquid can be estimated easily by analyzing acoustic fluid level records that include measurement of casing pressure buildup rate.

As the liquid inside the separator is moving downwards, it drags a certain amount of gas bubbles towards the bottom of the separator at a net velocity that is equal to the liquid velocity minus the gas bubble slip velocity. For example, the duration of the plunger upstroke for a pumping speed of 10 strokes per minute is approximately 3 seconds (assuming a conventional beam pump). Assuming that for the current pumping speed the liquid is moving down at an average of about 6 inches per second it would travel a distance of 18 inches from the bottom of the separator openings by the end of the plunger upstroke. Small gas bubbles that have an upwards slip velocity of only 2 inches per second will have an average downwards net velocity of 6-2=4 inches/second and will be dragged down a distance of 12 inches from the bottom of the openings by the end of the plunger upstroke. Large bubbles that have a slip velocity greater than 6 inches per second inches per second would not be dragged down towards the bottom of the separator annulus.

During the approximate 3 second duration of the plunger down stroke, the flow of liquid into the dip tube and the pump stops and the downward velocity of the liquid in the separator annulus becomes zero. The small gas bubbles will rise at a rate of 2 inches per second (the liquid is at rest) to a distance of 6 inches from their current position. At that time they still will be located inside the separator annulus at 6 inches below the bottom of the separator openings. During the next plunger upstroke they will be dragged further down another 12 inches and reach a point 24 inches from the openings. This process will continue until the small bubbles eventually will reach the entrance to the dip tube (regardless of the length of the dip tube) and will flow into the pump. Those bubbles that have a slip velocity greater than 6 inches per second will not be dragged below the bottom of the separator openings and will exit through the separator openings. Most gas bubbles that are in the separator annulus below the bottom of the ports at the beginning of the upstroke will eventually be drawn into the pump.

This model of the flow mechanism inside the separator annulus is much simplified since the velocity of the pump plunger is not a constant but goes from zero to a maximum at about the middle of the upstroke and then back to zero at the top of the stroke. Also the flow into the pump barrel occurs only during the time when the standing valve is open. The operation of the standing valve is controlled by the difference in pressure between the pump barrel and the pump intake which does not necessarily occur from the beginning to the end of the plunger upstroke. **Figure 4** displays the detailed analysis of a dynamometer record acquired in a pumping well where the pump liquid fillage was about 94%. The figure on the left shows the actual instantaneous plunger velocity (green line) during one stroke for a rod pump operating at about 7 strokes per minute. From inspection of the pump dynamometer card for this stroke, displayed at the bottom right, we can see that the tubing is not anchored and the pump barrel is filled with liquid. Notice that the plunger velocity starts at zero, increases slowly then speeds up (at point where the SV opens) then peaks at about 55 inch/sec at about 3.1 seconds. The plunger then slows down as it reaches the top of the stroke where the standing valve closes. Knowing the plunger area and the cross sectional area of the separator annulus one can compute the instantaneous velocity of the liquid moving down inside the separator. The corresponding value for this upstroke is plotted on the graph as the black curve. The liquid velocity in the separator annulus is plotted as a negative value indicating liquid is moving down. The velocity is zero until about 1.9 seconds when the standing valve opens, then reaches a maximum of about -

17 inches/second then back to zero when the standing valve closes at about 4.1 seconds. Therefore downward flow of liquid in the separator annulus occurs only during (4.1-1.9) = 2.2 seconds out of the 8.6 seconds of the total stroke period. This means that the liquid in the separator annulus is practically stationary during 6.4 seconds which is the time available for gas bubbles to slip upwards and out of the separator. The simplified separator model discussed earlier considers that the liquid's "quiet" time would be one half of the stroke period, or only 4.3 seconds.

This illustrates the need to couple a realistic model of the plunger operation and the separator flow model in order to correctly evaluate the liquid capacity of a specific separator design. However, for separator design and comparison purposes it is sufficient to represent the plunger velocity function with an approximate but realistic model that corresponds to the type of pumping unit used. (Note: a more accurate separator design application could use the plunger velocity function that could be exported from the QRod program)

**Figure 5** shows the generalized liquid inflow profile that is a default option in the simulation software presented in this paper. It assumes that the pump is operated by a beam pump and that operation of the standing valve follows a normal pattern so that downward liquid flow in the separator annulus occurs during about 43% of the pumping period. The maximum flow rate corresponds to about 3.77 times the average plunger displacement rate assuming the pump is full of liquid at the top of the pump stroke. The trapezoidal shape is derived from studying the plunger movement observed in a large number of dynamometer cards in wells producing at significant rates and with no gas interference. Future versions of the application will include the ability to specify or import different plunger velocity profiles such as for linear motion pumping units and progressing cavity pumps.

Gas Separator Simulation Application
To evaluate the performance of the separator it is necessary to simulate the operation of the combined system consisting of the separator, the down-hole pump and the pumping unit, in conjunction with the operating parameters. The characteristics of the system have to be defined by the user through input data provided to the application.

The objectives of the application are:

- Provide to the user a tool to easily compare the probable performance of different designs pumping system combinations and fluid properties.
- Present results in a simple and graphical format.
- Visualize the effect of modifying separator and pumping system parameters on the performance of the gas separator.
- Facilitate data input and user interaction with software

**Figure 6** shows the display screen presented to the user for input of the simulation parameters. Data shown are default values representing a system that is commonly used by most operators and include:

- Casing size
- Separator Type
- Separator outer barrel OD and ID (inches)
- Dip Tube OD and ID (inches)
- Dip Tube Length below separator annulus inlet openings (inches)
- Gas Bubble Slip Velocity (inch/second
- Production rate (Bbl/day)
- Pumping speed in strokes per minute

To facilitate interaction with the application a number of preset separator types are included in the pull-down menu so the user only has to choose from the following:

- Collar Size Separator (Echometer)
  - o   2 3/8 inch collar size separator

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- o 2 7/8 inch collar size separator
- o 3.5 inch collar size separator

- Poor Boy Separator
  - o 2 3/8 inch poor boy with 8 foot dip tube and 4 ft perforated nipple.
  - o 2 7/8 inch poor boy with 8 foot dip tube and 4 ft perforated nipple.

- Custom Separator
  - o Dip tube length below separator inlet (default  4 ft)
  - o OD of gas separator outer barrel
  - o ID of gas separator outer barrel
  - o OD of dip tube
  - o ID of dip tube

The user can accept the preset values or input his particular design and operating conditions.

 Once the pumping/separator system has been defined the simulation is executed by clicking on the large green button on the top which starts pump operation and switches to the separator visualization and animation screen shown in **Figure 7** where the user can see observe in real time the distribution and flow of the gas and liquid in the separator.  In the figure, one can observe that when a particular separator is operating near capacity, mostly liquid occupies the lower portion of the separator annulus and mostly gas is in the upper part with a net gaseous/liquid interface at about 3/4 of the distance from the separator openings to the entrance to the dip tube. This interface oscillates up and down as the plunger strokes but it never reaches the bottom of the dip tube so that only a minimal volume of gas reaches the pump intake. For this example this condition occurs at a pumping speed of about 7 SPM with a corresponding pump displacement of 100 Bbl/day. From this screen the user can start and stop the pump and change the pumping speed so as to observe the effect of SPM on the separator's performance and the position of the gas bubbles within the separator annulus. The liquid rate that corresponds to a particular condition is displayed in real time and a warning message is shown when the gas breaks through into the bottom of the dip tube and into the pump.

The simulation and visualization software lets the user make adjustments to the separator design in order to develop the best arrangement for the particular well conditions. Returning to the input the separator parameters can be easily modified and the new results observed in the animation screen.

The separator simulation application can also be valuable in training of personnel that are involved in monitoring and optimizing the operation of pumping wells.

Field studies will be conducted with operators in specific areas to determine the recommended bubble slip velocity to be used for wells in that area.

Following are the principal assumptions that have been considered in the development of the simulation:
- A gaseous fluid column exists above the pump and separator ports.
- The dip tube and standing valve are properly sized and installed for minimum pressure drop so gas is not released from oil in the dip tube and in the pump intake standing valve flow path.
- The plunger does not leak excessively.
- The Production Rate that the operator enters is the actual production rate which would also be the pump displacement assuming 100% pump fillage and minimum plunger leakage.

These conditions must be satisfied for the simulation to provide a reasonably accurate representation of the operation of the separator.

The *Down-Hole Gas Separator Simulation and Visualization* is a free application for Windows OS that can be downloaded from the Echometer web site www.echometer.com.

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## Down-Hole Gas Separator Design Recommendations

The following summary recalls some of the most important concepts about down hole gas separator design that have been developed over numerous years of field experience and laboratory testing [1-9].

- Maximize the size of the separator annular area to maximize the separator liquid capacity.

- Using a mud anchor with thin walls increases the size of the separator annular area. But efforts should be made to ensure that the mud anchor walls have the necessary strength.

- For gravity-driven separators in low viscosity fluid applications, good gas-liquid separation occurs when the superficial downward liquid velocity inside the separator is 6 in/second or less. The separator pump fillage factor decreases rapidly when this liquid velocity is exceeded.

- Excessive gas velocity in the casing annulus reduces the separator performance since it prevents liquid from entering the separator openings. The annular area between casing and separator should be large enough so that gas velocity in the casing annulus is less than 10 ft/sec.

- A long dip tube can be detrimental. A 5.5 ft long dip tube is enough for efficient gas separation for gravity-driven separators. The dip tube should extend about 4-5 feet below the separator inlet openings.

- The inner diameter of the dip tube should be sufficient to minimize the overall pressure drop through the separator.

- Under laboratory conditions[2], increasing the total area of the openings into the separator to over 65% of the separator outer barrel-dip tube annular area does not considerably improve the separator efficiency.

- Multiple rows of opening are not necessary. Additional rows should only be considered if port plugging is anticipated.

References

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11) Contacts: Tonypodio@aol.com  Jim@echometer.com

Table 1 – Efficient Operation Capacity of Typical Down-Hole Gas Separators

| Separator Type | OD barrel, inch | ID barrel, inch | OD dip tube, inch | Annular Area $in^2$ | Efficient Operation Capacity Bbl/day |
|---|---|---|---|---|---|
| 2-3/8 Poor Boy | 2.375 | 1.990 | 1.320 | 1.76 | 94 |
| 2-3/8 Collar Size | 3.000 | 2.750 | 1.320 | 4.57 | 244 |
| | | | | | |
| 2-7/8 Poor Boy | 2.875 | 2.441 | 1.660 | 2.51 | 134 |
| 2-7/8 Collar Size | 3.750 | 3.500 | 1.660 | 7.45 | 398 |
| | | | | | |
| 3-1/2 Poor Boy | 3.500 | 2.990 | 1.900 | 4.18 | 223 |
| 3-1/2 Collar Size | 4.500 | 4.250 | 1.900 | 11.34 | 606 |

Figures
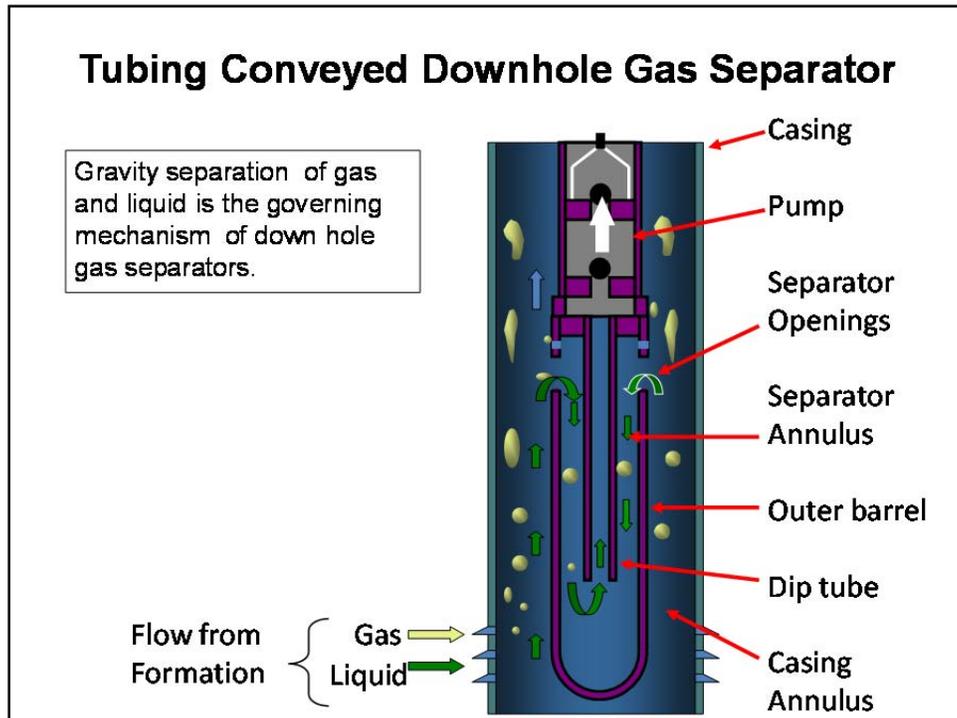


Figure 1 – Schematic Diagram and Definition of Terms for a Tubing Conveyed Down Hole Gas separator[1].
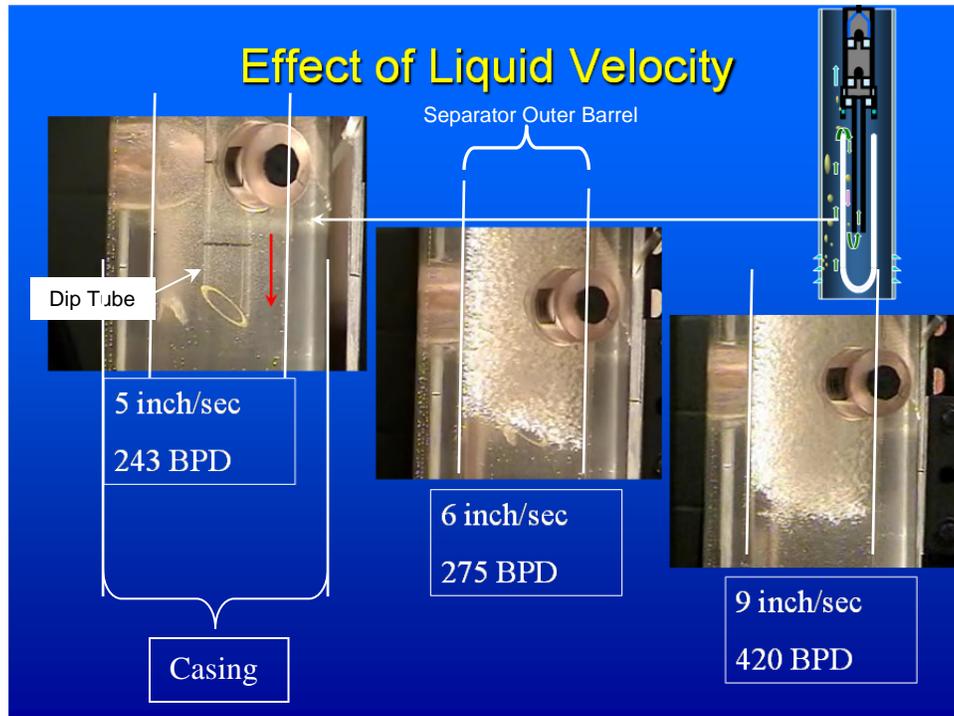
Figure 2 – Video Snap-shots of Gas Bubble Concentration[2] in Separator Annulus as a Function of Downward Liquid Flow Rate for Annular Area of 5.15 in$^2$
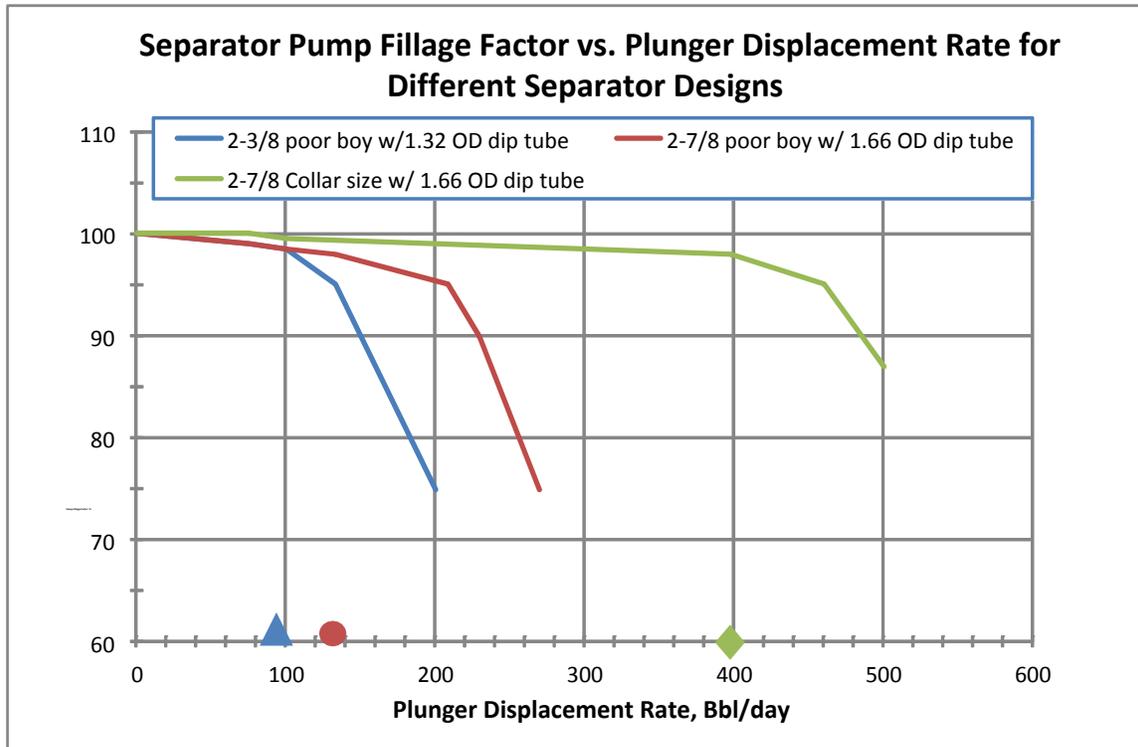
Figure 3 – Pump Fillage Factor as a Function of Plunger Displacement Rate for 3 Separator Designs. (Colored markers on horizontal axis indicate individual separator capacities from Table 1)
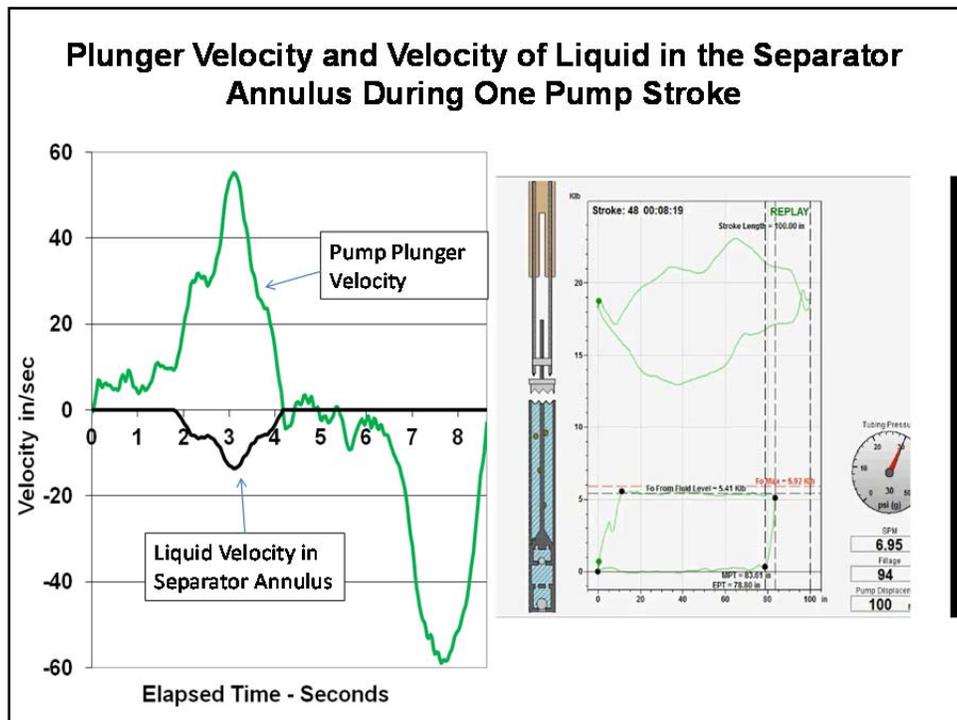
Figure 4 – Pump Plunger Velocity and Velocity of Liquid in Separator Annulus for Conventional Beam Pump Operating at 6.95 Strokes per Minute.
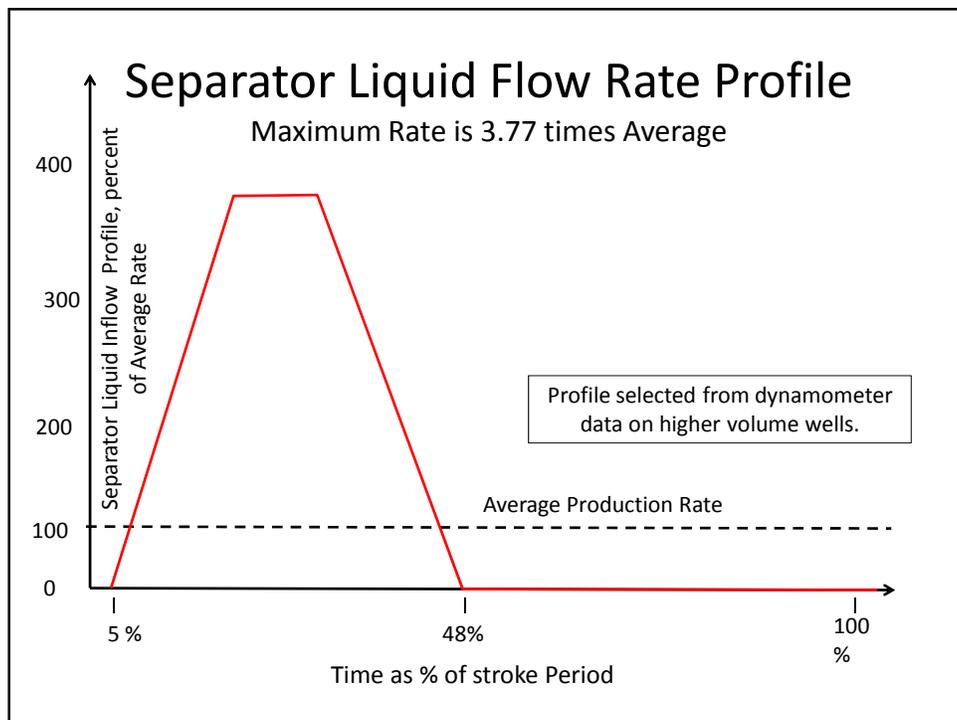


Figure 5 – Generalized Liquid Inflow Profile for Separator Simulation

Figure 6 – Simulator Input Screen for Definition of Gas Separator Dimensions and Pumping System and Fluid Properties.
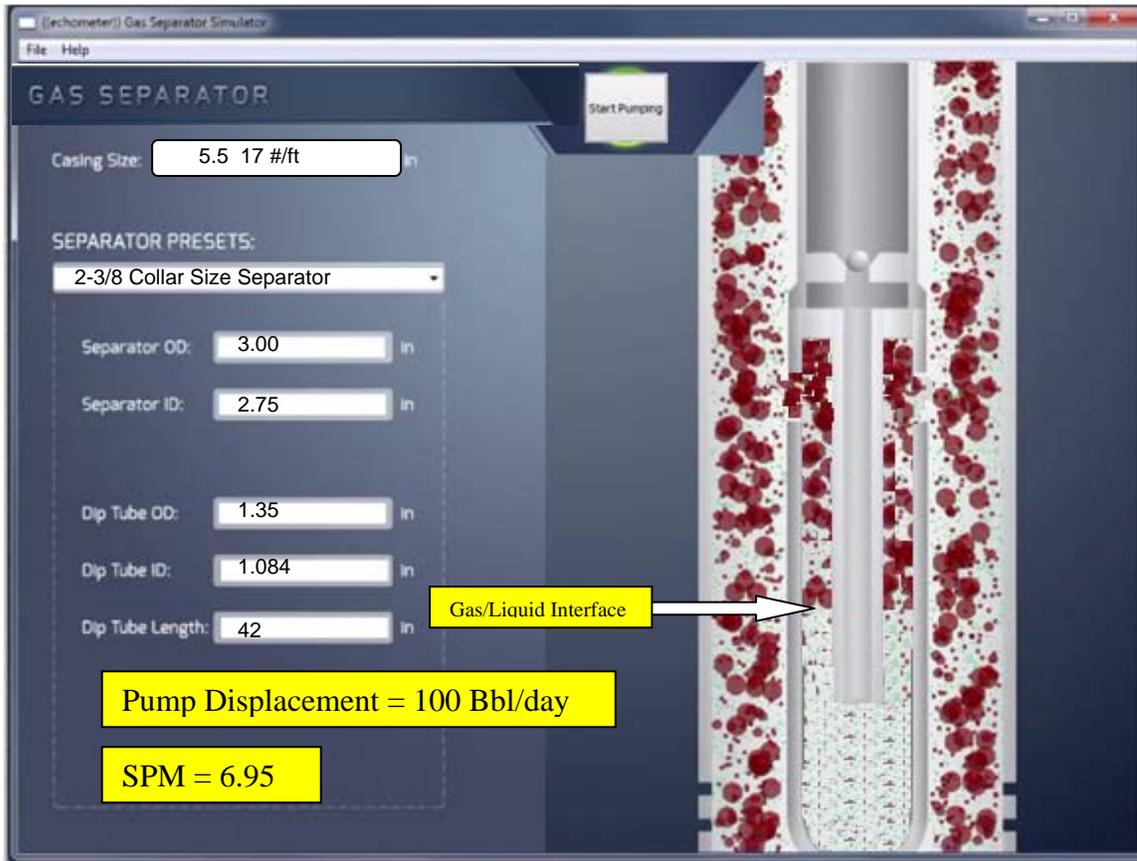
Figure 7 – Separator operation simulation and visualization screen.