DESIGN AND FIELD TESTING OF A DECENTRALIZED, CONTINUOUS-FLOW DOWNHOLE GAS SEPARATOR

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ABSTRACT

A gas separator has been developed and successfully field tested in several beam pumped wells which were subject to severe gas interference.
The new design is based on several innovations:

- Decentralization of the gas separator in the casing, insures that a minimum amount of gas enters the separator.
- The presence of two or more ports located on the narrow side of the annulus where the gas separator touches the casing wall.
- Sizing the OD of the outer tube of the separator so that it is equal to or greater than the OD of the tubing collars.
- The addition of a diverter at the bottom of the separator to direct most of the gas flow towards the wide side of the annulus.

These innovations have resulted in a gas separator efficiency much greater than that of conventional designs.

INTRODUCTION

Numerous studies have been performed in recent years in an attempt to improve the performance and efficiency of a beam pumped system. See references 1 through 8. The studies include the motor or power unit, the surface pumping system, the rod string and the downhole pump. In wells which produce gas, the inefficient separation of gas from liquid at the pump inlet often results in very poor pump performance and low overall efficiency of the entire pumping system. This can be verified by obtaining a dynamometer pump card on a well which indicates considerable free gas in the pump even though liquid is present in the casing annulus in the form of a high gaseous liquid column.

Terminology
When discussing handling downhole gas in pumped wells there appears to be various terms which are used indiscriminately: gas anchor, mud anchor, dip tube, perforated sub, etc. In order to avoid confusion, the terminology adopted in this paper is as follows:

- Gas Separator: The complete assembly of elements installed below the seating nippleand the pump intake with the purpose of minimizing the amount of gas entering the pump.
- Outer Barrel: The outermost element of the gas separator and which is connected to the tubing. (often called mud anchor)
- Dip Tube: The innermost element of the gas separator and which is attached to the pump intake. (often called gas anchor)

"Natural" Gas Separator
The preferred technique for separating gas from the pump is to place the tubing fluid entrance ports (or gas separator ports) below the bottom of the formation's perforated interval as shown in Figure 1. The natural separation of gas and liquid by gravity will result in relatively gas-free liquid entering the pump intake if the downward liquid velocity in the casing/tubing annulus is less than approximately 6 inches per second. The gas separator inlet should be placed at least 10 feet below the formation gas entry zone to allow free gas separation from liquid between the tubing O. D. and the casing I. D.. See Table 1 for natural gas separator capacities.

For greater capacity, it is necessary to use a modified gas separator with an outer diameter smaller than the tubing. See Figure 2. When additional gas separation capacity is needed, the tubing can be run open-ended with a seating nipple on the bottom; and a 1-1/4" by 10 feet dip tube is used below the pump. The dip tube opening must be at least 10 feet below the formation producing interval. This permits removal of the dip tube with the pump to allow inspection for clean perforations.

"Poor Boy" Gas Separator
In many wells, the gas separator perforations cannot be placed below the bottom perforated interval. This may be due to lack of hole, sand fillage, operator preference, obstructions, or other reasons. When the pump inlet is placed in or above the formation perforated interval, a gas separator should be used below the pump in wells which produce free gas. This helps to separate the gas from the liquid in an effort to fill the pump with liquid instead of gas.

Please refer to Figure 3 which shows the operation of a downhole pump. On the upstroke, gas and liquid normally flow into the pump due to wellbore pressure. The volumes of oil and gas that are forced into the pump depend upon the fluids surrounding the inlet to the pump. On the downstroke, the lower valve is closed, and fluid does not enter the pump.

Figure 4 is a drawing of a "Poor Boy" gas separator. This gas separator consists of an outer tube which is attached at the upper end to a collar that is immediately below the seating nipple. The lower end of the tube is closed. Holes are present in the upper portion of the tube. A dip tube extends from the pump downward into the outer tube. Gas and liquid enter the holes in the outer tube. The liquid falls to the bottom of the outer tube annulus and is drawn into the pump through the dip tube. The gas separator can be "modified" to have an outer tube diameter greater than the tubing diameter. Many papers (References 9-21) have addressed the problem of a high downward liquid velocities dragging gas bubbles with the liquid. Reducing the average downward flow rate of liquid in the gas separator annulus to less than approximately 6 inches per second will allow gas to flow upward and be liberated from the liquid.

In the particular example however, one set of perforations surrounding the gas separator is shown as the fluid entry point from the casing annulus into the gas separator. Flow will occur into the chamber during the upstroke because the pressure in the casing annulus is always greater than or equal to the pressure inside the gas separator. As the pump removes liquid from the gas separator, additional fluid will be forced into the gas separator. During the downstroke if there is sufficient pressure inside the gas separator, gas will flow out of the upper perforations and when the pressure reduces to a value equal to or less than the casing annulus pressure, some liquid will enter through the lower perforations. For large gas fractions it may not be possible for all the gas to escape from the separator and gas will be drawn into the pump. Even though the gas separator annulus allows separation of the gas and liquid, during the upstroke the pump will draw the liquid into the pump first with gas following the liquid.

CONTINUOUS FLOW GAS SEPARATOR

The majority of published studies related to downhole gas separator design have been primarily concerned with the problem of allowing gas to evolve from the separator chamber before it is drawn into the pump intake. Thus guidelines have been expressed in terms of liquid velocity and number of pump volumes for adequate retention time. The design that is proposed in this paper addresses instead the problem from the standpoint of minimizing the amount of gas that enters the separator and sizes the separator as a function of both the liquid and gas rates that are present in the wellbore.

Effect of Eccentricity

Visual studies (References 22,23,24) of multi-phase flow in clear Lucite tubes have shown that large gas bubbles normally exist in gaseous liquid columns, such as gaseous liquid columns in the casing annulus of an oil well, where the liquid remains in the annulus but gas flows through the liquid column and is produced at the surface. When the inner tubing is concentric with the casing, the gas distribution will be uniform throughout the annular area. When the tubing is pushed against one side of the outer casing, so as to form an eccentric annulus, gas will flow preferentially in the larger side of the annulus. Liquid concentration will be higher in the narrow portion of the flow stream where the two tubes are nearly touching. A continuous circulation of fluid takes place with liquid being entrained from the narrow side into the high-velocity wide side, then carried upwards some distance and then as the gas slips through, the liquid is shed back to the narrow side. The liquid near the narrow side of the annulus then moves downwards under its own hydrostatic and eventually is re-entrained into the wide side of the annulus.

A similar condition will occur in a pumping well if the gas separator is pushed against the casing wall using a decentralizer that is welded or fixed to the gas separator. Decentralization forces the gas separator against the casing wall so that an enlarged area exists on one side of the gas separator allowing gas flow upward. Locating the fluid ports (A and B) diametrically opposed to the decentralizer places them in the region of the wellbore which has a higher concentration of liquid. Thus the fluid entering into the separator's quieting chamber will have a much lower concentration of gas than if the separator were concentrically located inside the casing.

During the pump upstroke, fluid is removed from the lower portion of the gas separator annulus through the dip tube. Fluid (both liquid and gas) will flow into the gas separator annulus through the upper port. The liquid and large gas bubbles will tend to separate with the liquid falling into the quieting chamber and the gas flowing upward toward the port. The lower portion of the gas separator annulus below the lower port acts as a quieting chamber where some gas bubbles are released from the downward liquid flow if they are sufficiently large. If the average downward liquid flow rate (including upstroke and downstroke) is less than 6 inches per second, gas bubbles will migrate upward and be released from the downward flowing liquid. On the pump upstroke, the liquid in the gas separator annulus may fall at a rate of 10 inches per second. During this liquid drop, the gas bubbles will be rising at a rate of approximately 6 inches per second relative to the liquid flow. So, free gas will be released from the liquid even though the liquid fall rate exceeds 6 inches per second during the pump upstroke.

Sufficient distance between (A) and (B) insures that a sufficiently large hydraulic head is established that will maintain the flow-through characteristics. The average gradient of the fluid in the separator is significantly higher than that of the gaseous fluid column in the wide section of the casing annulus. This insures that fluid will continually flow from the top port to the lower port even during the pump's downstroke. Above the upper port, gas will accumulate in the dead space sealed at the top by the landing nipple. Any large gas bubble that enters the separator will rise to the top and exit through the upper port. The smaller bubbles (with negligible slip velocity) will be entrained by the liquid flowing downwards towards the dip tube inlet. A portion of the fluid will exit from the lower port, carrying with it the small bubbles, and only the fluid volume corresponding to the pump's upstroke displacement continues downwards towards the dip tube inlet. During the downstroke, the fluid below the lower port will be at rest with some of the larger bubbles rising and exiting, while flow of fluid will continue between the top and the lower port. This mechanism insures that as long as there is liquid in the annulus above the landing nipple, the gas separator's quieting chamber will remain filled with liquid and that the gas concentration in this liquid will be at a minimum. If the pump capacity is greater than the well's inflow rate, then the fluid level in the annulus will fall below the lower port and a pumped-off condition will be established.

Figures 6 and 7 are examples of gas separators which can be made using thin wall tubing as a means to increase the flow areas to a maximum.. A bow spring decentralizer is used to place the inlet/outlet ports in the area of high liquid to gas ratio.

Continuous Flow Gas Separator Capacity

The gas separator capacity must equal or exceed the pump capacity for efficient pump operation. The capacity of the various gas separators is given in Table 2. While many assumptions are made in the design of these gas separators, the following average conditions were assumed. First, a gradient of approximately 0.1 PSI per foot is present in the gaseous liquid column in the large side of the casing annulus. Such an aerated liquid column will have oil with gas migrating upward with a ratio of gas volume to liquid volume of five or more to one. Second, free gas is assumed to be liberated from liquid if the average downward liquid flow rate is less than 6 inches/second. Third, the volume of the gas separator quieting chamber below the lower port is to be at least equal to the pump stroke volume. The distance between the lower and the upper gas separator ports should be sufficient to result in a hydrostatic head sufficient to maintain the continuous flow of fluid. Yet the distance should be short enough that the pressure drop that occurs inside the dip tube between the lower inlet port and the pump is a minimum. The liquid that is flowing upward in the dip tube should not be subjected to a large pressure drop which will liberate gas and force gas entry into the pump. For the dip tube sizes suggested in Table 2 the frictional pressure drop was calculated to be less than 1 psi at the indicated capacities. The gas separator length is minimized to locate the gas separator inlet port and pump as low in the hole as possible in an attempt to maximize the production from the well. Figure 8 shows recommended internal dimensions as a function of pump rate.

The annular gas flow velocity controls the liquid fraction present in the annulus. At large gas flow velocities it is possible to carry liquid droplets past the separator ports reducing the liquid fallback even in the narrow side of the annulus. This will reduce the rate at which liquid can enter the separator and will result in partial fillage of the pump. It is thus necessary to balance the available wellbore space between the area required in the annulus, which is a function of gas rate, and the area required inside the gas separator, which is a function of pump capacity. A study is in progress, with the objective of obtaining field data to develop practical guidelines for solving this problem.

Pump Spacing

Oftentimes, a gas locked condition can be helped by lowering the traveling valve so that a higher compression ratio is obtained in the pump. Lowering the traveling valve to a position close to the standing valve at the bottom of the downstroke will tend to force pump action more often because the traveling valve will open when the traveling valve "hits" the liquid in the pump or when the gas in the pump is compressed to a pressure greater than the pressure above the traveling valve. Lowering the traveling valve near the standing valve does not improve the gas separator efficiency however. If the gas separator does not efficiently separate gas from the liquid that enters the pump, the pump will still perform inefficiently regardless of the traveling valve/standing valve spacing.

Construction Details

In order to achieve the maximum benefits derived from decentralization it is necessary that the outer tube be in contact with the inner wall of the casing. Unless a specially built eccentric coupling is used, the outer tube OD must be larger than or equal to the tubing collar OD.

A bow spring decentralizer is welded to the gas separator to position the inlet port against the casing, and the spacer width plus the gas separator OD should not exceed the minimum ID of the heaviest wall casing in the well. Port sizes are shown on the table. The mud separator should be plugged at the bottom by welding the collar inside the thin wall pipe. This prevents sand from accumulating above a collar which would possibly hinder removal of the gas separator. The gas separators are constructed such that if both the inlet and outlet ports are covered with sand and thus fluid entry into the pump is stopped, a diameter larger than the mud separator does not exist in the sand fillup region which might make pulling more difficult. The total length of the gas separator varies from 8 to 16 feet depending on desired capacity. The bottom of the dip tube is positioned within one foot of the bottom of the gas separator.

Field Applications
Initially two continuous flow gas separators were built and tested in the following wells:

Well X - Recent Spraberry recompletion

Before:
Originally outfitted with a conventional poor boy gas separator. Fluid level near the surface. Gaseous annular liquid column. Well would not pump after a pump change. Numerous dynamometer cards indicated severe gas interference. Tubing intake at mid perfs with seating nipple at 7015.

After:
Tubing was re-run with Decentralized Continuous Flow gas separator. Seating nipple set at 6975. After one week well was producing 286 barrels of liquid and 33 MCF per day.

Well Y - Gas locking history

Before:
Well on pump-off control running 14 to 18 hours per day.

After:
Installed Decentralized Continuous Flow gas separator. Well produces same fluid volume in 3 hours per day. Full pump cards when pump is operating.

Figures 9A and 9B show dynamometer cards from a problem well before and after installation of the decentralized gas separator. The upper chart shows surface dynamometer cards over a one minute time interval. Note the variation in pump fillage before installation of the gas separator. Below the one minute recording of surface dynamometer cards is a four screen analysis showing a single surface card (stroke number 7) and the related pump card which shows a pump fillage of 44%. Figure 9B shows the same information after installation of the decentralized gas separator. The surface dynamometer card shows consistent operation and the pump card indicates 97% fillage.

Installation of the decentralized continuous flow gas separator in over 20 wells has shown that in all cases either the production increased significantly (24% average increase) or the average run time was reduced while producing essentially the same or larger volume of fluid. Figures 10 and 11 show the results for a representative sample of wells.

CONCLUSIONS

In wells which produce gas up the casing annulus, the pump efficiency can often be significantly improved by utilizing a better downhole gas separator. In the past, many different gas separators have been run with varied success. The gas separator designs presented in this paper offer efficient and proven gas separators. The drawings, dimensions, capacities, tables and figures are presented to aid in the selection of a gas separator which has a capacity equal to or greater than the calculated pump capacity.

These gas separators have been tested using production tests, dynamometer equipment and acoustic liquid level measurements to verify the performance and capacities of the systems.

FUTURE WORK

In order to further develop the design criteria for downhole separators, a laboratory setup has been developed at the University of Texas at Austin, department of Petroleum and Geosystems Engineering. The facility permits visual observation of annular flow into a pumping well at various gas and liquid rates. It consists of a 5 inch clear plastic casing suspended from the wall of a laboratory which spans the six floors of the building (total height 60 feet) and inside which is installed a 2.5 inch clear plastic tubing. A rod pump (1.5 inch diameter plunger) is landed at the bottom of the tubing. The rod pump is driven by a conventional beam pump capable of 30 inch stroke and powered by a variable speed motor. Synthetic mineral oil is pumped from the well into a surface tank and then recirculated to the wellbore. CO_2 gas can be injected at various rates at the bottom of the well to simulate the effect of gas flow into the annulus. Further studies are in progress with the objective to determine the optimum separator configuration. Anyone interested in visiting this facility and/or participating in an ongoing study group is welcome to contact A. L. Podio at 512-471-3161.

ACKNOWLEDGMENT
The authors express their appreciation to Mobil Exploration and Production US Inc, for permission to publish this paper.

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Table 1 - "Natural" Gas Separator
Capacities in BPD

	1-1/4" separator	2-3/8" Tubing	2-7/8" Tubing
4 - 1/2 inch Casing	550	430	320
5 - 1/2 inch Casing	925	800	700
7 inch Casing	1550	1400	1300

Table 2 - Downhole Gas Separator
Dimensions and Capacities

Tubing or Line Pipe Size, inch	3" O. D.	3-5/8" Thin Wall	5" Thin Wall
Collar OD, inch	3.068	3.668	
Outer Barrel OD, inch	3.0	3.625	5.000
Outer Barrel ID, Inch	2.81	3.375	4.750
Dip Tube Size, nominal	1	1-1/4	1-1/4
Dip Tube OD, inch	1.315	1.315	1.660
Dip Tube ID, inch	1.088	1.088	1.440
Decentralizer-Outer Barrel OD, inch			
For 4-1/2" (3.920 ID)*	3.8	-	-
For 5-1/2" (4.670 ID)*	4.6	-	-
For 7" - 23 # (6.365 ID)	6.25	6.25	6.25
Port Size, Inches	2.8x2.8	3.3x3.3	4.7x4.7
CAPACITY, BPD	275	400	825

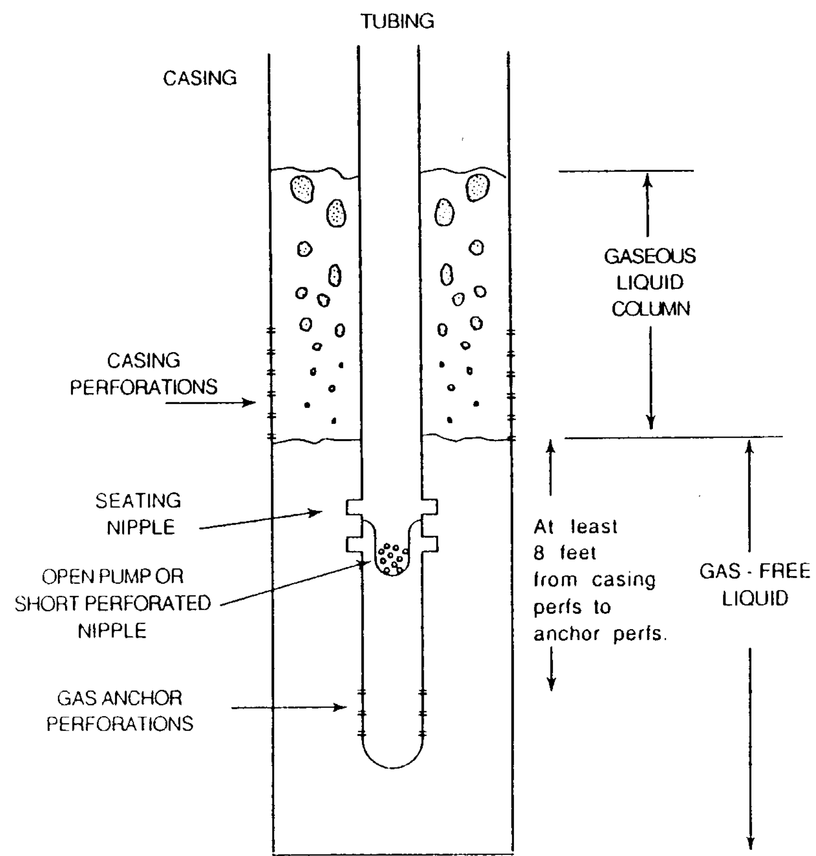

Figure 1 - Natural Gas Anchor

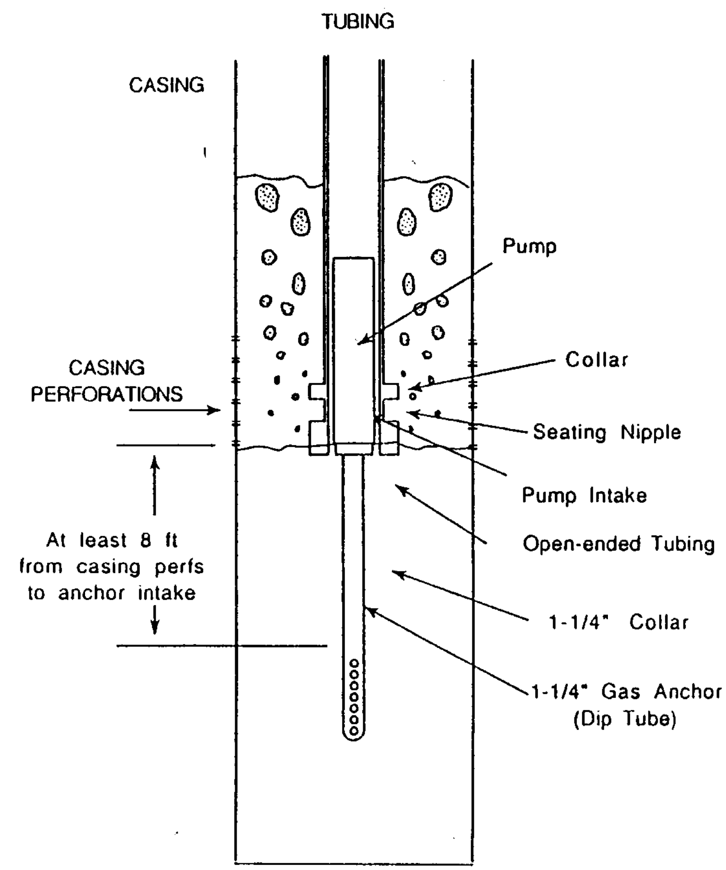

Figure 2 - Modified Natural Gas Anchor

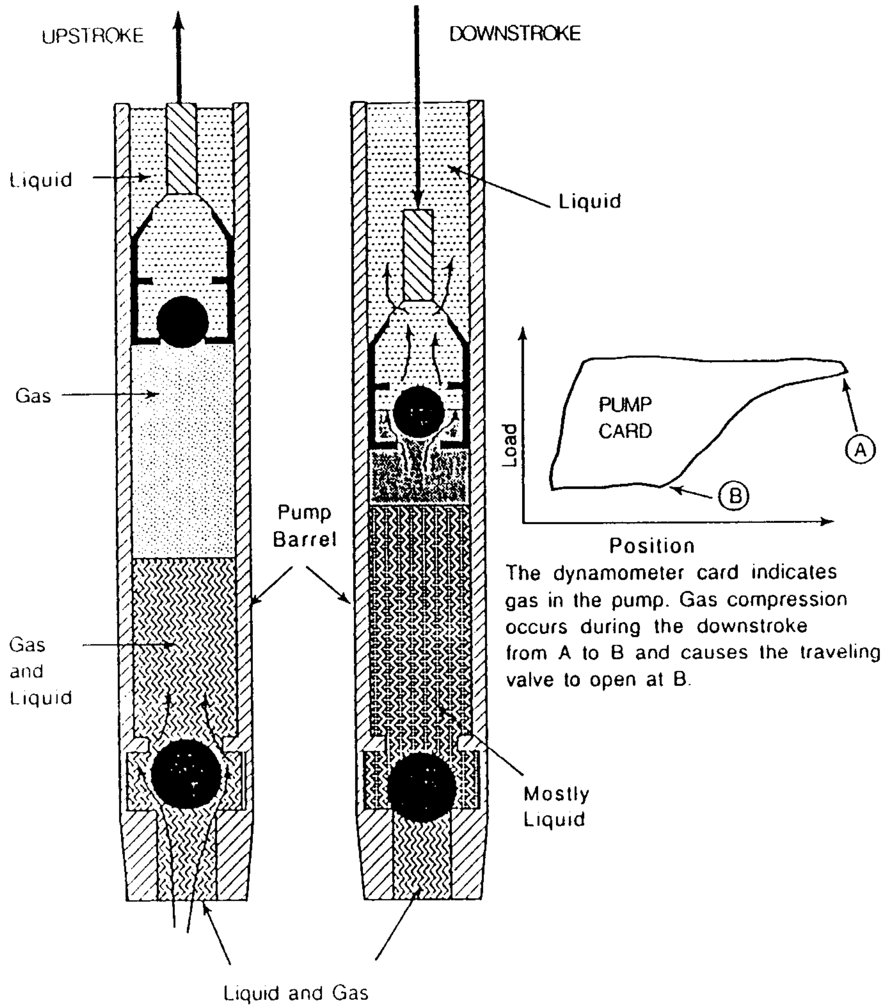

Figure 3 - Gas Interference in Plunger Pump

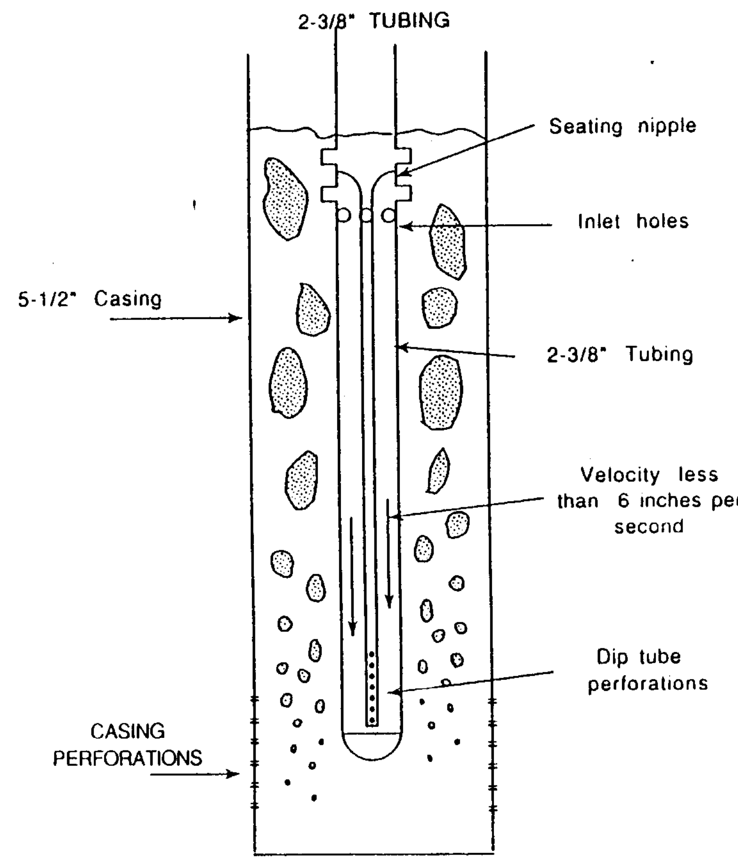

Figure 4 - Limited Entry Gas Separation

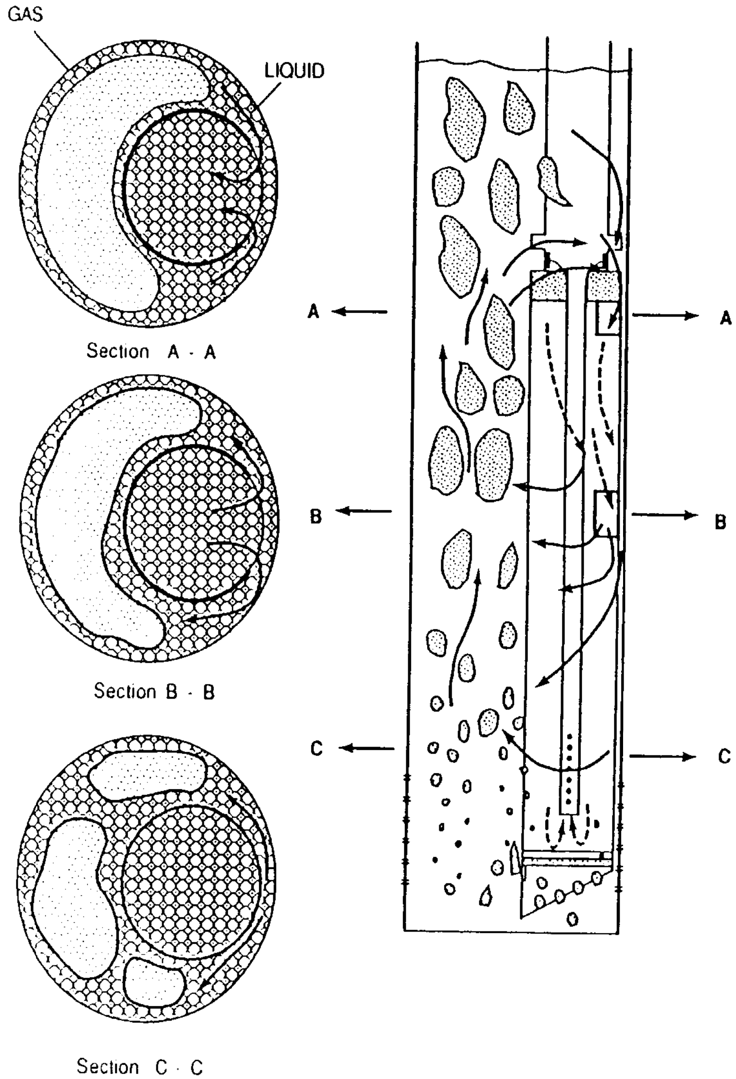

Figure 5 - Schematic of Fluid Distribution and Flow Pattern

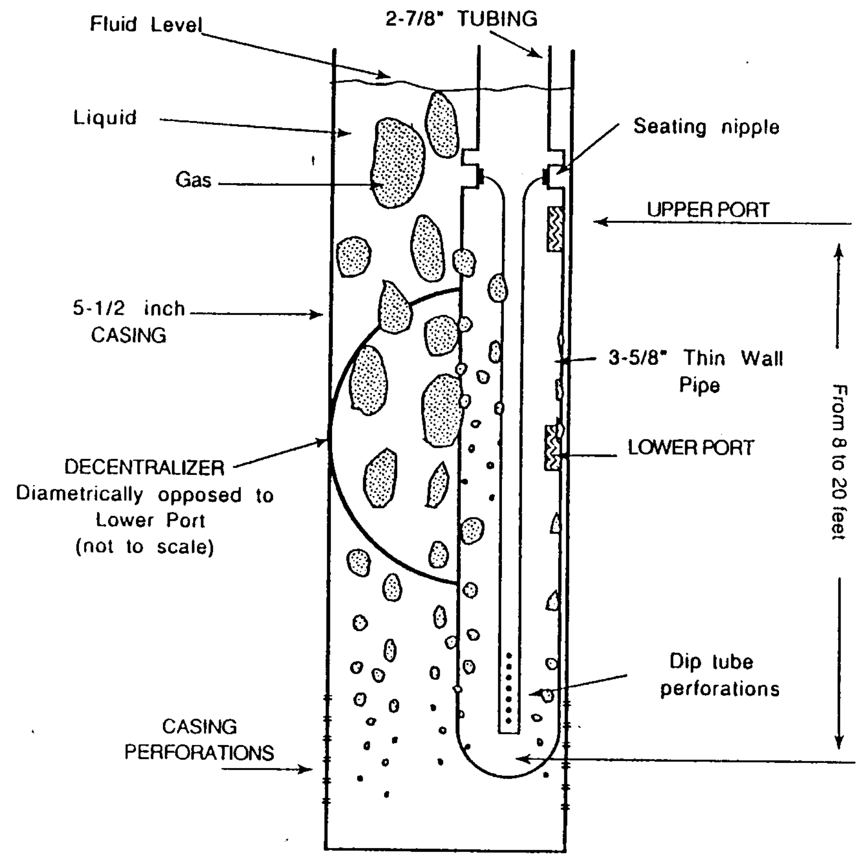

Figure 6 - 3-5/8" O.D. Thin Wall GAS SEPARATOR Capacity 400 BPD

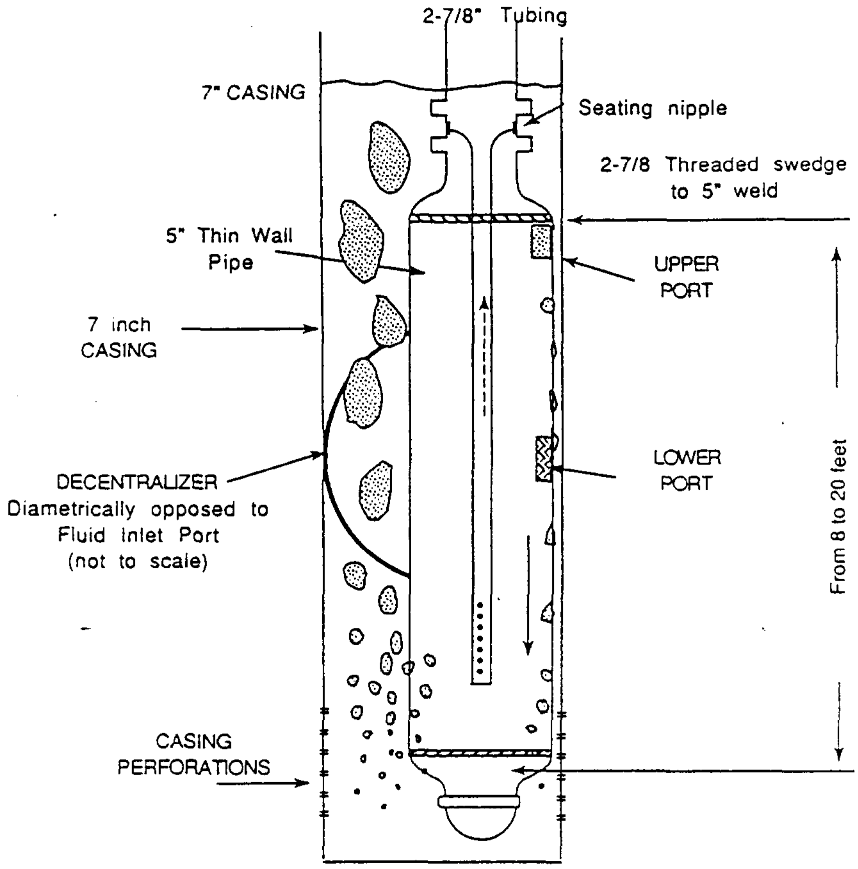

Figure 7 - 5" O.D. Thin Wall by 20 feet
GAS SEPARATOR Capacity 825 BPD

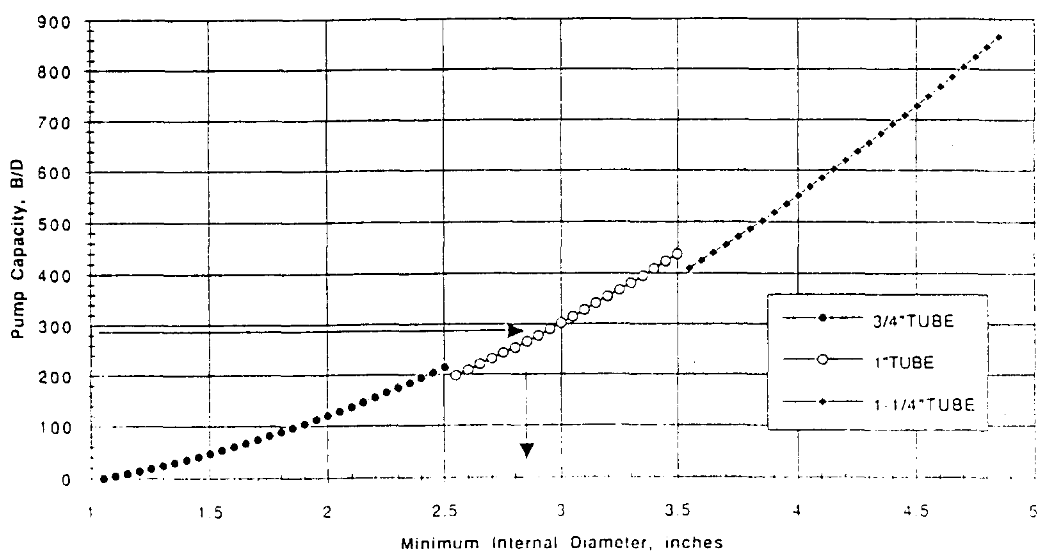

Figure 8 - Downhole Gas Separator Selection Chart, Minimum Internal Diameter as a Function of Pump Capacity and Dip Tube Nominal Diameter

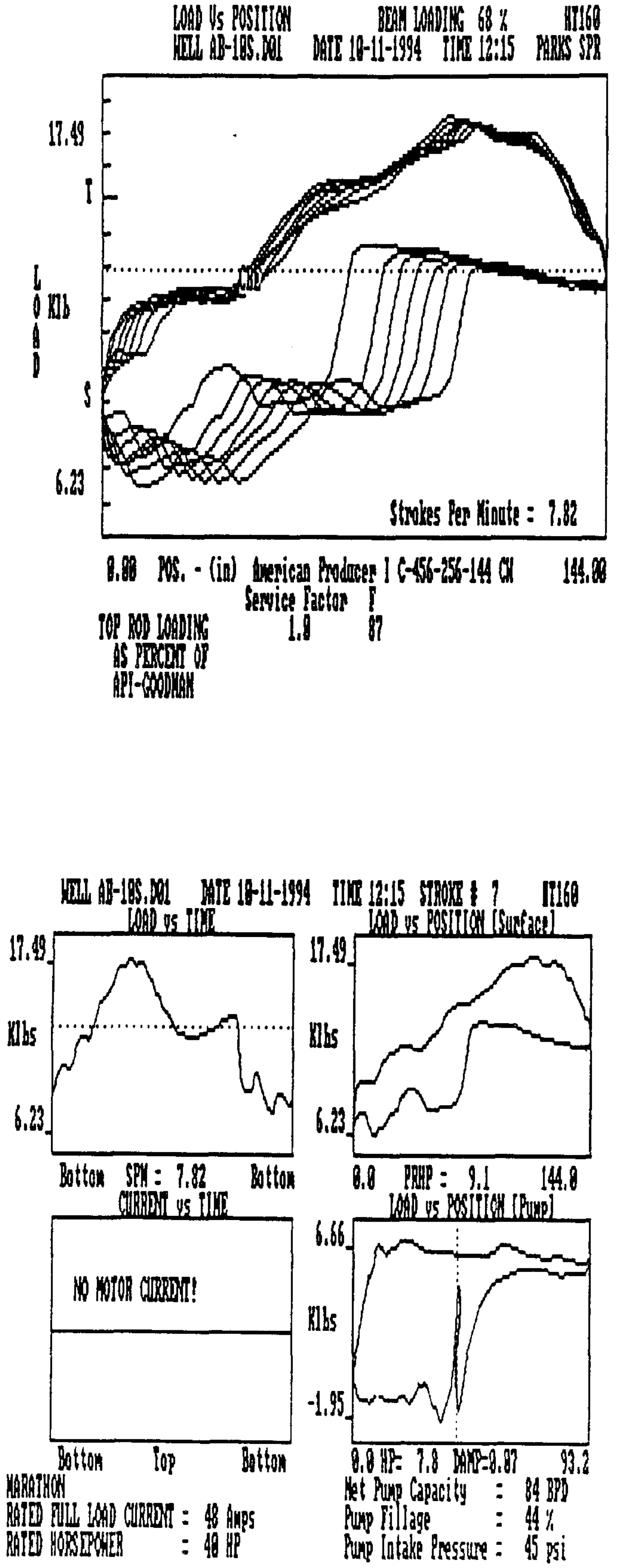

Figure 9a - Before Gas Anchor

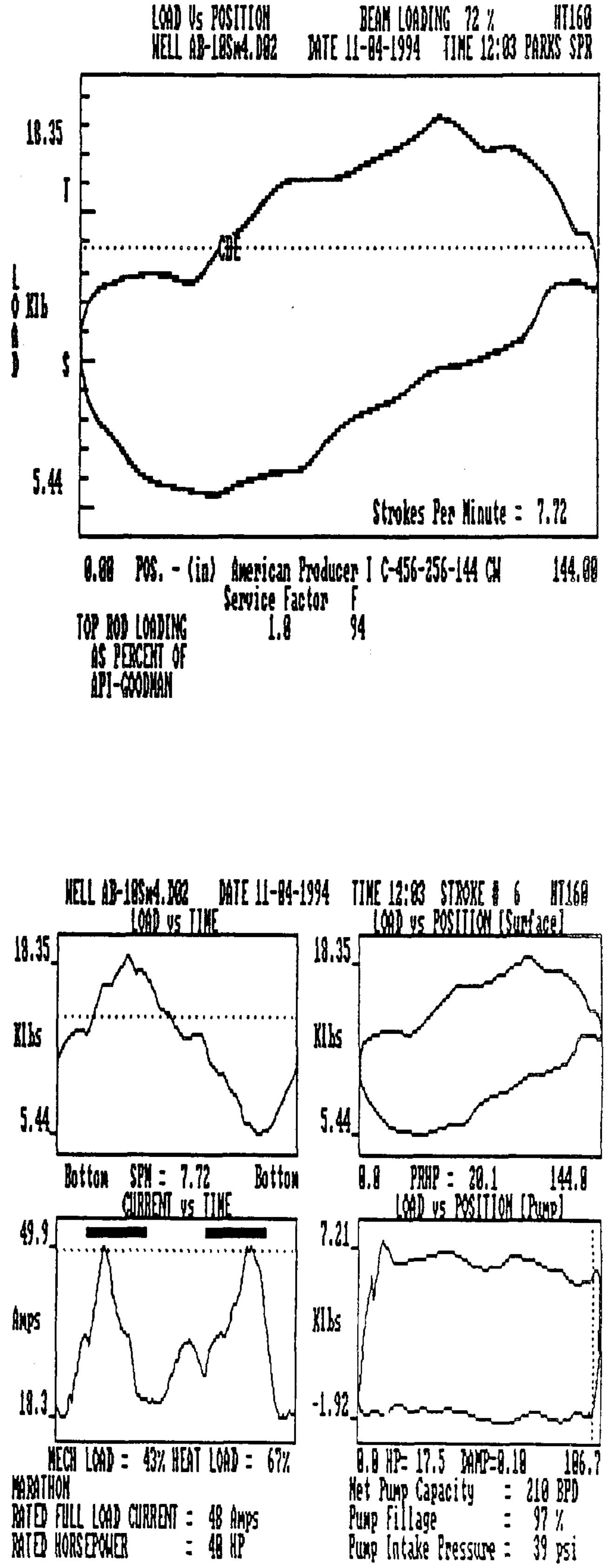

Figure 9b - After Gas Anchor

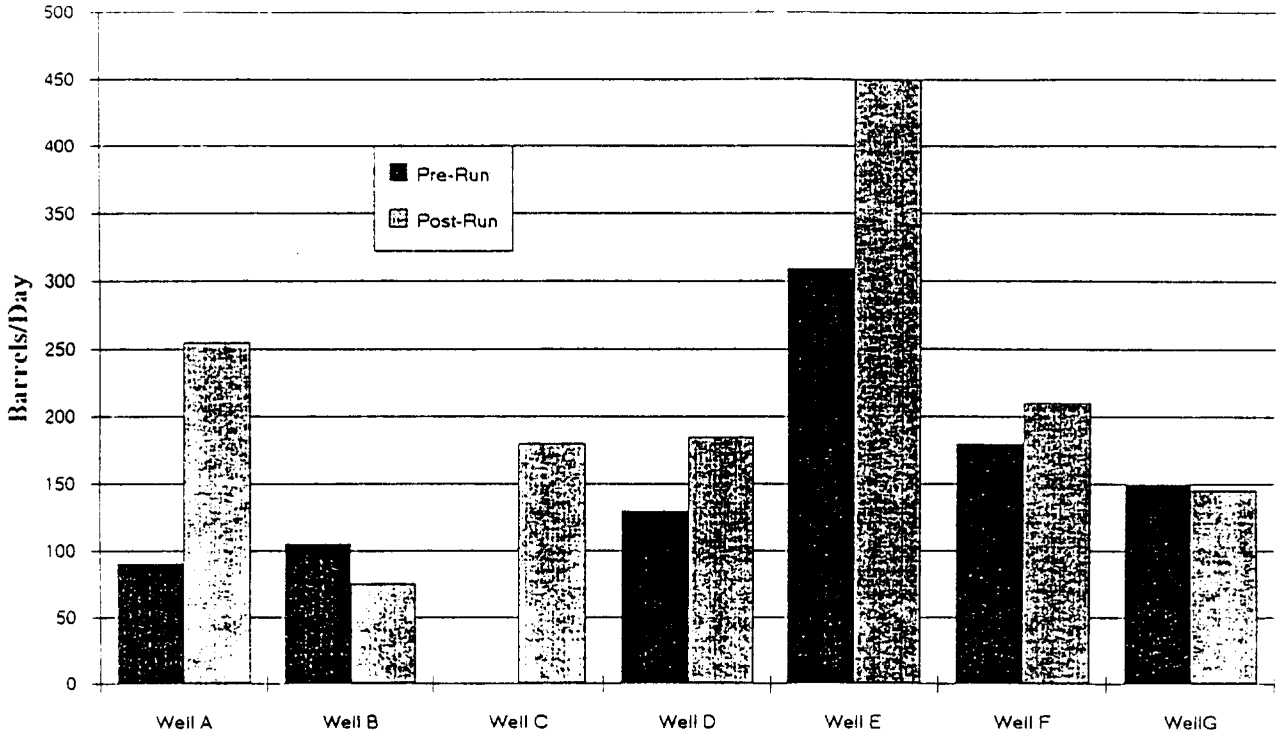

Figure 10 - Total Fluid Production

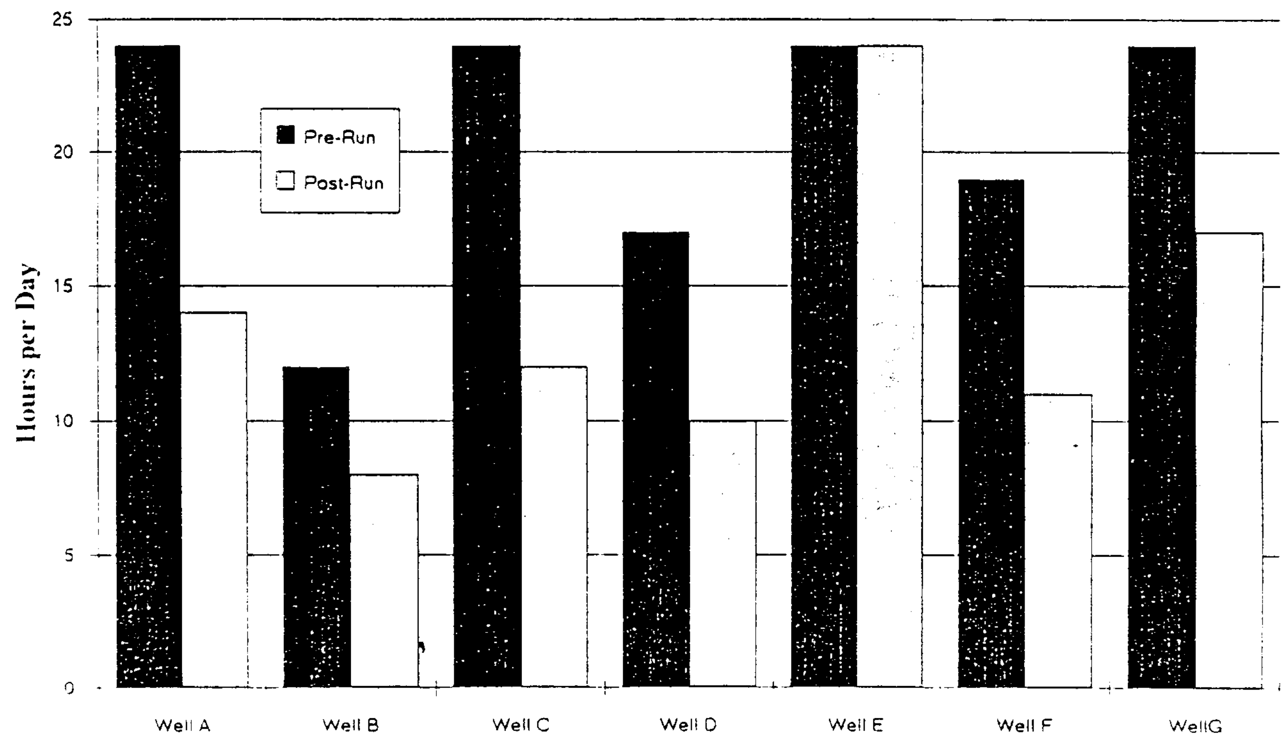

Figure 11 - Average Run Time