PRODUCTION OPTIMIZATION THROUGH IMPROVED DOWNHOLE GAS SEPARATION

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I. Abstract

Pumping efficiencies are severely affected when gas is produced through the downhole pump. In order to maintain optimum production from a well producing free or solution gas through the pump, pumping times or speeds must often be maximized to compensate for reduced efficiency. As a result, surface and downhole equipment life is drastically reduced. Accordingly, proper downhole gas separation greatly enhances equipment performance, life and wellbore productivity. This paper will illustrate three (3) basic methods of downhole gas separation, a method of designing "modified" poor boy gas anchors and results obtained from improved downhole gas separation in the University Waddell (Devonian) Field in Crane County, Texas.

II. Introduction

The physical mechanism which separates free or solution gas from the fluid in the wellbore can be described as a gas separator. The basic premise of gas separation focuses on gas and fluid velocities in the wellbore and downhole production equipment. When oil containing solution gas crosses the perforations or slots in a mud anchor, a pressure drop is observed resulting in the evolution of free gas bubbles. In addition, agitation, change in direction, and sudden velocity increases result in the evolution of free gas. Depending on the size and shape of the bubbles, fluid viscosity and velocity, the free gas bubbles will attempt to migrate upward while the fluid moves downward. If the downward fluid velocity exceeds the critical velocity required for upward migration of the gas bubbles, free gas will be forced through the production equipment. For wells producing with a water cut greater than twenty percent (20%), the critical downward velocity of fluid is .5 ft/sec. For wells producing with water cuts less than twenty percent (20%), the critical velocity of the fluid is .5 ft/sec divided by the viscosity of the fluid in centipoise. Therefore, successful gas separation may be achieved by employing gas separators that ensure downward fluid velocities which do not exceed the aforementioned critical velocities.

III. Types of Gas Separators

Through the years many different types of gas separators have been developed and utilized in sucker rod lift applications with varying degrees of success. However, this paper will focus on the three most common types of gas separators utilized in sucker rod lift applications: the natural gas separator, the poor boy gas separator and the modified poor boy gas separator. To ensure common identification with the parts composing a gas separator, this paper will refer to the piping that attaches to the pump or seating nipple as a gas anchor and the piping which surrounds the gas anchor will be labeled as the mud anchor.

A. Natural Gas Separator

The natural gas separator is the simplest type of gas separation device. Natural gas separation is achieved by placing the gas anchor or pump intake below the casing perforations without a mud anchor attachment (please refer to Fig. I). The gas-liquid separation capacity of the natural gas separator is greater than the capacity of any other separation device because the casing is utilized as the mud anchor, providing the largest possible separation chamber which can be employed in the wellbore. When installing a natural gas separator, the gas anchor or pump intake should be placed at least twenty to thirty feet (20'-30') below the lowest active perforation ensuring that the gas anchor is not in the turbulent zone of the wellbore. Employing a natural gas separator requires the following:

1. Sufficient rathole to allow placement of the gas anchor at the specified depth.

2. Formations which do not produce debris, formation or frac sand or large amounts of paraffin.

3. Special consideration should be given before installing in an open hole environment.

A disadvantage to the natural gas separator is that the fluid is not subject to a reduced pressure prior to entering the pump. Valve spacing in the downhole pump is critical. A high compression ratio should be maintained in the pump since all the solution gas will be processed through the pump. In conjunction, the diameter of the gas anchor should be as large as possible with minimal length in order to eliminate friction pressure drop and minimize the occurrence of gas evolution inside the gas anchor. Concluding, if wellbore conditions permit, the best chance of achieving downhole gas separation is with the natural gas separator.

B. Poor Boy Gas Separator

When rathole is limited, gas separation is usually achieved with the installation of a poor boy gas separator. The poor boy gas separator consists of a slotted mud anchor or perforated nipple/mud anchor combination and a gas anchor (please refer to Fig. II). The mud anchor is usually one to three (1-3) joints of pipe with the same outside and inside diameters as the production string with the end orange peeled closed. The mud anchor might be slotted at the top to allow fluid entry if a perforated nipple is not employed in conjunction with the mud anchor. The gas anchor is piping usually one inch (1") in diameter and six to ten feet (6'-10') in length with the end orange-peeled closed. Fluid entry is achieved through perforations or slots placed in the bottom of the gas anchor. During normal pumping operations, fluid enters the perforated nipple or slots in the mud anchor, travels down the annular space between the gas and mud anchors, and enters the pump via the gas anchor perforations or slots. Initial gas separation occurs at the mud anchor or perforated nipple-openings due to the pressure drop required to achieve entry coupled with the turbulence created as fluid flows into the separator. Secondary gas separation occurs at the gas anchor openings due to the pressure drop required to enter the pump. The downward flow rate of the fluid inside the separator should be below the critical velocity in order to allow the secondary gas to escape into the casing. However, historical practices and procedures often do not ensure that critical velocity requirements are met, therefore, the separator does not function properly. Existing separators should be examined to ensure that the design accounts for the critical velocity of the produced fluid. Placement of the mud anchor or perforated nipple openings may be above or below the casing perforations, but most often the openings are placed above the perforations due to limited rathole. As with the natural gas separator, the mud anchor openings should be placed twenty to thirty feet (20'-30') above or below the uppermost or lowermost active perforation, to ensure that the openings are not in the turbulent zone of the wellbore. In association, gas evolution inside the gas anchor should be minimized by utilizing the largest diameter possible in design of the gas anchor, thereby minimizing friction pressure drop. Gas anchor size will be limited by mud anchor size which in turn is limited by casing size. Optimizing the design will require balancing trade offs in equipment sizes. When utilizing a poor boy gas separator, the following design conditions should be specified:

1. The ends of the mud anchor should be orange peeled closed. Bullplug and collar combinations are often hard to remove from sand or scale. If removing debris from the mud anchor is a necessary requirement, female threads should be cut in the end of the anchor and a male plug installed.

2. The outside diameter of the mud anchor should be less than the internal diameter of the largest overshot which might possibly be

employed in fishing operations.

3. The slots or perforations in the mud anchor should start as close as possible to the seating nipple but should not remove more than half (.5) of the mud anchor circumference.

4. The mud anchor length should be no more than two to five feet (2'-5') longer than the gas anchor.

5. If the mud anchor is to be placed below the perforations, the formation should be sand or debris production free.

6. Special consideration should be given before installing in an open hole environment.

When rathole does not permit the installation of a natural gas separator, availability of materials and economics makes the poor boy gas separator the most widely utilized gas separator in sucker rod lift applications.

C. Modified Poor Boy Gas Separator

When rathole is limited in a wellbore with large casing (usually greater than 4 1/2"), gas separation can be enhanced by modifying the poor boy gas separator. The modification involves the use of a mud anchor which has a larger outside diameter than the production string (please refer to Fig. III). Gas separation is enhanced because gas is forced out of solution due to an increase in velocity in the reduced casing/mud anchor annulus. In accordance, the gas anchor/mud anchor annulus becomes enlarged, and downward fluid velocity is minimized thereby improving secondary gas escape into the casing. When considering the use of a modified poor boy gas separator, care should be taken to adhere to the aforementioned design conditions specified for the poor boy gas separator. The probability of sticking the mud anchor is greatly increased with the modified poor boy gas separator. Wellbore conditions should be carefully evaluated before placing the mud anchor below casing perforations. The modified poor boy gas separator should never be placed in an open hole environment. If wellbore conditions permit, the modified poor boy gas separator should be used instead of the poor boy gas separator because of superior performance.

Concluding, industry has developed and tested several different varieties of gas separation devices for sucker rod pumped wells. However, industry has yet to develop a gas separation system that will perform effectively in every well, formation, or field. If gas interference is limiting production, several systems may have to be tested in several wells before the most effective means of gas separation is achieved for a particular field.

IV. Basic Principles of Gas Separator Design

Before deciding on what type of gas separator is best suited for a given well, a study of the well's history should be undertaken. The following questions should be answered in order to facilitate selection of gas separator type, size and placement:

A. How much rathole does the well have?
B. What is the casing size and integrity?
C. What is the stimulation history of the well?
D. Does the well have paraffin, scale, or debris problems?
E. What is the productive capacity of the well?

After answering the above questions and selecting the type, size, and placement of the gas separator, the actual design of separation equipment may commence. Listed below are seven basic principles applying to the design of poor boy gas separators:

Principle Number One: The minimum separation area (gas anchor/mud anchor annulus) should be large enough so the fluid velocity does not exceed the critical velocity of .5 ft/sec. If the viscosity of the produced fluid is significantly more viscous than water, the critical velocity should be adjusted by dividing by the viscosity of the produced fluid. The only limitation on separation area is casing size. The outside diameter (O.D.) of the mud anchor should be less than the inside diameter (I.D.) of the largest overshot which can be run in the casing in question.

Principle Number Two: The area of the mud anchor or perforated nipple openings should be equal to or greater than four times the minimum separation area. The openings should be placed as close to the seating nipple as possible. The slot area should be within one and one-half to two feet (1 1/2'-2') of the seating nipple. Recommended dimensions are one-half inch (1/2") in width and four inches (4") in length. Never remove more than half (.5) of the mud anchor circumference.

Principle Number Three: The area of the openings in the gas anchor should be equal to or greater than four times the standing valve inside diameter area. If slots are utilized, the dimensions should be one half inch (1/2") in width and four inches (4") in length.

Principle Number Four: The separation volume (vertical space between the bottom of the mud anchor openings and top of the gas anchor openings) should be a minimum of one and one-half (1 1/2) pump displacements and no greater than two (2) pump displacements.

Principle Number Five: The gas anchor length should be minimized to prevent excessive pressure drops. The total length of the gas anchor is the sum of the separation length (separation volume divided by separation area), the perforated nipple or slot length, and the seating nipple length. The end of the gas anchor should be orange peeled closed.

Principle Number Six: The mud anchor should be no more than two to five feet (2'-5') longer than the gas anchor with the end orange peeled closed.

Principle Number Seven: Placement of the separator should be at least twenty to thirty feet (20'-30') above or below the highest or lowest active perforation.

Understanding and adhering to these seven basic principles will improve the chance of success and performance of the poor boy gas separator.

V. Modified Poor Boy Gas Separator Design

As mentioned previously, the most effective type of gas separator is the natural gas separator. However, sometimes wellbore conditions do not permit the use of the natural gas separator. In such an event, the modified poor boy gas separator should be utilized if casing size permits. The following is a detailed discussion explaining the steps necessary to design a modified poor boy gas separator:

Required Data

1. Expected total fluid production at one hundred percent (100%) volumetric efficiency in barrels per day (BPD).

2. Pump plunger diameter.

3. Pump stroke length. (If the pump stroke length is unknown, use the polish rod stroke length.)

Design Calculations

A. Select the gas anchor size and outside diameter area from Table I based on total fluid production from Step 1.

B. Determine the area of the plunger and the internal diameter area of the standing valve seat from Table II based on the plunger diameter specified in Step 2.

C. Calculate the required separation area:

$$RSA = \frac{TFP\ (bbl/day) \times 9702\ (in^3/bbl)}{VEL\ (ft/sec) \times 12\ (in/ft) \times 86{,}400\ (sec/day)}$$

$$= \frac{.009358\ \left(\frac{in^2\text{-}ft\text{-}day}{sec\text{-}bbl}\right) \times TFP\ (bbl/day)}{VEL\ (ft/sec)}$$

where:

RSA = Required Separation Area (in^2)
TFP = Total Fluid Production (bbl/day) at 100% V.E.
.009358 = Conversion factor $\left(\frac{in^2\text{-}ft\text{-}day}{sec\text{-}bbl}\right)$
VEL = Critical Velocity (ft/sec)

For most design applications the critical velocity will be .5 ft/sec, and the formula is reduced to:

$$RSA = .0187\ \left(\frac{in^2\text{-}day}{bbl}\right) \times TFP\ (bbl/day)$$

D. Calculate the area of the openings (flow area) in the mud anchor or perforated nipple.

$$MAFA = 4 \times RSA$$

where:

MAFA = Mud Anchor Flow Area (in^2)
RSA = Required Separation Area (in^2) From Step C

E. Calculate the number of slots required in the mud anchor if the slot dimensions are one-half inch (1/2") by four inches (4"):

$$\text{No. of Slots} = \frac{MAFA\ (in^2)}{(.5\ in)(4\ in)}$$

$$= \frac{MAFA\ (in^2)}{2\ (in^2)}$$

F. Calculate the area of the openings (flow area) in the gas anchor.

$$GAFA = 4 \times IDSVA\ (in^2)$$

where:

GAFA	=	Gas Anchor Flow Area (in^2)
IDSVA	=	Internal diameter area of the standing valve seat (in^2) from Step B

G. Calculate the number of slots required in the gas anchor if the slot dimensions are one-half inch (1/2") by four inches (4").

$$\text{No. of Slots} = \frac{GAFA\ (in^2)}{(.5\ in)(4\ in)}$$

$$= \frac{GAFA\ (in^2)}{2\ (in^2)}$$

H. Determine the minimum internal diameter of the mud anchor. The minimum internal diameter of the mud anchor is obtained by employing Table III. Calculate the minimum separation area by using the following formula:

$$MSA = RSA\ (in^2) + GAODA\ (in^2)$$

where:

RSA	=	Required Separation Area (in^2) from Step C
GAODA	=	Gas Anchor Outside Diameter Area (in^2) from Step A.

After determining the minimum separation area, enter column three (3) in Table III and select the pipe size which has an internal diameter (I.D.) area equal to or just larger than the minimum separation area. The minimum separation area should be larger than the required separation area obtained in Step C. Make sure the restrictions outlined in Principle Number One are considered before selecting the mud anchor size.

I. Calculate the actual separation area

$$ASA = MIDAMA\ (in^2) - GAODA\ (in^2)$$

where:

ASA	=	Actual Separation Gas (in^2)
MIDAMA	=	Minimum Internal Diameter Area of Mud Anchor (in^2) From Step H
GAODA	=	Gas Anchor Outside Diameter Area (in^2) from Step A

J. Calculate the separation volume

$$SV = 2 \times PA\ (in^2) \times S\ (in)$$

SV	=	Separation Volume (in^3)
PA	=	Plunger Area (in^2) from Step B
S	=	Pump Stroke (in) from Step 3

K. Calculate the separation length

$$SL = \frac{SV\ (in^3)}{ASA\ (in^2)}$$

where:

SL	=	Separation Length (in)
SV	=	Separation Volume (in^3) from Step J.
ASA	=	Actual Separation Area (in^2) from Step I.

L. Calculate gas anchor length

$$GAL = SL\ (in) + PNL\ (in) + SNL\ (in)$$

where:

GAL	=	Gas Anchor Length (in)
SL	=	Separation Length (in) from Step K
PNL	=	Perforated Nipple Length (in). Usually thirty six inches (36"). When the mud anchor is slotted, use the distance from the top of the first layer of slots to the bottom of the last layer of slots. Should be eighteen to twenty-four inches (18"-24")
SNL	=	Seating Nipple Length (in). Usually twelve inches (12")

M. Calculate mud anchor length

$$MAL = GAL\ (in) + 24\ (in)$$

where:

MAL	=	Mud Anchor Length (in)
GAL	=	Gas Anchor Length (in) from Step L.

The aforementioned discussion can be utilized in designing poor boy gas separators as well. For poor boy gas separator design, substitute the tubing internal diameter (I.D.) area for the minimum internal diameter area in Step H. Depending on the gross fluid production, the poor boy gas separator may not provide enough area to obtain adequate separation. After performing several designs for a given field, a table of various productive rates versus separator sizes may be developed, thereby facilitating design. As mentioned previously, several different types of gas separators may have to be tested before an effective method is discovered. However, following the seven basic principles and the design procedure will enhance the chance of success. To aid in the design of modified poor boy gas anchors, a data sheet and sample problem have been included (please refer to Figures IV and V).

VI. Case Histories

In association with improving equipment life and efficiency, proper gas separation will optimize production from the wellbore. The University Waddell (Devonian) Field is located in Crane County, Texas. Production originates from three distinct Devonian intervals located at a depth of 8400'-9200'. The field is currently under secondary recovery operations, and the average well produces 22 BOPD, 108 BWPD, and 31 MCFD. The majority of the wells employ sucker rod lift utilizing fiberglass or steel rod strings. Prior to May 1991, gas separation was achieved by implementing the following assembly:

A. The seating nipple placement was at ±8400', slightly above or in the top set of perforations.

B. Tailpipe with the same outside diameter as the production tubing was installed open-ended to a depth of 8800'-9000', above or in the middle and lower sets of perforations.

C. The insert pump was equipped with a short strainer nipple.

The aforementioned gas separation design was actually a lethal gas trap. As a result of the tailpipe length, placement, and configuration the majority of the free gas entered the pump, taking the path of least resistance. The gas which broke out of solution at the strainer nipple was forced through the pump because of the absence of an escape path (i.e. no slots were cut in the tailpipe). As might be expected, pump efficiencies were low and fluid levels were high due to the gas interference in the downhole pumps. In association, several of the fiberglass rod strings were failing due to the excessive minimum stresses encountered in the "gas pound" environment. In order to eliminate the gas interference, whenever a well experienced a downhole failure, a modified poor boy gas separator was designed and installed in the wellbore. Care was taken to ensure that the placement of the mud anchor openings was not in the turbulent zone of any set of perforations. As a result of the installations, pump efficiencies improved, fluid levels dropped, failures decreased and production increased (please refer to Table IV and Fig. VII). As one may readily observe, the success rate varied from well to well, but the economic benefits of proper gas separator design and installation are readily apparent.

VII. Conclusions

Adhering to the basic principles of gas separator design will improve the effectiveness and efficiency of the separator by ensuring that the critical velocity requirements are satisfied. However, the best designed separator will not function properly unless care is taken to ensure proper installation. Communication between engineering and field personnel is essential to the implementation of a successful gas separation program. As mentioned previously, extensive testing may be required to determine the optimum separator application for a given field. Communication is essential to guarantee that test results are interpreted accurately and corresponding modifications implemented correctly. Regardless, the cost of testing and employing a gas separation technique for a given field will be offset by the economic realization of reduced lifting cost and optimum wellbore productivity.

VIII. Acknowledgements

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Table I
Gas Anchor Selection Chart

Production Rate (BPD)	Nominal Pipe Size (in)	ID (in)	Area (in²)	OD (in)	OD Area (in²)	Collar OD (in)
<100	3/4	.824	.533	1.050	.866	1.313
100-200	1	1.049	.867	1.315	1.358	1.576
200-400	1-1/4	1.380	1.496	1.660	2.164	2.054
>400	1-1/2	1.610	2.036	1.900	2.835	2.200

Table II
Pump Data

Pump Plunger Diameter (in)	Pump Plunger Areas (in²)	ID S.V. Seat (in)	ID Area S.V. Seat (in²)
1-1/16	.886	.500	.196
1-1/4	1.227	.578	.262
1-1/2	1.767	.656	.338
1-3/4	2.405	.844	.559
2	3.146	.937	.689
2-1/4	3.976	1.062	.887
2-1/2	4.909	1.312	1.350
*2-3/4	5.940	1.312	1.350
*3	7.069	1.688	2.238
*3-1/4	8.296	1.688	2.238
*3-1/2	9.621	1.750	2.405
*3-3/4	11.045	1.750	2.405

*Not API

Table III
Mud Anchor Selection Chart

Nominal Pipe Size (in)	ID (in)	ID Area (in²)	OD (in)	OD Area (in²)	Collar OD (in)
*2	1.995	3.125	2.375	4.430	3.063
*2-1/2	2.441	4.680	2.875	6.492	3.668
3	3.068	7.393	3.500	9.620	4.250
3-1/2	3.548	9.886	4.000	12.566	4.625
4	4.026	12.730	4.500	15.900	5.200

*External upset; all others are line pipe

Table IV
Lift Design - University Waddell (Devonian) Field
East Waddell Ranch

		Production			
Well #	Battery	Before BOPD	After BOPD	Incremental BOPD	Action Taken
164	130	25	32	7	Install MA/GA, lower pump intake
165	101	112	129	17	Install MA/GA, lower pump intake
267	101	30	35	5	Install MA/GA, lower pump intake
666	429	18	30	12	Install MA/GA
718	123	60	94	34	Install MA/GA, lower pump intake
742	429	9	30	21	Install MA/GA, lower pump intake
978	130	22	46	24	Install MA/GA, lower pump intake
988	429	15	16	1	Install MA/GA, lower pump intake
1099	101	20	22	2	Install MA/GA
1101	123	22	26	4	Install MA/GA
1103	123	22	27	5	Install MA/GA, lower pump intake
1105	101	25	46	21	Install MA/GA, lower pump intake
1119	123	19	24	5	Install MA/GA
1123	101	25	25	0	Install MA/GA
1126	101	95	105	10	Install MA/GA, lower pump intake
		519	687	168	

MOST SUITABLE FOR USE IN WELLS

1. With relatively low fluid levels or low intake pump pressures.

UNSUITABLE FOR USE IN WELLS

1. Which do not have sump.
2. Which produce a considerable amount of sand.

ADVANTAGES

1. Installation benefits from maximum submergence.
2. The small suction and large casing annulus offer maximum gravity separation.

DISADVANTAGES

1. The fluid is not subjected to a reduced pressure prior to entering the pump.
2. All the gas contained or trapped within the fluid must be processed through the pump.
3. The pump, anchor, and screen are susceptible to the blocking action of cavings.
4. Some formations will be more readily blocked by paraffin using this system.

Note: The seating nipple and gas anchor should be at least 30′ below the bottom producing zone; the tubing anchor should be set just above the casing perforations.

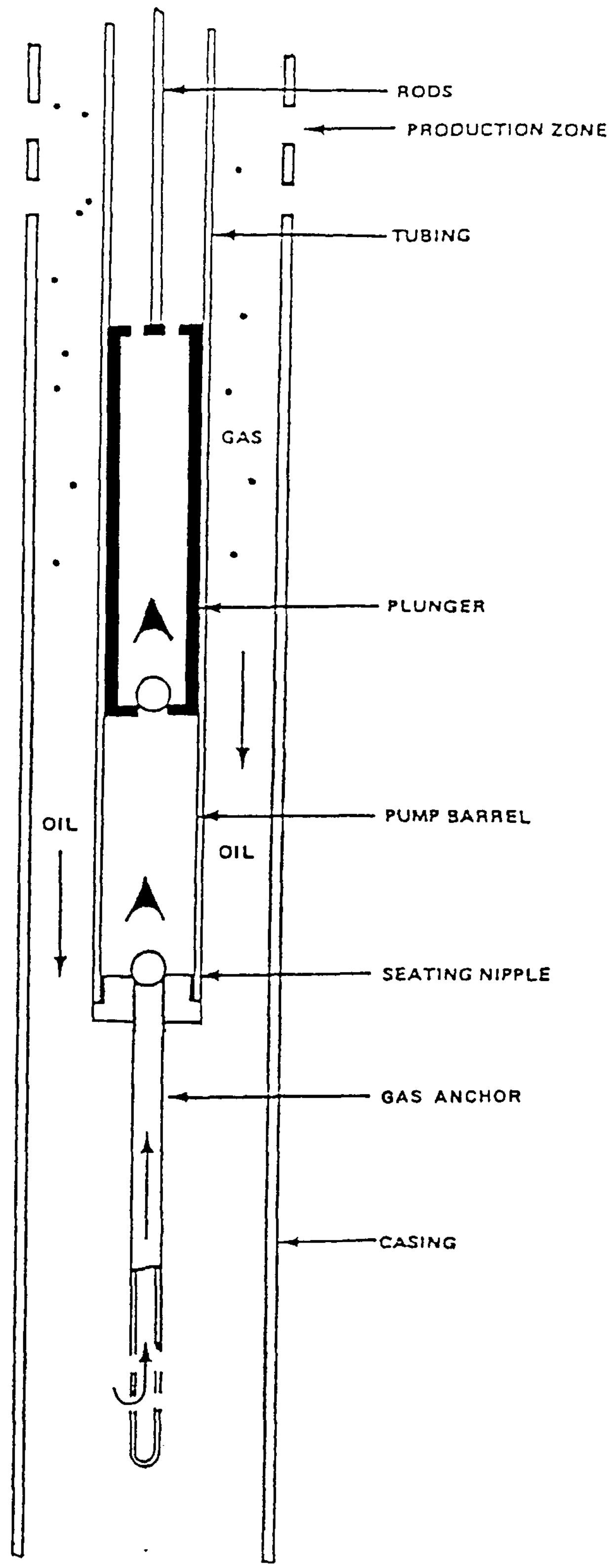

Figure I - Natural gas separator

ADVANTAGES

1. System permits fluid to rise to a lower pressure area and to fall back to the pump suction.

2. The fluid velocity is stabilized after the fluid enters the mud anchor.

3. System is economical. Material is available in field.

DISADVANTAGES

1. The fluid velocity is not increased to force gas breakout prior to fluid entrance into the mud anchor.

2. The mud anchor size does not offer the benefit of maximum gravity separation.

Mud anchor is usually two inch pipe and the gas anchor is one inch pipe or smaller.

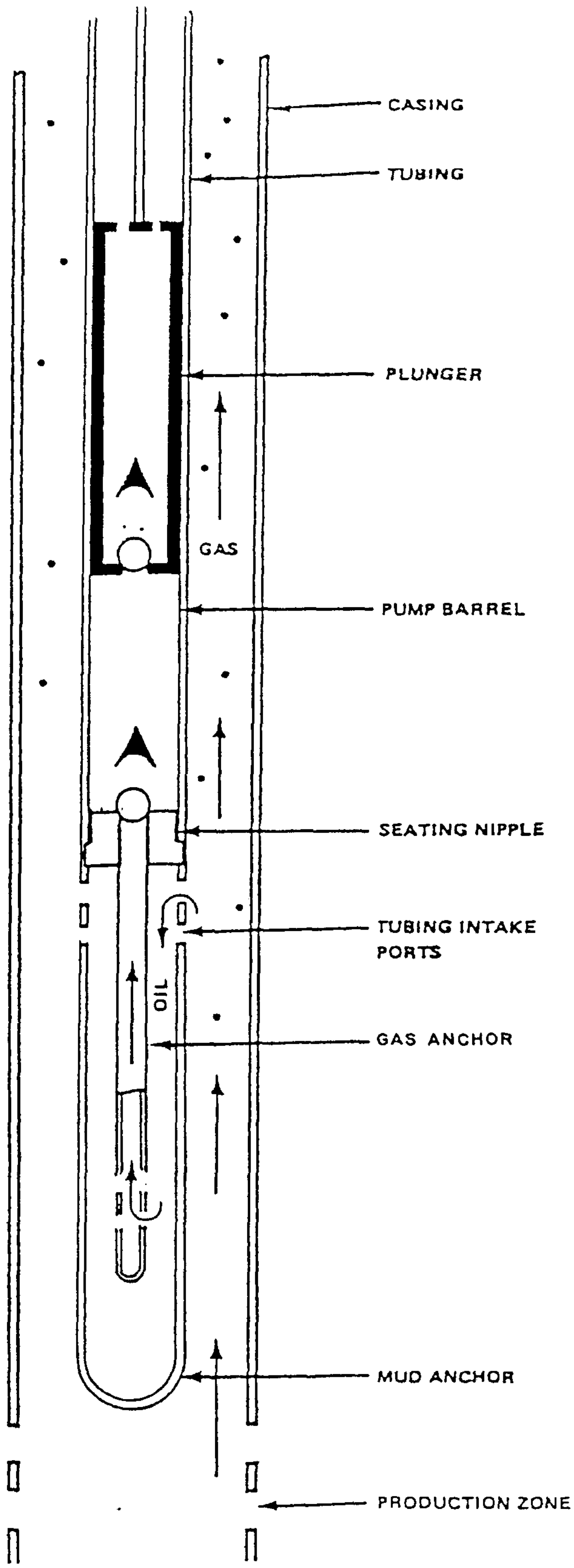

Figure II - Poor boy gas separator

ADVANTAGES

1. System permits fluid to rise to a lower pressure area and to fall back to the pump suction.

2. Over-sized mud anchor permits gravity separation.

3. System is economical. Material is available in the field.

4. System permits fluid velocity increase in casing annulus to breakout gas.

5. Mud anchor/gas anchor size ratio can be varied as circumstances require.

DISADVANTAGES

1. Over-sized mud anchor could cause a recovery problem.

2. A fluid velocity change that could cause a gas breakout will exist at the gas anchor inlet.

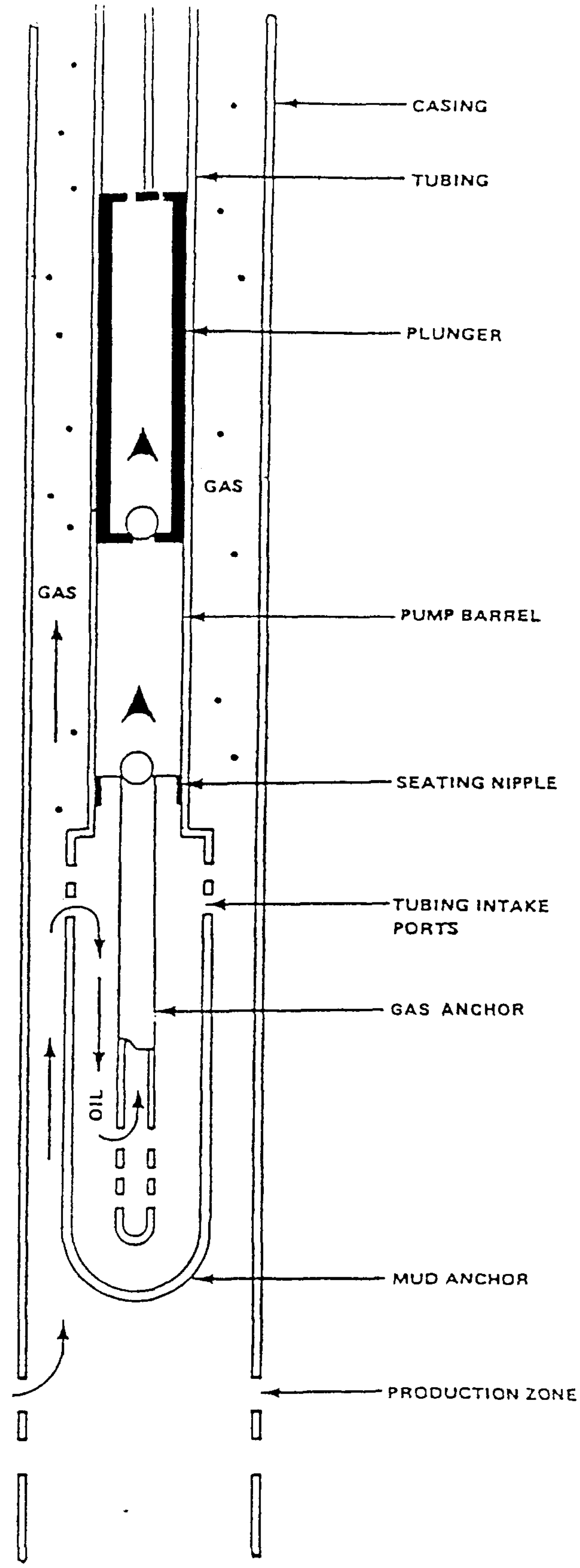

Figure III - Modified poor boy gas anchor

REQUIRED DATA

1.	Total fluid production (TFP) at 100% V.E.	_____ (BPD)
2.	Pump plunger diameter	_____ (in)
3.	Pump or surface stroke length (S)	_____ (in)
4.	Seating nipple length (SNL)	_____ (in)
5.	Perforated nipple length (PNL)	_____ (in)

CALCULATIONS

A. Gas anchor size: _____ (in)
[From col. 2 - Table I]

1. Gas anchor outside diameter area (GAODA): _____ (in^2)
[From col. 6 - Table I]

B. Pump plunger area (PA): _____ (in^2)
[From col. 2 - Table II]

1. Internal diameter area of standing valve seat (IDSVA): _____ (in^2)
[From col. 4 - Table II]

C. Required separation area (RSA):

RSA = .0187 x TFP
= .0187 x _____ (Line (1)) _____ (in^2)

*Note: Assumes critical velocity to be .5 ft/sec.

D. Mud anchor flow area (MAFA):

MAFA = 4 x RSA
= 4 x _____ (Line (C)) _____ (in^2)

E. Number of mud anchor slots:

= MAFA / 2
= _____ / 2 (Line (D)) _____

*Note:Assumes slot dimensions of ½ inch wide by 4 inches long.

F. Gas anchor flow area (GAFA):

GAFA = 4 x IDSVA
= 4 x _____ (Line B (1)) _____ (in^2)

G. Number of gas anchor slots:

= GAFA / 2 =
= _____ / 2 (Line F) _____

*Note: Assumes slot dimensions of ½ inch wide by 4 inches long

Figure IV - Modified poor boy gas separator design sheet

H. Minimum separation area (MSA):

MSA = RSA + GAODA
= ____ + ______ ______ (in²)
Line C   Line A (1)

1. Minimum internal diameter area of mud anchor (MIDAMA): ______ (in²)
[From col. 3 - Table III]

2. Mud Anchor Nominal Size ______ (in)
[From col. 1 - Table III]

I. Actual separation (ASA):

ASA = MIDAMA - GAODA
= ______ - ______ ______ (in²)
Line H (1)   Line A (1)

J. Separation volume (SV):

SV = 2 x PA x S
= 2 x ____ x ____ ______ (in³)
Line B   Line 3

K. Separation length (SL):

SL = SV / ASA
= ____ / ____ ______ (in²)
Line J   Line I

L. Gas Anchor Length (GAL):

GAL = SL + PNL + SNL
= ____ + ____ + ____ ______ (in)
Line K   Line 5   Line 4

*Note: May substitute slot length for perforated nipple length if slots are placed in the mud anchor.

M. Mud anchor length (MAL):

MAL = GAL + 24
= ____ + 24 ______ (in)
Line L

CALCULATED GAS ANCHOR SIZE (IN)

Dia = ______ Lgth = ______
Line A   Line L

CALCULATED MUD ANCHOR SIZE (IN)

Dia = ______ Lgth = ______
Line H (2)   Line M

Figure IV (cont.) - Modified poor boy gas separator design sheet

1. Utilizing the design sheet and the information provided in the text; design a modified poor boy gas separator for the well conditions listed below:

Well Name:	Sample I
Reservoir:	Tubb - Dolomite
PBTD:	4065'
Casing Size:	7" 23#
Completion Interval:	4000' - 4050' (2 JSPF)
Stimulation History:	Acidized with 10,000 gals 15% NEFE
Current Production:	25 BOPD, 225 BWPD, 50 MCFD
Pump Type:	2.875" X 1.5" X 14' RWBC
Pump Vol EFF:	85%
Tubing Size:	2.875"
Surface Stroke Length:	120"
Seating Nipple Length:	12"
Perforated Nipple Length:	36"

Figure V - Modified poor boy gas separator design problem

REQUIRED DATA

1. Total fluid production (TFP) at 100% V.E. — 294 (BPD)

2. Pump plunger diameter — 1.5 (in)

3. Pump or surface stroke length (S) — 120 (in)

4. Seating nipple length (SNL) — 12 (in)

5. Perforated nipple length (PNL) — 36 (in)

CALCULATIONS

A. Gas anchor size: — 1.25 (in)
[From col. 2 - Table I]

1. Gas anchor outside diameter area (GAODA): — 2.164 (in^2)
[From col. 6 - Table I]

B. Pump plunger area (PA): — 1.767 (in^2)
[From col. 2 - Table II]

1. Internal diameter area of standing valve seat (IDSVA): — .338 (in^2)
[From col. 4 - Table II]

C. Required separation area (RSA):

RSA = .0187 x TFP
= .0187 x 294 (Line (1)) — 5.50 (in^2)

*Note: Assumes critical velocity to be .5 ft/sec.

D. Mud anchor flow area (MAFA):

MAFA = 4 x RSA
= 4 x 5.50 (Line (C)) — 22 (in^2)

E. Number of mud anchor slots:

= MAFA / 2
= 22 / 2 (Line (D)) — 11

*Note:Assumes slot dimensions of ½ inch wide by 4 inches long.

F. Gas anchor flow area (GAFA):

GAFA = 4 x IDSVA
= 4 x .338 (Line B (1)) — 1.35 (in^2)

G. Number of gas anchor slots:

= GAFA / 2 =
= 1.35 / 2 (Line F) — .676

*Note: Assumes slot dimensions of ½ inch wide by 4 inches long

Figure VI - Modified poor boy gas separator design problem solution

H. Minimum separation area (MSA):

MSA = RSA + GAODA
= 5.50 + 2.164 — 7.664 (in²)
Line C Line A (1)

1. Minimum internal diameter area of mud anchor (MIDAMA): 9.886 (in^2)
[From col. 3 - Table III]

2. Mud Anchor Nominal Size 3.5 (in)
[From col. 1 - Table III]

I. Actual separation (ASA):

ASA = MIDAMA - GAODA
= 9.886 - 2.164 — 7.72 (in^2)
Line H (1) Line A (1)

J. Separation volume (SV):

SV = 2 x PA x S
= 2 x 1.767 x 120 — 424 (in^3)
Line B Line 3

K. Separation length (SL):

SL = SV / ASA
= 424 / 7.72 — 55 (in^2)
Line J Line I

L. Gas Anchor Length (GAL):

GAL = SL + PNL + SNL
= 55 + 36 + 12 — 103 (in)
Line K Line 5 Line 4

*Note: May substitute slot length for perforated nipple length if slots are placed in the mud anchor.

M. Mud anchor length (MAL):

MAL = GAL + 24
= 103 + 24 — 127 (in)
Line L

CALCULATED GAS ANCHOR SIZE (IN)

Dia = 1.25 (Line A) Lgth = 103 (Line L)

CALCULATED MUD ANCHOR SIZE (IN)

Dia = 3.5 (Line H (2)) Lgth = 127 (Line M)

Figure VI (cont.) - Modified poor boy gas separator design problem solution

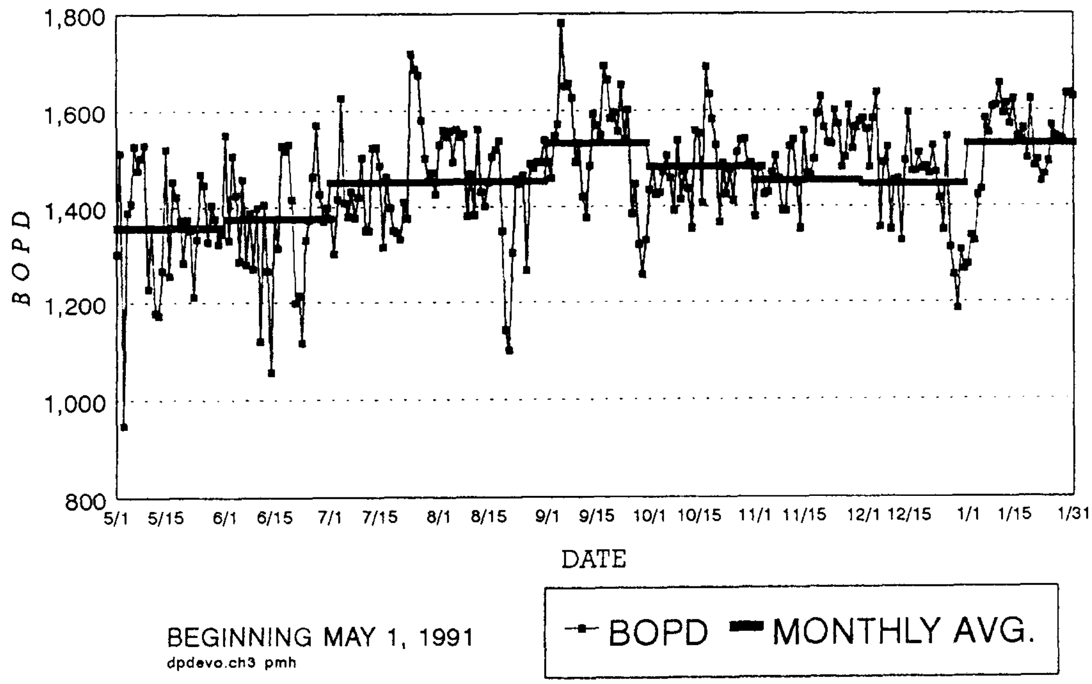

Figure VII - Daily production - University Waddell (Devonian) Field
(Coastal Management Corporation)