EFFORTS TO IMPROVE DETERMINATION OF PUMP INTAKE PRESSURE FROM FLUID LEVEL

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ABSTRACT

America needs energy. Good techniques such as Vogel's Method and Constant PI exist for estimating production from wells. These are phrased in terms of pressure. Pressure is not easy to measure especially in deep gassy, wells. Fluid levels (L) are inexpensive and provide a logical alternative to pressure measurements in gathering information of interest at virtually any depth. This creates the need for a method for deriving pump intake pressure (P) from FL which is the subject of this paper. W.E. Gilbert derived the first method in 1955. It was not used widely because casing gas (mcf/d) was required to determine the gassy oil gradient in the casing. This gas had to be vented to the atmosphere while being measured. This was a pollution no-no then and now. In 1988 a method (by ECHOMETER) for determining casing gas rate and P based on shut-in casing pressure buildups (BUP, psi/min) was developed. This method became the industry standard. Recently a New Device (GreenShot) appeared which can supply Gilbert with L and casing gas in a non-polluting fashion. Thus there are now two methods for deriving P from L. It is relevant to mention a third method of the 1930's by C.P. Walker. This determined accurate P in gassy wells by adding casing pressure to force the fluid level down in stages. It is commonly called the Fluid Level Depression method. Unfortunately the Walker Method is very labor intensive and is seldom used.

This paper discusses the Industry Std. method and the Gilbert Method. It is found that both give Ps that are not accurate enough for use, particularly in gassy wells with high fluid levels. This paper documents efforts to improve the Gilbert method, but not the Industry Std. method. It is thought that authors of the Industry Std. method are better qualified to improve their method than the authors of this paper.

The data set for computing P from L needs to be enlarged with more wells. Naturally occurring variation of gas pressure in the annulus (heading?) is thought to be a cause for P inaccuracy. Steps to include this effect are taken. The New Device will be used to quantify and mimic the heading effect.
The contribution of this paper is to (1) summarize findings so far and (2) to introduce a method for including the heading effect in the Gilbert Method.

HISTORICAL INTRODUCTION

For years the accuracy of P determined from fluid level has been questioned, particularly in deep wells with high, gassy fluid levels. In June 2017 a project was initiated to investigate this issue. ESP pumps were selected to gather data. Why? Because ESP's have downhole sensors with surface readouts that measure P, the very quantity to be studied!

The results of this project are summarized in Table 1. It is a veritable treasure trove of information. Column 8 shows casing gas measured with the New Device. This measurement is known to be very accurate. Figure 1 shows a standard orifice meter run placed downstream of the New Device in its testing stage. The downstream meter run measures the same gas as the New Device. In hundreds of tests, the measurements were virtually identical. The new Device is permanently installed and has multiple purposes. It automatically shoots a green fluid level using the well's own energy in a closed system. The fluid level is green because nothing foreign is introduced to create the wave and nothing polluting is emitted. Also it works with a smart POC to provide continuous well tests. It also can play a role in gathering averages of multiple buildups.

Note in Column 7 how the casing gas calculated with the Industry Std. far exceeds that of the New Device (Column 8). This reveals an error in the Industry Std. method, namely that free gas is erroneously being included in the oil column below the fluid level (see Figure 3). This causes the calculated casing gradient to be too low, hence making the calculated P too low. An example is Well No. 3. L is shallow (7451 ft of submergence, Column 2); calculated gas rate is too high (988 mcf/d Column 7); calculated P is too low (640 psi versus measured value of 1737 psi, Columns 5 and 3). Developers of the Industry Std. method indicate that, in future work, gas below the fluid level will **not** be included. Casing gas above L is all that matters. Figure 2 properly depicts no free gas in the gassy oil column below the fluid level. Figure 2 also reveals the non-intuitive fact that the gradient in the gassy oil column is constant. This was first reported by Gilbert in 1955. No water buildup is considered in the computations of oil and gas. Water is heavier and falls to bottom and is pumped out by the lift equipment.

Column 3 shows measured P obtained with the ESP downhole sensor. These are the values that Gilbert and the Industry Std. should reproduce. In this paper we will not work to improve the Industry Std. method. As mentioned before, we feel that the developers of that method are better qualified. These workers have a good track record of evolving and improving their products. It is expected that we will see improved versions of the Industry Std. method in future papers.

EFFORTS TO IMPROVE GILBERT'S METHOD

The Gilbert method has been sitting on the shelf for decades. The method must model the trek of gas in the casing from the fluid level to the surface. It is not difficult to imagine that variations in pressure exist from 'heading' effects along the way. The New Device plays an important role in simulating these so called heading effects. It is programmed to make buildups (BUPs) every 10 minutes to simulate the postulated heading effects. The BUP used to calculate P will be the average of 20 BUPs taken in Well 8. This is a main contribution of this paper and is described next and incorporated into the New Device.

BUP Calculus

This describes how averages of many BUPs rather than a single BUP are created. The dimension of BUP is psi/min. The process starts by averaging one BUP then averaging two BUPs then averaging three BUPs, etc. until **N** the maximum number of averaged BUPs is reached. The BUPs used in this example were gathered manually from Well 8 (lifted with ESP) over a 4 day period. A total of **N = 20** BUPs were gathered. The average of the 20 BUPS is 3.422. This number and its significance is important to remember. The process is

BUP	psi/min
1	BUP = 3.878; average BUP = 3.878
2	BUP = 4.759; average BUP = (3.878 + 4.759) / 2 = 4.319
3	BUP = 6.071; average BUP = (3.878 + 4.759 + 6.071) / 3 = 4.903
4	BUP = 7.378; average BUP = (3.878 + 4.759 + 6.071+ 7.378) / 4 = 5.522
etc.	
20	BUP = 1.393; average BUP = (3.878 + 4.759 + 6.071+ . . . + 1.393) / 20 = 3.422 psi/min

The procedure keeps the maximum number of BUPs to be averaged at **N**. It is helpful to imagine that the BUPs are arranged sequentially right to left.

$BUP_{\mathbf{N}}$, BUP_{N-1} , BUP_{N-2} . . . . . . BUP_3 , BUP_2 , BUP_1

When **N** is reached, the BUPs are re-numbered left to right in a special way:

BUP_{N-1} becomes BUP_N, BUP_{N-2} becomes BUP_{N-1}, BUP_{N-3} becomes BUP_{N-2} . . . . . .

. . . . BUP_4 becomes BUP_3, BUP_3 becomes BUP_2, and BUP_2 becomes BUP_1

Note that the original BUP_N has disappeared. Note also that the original BUP_1 is gone but will be replaced when time comes for the next BUP. There will still be **N** active BUPs. The average still keeps updating as a new BUP moves into position 1 and BUP_N falls off the list. This is a useful effect.

The pressure buildup measurements on Well 8 are recorded in Table 2. The average measured P of 745 psi is shown on Table 1.

PICTORIAL ILLUSTRATION OF USING GILBERT TO COMPUTE P FROM FLUID LEVEL

Gilbert's work was never published in the open literature. Copies must be surreptitiously obtained. Appearance of the new device has revived Gilbert as a method for computing P (pump intake pressure) from fluid level L (ft from surface). How? By supplying Gilbert with a casing gas rate (mcf/d) in a non-polluting fashion! The formula is

$$Q = [\ 79004 * V_c\ /\ (\ 1544 * Z * (\ 0.01 * G_e * L + 460\ )\ ]\ dp/dt$$

We intend to show that, if we execute this equation with dp/dt = 3.224 (the average of 20 BUPs), we will obtain a more accurate P than if we use a single BUP.

Our approach will be pictorial. Many solutions will be shown on Gilbert's S curve. The quality of the solutions will be judged by how close they lie to Gilbert's curve. All of our tests will be made on wells producing high gravity Permian Basin crude (API ~ 40). Gilbert's S curve was based on lower gravity, shallow, California Dominguez crude (API ~ 28). Thus a new Gilbert S curve will need to be created for high gravity Permian Basin crude. This is a long term project.

Locating a Solution On Gilbert's S Curve

$Q / (aP^{.4})$ locates the solution on the vertical axis.
r_m locates the solution on the horizontal axis.

Following are relations that will help compute r_m and other quantities.

dead oil gradient = 0.433 [141.5/(131.5 + API)]
pump submersion = S = D_p - L
casing gradient = r_m (dead oil gradient) = (P – $P_{L)}$ / S
P_L = Pc exp[0.01876 G L / Z Ta]
P = P_L + S (casing gradient) . . . Note: This is the formula for pump intake pressure.
r_m = (casing gradient / dead oil gradient) = (P – P_L) / S(dead oil gradient)

WHAT DOES THE PICTORIAL INFORMATION SAY?

Figure 4 shows the 8 wells scattered above and below the Gilbert curve. Well 8 is close to the curve because it is the only well for which multiple buildups were available over a longer period of time. Well No. 7 has no significant BUP and a dead oil column. The remaining 6 wells used the average of 6 BUPs at 10 minute intervals over a period of 1 hour in locating the wells on the Gilbert curve. BUPs are known to vary widely. Thus the location of a given well on the Gilbert plot with a single BUP or even multiple BUPS over a short period of time is governed by a process like rolling dice. That said, the normal procedure for gathering data for P in deep gassy wells with high FLs is to shoot one FL accompanied by one BUP.

Figure 5 is the culminating illustration of the entire study. It shows how a single BUP does not produce the best fit to the Gilbert curve. The largest single BUP of 7.378 psi/min (Table 2) leaves the solution far from the Gilbert curve. Similarly the smallest single BUP of 1.156 psi/min does not produce a solution close to the Gilbert curve. Only the 20 BUP average of 3.422 psi/min positions the solution very near the Gilbert curve. Being closest to the Gilbert curve is tantamount to calculating the most accurate P.
Will P be exact if the well falls right on the Gilbert curve? Probably not! because the Gilbert curve was made for low gravity crude! The wells studied herein have high gravity crude.

SUMMARY AND CONCLUSIONS

1. It is ironic that, after 63 years of trying, the industry does not have an accurate method for computing pump intake pressure in gassy wells with high fluid levels. This need is now greater than ever. Specifically, these are horizontal wells with high fluid levels and high gas rates up the casing. Present methods work when there is no gas. Present methods also give reasonable answers in pumped off wells. The errors are small enough to use the predictions to safely operate the well.
2. More testing should be done. A sample set of only 8 wells is not sufficient. With a larger data set, more problems to be fixed will be revealed.
3. The Industry Std. method has been shown to calculate questionable Ps in deep gassy wells with high fluid levels. It is hoped that its developers will continue work to rectify its problems.
4. Averaging multiple pressure buildups has proven useful in computing P. Its use should be continued as implemented in the permanently installed New Device.
5. Measurements have shown that fluid level and P change slowly. Measured pressure buildups change rapidly. This is justification for using averaged multiple buildups. Gathering multiple buildups is labor intensive for a human. It is a job for a permanently installed programmable device.

NOMENCLATURE

Symbol	Description	Unit
a	Area of casing annulus	sq in
API	Gravity of oil	deg API
BUP	Pressure buildup	psi/min
D	Dead fluid over pump	ft
D_p	Depth of pump	ft
G	Gas gravity	refer to air = 1
G_e	Thermal gradient of earth	deg F/100 ft
L	Fluid level	ft from sfc
N	Number of BUPs to average	-
P	Pump intake pressure	psi
P_c	Surface casing pressure	psi
P_L	Pressure at fluid level	psi
Q	Casing gas rate	mcf/day
r_m	Mixture density/Liquid density	-
S	Pump submergence	ft
T_a	Average temperature of gas above FL	deg Rankine
V_c	Casing volume	cu ft
z	Gas compressibility	psi reduced

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3. J. N. McCoy, A. L. Podio, and K. Huddleston, ”Acoustic Determination of Producing Bottom Hole Pressure,” *SPE Formation Evaluation*, September 1988.
4. K.B. Nolen and S.G. Gibbs, Ph.D., “Improving Determination of PIP from Fluid Level”, 2017 Permian Basin Artificial Lift Forum

Table 1. Comparison of Industry Standard with Gilbert

1	2	3	4	5	7	8
Well ID	**Pump Submerg. (ft)**	**Measured P (psi)**	**Gilbert P (psi)**	**Industry Std. P (psi)**	**Industry Std. Csg. Gas (MCFPD)**	**New Device Csg. Gas (MCFPD)**
Well No. 1	5823	550	724	498	487	210
Well No. 2	8256	1214	1379	641	731	141
Well No. 3	7451	1737	1187	640	988	177
Well No. 4	7056	1783	1447	675	546	103
Well No. 5	4311	550	705	435	203	115
Well No. 6	2015	332	275	308	428	370
Well No. 7	3977	1416	1523	1416	0	3
Well No. 8	4271	745	835	516	216	120

Table 2. Well No. 8 Pressure Buildups and Pump Intake Pressure

One Minute Pressure Buildups at 10 Min Intervals			
12/4/2017	12/11/2017	12/12/2017	12/13/2017
3.878	4.670	1.477	3.468
4.759	4.206	1.318	1.727
6.071	3.878	1.223	1.656
7.378	3.466	2.341	1.156
7.359	2.869	4.147	1.393
Pump Intake Pressure			
755	751	736	737

Min Buildup = 1.156 psi/min   Max Buildup = 7.378 psi/min   Avg Buildup = 3.422 psi/min

Avg Measured Pump Intake Pressure = 745 psi

Figure 1 - New Device for Measuring Casing Gas and Green Fluid Level

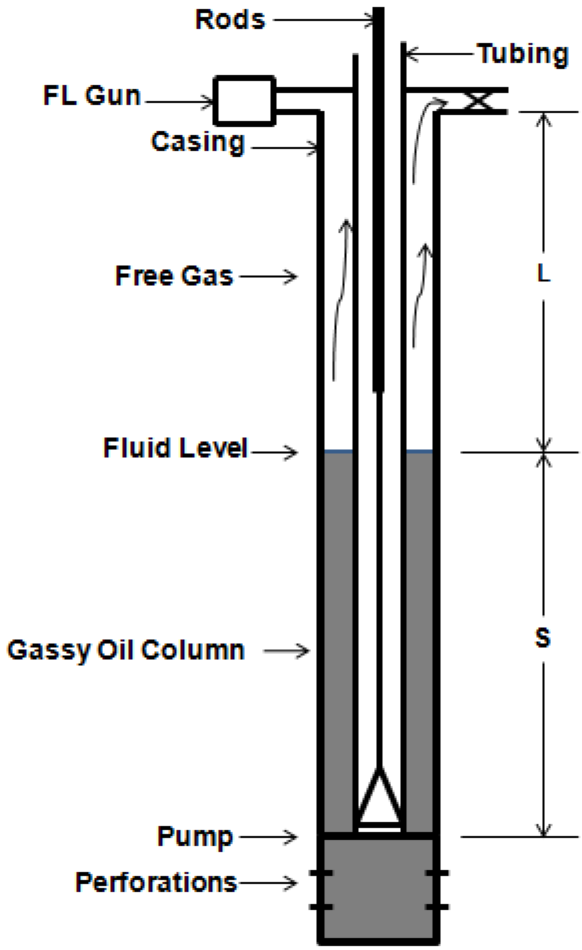

Figure 2 – Well Bore Diagram Showing Gassy Oil Column

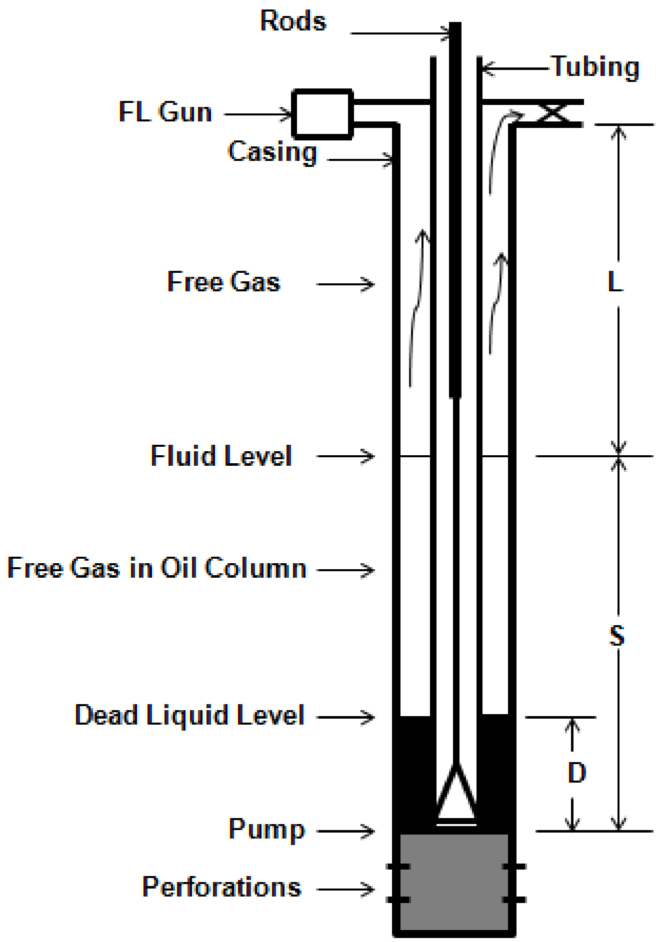

Figure 3 – Well Bore Diagram Showing Free Gas in Oil Column

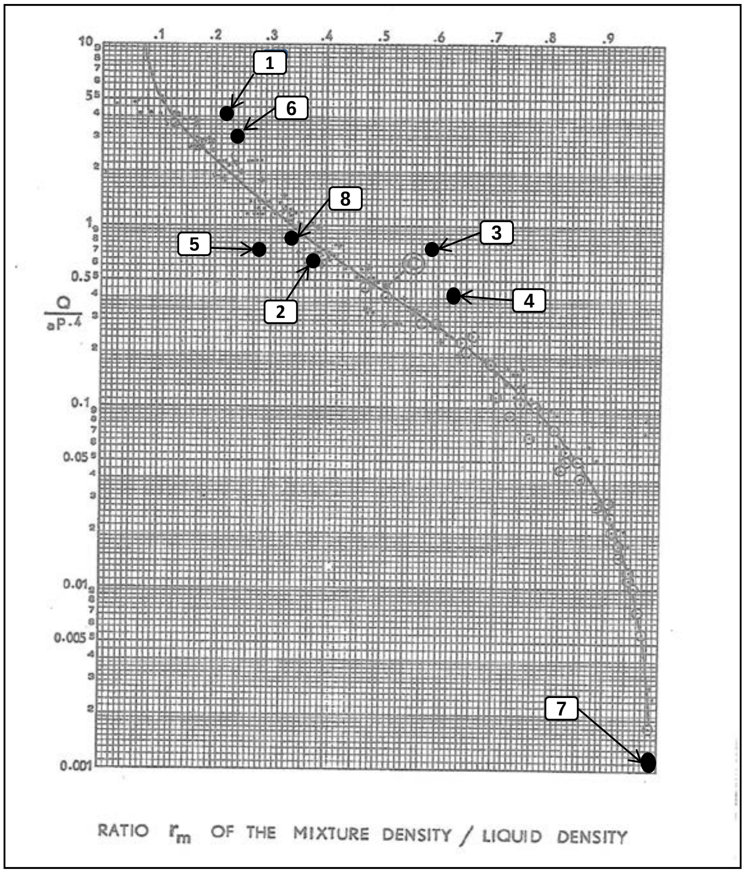

Figure 4 –Gilbert's "S" Curve, 8 Wells

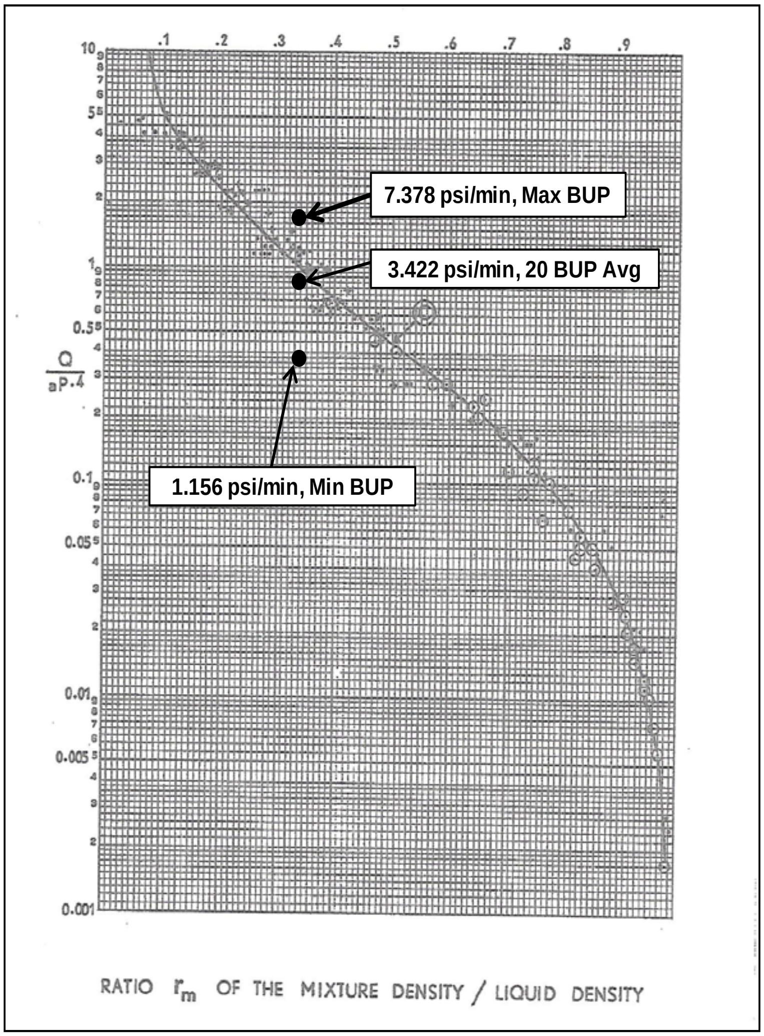

Figure 5 – Gilbert "S" Curve, Well No. 8