Fluid Levels - Application, Interpretation, and Evaluation

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ACOUSTICAL WELL SOUNDERS

During the last ten years, the acoustical well sounder has really come into its own as a production tool. These instruments are used to determine the fluid level in wells by the echo method. In addition, the location of various subsurface equipment items can be determined.

At the present time, there are two major manufacturers of acoustical well sounders. Both of these manufacturers use two small trunks to house their instruments. One trunk contains the wellhead attachment with the necessary interconnecting cables. The second trunk contains the amplifier-recorder. A description of these two principal components is as follows:

Wellhead Attachment

The wellhead attachment is a pressure-tight housing which is affixed to the wellhead and contains a firing mechanism, a microphone, and a bleed valve. In physical appearance the wellhead attachments of the two manufacturers vary, but each contains essentially the same components and performs the same basic function. The firing mechanism detonates a blank cartridge which generates a sound wave. This sound wave is reflected by various subsurface items (particularly tubing collars) and by the fluid level. The reflected sound waves are picked up by the microphone and converted into an electrical impulse which is recorded by the amplifier-recorder.

Amplifier-Recorder

The primary purpose of the amplifier-recorder is to record the fluid level reflection. However, reflections from the tubing collars and other inhole equipment such as gas lift valves, tubing anchors, etc., will also be recorded. Since the intensity and frequency of sound progressively decreases as it travels down the annulus, the reflections from the tubing collars near the top of the well are sharp and strong, whereas, reflections from deeper collars are weak. Similarly, the reflections from a shallow fluid level are sharp and strong, whereas the reflections from a deep fluid level are much weaker. Pressure also affects the character of sound, since the propagation of a sound wave in gas is directly proportional to pressure. The higher the casing pressure, the sharper and stronger the sound reflections.

The two manufacturers use different approaches to amplify the reflected sound waves. The instrument manufactured by the Keystone Development Corporation operates with two separate amplifiers because of the variance in reflected impulses. One amplifier is a relatively low frequency amplifier of very high sensitivity suitable for recording weak low frequency impulses. The second amplifier is a relatively high frequency amplifier of lower sensitivity suitable for recording the stronger high frequency impulses.

The instrument manufactured by the Associated Engineering and Equipment Company operates with a single amplifier and utilizes an automatic gain control to obtain results which can be interpreted from a single trace record. The gain of the amplifier circuits is determined by the magnitude of the average signal passing through them. If the signal is very small, the gain is great; if the signal is large, the gain is very little.

Both recorders are of the pen and ink type, producing an instantaneous record. The essential element of the recorder is a D'Arsonval-type galvanometer. The inking pens are attached to the upper end of the moving coil systems.

These well sounder instruments are portable, can be operated from either a 6 volt or 12 volt battery, and require no special equipment for field operation.

APPLICATIONS FOR USING FLUID LEVEL DATA

Fluid level data can be used advantageously as follows:

1. For the analysis of artificial-lift operations. A knowledge of the fluid level permits:
   (a) The determination of pump submergence for rod, hydraulic, and submergible centrifugal pumping installations.
   (b) The determination of the probable operating valve in a gas lift installation.
   (c) The evaluation of the efficiency and ability of subsurface lift equipment.
2. For the determination of the bottom hole pressure. The bottom hole pressure is the sum of the surface casing pressure, gas column weight, and fluid column weight.
3. For the determination of the productivity index (P.I.). A plot of fluid level against production rates permits the determination of the productivity index.

Fluid level measurements are not restricted to the annulus between the casing and the tubing. They can be made inside the tubing and also in wells which do not contâin tubing. In such cases, reflections are normally obtained from the recesses in the tubing or casing joints, as well as from the fluid level.

INTERPRETATION

The acoustical well sounder is normally used to determine the fluid level in the casing-tubing annulus. The depth to the fluid is measured in terms of tubing joints. If tubing collar reflections can be identified all the way to the fluid level, the determination of the depth to the fluid is simply a matter of counting the number of collar reflections and multiplying by the average tubing joint length. In those cases where collar reflections cannot be identified over a portion of the record, a set of dividers is used to measure that portion of the record. The scale used should be established from the nearest collar reflections.

Either trace of the double trace record produced by the Keystone instrument (Sonolog) may be used for interpretation. Normally, the one with the more pronounced collar "kicks" is used for this purpose. For ease in interpretation, it is sometimes desirable to shift from one trace to the other if certain portions of one are clearer than the other.

In examining the well sounder record, it should be realized that in addition to collar reflections, there may also occur reflections and multiple reflections from any other constriction or enlargement in the annulus space of the well. Objects such as gas lift valves, tubing catcher, liner top, casing seat, shot cavity, or perforations can yield a strong reflection, although none should be as strong as the fluid reflection since it reflects the entire sound wave.

The sound impulse reflected from the fluid level is reflected again at the wellhead and often starts a second trip down the annulus. Generally, the amplitude is sufficient to obtain a record of two, three, or even more reflections of the fluid level. Many times, the second recorded reflection of the fluid level is mistaken for the first reflection, particularly if the sensitivity setting is rather high. For this reason, it is important to examine the point in a record which is exactly halfway between the shot instant and the presumed fluid level. If there is an unusual indication at this point, reduce the sensitivity and repeat the shot.

There are no hard and fast rules for identifying any particular "kick" on the well sounder record. If in doubt, it is advisable to alter the operating conditions of the well, i.e., increase or decrease the casing pressure, reduce pumping speed, etc., in order to move the fluid level. By comparing several records, it should be possible to identify which "kick" is the fluid level.

Aids For Securing Satisfactory Results

If, with the maximum practical sensitivity setting, it is not possible to secure conclusive results, the following steps should be taken in an effort to secure the desired data. Even with these efforts there will be an occasional well in which the fluid level determination is not conclusive.

1. Decrease the background noise. This would consist of eliminating leaks, stopping the pumping unit, or "killing" the engine. In order to get a usable record, the signal impressed on the microphone from the tubing collar and fluid echoes must be greater than that from random noise.
2. Increase the output noise level by use of a larger cartridge (instruments can use a blank .38 cal., .45 cal., or a 10 gauge shell).
3. Allow casing pressure to increase. The propagation of a sound wave in gas is in direct proportion to pressure. The higher the pressure, the farther and faster the sound wave will travel.
4. Use special instrument controls which are capable of regulating the frequency response or otherwise affect the pickup ability of the amplifier. These controls are discussed in the following paragraphs.

The Keystone instrument (Sonolog) has a special switch which controls the frequency response of one of the amplifiers. In the normal position, the amplifier has a maximum sensitivity of about fifteen cycles per second. Both higher and lower frequencies are suppressed. For difficult fluid levels, this switch is used in one of two other positions, both of which shift the response to extremely low frequencies (approximately one cycle per second). In either of these positions, the sensitivity of the amplifier is increased considerably.

These special switch positions are normally used with a closed by-pass valve on the wellhead attachment. The Associated instrument also has a special switch which is spring-loaded in the "High" position. Holding this switch in the "Low" position changes the characteristics of the amplifier so that it responds more favorably to the very low frequency sound reflections and discriminates against higher frequencies. Thus, the instrument has a high gain for low frequency sounds and very little gain for high frequency sounds.

For fluid level data to be of the greatest value and assist in the solution of producing problems, the following information should be recorded on each record made: (a) well name and number, (b) date, (c) time of day, (d) instrument setting, (e) cartridge size used, (f) casing pressure, and (g) well status, i.e., pumping intermitting, shut-in, etc.

EVALUATION

Misleading results are sometimes obtained where foam or gas-cut fluid is present in the annulus. The top of foam will return an echo which cannot be distinguished from a solid fluid level on a well sounder record. In such cases, additional testing is necessary to evaluate the type fluid in the annulus.

Before discussing an evaluation method, one should be familiar with certain terms such as density, gravity, gradients, and fluid pressure.

Density - The weight of a substance per unit volume and usually expressed in pounds per cubic foot. For example, a cubic foot of fresh water weighs 62.4 pounds. Thus, the density of fresh water is 62.4. Crude oil has a lower density than fresh water and salt water has a higher density.

Specific Gravity - The ratio of the density of a solid or a liquid to that of fresh water. For example, the specific gravity of any salt water is its density divided by 62.4. The specific gravity of salt water varies, but will always be greater than 1.0.

API Gravity - Used to classify the specific weights of crude oils at 60°F. In this system, fresh water has been artibrarily designated as having an API gravity of 10. Therefore, each higher number designates a proportionately lighter density.

Fluid Gradient - The weight in pounds of a column of fluid one foot high which has a cross sectional area of one square inch. Since there are 144 square inches in a square foot, the fluid gradient is equal to 1/144th of the fluid density. Therefore, the heavier the

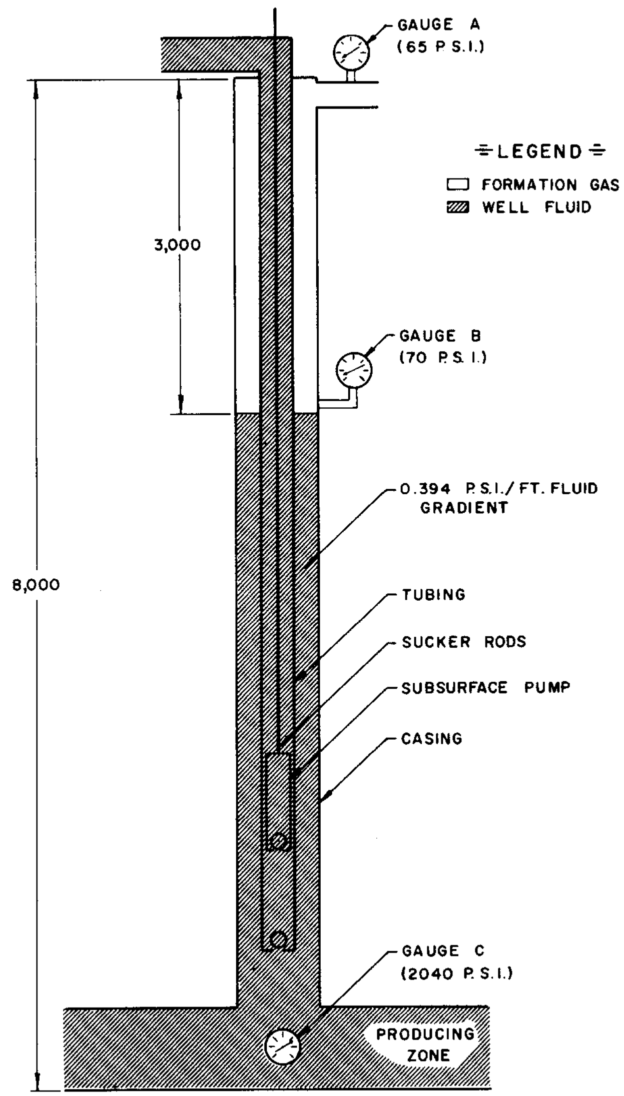

FIG. I

SCHEMATIC ROD PUMP INSTALLATION

density of a fluid, the higher the fluid gradient will be.

Fluid Pressure (hydrostatic head) - The total weight of a fluid column which has a cross sectional area of one square inch. When the fluid gradient is known, the fluid pressure or hydrostatic head is easily computed by multiplying the length of the fluid column in feet times the fluid gradient which is expressed in psi/ft.

With these terms defined, let us consider the factors which make up the bottom hole pressure of an oil well. Fig. 1 is a schematic drawing of a typical well being produced with rod pumping equipment.

Assuming that pressure gauges could be installed at various points in the well bore, the following conditions may be noted. Gauge A reads the back pressure being held on the casing-tubing annulus by the flow line. In this example, it has been assumed this gauge reads 65 psi. Gauge B located at the fluid level in the casing-tubing annulus reads the pressure exerted by the gas column. Note that Gauge B reads 70 psi or 5 psi more than Gauge A. This 5 psi is the pressure due to the weight of a 3,000 foot column of 65 psi gas.

Gauge C located at the bottom of the well bore, reads the total column pressure. This is the surface pressure of the gas (65 psi), plus the weight of the gas column (5 psi), plus the pressure exerted by the fluid column (5,000 feet of 0.394 psi/ft. fluid or 1,970). Assume the well produces 35° API gravity oil with 35% salt water which has a specific gravity of 1.05. This results in a calculated fluid gradient of 0.394 psi/ft. Therefore, in this example, Gauge C reads 2,040 psi.

Actually, the fluid column can consist of dead fluid only, dead fluid with foam on top, aerated fluid with foam on top or entirely of foam. Wells with these types of fluids are shown schematically in Fig. 2. It is realized that the interfaces will not be as pronounced as shown on these examples. In addition, the fluid or foam gradient will probably vary slightly from top to bottom.

The following definitions further define the types of fluid columns which you may expect to find in producing wells.

Dead fluid - Well fluid which contains no free gas. If the gravity of the produced oil, the percent water production and the specific gravity of the water are known, the dead fluid gradient can be easily determined. The gradient for dead fluid normally exceeds 0.35 psi/ft.

Aerated fluid - Well fluid which contains entrained gas bubbles. In normal pumping installations, formation gas is vented up the casing-tubing annulus. This formation gas percolates up the fluid column and on to the surface where it is usually bled into the flow line. However, depending on the nature of the fluid in the annulus, part of this gas may be held in the form of bubbles in the fluid column. These gas bubbles dilute the fluid and reduce the fluid gradient. The gradient of aerated fluid normally is above 0.10 psi/ft. but less than dead fluid gradient.

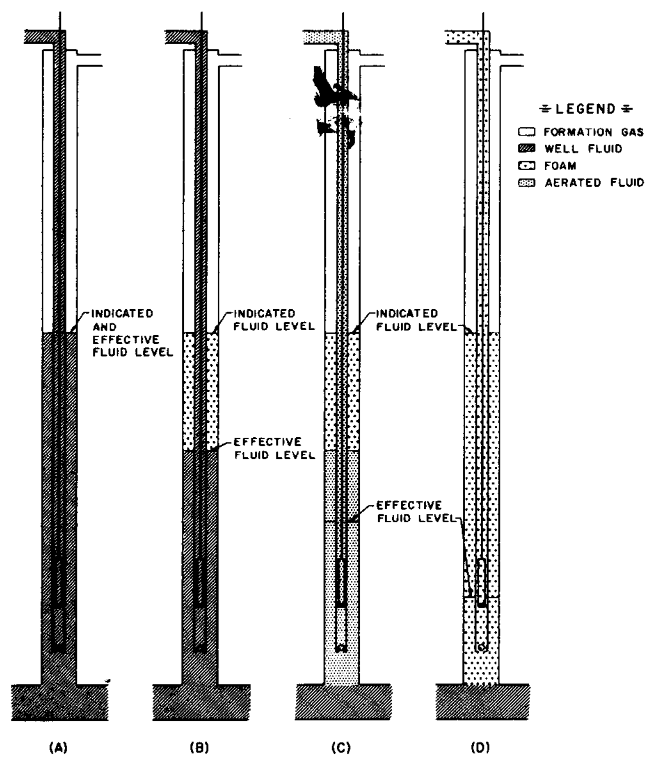

FIG. 2
TYPES OF FLUID COLUMNS

Foam - Foam can be considered as extremely light aerated fluid. The foam, when present, would be at the top of the fluid column with either dead or aerated fluid beneath it. It may be considered that aerated fluid is predominantly fluid where foam is predominantly gas. The gradient for foam is normally less than 0.10 psi/ft.

To simplify the evaluation of pumping fluid levels, let us neglect the weight of the gas column since it is very small and assume the casing pressure plus the weight of the fluid column will equal the bottom hole pressure. Thus, any increase in the surface using pressure must reduce the fluid column pressure and thus the fluid level. The amount the fluid level drops for a given increase in surface pressure indicates the weight per foot of fluid or the gradient of the fluid below the recorded fluid level. An example of this statement is shown schematically in Fig. 3.

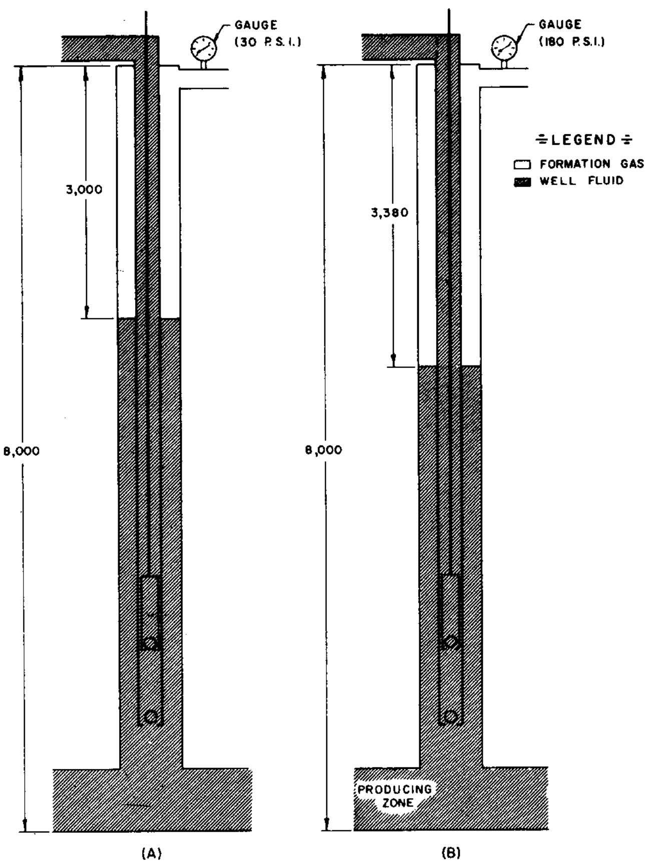

FIG. 3
EFFECT OF INCREASED CASING PRESSURE ON THE FLUID LEVEL

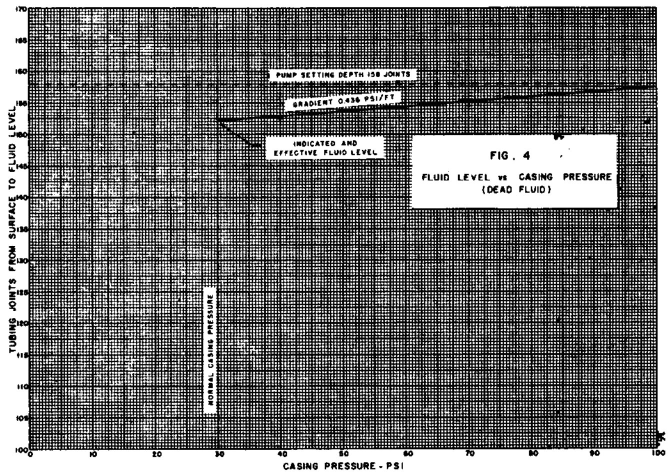

FIG. 4
FLUID LEVEL vs CASING PRESSURE
(DEAD FLUID)

The left example shows a fluid level located 3,000 feet down with a casing pressure of 30 psi. With an increased casing pressure of 180 psi as shown in the example on the right, the fluid level is now shown to be located 3,380 feet down. This means that with a pressure increase of 150 psi, the fluid level dropped 380 feet, indicating the gradient of the annulus fluid to be $\frac{150 \text{ psi}}{380 \text{ ft.}} = 0.394$ psi/ft. In this example, the figures chosen were intended to indicate dead fluid, in which case only two points are needed to establish the fluid gradient in the annulus of a well.

In actual test work, it is best to make a sufficient number of records at increasing pressures during normal producing operations until a definite trend is established as shown in Figs. 4, 5, 6, and 7. The importance of such an evaluation is to make sure that subsurface lifting equipment is sufficiently submerged for best efficiency and to increase the accuracy of bottom hole pressure calculations. This method also makes it possible to establish an effective datum to which fluid level surveys may be compared in order to determine changes in well productivity or to indicate relative conditions of the bottom hole pump.

Since it is not possible to tell the difference between a recorded fluid level from foam and one from a more solid fluid, let the following terms be used to differentiate between them. This terminology is shown on Fig. 2.

Indicated Fluid Level - The fluid level actually recorded by the acoustic well sounder.

Effective Fluid Level - An evaluated fluid level which is determined by converting the aerated fluid column

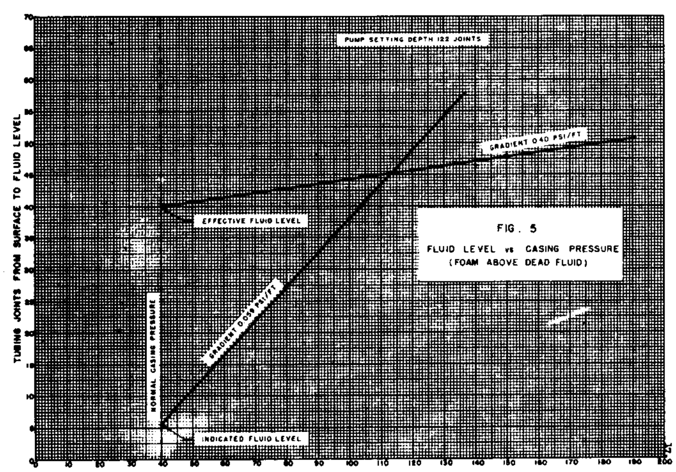

FIG. 5
FLUID LEVEL vs CASING PRESSURE
(FOAM ABOVE DEAD FLUID)

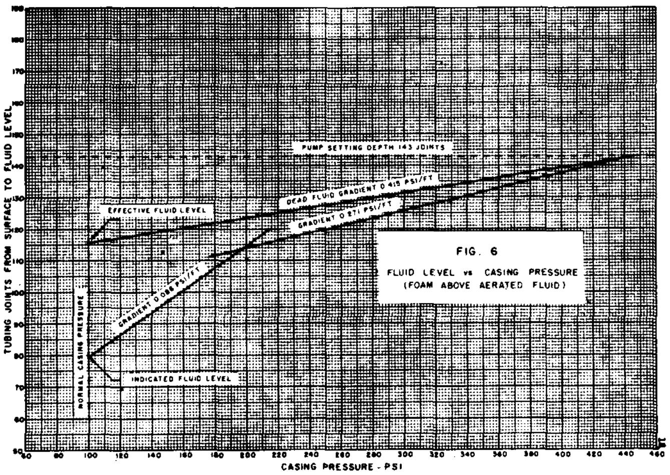

FIG. 6
FLUID LEVEL vs CASING PRESSURE
(FOAM ABOVE AERATED FLUID)

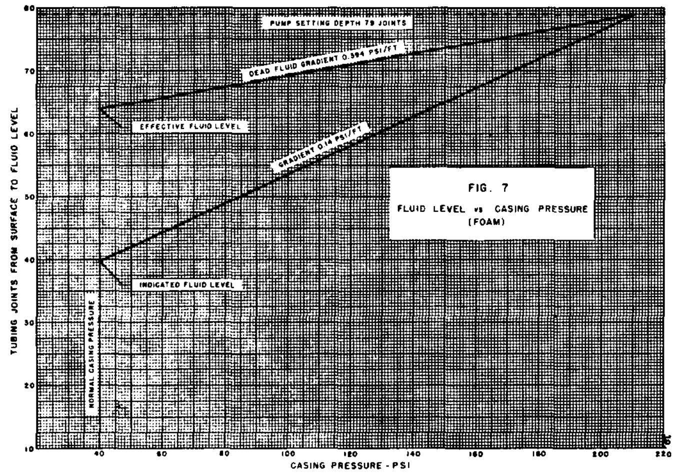

FIG. 7
FLUID LEVEL vs CASING PRESSURE
(FOAM)

above the pump into a dead fluid column based on the API gravity of the oil, the specific gravity of the produced water and its percent of the total fluid produced.

Individual discussion of Figs. 4 through 7 is as follows:

Figure 4 - (Dead fluid only) This figure contains a plot of fluid level data on a well which indicates the fluid in the annulus to be dead fluid having a gradient of 0.436 psi/ft. The indicated and effective fluid level would be at the same point.

Figure 5 - (Foam above dead fluid) A plot of fluid level data on this figure shows a well whose annulus fluid has a head of foam on top of dead fluid. Note the extremely low gradient of 0.059 psi/ft. for the foam. At a depth of approximately 1,400 feet, a fluid with a gradient of 0.40 was located. The indicated fluid level on this well was located 170 feet from the surface. The effective fluid is approximately 1,250 feet from the surface.

Figure 6 - (Foam above aerated fluid) This figure shows a similar well which has an indicated fluid level of 2,480 feet with 100 psi casing pressure. Note the gradient of the foam in this well is only 0.086 psi/ft. and extends to a depth of nearly 3,500 feet. At this point, an aerated fluid column is indicated, since the fluid has a gradient of 0.271 psi/ft. This well has an effective fluid level of 3,515 feet from the surface.

Figure 7 - (Aerated fluid only) A plot of the fluid level data on this well indicates that a foam or light aerated fluid of uniform gradient was found in the annulus. As noted, it has a very low gradient of 0.14 psi/ft. The dead fluid gradient for this well is 0.394 psi/ft. based on 31 API gravity oil, 16% water, having a specific gravity of 1.135. By plotting this data, the effective fluid level on this well was determined to be at 1,940 feet as compared to an indicated fluid level of 1,197 feet.

CONCLUSION

By using the suggested techniques outlined in this paper for securing, interpreting, and evaluating acoustical well sounder records, it is believed that the value of such data can be increased considerably. This should result in an increased demand for a service of this type to assist in the analysis of production problems.