Oct. 17, 1944. F. J. TOTH ET AL 2,360,742

APPARATUS FOR DETERMINING PRODUCTION POTENTIALS OF OIL WELLS

Filed March 8, 1941 2 Sheets-Sheet 1

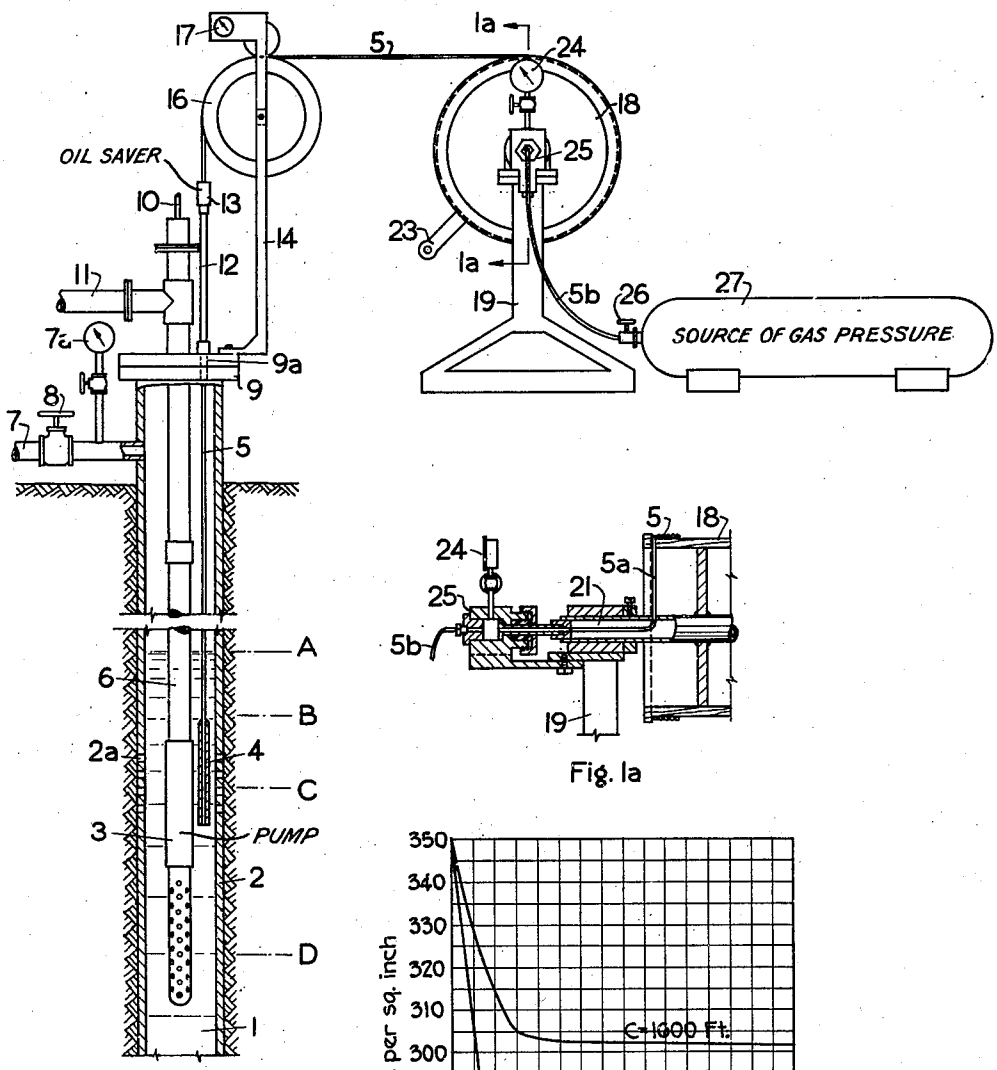


Fig. I

Fig. Ia

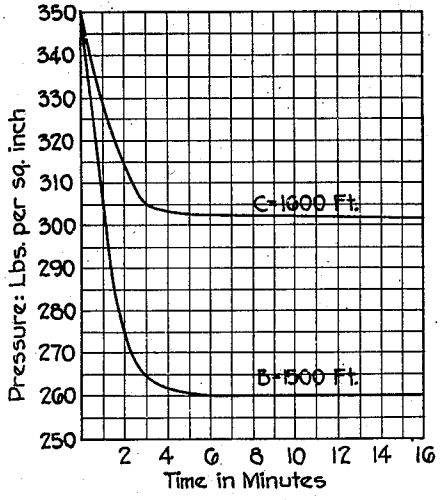


Fig. 3

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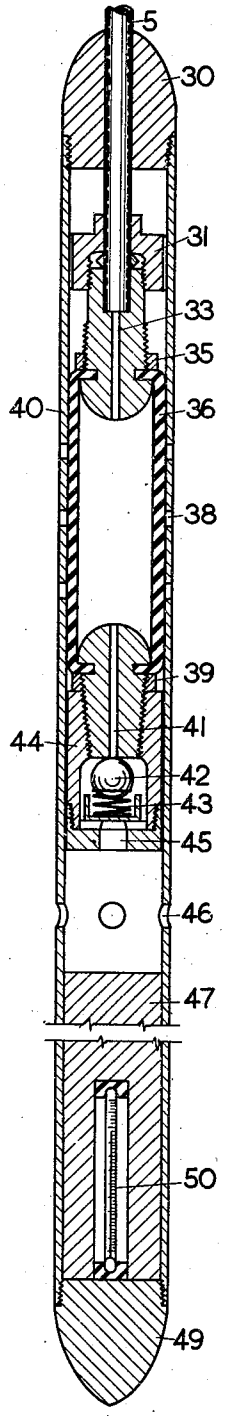


Fig. 2

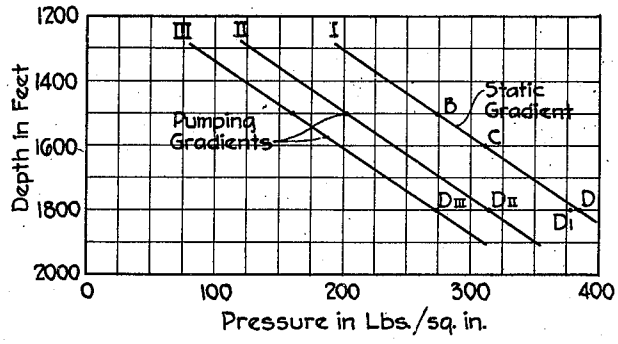


Fig. 4

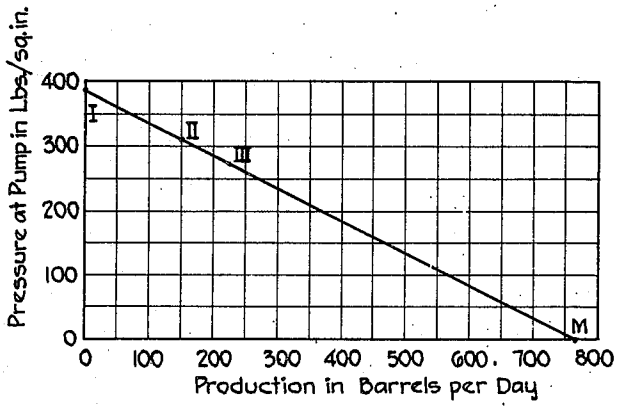


Fig. 5

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UNITED STATES PATENT OFFICE

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APPARATUS FOR DETERMINING PRODUCTION POTENTIALS OF OIL WELLS

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Application March 8, 1941, Serial No. 382,400

1 Claim. (Cl. 73—155)

This invention pertains to apparatus for the measurement of fluid levels, pressures and densities in oil wells, and for the determination of the production potentials of wells, and relates more specifically to apparatus for effecting such measurements in flowing, gas lift or pumping type wells.

Determinations of oil well potentials or productive capacities, involving fluid level, pressure and density measurements, are necessary for purposes of efficient and economical production of mineral oil, and for purposes of compliance with proration laws regulating so-called production allowables from oil wells.

Various methods have been applied for effecting these measurements in wells, involving, for example, the use of bailers lowered on sand lines for fluid level measurements and the use of pressure recorders connected into the pump string near the pump for the measurement of pressure at any depth within the well.

Since these methods, however, generally require the pumping operations to be stopped, there are also in use so-called sonic methods whereby all necessary measurements may be effected, and the production potential of a pumping well may be determined without stopping pumping operations.

These methods, for example, as described in the U. S. Reissue Patent No. 21,383 to Walker, comprise broadly the following steps: Closing the annular space between the casing and the pump tubing while operating the pump at a predetermined constant rate; allowing the pressure of the formation gas accumulating in said annular space to depress the level of the fluid standing in the well; effecting level measurements by the sonic method and noting the annular space gas pressures corresponding to each of the measured levels; determining from these level and pressure measurements the density of the well fluid and the pressure at the pump; changing the rate of pumping and repeating said measurements and determinations, and establishing, by combining the data thus obtained, the well potential or the maximum production capacity of the well, which may be expressed in terms of barrels per day.

The above methods, however, are ineffective in wells producing a relatively large amount of liquid and a relatively small amount of gas, since the gas pressure building up in the well when the casing head is closed is insufficient to depress the fluid level as required for the use of said method. The application of extraneous gas pressure, as, for example, from a compressor, is prohibitively expensive and wasteful. Neither the natural, nor the artificial gas pressure method can be effectively used in wells having leaky casings.

Furthermore, in wells producing a low gravity and/or high viscosity crude oil, which has a tendency to retard the liberation of minute quantities of entrained formation gas, there is usually formed in the annular space between the casing and the tubing, a layer of more or less stable foam. This layer, whose height is indefinite and subject to change, may sometimes detract from the accuracy of the sonic method, since the latter is based primarily on the principle of the reflection of sound from a true liquid surface.

The above-outlined method has furthermore the disadvantage of consuming a relatively large amount of time due to the necessity of taking level and pressure measurements at a plurality of points, and of giving the pressure at the pump only by an indirect extrapolation process instead of by direct reading. Likewise, pressure and level determinations at some other points of special interest in the well, such for example, as the mid-point of a perforated interval of the casing or liner string, often have to be effected by the same indirect process of extrapolation, because it is not always possible to depress the fluid in the well to a level sufficiently low to take direct readings at said points.

It is, therefore, the object of the present invention to provide apparatus for the measurement of oil well conditions such as pressures and fluid levels and densities, and for the determination of well potentials, which apparatus is applicable in wells producing relatively small amounts of gas.

It is also an object of this invention to provide apparatus for effecting the above determinations in wells producing oil which results in the formation of a foam layer in the annular space between the casing and the tubing.

It is also an object of this invention to provide apparatus for effecting the above determi-

nations without withdrawing the pump string from the well and without stopping the pumping operations, by means comprising devices lowered into the annular space between the casing or the walls of the well and said pump string.

It is also an object of this invention to provide apparatus for effecting the above determinations, which may, if desired, be used without stopping the pumping operations and without closing the annular space between the casing and the tubing, or without applying an artificial gas pressure to said space in order to depress the fluid level.

It is also an object of this invention to provide apparatus for effecting the above determinations, whereby the pressure at the pump or at any other desired point, such for example, as the mid-point of a perforated interval of the casing or liner string, may be measured by direct readings rather than by a process of indirect extrapolation.

These and other objects of this invention will be clearly apparent from the following description taken with reference to the appended drawings, wherein:

Fig. 1 shows the general arrangement of the apparatus used in applying the present method;

Fig. 1*a* is a cross-section view of a detail of the apparatus of Fig. 1, taken along line 1*a* of Fig. 1;

Fig. 2 shows a valve, chamber and sinker assembly which may be lowered into a well according to the present method; and

Figs. 3, 4 and 5 are graphs showing the manner in which the data obtained by the use of the present method are combined to obtain the desired well potential values.

Briefly stated, the method of the present invention comprises the steps of effecting simultaneous pressure and level measurements in the annular space between the walls of the well or the casing and the pump string by means of apparatus such as a pressure bomb lowered into said annular space on a measured wire line, or a string of flexible, small diameter tubing to which gas pressure is applied from the surface. More specifically and in greater detail, a preferred embodiment of the present invention comprises apparatus for lowering into the annular space between the casing and the pump tubing a string of flexible small-diameter tubing, submerging the lower end of said flexible string in the bore-hole fluid to any desired level, measuring said level, applying to the upper end of said flexible string a gas pressure capable of balancing the liquid head under which the lower end of said string is submerged, measuring said equilibrium pressure, and calculating from said level and gas pressure measurements the total pressure at the lower end of the flexible string. By repeating these determinations for different levels or different constant pumping rates and, if desired, for different values of gas pressure in the annular space between this casing and the tubes, the well potential and the productivity index may be determined in a manner similar to that used in the sonic methods referred to above.

Figure 1 shows a well 1, having a casing or liner string 2, closed by means of a flanged casing head 9, which supports a tubing string 6 provided with a pump 3 and means, such as a sucker rod string shown at 10, for supplying mechanical power to the pump, said pump being adapted to raise the well fluid to a suitable reservoir at the surface through a pipe 11. The annular space between the casing 2 and the tubing 6 may be vented through a pipe 7 or closed by means of a valve 8 provided in said pipe, a gauge 7*a* being used to indicate the gas pressure in said annular space.

The casing head flange has a suitable perforation 9*a* in communication with a lubricator 12 and an oil saver 13, through which a string of copper tubing 5, carrying at its lower end a sinker bar or a special assembly 4, to be described later, may be lowered into the annular space between the casing and the pump tubing of the well. This lubricator may also be used, if desired, to lower a pressure bomb on a wire line into the annular space, if it is desired to determine the pressure therein in this manner instead of the conventional method of connecting the bomb into the pump string.

The string 5 consists of flexible copper tubing of relatively small diameter, for example, $\frac{1}{16}$ inch inside and $\frac{1}{8}$ outside diameter. This tubing may be manufactured in any suitable lengths, such as 1000 feet, and may then be joined, by flux, acid or silver soldering, into strings having desirable lengths such as 2000 feet, 4000 feet or more, said solder joints having a tensile strength of 300 pounds or more.

Upon coming out of the well through the lubricator 12 and oil saver 13, the flexible copper tubing passes over a sheave 16, cooperating with a metering device 17 adapted to indicate the depth at which the lower end of the tubing 5 is located at any given moment. It is, however, obvious that said depth may be measured by other means, for example, by placing suitable markers on the tubing 5 and counting said markers, in which case the metering device 17 may be dispensed with.

After passing over the sheave 16, the copper tubing is wound on a reel or drum 18 rotatably supported on a base or frame 19. The reel 18 may be operated mechanically or manually, as, for example, by means of a handle 23.

The tubing 5 is connected to a source of gas pressure 27, such as a tank or a compressor, by any suitable means, the following being given by way of example and illustrated in Fig. 1*a*. The upper end of the tubing 5, wound as the innermost layer of tubing on the drum 18 is led toward and into the shaft 21 of the drum, as shown at 5*a*. The shaft 21 is made hollow and is provided at one end with a ball-bearing thrust packing box 25 mounted rotatably with regard to said shaft 21 and fixedly with regard to the frame 19. A conduit 5*b*, provided with a valve 26, connects the bearing box 25 with the reservoir of pressure gas 27. By opening the valve 26, gas may thus be admitted to the tubing 5, the pressure of said gas being indicated by a gauge 24 mounted at any suitable place, for example, on the box 25 as shown in Figs. 1 and 1*a*.

The reservoir 27 may be filled with compressed air or gas of any type, the use of hydrogen being, however, preferred, as will be shown below.

The lower end of tubing 5 may simply open to the fluid within the well, being provided with suitable weighting means, such for example, as 10-foot round stock steel sinker bar of about $\frac{7}{16}$ inch outside diameter, as shown in Fig. 1, or may have attached thereto a special assembly of the type shown in Fig. 2.

The arrangement of Fig. 2 comprises a metallic tubular member 40 having preferably an outside diameter of less than one inch and pro-

vided with top and bottom closure pieces 30 and 49. The lower end of tubing 5 is led through an opening in the top piece 30 and is affixed within the tube 40 by clamping means generally shown at 31.

The clamping means are provided with an axial passage 33, in register with the tube 5, and support, for example, by means of a ring 35, a flexible rubber sleeve 36 adjacent the inside wall of tubing 40. The lower end of the sleeve 36 is affixed, by means of a ring 39, to a ball valve chamber held within the tubing 40 and generally shown at 44.

The tubing 40 is provided with perforations 38 whereby pressure variations occurring in the well are applied from the outside to the chamber formed by the flexible sleeve 36 and serve to vary the volume of said chamber.

The chamber within the sleeve 36 is in direct communication with the space within the well by means of passages 41 and 45 in the valve chamber 44, and perforations 46 in the tubing 40, the valve chamber being also provided with a non-return valve 42, which may be of the ball type and is actuated by a spring 43 to close the passage 41 against the entry of the well fluid.

The lower portion of the tubular member 49 serves as a housing for weighting or sinker means, such for example, as a body of lead shown at 47.

A thermometer, for example, of the maximum registering type may also be housed within the tubular member 49 for purposes to be described below, as shown at 50.

The arrangement shown in Fig. 2 has therefore a threefold use. First, the surge chamber within the flexible sleeve 36 serves to smooth the effect of the pressure variations occurring within the well, whereby average, rather than instantaneous values, are indicated by the gauge 24 in applying the present apparatus; second, the non-return valve 42 closes the small-diameter tubing 5 to the entry of the well fluid, thereby preventing the possibility of its becoming clogged by impurities carried by the fluid; and third, the whole assembly, and especially the lead body 47, serves as a sinker bar for the tubing 5.

In applying the present apparatus, the fluid in the well is allowed to assume a stable level such as shown at A in Fig. 1, while either stopping the pump 3, if it is desired to obtain the so-called static well gradient, or operating said pump at a predetermined constant rate, if it is desired to obtain the so-called pumping or producing well gradient. The tubing 5, having at its lower end either the sinker bar shown in Fig. 1 or the arrangement shown in Fig. 2 is then lowered into the annular space between the casing and the tubing by the use of the lubricator 12.

When the lower end of the tubing 5 reaches any desired level, such for example, as shown at B in Fig. 1, as determined by the metering device 17, the valve 26 is momentarily opened, admitting a certain quantity of the pressure gas from reservoir 27 into the tubing 5.

This causes within the tubing 5 a pressure surge which is gradually dissipated as the gas expands and escapes by bubbling through the well fluid from the lower end of tubing 5 or from the openings 46 of the apparatus of Fig. 2, until said pressure reaches a constant value in equilibrium with the fluid head under which the tubing is submerged.

By referring to curve B in Fig. 3, which illustrates a case wherein the lower end of the tubing 5 was held at a level B equal to 1500 feet, it will be seen that an initial pressure surge of 350 lbs./sq. inch, as indicated by the gauge 24, decreased in 6 minutes to a substantially constant value of 260 lbs./sq. inch, which is the equilibrium pressure at said level.

The total subsurface pressure at level B or at any other level is obviously equal to said equilibrium pressure plus the computed pressure head exerted by the gas column within the copper tubing. This last pressure may be computed by the well-known Dice formula:

$$P=P_G\left(e^{\frac{(S)(d)}{53.33T}}-1\right)$$

wherein:

P=pressure due to static head of gas column in lbs./sq. in.
P_G=absolute gauge pressure in lbs./sq. in.
e=2.718
S=specific gravity of gas referred to air
d=depth in feet
T=mean absolute temperature of gas in degrees Fahrenheit

The mean absolute temperature of the gas in tubing 5, which is substantially the same as the mean temperature in the well, can be determined in a manner well understood by petroleum engineers, for example, from readings obtained by means of the thermometer 50.

It will be seen that the specific gravity of the gas within the tubing 5 is a factor entering in the above formula. It is, therefore, of great advantage to use for the purpose described a pressure gas having a very small specific gravity whereby errors due to small inaccuracies in temperature or level measurements are minimized.

After measuring the equilibrium pressure and computing the total pressure at level B, the lower end of tubing 5 may be raised or lowered to any other desired level, such as C, which may, for example, be the mid-point of a perforated interval of the casing or liner, and where direct pressure measurements may for this reason be considered of importance.

By repeating the operations described above, the equilibrium pressure at level C, for example, 1600 feet, may be determined to be 302 lbs./sq. in. as shown by curve C in Fig. 3.

By correcting this value to obtain the total pressure at level C in the same manner as described above, plotting the total pressures at levels B and C against corresponding depths, as shown in Fig. 4, and drawing a line I through the points B and C, the pressure gradient of the well may be obtained, from which the well pressure at the level of the pump may be determined. Thus, if the pump is located at a level D equal to 1800 feet, the well pressure at the pump will be found to be 385 feet.

If permitted by other conditions of the well, such as depth of the pump, length of the available copper tubing equipment, etc., the pressure at the pump may be determined by the present apparatus directly, by lowering the tubing 5 to the level D and effecting a measurement at said level. This procedure gives quicker results, as only one measurement is necessary in such case, and may likewise be used to check the result obtained by the extrapolation method described above. A reading obtained in this manner is shown at D_1 in Fig. 4, checking closely the result obtained by extrapolation.

Knowing the depth of the levels B and C and

the pressures prevailing at these levels, the density of the fluid standing in the well, which may be water, oil and water mixture, oil, gas-cut oil or foam formed as described above, may be readily determined from the following formula:

$$D_F = \frac{P_C - P_B}{L_C - L_B}$$

wherein:

D_F=density of fluid in lbs./sq. in. per foot of fluid
P_C=total pressure at level C in lbs./sq. in.
P_B=total pressure at level B in lbs./sq. in.
L_C=depth from surface to level C in feet
L_B=depth from surface to level B in feet

If the measurements described above are made while the pump 3 is stopped, the values obtained and plotted as shown by line I in Fig. 4 give the so-called static gradient of the well.

If the pump is then started and operated at a predetermined constant rate for a length of time sufficient for the fluid to recede to a new constant level, and the above measurements are repeated for the levels B and C, or for any different levels, so-called pumping gradients for the well may be determined.

Thus, for example, if the pump is operated at a constant rate to give a production of 150 barrels per day, the static fluid level A will recede to a lower constant level, and the pressure determined for the pump level will correspondingly decrease, for example, from a value of 385 lbs./sq. in. to a value of 315 lbs./sq. in., as shown at point D_{II} on the pumping gradient line II in Fig. 4.

By plotting the values of pressure at the level of the pump against the corresponding rates of production, it is possible to determine the well potential or the maximum production capacity of the well.

Thus, by plotting the above pump pressure values of 387, 315 and 275 lbs./sq. in. against corresponding production rates of 0, 150 and 225 barrels per day, respectively, as shown at points I, II and III in Fig. 5, it will be seen that the maximum potential production of the given well, which is the production rate required to reduce the pressure at the level of the pump to zero, is equal to 765 barrels per day. From this value, it is further possible to determine the productivity index of the well which is defined as the well production in barrels per day for each pound per square inch of pressure at the pump.

If the well in which it is desired to carry out the above determinations produces gas, the annular space between the casing and the tubing may be closed by means of a valve 8, and the gas pressure built in said annular space may be utilized to depress the well fluid to a desired level. By effecting the measurements described above under different conditions of gas pressure for different levels and different rates of pumping, determinations of well pressure, level and potential may be effected in a manner and with results similar to the above, the pressure at any level within the well being in such case equal to the sum of the fluid head obtaining at any point and of gas pressure applied to the surface of said fluid within the annular space between the casing and the tubing, said gas pressure being indicated by a gauge 7a in communication with said annular space.

We claim as our invention:

In apparatus for measuring conditions determining the production of a well having a casing and a pump suspended therein on a tubing string, a string of flexible small diameter tubing insertable into the annular space between the casing and the pump strings of said well, the lower end of said flexible string opening to a flexible-wall surge chamber externally exposed to well pressures, a non-return valve in communication between the inside of said chamber and the well, means for lowering said tubing into said annular space, indicating means for determining the position of the lower end of said small diameter tubing within the well, means for applying a gas under pressure to the upper end of said small diameter tubing, and gauge means for indicating the gaseous pressure within said tubing.

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