BOTTOM-HOLE PRESSURE

by

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Digest Prepared by Author

In the presentation of this paper it is not the aim to suggest anything new in the measuring and application of bottom-hole pressures, but rather to summarize the progress which has been made for those of you who are not intimately familiar with the subject.

INSTRUMENTS

There are at present nine different instruments for doing the work. In their mechanical construction these embrace about all the known methods of transforming pressure into mechanical motion.

Bourdon tube type. The Bourdon tube is a curved tube closed at one end, the position of which is fixed. Under pressure the tube tends to straighten, and movement of the closed free end is proportional to the pressure in the tube. Two instruments widely different in construction employ this principle.

The Amerada gauge uses a spirally coiled tube having about 10 coils. This tube is mounted within the case with its axis vertical. Attached to the free end of the tube is a steel stylus which presses against a record chart on the inside circumference of the case. Uncoiling of the tube under pressure marks a horizontal line on the chart. A clock mechanism moves the record chart vertically downward during operation giving a continuous and automatic record of pressure changes. When the instrument is held stationary at any point in the hole, movement of the chart causes the stylus to make a vertical line. The distance of this line from a base line at zero pressure shows the amount of movement of the free end of the tube under the pressure at that point.

The Wright gauge employs a single 180° bend of tube, exactly similar to the common steam or air pressure gauge. Movement of the free end of the tube is transmitted through gears to a pointer arm which moves over the face of the dial. In this instrument the outer end of the pointer arm is turned downward to form a pin-point which pricks the blank face of the dial. The mechanism is mounted within the case so that the dial is horizontal. Above the dial a circular weight is suspended upon a coil spring. In operation the outer end of the pointed arm moves around the circumference of a blank paper chart on the dial, remaining stationary as the instrument is suspended at any point in the hole. A jerk upon the line holding the instrument throws the weight by momentum down onto the pointer arm, making a pin-prick in the paper dial. A specially designed card permits reading the angular

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position of the hole in the card, which is proportional to the pressure exerted. This instrument is not continuously recording, but makes a record only at those places in the hole where the line is jerked.

Piston type. The piston type instruments employ the common principle of movement of a piston within a cylinder by direct pressure, or some modification of it. In the *Humble* instrument direct pressure against a piston moves a stylus point vertically. This stylus presses against a recording chart on the inside circumference of the case. Action of the piston is stabilized by means of a coil spring as in the common spring balance. A rack and pinion device actuated by jerking the line serves to rotate the recording chart where multiple readings are desired. Without this, the instrument operates automatically as a maximum-reading gauge, the length of line drawn by the stylus being proportional to the movement of the piston under pressure.

Piston-Diaphragm type. These instruments employ both the diaphragm and piston principles, pressure from the fluid in the well being transmitted through a diaphragm to a piston instead of acting directly upon the piston itself.

In the *Bureau of Mines* gauge fluid pressure in the well squeezes a sylphon bellows diaphragm, forcing fluid inside the bellows against a piston. Movement of the piston is recorded on a chart on the inside of the case exactly as in the Humble instrument. A clock mechanism turns the chart and makes the instrument continuous and automatic in operation.

This instrument also makes a continuous and automatic record of temperature. Expansion of mercury under influence of temperature moves a piston similar in design to the one actuated by pressure. A stylus draws a temperature line on the same chart on which pressure is recorded.

The Gulf instrument employs the same principle of pressure transmission, through a sylphon bellows to a piston, that is used in the Bureau of Mines gauge. Instead of making a record on a chart, the piston in this gauge moves an indicating pointer over a fixed printed dial similar to the ordinary pressure gauge. The pointer remains stationary at the highest pressure reached, and maximum pressure only is read when the instrument is removed from the hole.

In the *I. T. I. O.* gauge, pressure from fluid in the well is transmitted to a bellows filled with mercury. Under pressure the mercury is squeezed up a tube and spilled out at the top. The tube is filled to the top at atmospheric pressure, and the maximum pressure attained is indicated by the amount of recession of the mercury in the tube when the instrument is removed from the well. This instrument includes as an integral part a maximum reading thermometer in which the mercury remains at the highest point reached during the test.

The Alcorn gauge employs a principle similar to the thermos couple It is run on the bottom of the tubing, and remains permanently in the well. Pressure changes are transmitted electrically to a recording gauge at the surface. This is the only instrument so far made which is intended to be used as a permanent part of the well equipment.

An early attempt was made to measure well pressures by displacement in a tube. The end of a small diameter tube was run into the point at which pressure was desired to be known. The static head of fluid forced into this tube by well pressure was again forced out by compressed gas or air from the surface. The pressure necessary to clear the tube of fluid was the well pressure at the end of the tube.

The Barnsdall gauge consists merely of a closed bailer. It is run into the hole to the point at which pressure is desired, and removed from the hole full of fluid under the pressure at which it was filled. Reading is made by attaching an ordinary gauge after the bailer is removed from the hole.

Auxiliary Equipment. The Bureau of Mines and I. T. I. O. gauges contain thermometers as described, the former being the only one in which continuous record of temperatures has been attempted. The Wright gauge is so designed that the use of a maximum-reading thermometer is optional. Most of the others can be made to carry thermometers by slight changes in design or the addition of a separate section.

The Wright gauge carries a simple bailer as a bottom section if desired, so that a sample of fluid may be obtained.

Calibration of Instruments. Since most of these instruments do not use a direct-reading dial of any sort, special calibration charts are necessary. The amount of movement of the indicating mechanism in accordance with known pressures is determined on some form of deadweight or fluid-pressure instrument. A chart is then prepared on which amount of movement is plotted against known pressure. By means of this chart pressures indicated by the instrument are readily interpreted.

It is to be remarked and noted that most of these instruments perform under the rigors of field usage with an accuracy commonly expected from only high type laboratory equipment. Inaccuracy greater than one-half of one per cent is usually not acceptable, and common field practice reveals many instances of much smaller error than that.

Mode of Operation. With exception of the Alcorn gauge which is run on tubing, and the small tube which is run in from the top of the hole, all the gauges are operated on a Halliburton measuring line. This consists of a high tension steel wire of about the same diameter as ordinary bailing wire, which is run into the hole through a stuffing box. The instrument is put into an adequate “lubricating” section placed on the well-head hookup above the control gates, and the stuffing box head put on above it. When the gate is opened the stuffing box holds the pressure while the gauge is being run.

USE OF BOTTOM-HOLE PRESSURE DATA

The ability to measure fluid pressures in the well hole has opened to the producing branches of the oil industry an opportunity to store a vast fund of knowledge which will be of inestimable value in future operations. As a primary principle it is obvious that there can be no movement of fluid without the existence of differences in pressure. The whole industry is concerned with the movement of fluid in the reservoir. The petroleum business has grown in a period of 70 years to be one of the world's most important industries, if not indeed, its largest. It has stumbled into that position in almost complete and total ignorance of the basic natural forces upon which depend its very existence. When we know more of the pressures which exist in underground formations we will be able to approach with more confidence the problem of the migration and accumulation of oil. Measurement of pressures during the past two years has led directly to a marked improvement in the methods of control both of individual wells and of entire oil fields. The results already obtained are but an indication of much more that may be accomplished in the future.

CONTROL OF INDIVIDUAL WELLS

The whole trend of thought in the producing branch of the industry for some years past has been to prolong the flowing life—the period of low-cost operation—of oil wells. To this end there have been designed many and various devices, some to use more efficiently the natural forces involved and some to supplement those forces with mechanical means of one kind or another. Most of these devices have been intended for use at or near the end of the natural flowing life of the well. Many installations have been completed failures, due largely to inability properly to gauge the flowing characteristics of the wells. Basic principles for a field may perhaps be established from a few wells but successful application of scientific control to a given well must be based upon measured conditions in the well itself.

The measure of a well's capacity to produce is a measure of the drop in pressure at the bottom of the hole, and obviously the best well is the one which produces the greatest amount of oil with the least drop in pressure. That the pressure drop per barrel of oil produced may vary widely among wells is illustrated by some recent tests in East Texas. Two wells one-half mile apart were tested before and after a 15-minute flow. One of them produced 18 barrels of oil and showed a pressure drop of 110 pounds. The other produced 52 barrels during the flow period and had a corresponding pressure drop of only 23 pounds.

Characteristic shut-in and flowing pressure curves of East Texas wells are shown on a chart published by D. G. Hawthorne.[2] Pressure is plotted as the vertical co-ordinate and depth in the hole as the horizontal.

In the upper, closed-in pressure curve, note at the left, the slight increase in pressure with depth, due to the weight of gas only. At the fluid level, shown to be at

[2] Oil and Gas Journal, October 6, 1932, page 35, Fig. I.

about 700 feet the pressure gradient breaks sharply upward. The curve is a perfect straight line from the fluid level to the bottom of the hole, showing that the column of fluid is of uniform density throughout its entire depth.

The lower curve was taken with the same well flowing. Note at the right the lowered pressure at the bottom of the hole under flowing conditions. This curve remains a straight line until the point in the hole is reached where gas comes out of solution in response to lowered pressure. From that point upward the fluid column becomes increasingly light, which condition is shown by gradual flattening of the curve at the left as the depth becomes less. Except for occasional local differences all East Texas curves show the same thing—complete separation of gas and oil with the wells shut in, and all gas in solution at pressures above 750 pounds per square inch.

Contrast the East Texas shut-in pressure curve with some others from Oklahoma City[3] Note in the latter that while surface pressures vary from 400 to nearly 1,300 pounds, bottom-hole pressures are all very close to 2,000 pounds. Note also that in only two curves out of the seven is there complete separation of oil and gas in the hole. The pressure gradients are not straight lines, and most of them have slopes of less degree than is normal for crude oil of like gravity.

These curves reflect conditions in two widely different types of oil field. In the one the gas content is low and all of it is in solution at normal reservoir pressure. From this evidence alone it could be concluded that the propulsive force for flowing the wells must be something else than dissolved gas. It is a perfect example of a water-drive field.

In the other case free gas is shown to exist at normal reservoir pressures and it might readily be inferred that gas-oil ratios would increase as pressure decreased. Also that water-drive need not necessarily be an important source of flowing pressure. Both of these things we now know to be true.

A curve from a Seminole well, also taken from the paper by Mr. Hawthorne,[4] shows a well's maximum rate of efficient production. The pressure curve shows a uniform drop as the flowing rate increases to 50 barrels per day. Above this point bottom-hole pressure drops abruptly. The curve of gas production decreases uniformly to the same point of 50 barrels per day of oil, and then increases tremendously. It is obvious that gas does its work with increasing efficiency up to a maximum rate of production of 50 barrels, then apparently by-passes the oil in the sand and comes out as free gas. To produce this well at a rate greater than 50 barrels per day is wasteful of both gas and pressure, the two indispensable mediums for natural flow.

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[3] Unpublished curves shown on screen.
[4] Oil and Gas Journal, October 6, 1932, page 42, Fig. 4.

CONTROL OF PRODUCING FIELDS

In the same way that pressure tests are revealing hitherto unknown secrets of well performance, they are also giving us some intensely interesting and valuable data on the performance of fields as a whole. In the case of a field under considerable pressure from water at the edge, it would be expected that if all the wells were shut in encroaching water would tend to overcome the pressure loss occasioned by removal of fluid from the reservoir. This has actually taken place on each of the several occasions when the East Texas field has been completely shut down. Likewise, replenishment of pressure from an undrained area at one side of a field should be reflected in higher pressure at that side. This has been noted in the case of one major field. Lack of water pressure has been remarked in at least one instance by constantly falling pressure at the edge of a field unaccompanied by any intrusion of water.

Very valuable information concerning a field's production is gained by two sets of pressure data on all wells in a small Texas field. Both surveys, made some eight months apart, showed a uniform reduction of pressure across the field regardless of structural position of the wells. Both also showed highest pressures on the normal up-dip side of the field. The highest pressure wells were also the largest water-producers. Inquiry into the case of one well which showed abnormal pressure drop at the last survey revealed that this well had been over-produced in spite of remonstrance from other operators. These surveys present conclusive proof in this case of effective water-drive *down-dip* across the pool.

Bottom-hole pressures afford the best basis for control of oil fields under prorated production. Excessive production from any part of the field should be revealed by decreased pressures in that area. It is reliably reported that pressure data in East Texas are now being used to detect violators of the production allowables.

The advent of proration into oil production has made impossible the estimation of reserves of recoverable oil by any of the previously accepted methods. The use of pressure decline in connection with amount of oil produced, the same principle used for years in estimation of gas reserves, opens a way for determination of recoverable reserves which may prove more reliable than any previously used.

The study of well-pressures is likewise throwing much light on certain perplexing geologic problems. It has been shown definitely that there is no definite relation between depth and pressure. It has also been shown that pressures in different fields producing from the same sand bear no relation to their relative elevations. The hydraulic theory of accumulation needs as its basic facts a continuous sheet of water within the sand, which would mean pressure proportional to depth, and water-drive conditions in each field. Largely as a result of observations of well pressures it is now known that these conditions do not uniformly exist.