Money Saving Ideas From a Dynamometer Card

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INTRODUCTION

Sucker rod pumping is the primary method of producing oil from most oil reservoirs. Therefore, any instrument or method of analyzing pumping problems warrants consideration. The proven methods of analysis should be used to develop ideas for providing more economical operations.

Extensive testing has proved the dynamometer to be an efficient instrument for detecting malfunctions in the pumping equipment. The analytical methods derived from data provided by the dynamometer have contributed much to the economy of the oil industry. Before delving into the various aspects of the dynamometer as an analytical tool, we should first place it in its proper perspective by defining it and showing its relationship to the loads applied to the various components of the pumping system.

The dynamometer is simply an instrument for recording the weight of the sucker rod string and its related loads. It provides a continuous recording of the resultant of all forces acting along the axis of the polished rod at any particular instant.

SHAPE OF THE DYNAMOMETER CARD

The shape of the dynamometer card at the polished rod is affected by a number of forces, namely: the weight of the sucker rod string; size of the tubing and pump; weight of the fluid on the pump plunger; any resulting friction between the rods and tubing or rods and fluid; acceleration of the rods, which would cause a spring action of the sucker rod string; reciprocating speed; and, the counterbalance of the pumping unit. All of these forces combined, dictate the shape of the dynamometer card. This can be expressed by the illustration in Fig. 1.

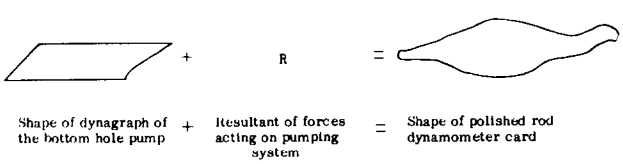


Fig. 1

The variation of any force acting on the pumping system will cause a corresponding alteration in the shape of the polished rod dynamometer card. These variations offer a clue to diagnosing malfunctions in the system. Also, these forces can be varied intentionally to cause a change that will provide a more desirable pumping condition.

The dynagraph card of a bottom-hole pump, as presented in Fig. 1, is a typical recording of the plunger load undisturbed by the influence of the rod string. It can be obtained by an instrument especially designed for installation in the rod string directly above the pump to record the load on the pump plunger. It was used in this illustration to emphasize the effects of the forces acting between the pump and surface equipment and to reveal their reflection on the surface dynamometer card.

Fig. 2 is a typical surface card obtained from a well producing from the San Andres formation in Yoakum County, Texas. A review of this card will illustrate how and at what position of the polished rod the various forces have altered the shape of the dynamometer card.

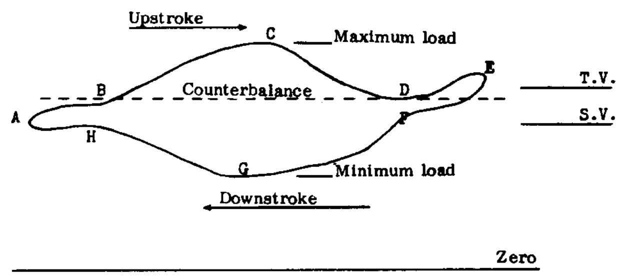


Fig. 2

The graphic line "ABCDE" is a recording of the upstroke load. Point "A" is the end of the downstroke and the beginning of the upstroke. At this point, a reversal in the movement of the rod string takes place. The polished rod starts its upward movement which is transmitted to the rod string. The sudden reversal causes a spring action in the rods and stores up energy that is released when the rod string starts its upward movement. This causes an acceleration of the pump plunger and helps to lift the fluid load. Therefore, the full load of the rods and fluid isn't applied to the polished rod during its upward movement from point "A" to "B". However, at point "B" the energy caused by the spring action has dissipated and the velocity of the polished rod begins to exceed the velocity of the pump plunger. Therefore, from point "B" to "C" a gradual load is applied to the polished rod until the maximum load is reached at point "C".

During the interval from "B" to "C" the rods have been stretched again, and a recoil action occurs. Therefore, from point "C" to "D" the spring action causes an acceleration of the pump plunger and its velocity exceeds the velocity of the polished rod, resulting in a decreased load at the surface. At point "D" the energy imparted by the recoil action, becomes dissipated, and again the load is gradually transferred to the polished rod until point "E", the top of the upstroke, has been reached.

The graphic line "EFGHA" is a recording of the downstroke load. The action of the downstroke is similar to that of the upstroke. The plunger travels from point "E" to "F" before the load is transferred from the rods to the tubing, relieving the rod string of its load. The recoil action of the rods causes a corresponding increase or decrease in the loads. The minimum load is recorded at point "G".

During both the upstroke and downstroke of the pumping cycle, the velocity of the polished rod is the primary factor that dictates the shape of the card. Also, any friction in the subsurface equipment will cause a greater load on the upstroke and a decreased load on the downstroke.

A measurement of the counterbalance, traveling valve, and standing valve loads can be obtained from static measurements with the dynamometer. These measured loads are needed for most analytical studies.

After reviewing these basic fundamentals, it is evident that an analysis of a dynamometer card should reveal any deviation, if present, from the normal loads and forces that can be anticipated from calculations. This, in turn, should initiate some ideas for correcting malfunctions in the pumping system.

INITIAL DESIGN OF PUMPING INSTALLATION

If the pumping situation is approached in the order in which the problems are most likely to occur, the initial installation should be considered first. Usually the oil reservoir characteristics will dictate the type down hole equipment that will be required. These reservoir characteristics are primarily: the type fluid (i.e., sour or sweet crude); gas-oil ratio; specific gravity; oil-water ratio; bottom hole pressure, and productivity index. Also, the current and anticipated well allowable will govern the pump size, unit speed, and stroke length. Therefore, the primary problem in the initial installation will be sizing the pumping unit and prime mover.

Pumping Unit

Four essential features must be considered when sizing a pumping unit for any installation. These are: (1) beam capacity; (2) required counterbalance; (3) peak torque on the gear reducer, and; (4) maximum stroke.

The discussion of the card in Fig. 2 revealed that the dynamometer will record the counterbalance effect and the maximum and minimum leads applied at the polished rod. Therefore, by utilizing these measured loads the necessary information for sizing a unit is available.

The peak torque on the gear reducer may roughly be defined as the amount of twist or force applied to the crankshaft of the gear reducer. This force is expressed in inch-pounds, and is a function of the unbalanced load (i.e., polished rod load minus the counterbalance effect) at the polished rod. It is continually changing and reaches its peaks during the upstroke and downstroke and is reduced to zero at the ends of each stroke. Fig. 3 is a graphic illustration of the torque in inch-pounds plotted versus the crank angle degrees. This curve was plotted by utilizing the torque factors published by the unit manufacturer.

By definition, the torque factors for any given crank angle is that factor which, when multiplied by the load in pounds at the polished rod, gives the torque in inch-pounds at the crankshaft of the pumping unit reducer. A number of detailed articles have been published concerning the derivation of torque factors; therefore, any further explanation of these factors will not be attempted in this paper.

The American Petroleum Institute has adopted Equation (1) as its standard for determining the net torque at the crankshaft of the gear reducer.

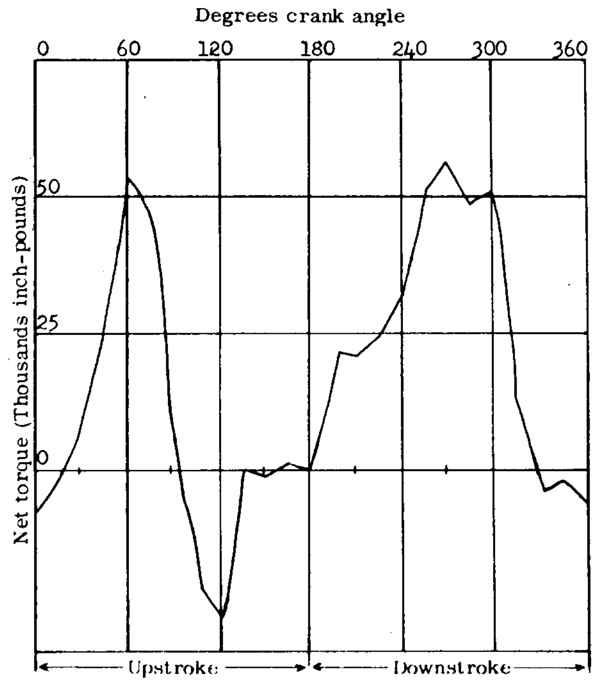


Fig. 3

(1) $T = \overline{TF}\,(PRL - B) - M \sin \Theta$

T = Net torque, inch-pounds
TF = Torque factor
PRL = Polished rod load, pounds
B = Structural unbalance of unit, pounds
M = Maximum moment of counterbalance, inch-pounds
Θ = Crank angle, degrees

The torque values at the various crank positions in Fig. 3 were calculated from Equation (1). The polished rod loads and counterbalance effect used in the calculations were measured from the dynamometer card in Fig. 4 which was obtained from a San Andres Well in Andrews County, Texas that was being pumped with a 57,000 inch-pound unit.

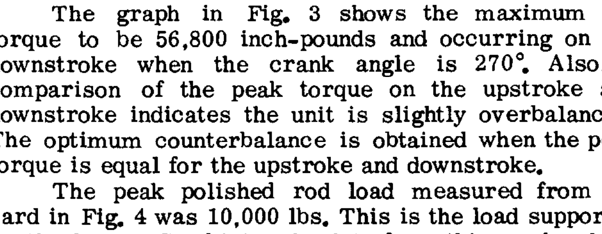


Fig. 4

The graph in Fig. 3 shows the maximum net torque to be 56,800 inch-pounds and occurring on the downstroke when the crank angle is 270°. Also, a comparison of the peak torque on the upstroke and downstroke indicates the unit is slightly overbalanced. The optimum counterbalance is obtained when the peak torque is equal for the upstroke and downstroke.

The peak polished rod load measured from the card in Fig. 4 was 10,000 lbs. This is the load supported by the beam. Combining the data from this card and the graph in Fig. 3, it can be concluded that the minimum size unit required to pump this well should have a beam capacity of 10,000 lbs., a gear reducer of 56,800 inch-pound torque capacity, and at least 8694 lbs. of counterbalance effect, and a stroke length of 42 in. The minimum size API rated unit that will meet these requirements is a unit with a 57,000 inch-pound gear reducer, a 10,900 lb. beam capacity, and a 42 in. stroke length.

However, in sizing a unit, the future demand that may be imposed on the unit must be taken into consideration. If water encroachment into the reservoir is anticipated, a larger load may be assumed for the future. The increase load would cause a corresponding increase in peak torque, counterbalance, and beam capacity. Also, any increase in production could necessitate a longer stroke length.

Careful consideration should be taken when sizing a unit which is approaching a borderline case. However, money can be saved on the initial investment if the minimum unit size can be used. An example is a recently completed well producing from the Clearfork formation in the Goldsmith 5600 ft. Field, Andrews County, Texas. This installation will approach the limits of an 80,000 inch-pound unit. However after reviewing the reservoir characteristics and using data from other installations, it was concluded the 80,000 inch-pound unit would meet the future load requirements for this well. A decision to purchase the 80,000 inch-pound unit instead of the next larger size, which would be a 114,000 inch-pound unit, resulted in a saving of $400 on the initial investment.

Often, before ordering a pumping unit for a new installation, a test unit is temporarily installed to determine the producing capabilities of the well. This is especially desirable in a new field. A dynamometer card may be obtained from the temporary installation and utilized to size the permanent equipment and establish a standard for sizing units to be used in that particular field.

Many times, permanent installations are sized from published data or calculations based on a given amount of production being produced from a known depth. It is wise to obtain a dynamometer card as soon as possible from such an installation to ascertain whether the measured loads are in line with the calculated loads.

Very often, money can be saved by using a small unit from surplus stock, with the intention of replacing it with a larger size when the load increases. The dynamometer can be especially helpful in determining the minimum size unit that could be used in this case.

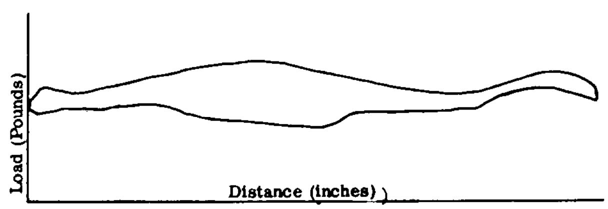


Fig. 5

Prime Mover

The size prime mover required for any pumping installation is derived from the horsepower requirement for lifting the fluid from the pump to the surface. Horsepower is a function of the amount of work done; therefore, by measuring the work at the polished rod, the horsepower can easily be calculated. The dynamometer card can be utilized to determine the horsepower because the area of the card is a direct measurement of the work done at the polished rod. This can be explained by Fig. 5 and Equations (2), (3), and (4).

By definition, work is the product of force multiplied by the distance through which the force acts (Equation 2).

(2) $W = FD$

W = Work, measured in foot-pounds
F = Force, measured in pounds
D = Distance, measured in feet

The dynamometer card in Fig. 5 was recorded with the vertical coordinate proportional to the load or force and the horizontal coordinate proportional to the polished rod stroke length, which is the distance the load or force has been moved. Therefore, it is a direct measurement of the work done.

Figure 5

By using a planimeter to measure the card area, in square inches, and inserting the results in Equation (3), the work done by one pumping cycle can be determined.

(5) $$W = \frac{AKL}{S}$$

W = Work in inch-pounds
A = Area of dynamometer card, square inch
K = Dynamometer constant, pounds per inch
L = Length of polished rod stroke, inch
S = Length of dynamometer card, inch

The uniqueness of Equation (3) is that none of the factors were assumed; each one was an actual measurement made directly from the dynamometer card and the polished rod. The results from Equation (3) can easily be converted to horsepower.

By definition, one horsepower is equal to 33,000 foot-pounds per minute. Therefore, to convert the work calculated from Equation (3) to horsepower, it will be necessary to multiply Equation (3) by the number of strokes per minute, and to divide by 12. This will convert work from inch-pounds to foot-pounds per minute. Also, by dividing this result by 33,000, the work done at the polished rod is converted to horsepower (Equation 4).

(4) $$PRHP = \frac{AKLN}{(12)\ (33{,}000)\ (S)}$$

PRHP = Polished rod horsepower
N = Number strokes per minute

The horsepower required at the prime mover is the brake horsepower and is equal to the polished rod horsepower plus the horsepower required to overcome the friction and motion in the pumping unit, belts, and motor. (Equation 5)

(5) $BHP = PRHP \times F$

BHP = Brake horsepower
PRHP = Polished rod horsepower
F = Surface efficiency factor

The surface efficiency factor in Equation (5) is the ratio of the brake horsepower to the polished rod horsepower. This factor is variable, depending primarily on the geometry of the pumping unit, and may vary from 1.5 to 2.5. Manufacturers are constantly making alterations in an effort to decrease this factor.

When sizing a prime mover by this method, care should be taken to obtain a card that represents the maximum well load. Cards "A" and "B" in Fig. 6 show different loads from the same well. Card "A" was obtained when the well was pumping its maximum load and Card "B" was taken after the well started pounding fluid. These cards were obtained from a well in the Milnesand-San Andres Field, Roosevelt County, New Mexico.

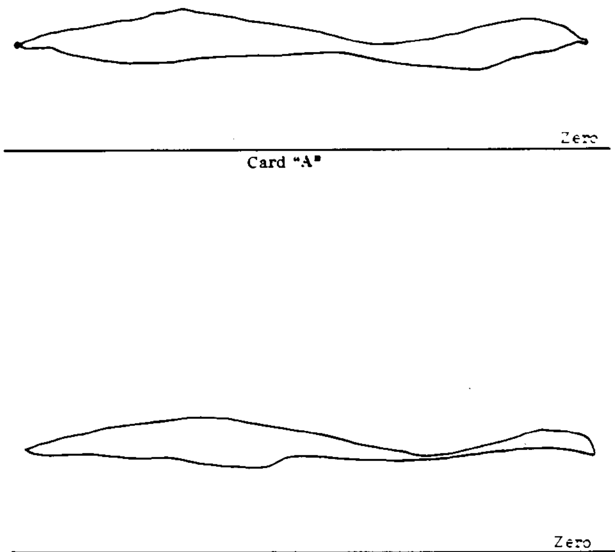


Fig. 6

Using Equation (4), a polished rod horsepower of 2.91 was calculated from Card "A", whereas the polished rod horsepower obtained from Card "B" was only 2.05.

$$\text{Card "A" PRHP} = \frac{(1.44)\ (8100)\ (48)\ (11)}{(12)\ (33000)\ (5.33)} = 2.91$$

$$\text{Card "B" PRHP} = \frac{(1.04)\ (8100)\ (48)\ (11)}{(12)\ (33000)\ (5.33)} = 2.05$$

If Card "B" were used to size the prime mover, an overloaded condition would occur if the well quit pounding fluid. On the initial electrical installation for this well, Card "A" was used to calculate a brake horsepower of 5.53 using a surface efficiency factor of 1.9.

$$BHP = PRHP \times 1.9$$
$$BHP = 2.91 \times 1.9 = 5.53$$

A 10 HP motor installation, based on offset information and on calculations, had been anticipated, but due to the dynamometer card analysis a 7-1/2 HP motor was installed. This resulted in a saving of approximately $50 on the initial investment. The lease has been expanded to 4 wells; therefore, a $200 saving on initial investment for motors was realized.

MODIFICATION OF PUMPING CONDITIONS

Modification of pumping conditions can be especially adaptable to water-flood leases, because the producing characteristics of the wells are constantly changing. Since the pumping speed is the easiest factor to modify, it can be utilized to correct a number of imprudent pumping conditions.

This was exemplified when a dynamometer survey was initiated on a lease in the Government Wells Field, Duval County, Texas. This lease was plagued with an abnormal number of pulling jobs resulting from split tubing joints, which was attributed to excessive rod against tubing wear.

All wells on this lease were being pumped at a speed fast enough to obtain a fluid pound that could be observed by watching the action of the polished rod hanger or by feeling the pound at the polished rod. It was imperative that the wells pound fluid to obtain the maximum production and prevent any oil from by-passing the well due to the sweeping effect of the flood water.

Dynamometer tests were conducted to ascertain the optimum pumping speeds that would permit each well to pound fluid on the first part of the downstroke. This eliminated the severe fluid pound and resulted in a large reduction of split tubing joints. These wells were kept under constant surveillance by periodic dynamometer surveys and since the prime movers were gas engines, the pumping speeds could easily be altered when necessary. The recommended pumping speed was stamped on the belt guard of each well and this enabled any of the personnel operating the lease to know the recommended pumping speed for each well.

One well on the lease was being pumped with a 80,000 inch-pound unit, but the dynamometer test showed the gear reducer to be overloaded. The pumping speed was decreased to the minimum speed that would allow a fluid pound. An analysis of the dynamometer card revealed that the decreased speed had reduced the maximum load and also, changed the position at which the peak torque occurred, from 70° crank angle to 60° crank angle. Since the peak torque is a function of the sine of the crank angle, the decreased angle and load resulted in a peak torque value less than the gear reducer rating. Therefore, it was not necessary to replace the unit with a larger one.

The data obtained from the dynamometer survey initiated ideas for modifying the pumping conditions on this lease and resulted in a more economical and efficient operation.

Modification of the pumping time on marginal or capacity wells has also proved to be an economical maneuver. Scheduling a well to produce for a definite length of time at various intervals during the day prevents wasted prime mover energy and also reduces equipment wear. Leases that are electrified are especially adapted to time-clock pumping.

In 1954, a dynamometer survey was conducted on a 10 well electrified lease in the McCamey Field, Upton County, Texas. All of the wells were marginal producers and would pump off at various intervals. The dynamometer was installed on each well to determine the time required for the well to reach a pumped-off condition. The well was shut down for an hour to allow fluid to enter the annulus, then pumping was resumed with the dynamometer installed. The time required to reach a pumped-off condition was again recorded. Through this method an optimum time-cycling was ascertained that would allow the maximum down time and still maintain capacity production.

Controlling the pumping intervals for each well not only decreased the electrical consumption, but also reduced the peak electrical demand for the lease. Also, from the dynamometer survey various changes in pump size, motor size, stroke length, and pumping speeds were made. During the 6 month period prior to the survey, the average monthly electrical cost for the lease was

$338. The year following the survey the average monthly electrical cost had decreased to $196, which resulted in an annual saving of $1704.

IMPROVING EFFICIENCY OF PUMPING EQUIPMENT

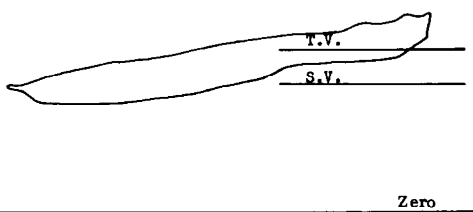
Improving the efficiency of the present pumping equipment in a well can be one of the most important contributions toward an economic operation. A periodic review of the pumping well should be made to determine the pumping efficiency, because producing characteristics are constantly changing.

One of the primary concerns about a pumping well should be the volumetric efficiency; that is, the ratio of the produced fluid volume to the theoretical volume obtained from calculations. A number of reliable formulas have been established and accepted by the industry for making these theoretical calculations.

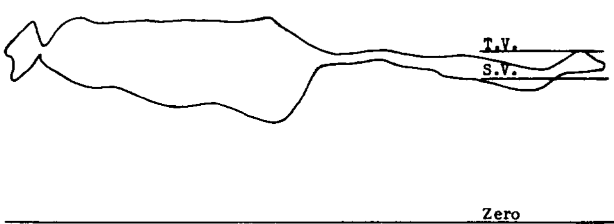
Although these calculations can be made, it is advisable to obtain a dynamometer card from the well to verify them. Also, the card can be used for future reference. Often a comparison of a new card with a reference card will offer some clue for diagnosing well problems.

There are a number of factors that can affect the efficiency of a pumping system and it would be impractical to consider all of these within the scope of this paper. However, 3 of the primary factors that can impair the efficiency will be briefly discussed in relation to the dynamometer card. These factors are: (1) rod and tubing stretch; (2) overtravel, and; (3) gas interference.

The shape of the dynamometer card can be utilized to detect these 3 factors. Cards "A" and "B" in Fig. 7 illustrate the effect of rod and tubing stretch on the pump plunger travel.



Card "A"



Card "B"

Fig. 7

These cards were obtained from a wildcat well producing from 10,100 ft. in the Dean Wolfcamp formation, Reeves County, Texas. The well was equipped with 2-1/2 in. tubing inside 10-3/4 in. casing. A compression type packer was installed during the initial well completion in this formation. The well failed to flow after being treated with acid and was placed on pump, leaving the packer in place.

The rod string consisted of 1800 ft. of 1 in. rods, 2400 ft. of 7/8 in., 5600 ft. of 3/4 in., and a 1-1/4 in. pump. The well was being pumped 10 x 100 inch strokes per minute by a 320,000 inch-pound air balanced unit. The 24 hour production test averaged 40 bbls. fluid per day, which indicated a very low volumetric efficiency.

A dynamometer survey was conducted and Card "A" obtained. The shape of the card indicated a continuous load increase on the upstroke, which is an indication of rod stretch caused by an abnormal load.

An analysis of the card was made using Slonneger's analytical approach for determining rod and tubing stretch, overtravel, and net plunger travel. The analysis revealed the rod stretch to be 41 in., the tubing stretch 7-1/2 in., and 2 in. overtravel. This resulted in a net plunger travel of 53-1/2 in., which is a loss of 46-1/2 in. when compared to the 100 in. surface stroke.

On the basis of 53-1/2 in. net plunger travel, the pump capacity was calculated to be 78 BFPD at 80% efficiency. The well was only producing 40 bbl. fluid per day. The dynamometer card did not indicate a fluid pound and showed the traveling valve and standing valve to be functioning properly. Therefore, the low volumetric efficiency was attributed to gas interference. However, the dynamometer card did not indicate any interference such as a gas lock or pound at the time the card was obtained. But, with the packer in place, it was necessary for all of the gas to pass through the pump; therefore the efficiency of the pump was decreased.

From the results of the analysis of Card "A", a decision was made to pull rods and tubing and replace the compression packer with a tension type tubing anchor. The average production increased to 96 bbl. fluid per day after this change.

A dynamometer survey was again conducted and Card "B" obtained. A different dynamometer was used on this survey, which accounts for the difference in the lengths of Cards "A" and "B". An analysis by Slonneger's method revealed the tubing stretch had been reduced to zero and the rod stretch decreased to 21 in. The overtravel on the top of the stroke was increased to 7 in. and on the bottom of the stroke it was 13 in. This resulted in a net plunger travel of 96 in.

The theoretical production at 80% efficiency with a 96 in. plunger travel was calculated to be 140 bbl. fluid per day. This volume compared to the actual produced volume of 96 bbl. fluid per day showed the volumetric efficiency to be only 66.6%. Card "B" revealed the well to be pounding fluid which accounted for the low volumetric efficiency.

The data provided by the dynamometer survey revealed the well was producing all of the fluid that was entering the annulus. Since this was a wildcat well, the information proved helpful in determining whether to continue producing from this formation.

CONCLUSION

The innovation of the dynamometer has provided a means whereby actual measurement of well loads can be obtained. The data provided by these measurements have greatly simplified the calculations for determining the numerous factors involved in a pumping system. The information revealed by dynamometer surveys has initiated ideas for the development of more prudent methods of operation, which have resulted in money saved for the oil industry.

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