

TRIGONAL INTERPRETATION OF RESERVOIR PERFORMANCE

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TRIGONAL INTERPRETATION OF RESERVOIR PERFORMANCE

by

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(Commander, U.S. Navy; U.S. Naval Postgraduate School)

B. S., University of California, 1934

Submitted to the Graduate School of the University
of Pittsburgh in partial fulfillment of the
requirements for the degree of
Master of Science

Pittsburgh, Pennsylvania

1954

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FOREWORD

The author of this thesis is a Commander in the United States Navy attending the Graduate School of the University of Pittsburgh under official orders from the Chief of Naval Personnel. In addition to his capacity as a graduate student at the University of Pittsburgh, he is also a student of the United States Naval Postgraduate School, Monterey, California.

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In the event of publication of this thesis, credit must be given to the U. S. Naval Postgraduate School, in addition to the usual credits.

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ANNOUNCEMENT

The author of this volume is the United States Army
attending the Institute of the University of Wisconsin
as an officer of the United States Army. In addition to his duties as a
graduate student at the University of Wisconsin, he has a review of the
United States Army, Wisconsin, and the United States Army.

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1941

- 1. The National Youth Administration (NYA) was established in 1935 to provide employment and training for young people.
- 2. The NYA was one of the largest federal agencies at the time.
- 3. It provided a wide range of services, including job training, financial aid, and recreational activities.
- 4. The NYA was instrumental in helping young people find employment and gain valuable experience.
- 5. It also provided a safe and supervised environment for young people during their leisure time.
- 6. The NYA was a key component of the New Deal's efforts to address the economic challenges of the Great Depression.
- 7. It played a significant role in the lives of millions of young Americans.
- 8. The NYA's programs were highly successful in providing support and opportunities for young people.
- 9. It was a major force in the development of the federal government's role in social welfare.
- 10. The NYA's legacy is still felt today, as it paved the way for many other social programs.

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I. INTRODUCTION AND BACKGROUND

A. Interpretation and Prediction of Reservoir Performance

An analysis of the performance of a producing petroleum reservoir is the basis on which the Reservoir Engineer will make his recommendations for a production program that will yield the optimum economic return. His analysis will be based upon his knowledge and understanding of the effect of the lithology of the reservoir rock, the characteristics of the reservoir fluids and the forces which act to expel or produce the reservoir fluids.

One of the basic tools available to the Reservoir Engineer is the material balance equation developed by Schilthuis,¹ and modifications thereto. This material balance equation of Schilthuis¹ is so derived that it can account for any one, or any combination of the three components, oil, gas and water, that occupies the pore space of the reservoir. With proper use of this equation, the performance of a reservoir can be interpreted and predicted. The literature contains much information on the use of the material balance equation in the analysis of reservoir performance. Each analysis is usually accompanied by a series of charts and graphs to illustrate the performance of the reservoir. It is noted, however, that these charts and graphs deal only with the variation of two components, while the third component is ignored or considered to be constant.

The purpose of this paper is to present a new and different method of interpreting the performance of a producing petroleum reservoir by developing a means of illustrating the variations of the three components simultaneously, or in other words, to present a visual representation of the material balance.

¹References in Bibliography

RESEARCH ON MATHEMATICS

Department of Mathematics, University of Toronto

The purpose of this paper is to present a study of the mathematical concepts of the calculus of variations and their applications to the theory of the minimum of a functional. The first part of the paper is devoted to the derivation of the Euler-Lagrange equations and the determination of the necessary conditions for a minimum. The second part is devoted to the study of the sufficiency conditions for a minimum.

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B. The Material Balance

Simply stated, a material balance is based on the premise that the amount originally present must equal the sum of the amount removed and the amount remaining. To obtain a material balance in the case of the petroleum reservoir, it is necessary to determine the original volume of each of the fluid components that occupied the virgin reservoir void space, measure the volume of each of the components that has been produced, and calculate the volume of each of the components remaining in the reservoir.

The void space in the petroleum reservoir is occupied by the three components, oil, gas and water, that must be accounted for in the material balance. The water exists as a liquid both in the reservoir and at the surface, and its volume changes only a negligible amount when it decompresses from reservoir pressure to surface pressure. The oil in the reservoir will contain dissolved gas. As this oil and dissolved gas is produced, the gas will evolve as the pressure reduces from reservoir pressure to surface pressure. The gas, when in the reservoir, may exist in two distinct states: as free gas under compression, and as gas dissolved in the oil. As the reservoir produces, the pressure on the produced fluids drops from reservoir pressure to surface pressure, dissolved gas comes out of solution in the produced oil and joins any free gas produced. All produced gas under surface pressure occupies a much larger volume than it occupied under reservoir pressure. In the development of the material balance for this paper, it is important that careful distinction be made between free gas and dissolved gas, and that the volumes of all components entering into this material balance be expressed in the same units and at reservoir conditions of pressure and temperature.

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of money and production.

C. The Driving Mechanisms

The fluids in the reservoir are produced or expelled from the reservoir by one or a combination of three driving mechanisms: water drive, dissolved gas or depletion drive, and expanding gas-cap or segregation drive. In all three mechanisms the driving force acts when there is a pressure differential within the reservoir.

Water drive occurs when there is edge-water encroachment due to artesian flow or expansion of the water on decompression.

Dissolved gas or depletion drive occurs when gas coming out of solution in the oil, due to reduction in reservoir pressure, expands and displaces the reservoir fluids.

Expanding gas-cap or segregation drive occurs when, upon reduction of reservoir pressure, the expansion of the free gas in the gas-cap displaces the reservoir fluids lying below the gas-oil interface in the reservoir.

THE HISTORY OF THE

The history of the world is a vast and intricate web of events, stretching across centuries and continents. It is a tapestry woven from the threads of human experience, from the dawn of civilization to the modern age. The story is one of constant change, of triumph and tragedy, of hope and despair. It is a story that has shaped the course of human destiny, and it is a story that continues to unfold before our eyes.

In the beginning, the world was a chaotic and unformed mass. It was a time of darkness and confusion, a time when the forces of nature were in constant conflict. But then, light came. The sun and moon appeared in the sky, and the world was brought into being. From that moment on, the story of the world began to unfold. It was a story of growth and progress, of the human race striving to overcome the challenges of nature and to create a better world for itself.

The history of the world is a story of the human spirit, of the human mind, and of the human heart. It is a story of the triumph of the human will over the forces of nature, of the human race's ability to create a world of its own. It is a story of the human race's quest for knowledge, for truth, and for a better life. It is a story that has inspired and motivated the human race for centuries, and it is a story that will continue to inspire and motivate us for centuries to come.

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II. STATEMENT OF THE PROBLEM

The void space in a producing petroleum reservoir is usually occupied by three components, (1) oil and dissolved gas, (2) free gas and (3) water. As production of the reservoir proceeds, the space vacated by the produced fluids must be filled by either expanding free gas or encroaching water, or both. While the volume of the void space remains constant during production, the volume of each of the components which occupies that void space is subject to change. The oil and dissolved gas volume will decrease as production proceeds. If the driving mechanism producing the reservoir is a gas drive and there is no water encroaching or being produced, the free gas volume will increase and the water volume will remain constant. If the driving mechanism is a water drive, the water volume will increase and the free gas volume will remain constant. If the driving mechanism is a combined water and gas drive, then both the water volume and the gas volume will increase.

The purpose of this study is to develop a visual representation of the performance of a petroleum reservoir by use of a trigonic graph, on which the per cent of the volume of void space occupied by each of the three components is shown at any time by a single point, and where a line plotted through successive points will indicate the trend of production of the reservoir.

An interpretation of the performance of the reservoir can be made from the trigonic plot and a production program that will yield the optimum economic return then can be planned.

THE HISTORY OF THE UNITED STATES

The first part of the history of the United States is the story of the early settlement of the eastern coast. The first permanent English settlement was founded in 1607 at Jamestown, Virginia. The early years were difficult, but the colony survived and grew. In 1776, the thirteen colonies declared their independence from Great Britain. The American Revolutionary War followed, and the United States emerged as a new nation. The Constitution was written in 1787, and the federal government was established. The United States then expanded westward, and the Civil War was fought between 1861 and 1865. After the war, the United States became a world power and played a major role in the world during the 20th century.

The second part of the history of the United States is the story of the westward expansion. The first major westward migration was the Oregon Trail, which was used by thousands of pioneers between 1811 and 1846. The California Gold Rush of 1849 led to a massive influx of people to California. The Mexican-American War of 1846-1848 resulted in the United States acquiring a large amount of territory in the southwest. The United States then continued to expand westward, and the frontier moved further and further west.

The third part of the history of the United States is the story of the industrial revolution. The industrial revolution began in the late 18th century and continued through the 19th century. It was a period of rapid technological change and economic growth. The United States was one of the leading nations of the industrial revolution. The invention of the steam engine, the cotton gin, and the power loom all played a major role in the industrial revolution. The United States became a major industrial power, and its economy grew rapidly.

The fourth part of the history of the United States is the story of the 20th century. The United States emerged as a world superpower after World War II. It played a major role in the Cold War, and it was a leading nation in the space race. The United States also faced major challenges in the 20th century, including the Vietnam War and the civil rights movement. The United States has continued to expand its influence around the world, and it remains a major power in the 21st century.

Continued on next page.

III. DEVELOPMENT OF THE TRIGONIC PLOT AS APPLIED TO THE RESERVOIR

A. Advantages and Disadvantages of the Trigonometric Plot

In any situation or condition in which the sum of three variables, expressed in the same units, comprises the whole, if the values for two of the variables are known, the value of the third variable becomes immediately apparent, since the sum of the three must always equal unity or 100 per cent. This situation can be illustrated graphically by use of the trigonic plot. The trigonic graph is an equilateral triangle with each base representing zero per cent and each apex representing 100 per cent of one of the three components. Any point within the trigon will indicate the portion of the whole or the percentage that each variable contributes to the whole.

In the case of the petroleum reservoir, the total pore volume of the reservoir is taken as the reference basis and represents 100 per cent. This pore volume may be occupied by any combination of (1) oil and dissolved gas, (2) free gas and (3) water. When the degree of occupancy by these three components is expressed in terms of per cent saturation, the sum will equal 100 per cent. When the percentage saturation is related to and plotted on the trigonic graph, the degree of occupancy of all three components will be represented by a single point.

The disadvantage of the trigonic plot is that it gives relative and not actual values. Additional calculations are required to reduce actual values in terms of barrels and cubic feet to relative values in terms of per cent of pore volume. Conversely, in analysing and interpreting the trigonic plot for production or economic purposes, the relative values in terms of per cent must be converted into actual values in terms of barrels and cubic feet.

THE HISTORY OF THE UNITED STATES OF AMERICA

In the history of the United States, the role of the individual is a central theme. The American dream, the pursuit of happiness, and the quest for a better life are the driving forces behind the nation's development. The story of the United States is a story of struggle, of triumph, and of the enduring human spirit.

The early years of the nation were marked by a sense of adventure and a desire for a new world. The pioneers who crossed the great plains and the mountains in search of a better life laid the foundation for the nation's growth. Their courage and determination are a testament to the American spirit.

The American Revolution was a turning point in the nation's history. It was a struggle for freedom and self-determination. The American people fought for the right to govern themselves and to live in a society where the rights of the individual are protected. The Revolution was a triumph for the American people and a source of inspiration for the rest of the world.

The American Civil War was another turning point in the nation's history. It was a struggle for the rights of the individual and for the preservation of the Union. The American people fought for the right to live in a society where the rights of the individual are protected. The Civil War was a triumph for the American people and a source of inspiration for the rest of the world.

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B. Effect of Driving Mechanisms on Saturation

There are three driving mechanisms that singly or in combination will expel the reservoir fluids from the reservoir into the well: water drive, dissolved gas drive, and expanding gas-cap drive. In the case of a water drive, the decrease in oil and dissolved gas saturation is made up by a corresponding increase in water saturation. In the case of a gas drive, the decrease in the oil and dissolved gas saturation is made up by a corresponding increase in the free gas saturation. For a combined water and gas drive, the decrease in oil and dissolved gas saturation is made up by an increase in both the water saturation and the free gas saturation, the relative increase of each being proportional to the relative magnitude of the driving forces.

To present a trigonic illustration of the effects of driving mechanisms on the saturation of a reservoir, a theoretical reservoir has been assumed. This theoretical reservoir has the following original saturation condition:

Oil and Dissolved Gas Saturation	- 65 per cent
Water (Connate) Saturation	- 20 per cent
Free Gas (Gas Cap) Saturation	- 15 per cent

Point A on figure 1 represents the original saturation condition of this theoretical reservoir on a trigonic plot.

1. Gas Drive

There are two types of gas drive for producing a reservoir, expanding gas-cap, and dissolved gas drives. In the theoretical reservoir, assuming that no connate water is produced, the saturation picture as the reservoir is produced by a gas drive will follow the line AB in figure 1. That is, as each unit volume of oil and dissolved gas is produced or removed from the reservoir, the space occupied by this unit volume will be filled by free gas, the

A Theory of Group Dynamics in Organizations

There are three distinct dimensions that apply to the organization. The first is the structure, which refers to the formal arrangement of roles and responsibilities. The second is the process, which refers to the way in which the organization operates. The third is the culture, which refers to the shared values and beliefs that guide the organization's behavior. These three dimensions are interrelated and influence each other in complex ways. For example, a change in structure may lead to a change in process, which in turn may lead to a change in culture. Understanding these relationships is essential for effective organizational management.

The organization's structure is a key determinant of its performance. A well-designed structure can facilitate communication, coordination, and decision-making. Conversely, a poorly designed structure can hinder these processes and lead to inefficiency and conflict. The organization's process is also a critical factor in its success. Effective processes ensure that the organization's resources are used efficiently and that its goals are achieved. Finally, the organization's culture is a powerful force that shapes its behavior and determines its long-term success. A strong, positive culture can foster innovation, collaboration, and a sense of purpose among employees.

In conclusion, the organization's structure, process, and culture are all essential components of its success. These three dimensions are interrelated and influence each other in complex ways. Understanding these relationships is essential for effective organizational management. By carefully designing and managing these three dimensions, organizations can create a strong, positive culture that fosters innovation, collaboration, and a sense of purpose among employees. This, in turn, can lead to improved performance and long-term success.

additional free gas required to occupy this space being supplied either by expansion of the gas-cap or by dissolved gas coming out of solution in the reservoir, or by a combination of both.

Let it be assumed that the oil and dissolved gas saturation is reduced from 65 per cent to 55 per cent by gas drive. If no water has been produced the water saturation remains at 20 per cent. Therefore, the free gas saturation must have increased from 15 per cent to 25 per cent in order to account for the total volume of the reservoir. On the trigonic plot of this reservoir (figure 1), this new saturation condition is represented by point b'.

If it so happens that some of the original connate water is produced or removed by the gas drive, then the line AB would be displaced to the left to indicate a decrease in both the water saturation and the oil and dissolved gas saturation.

2. Water Drive

If an ideal water drive situation is assumed for the theoretical reservoir, there will be no pressure drop in the reservoir, no expansion of the gas-cap, and no dissolved gas coming out of solution in the oil. Therefore, the space vacated by each volume unit of reservoir oil, with its dissolved gas still in solution, will be occupied by an equal volume unit of encroaching or driving water. The saturation picture as the reservoir is produced by the water drive will follow the line AB in figure 1.

Let it be assumed that the oil and dissolved gas saturation has been reduced from 65 per cent to 50 per cent by water drive. If the reservoir pressure has remained unchanged, the free gas (gas-cap) saturation remains at 15 per cent. Therefore the water saturation must have increased from

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20 per cent to 35 per cent in order to account for the total volume of the reservoir. On the trigonic plot of this reservoir (figure 1) this new saturation condition is represented by point d'.

3. Combined Gas and Water Drive

In the combined gas and water drive situation, the gas drive is provided either by expansion of the gas-cap, or by expansion of the dissolved gas coming out of solution or by both. If the magnitudes of the water and gas driving forces are equal, then for each unit volume of reservoir oil produced, the space vacated by this unit volume will be half occupied by free gas of the expanding gas-cap and/or gas coming out of solution, and half occupied by encroaching or driving water. The saturation picture as the reservoir is produced by this combined drive will follow the line AC in figure 1. The same saturation picture would hold if the gas drive energy came from the expanding gas-cap only, and no gas came out of solution in the reservoir.

Let it be assumed that the oil and dissolved gas saturation has been reduced from 65 per cent to 45 per cent by a combined drive where the water drive and the gas drive are equal. Since the 20 per cent of the space vacated by the produced oil and dissolved gas is equally occupied by free gas and water, the saturation of each is increased by 10 per cent. Therefore, the free gas saturation becomes 25 per cent and the water saturation becomes 30 per cent. On the trigonic plot of this reservoir (figure 1) this new saturation condition is represented by point c'.

If, in a combined drive situation, the magnitudes of the driving forces are not equal, then the saturation picture will vary proportionally as the relative magnitude of the driving forces. If the magnitude of the water drive force exceeds that of the gas drive, then more oil and dissolved gas will be replaced by water than by free gas, or the increase in water saturation will be greater than the increase in free gas saturation. In this case, the

It is not only the fact that the total volume of the
country is the subject of this study (Table 1) that the
national statistics is reported in Table 2.

3. National and local levels

In the context of the study, the national level is defined
as the country as a whole, and the local level is defined
as the region or the province. The study is based on the
national statistics and the regional statistics. The data
are collected from the national statistics and the regional
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4. Data sources and data collection

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5. Data analysis

The data are analyzed using the following methods:
1. Descriptive statistics: This method is used to
describe the data. It includes the calculation of the
mean, standard deviation, and other statistical measures.
2. Inferential statistics: This method is used to
test the hypotheses. It includes the calculation of the
t-statistic, F-statistic, and other statistical measures.
3. Regression analysis: This method is used to
estimate the relationship between the variables. It
includes the calculation of the regression coefficients
and the R-squared value.

saturation picture would be represented on the trigonic plot by a line lying between lines AC and AD in figure 1. The greater the displacement of reservoir oil by the water, the closer this line will approach the line AD, the situation of ideal water drive. Conversely, if the gas drive force were to predominate, then the saturation line would lie between lines AC and AB in figure 1.

From the foregoing discussion, it can be postulated that lines AB and AD represent respectively the limits for ideal gas drive and ideal water drive. In other words, when the change in saturation follows line AD, the driving or displacing force is due entirely to water drive. When the change in saturation follows line AB, the driving or displacing force is due entirely to gas drive.

4. Determination of the Magnitude of Driving Forces from the Trigonic Plot

In the foregoing discussion, it has been established that the driving or displacing forces are limited by the ideal conditions represented by lines AB and AD. It is apparent that any combination of gas and water drive will result in a saturation line falling between these two limits. It is also apparent that the position of this line with respect to the two limiting lines will be an indication of the relative magnitude of the two driving forces with respect to each other.

In the case where the two driving forces are considered to be equal, resulting in the saturation line AC, the two driving forces each displace an equal amount of reservoir oil. When the amounts displaced by each driving force are considered as a ratio, a numerical indication of the magnitude of the driving forces results. In this case, the ratio of reservoir oil displaced by gas drive to reservoir oil displaced by water drive will be 1/1. This ratio will be called the Displacement Index.

The Displacement Index may then be expressed as the ratio of the change of gas saturation to the change of water saturation, that is:

$$DI = ds_g / ds_w$$

The first part of the report is devoted to a general
 description of the work done during the year. It
 is divided into three main sections: the first
 deals with the general situation, the second
 with the work done in the various departments,
 and the third with the financial results.
 The first section deals with the general
 situation of the company. It is divided into
 three parts: the first deals with the general
 situation, the second with the work done in
 the various departments, and the third with
 the financial results. The second section
 deals with the work done in the various
 departments. It is divided into three parts:
 the first deals with the work done in the
 various departments, the second with the
 financial results, and the third with the
 general situation. The third section deals
 with the financial results. It is divided into
 three parts: the first deals with the
 financial results, the second with the
 general situation, and the third with the
 work done in the various departments.

Referring to figure 1 and the case where the driving forces are equal, point c', the gas saturation changes from 15 per cent to 25 per cent and the water saturation changes from 20 per cent to 30 per cent, therefore:

$$\begin{aligned} DI &= (25 - 15)/(30 - 20) \\ &= 1/1 \end{aligned}$$

In the situation represented by point c'', the gas saturation changes from 15 per cent to 35 per cent and the water saturation changes from 20 per cent to 25 per cent, therefore:

$$\begin{aligned} DI &= (35 - 15)/(25 - 20) \\ &= 4/1 \end{aligned}$$

In the situation represented by point c''', the gas saturation changes from 15 per cent to 20 per cent, and the water saturation changes from 20 per cent to 40 per cent, therefore:

$$\begin{aligned} DI &= (20 - 15)/(40 - 20) \\ &= 1/4 \end{aligned}$$

It is obvious, then, that a Displacement Index less than 1/1 will indicate a predominant water drive, while a Displacement Index greater than 1/1 will indicate a predominant gas drive.

In determining the Displacement Index from the change in saturation, it is necessary to take the different saturations in the proper vectorial direction, that is, the later saturation must be deducted from the earlier saturation. A negative Displacement Index will result when the free gas saturation is reduced by a water drive, or the water saturation is reduced by a gas drive.

Following the theory of the present theory, the results of the present theory are given by the following equations:

$$E_1 = (E_0 - 1) \sqrt{1 - \beta^2} \\ = E_0 \sqrt{1 - \beta^2}$$

In the present theory, the results of the present theory are given by the following equations:

$$E_2 = (E_0 - 1) \sqrt{1 - \beta^2} \\ = E_0 \sqrt{1 - \beta^2}$$

In the present theory, the results of the present theory are given by the following equations:

$$E_3 = (E_0 - 1) \sqrt{1 - \beta^2} \\ = E_0 \sqrt{1 - \beta^2}$$

In the present theory, the results of the present theory are given by the following equations:

$$E_4 = (E_0 - 1) \sqrt{1 - \beta^2} \\ = E_0 \sqrt{1 - \beta^2}$$

In the present theory, the results of the present theory are given by the following equations:

$$E_5 = (E_0 - 1) \sqrt{1 - \beta^2} \\ = E_0 \sqrt{1 - \beta^2}$$

In the present theory, the results of the present theory are given by the following equations:

$$E_6 = (E_0 - 1) \sqrt{1 - \beta^2} \\ = E_0 \sqrt{1 - \beta^2}$$

C. Calculation of Data for the Trigonometric Plot

In order to obtain values for use on the trigonometric plot, it is necessary to have production and laboratory data that will permit calculation of (1) original saturation conditions of the virgin reservoir, and (2) saturation conditions at any time, t , after production has started.

The equations to be used in calculating the original and subsequent saturation will be derived in the following paragraphs. The nomenclature used in these equations is as follows:

- V_t - total pore volume of reservoir, barrels.
- V_{og} - pore volume originally occupied by oil and dissolved gas, bbls.
- V_g - pore volume originally occupied by free gas (gas-cap), bbls.
- V_w - pore volume originally occupied by water (connate), bbls.
- v_{og} - volume of reservoir, in barrels, occupied by oil and dissolved gas after production to time t .
- v_g - volume of reservoir, in barrels, occupied by free gas after production to time t .
- v_w - volume of reservoir, in barrels, occupied by water after production to time t .
- S_{og} - original oil and dissolved gas saturation of reservoir.
- S_g - original free gas saturation of reservoir.
- S_w - original water saturation of reservoir (oil and gas-cap zones).
- s_{og} - oil and dissolved gas saturation at time t .
- s_g - free gas saturation at time t .
- s_w - water saturation at time t .
- N - barrels of stock tank oil originally in place.
- n - cumulative barrels of stock tank oil produced to time t .

Calculation of Data for the Tables

in order to obtain values for use in the tables, it is necessary

(2) to have provision for laboratory data that will provide estimates of (1) original estimated conditions at the right moment, and (X) estimated conditions at any time, if other provision can be made.

The equations to be used in obtaining the original and subsequent estimates will be found in the following paragraphs. The calculations used in these equations is as follows:

- 1 - Total time taken at working level.
- 2 - Time taken at working level, including all the intervals for data.
- 3 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 4 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 5 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 6 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 7 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 8 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 9 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 10 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
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- 13 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 14 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 15 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 16 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 17 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 18 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 19 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.
- 20 - Time taken at working level, including all the intervals for data, but excluding the intervals for data.

- B - formation volume factor; the volume occupied in barrels in the reservoir at pressure P by one barrel of stock tank oil plus the gas that will dissolve in it at that pressure.
- B_0 - original value of B .
- G_t - volume, in SCF, of dissolved gas and free gas initially in the reservoir.
- v - gas volume factor; the volume in barrels occupied in the reservoir at pressure P by one SCF of gas.
- v_0 - original value of v .
- r - dissolved gas-oil ratio at any pressure P ; the number of SCF of gas in solution per barrel of stock tank oil.
- r_0 - original value of r .
- R_a - cumulative actual gas produced to time t , in SCF.
- R_i - cumulative gas reinjected to time t , in SCF.
- R_p - cumulative net gas produced to time t , in SCF. Equal to $R_a - R_i$.
- W - cumulative gross water encroachment to time t , in barrels.
- W_N - cumulative net water encroachment to time t , in barrels.
- W_a - cumulative gross water produced to time t , in barrels.
- W_i - cumulative water injected to time t , in barrels.
- W_p - cumulative net water produced to time t , in barrels.
- P - reservoir pressure at any time t .
- P_0 - original value of P .
- SCF - Standard Cubic Foot: one cubic foot of gas at Standard Conditions of 60°F. and 14.7 psia.

It should be pointed out that the total pore volume of the reservoir, V_t , is the pore volume originally occupied by the connate water, by the oil and dissolved gas, and by the free gas (gas-cap), and does not include any of the pore volume of the reservoir sand that is occupied by water below the oil-water

interface. The original water saturation used in the trigonic plot is due to the connate water found in the oil and gas-cap zones as determined by core analysis.

1. Determination of Oil and Dissolved Gas Saturation

The volume of the reservoir originally occupied by oil and dissolved gas is best determined from geological information, that is, the number of acre-feet of producing formation containing oil and dissolved gas. The oil-gas interface and the oil-water interface in the reservoir must be known with reasonable accuracy.

If V_t equals the total pore volume of the reservoir, V_{og} equals the pore volume originally occupied by oil and dissolved gas, and S_{og} represents the per cent saturation by oil and dissolved gas then:

$$S_{og} = V_{og}/V_t \times 100$$

The original volume of oil and dissolved gas in place is also expressed in terms of barrels of stock tank oil and the formation volume factor; so:

$$V_{og} = NB_o$$

and:

$$S_{og} = NB_o/V_t \times 100$$

As production of the reservoir proceeds, n barrels (cumulative) of stock tank oil are produced and measured under standard conditions of pressure and temperature at the surface. The amount of stock tank oil remaining in the reservoir is then $(N-n)$ barrels, and the volume of oil and dissolved gas under the new reservoir condition is expressed as:

$$V_{og} = (N-n)B$$

and the saturation under the new conditions becomes:

$$s_{og} = (N-n)B/V_t \times 100$$

2. Determination of Free Gas Saturation

The volume of the reservoir originally occupied by free gas in the gas-cap is also best determined from geological information in the same manner

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The ... of the ... is ...

as the volume of oil and dissolved gas. Then, if V_g equals the pore volume (in barrels) originally occupied by free gas and S_g represents the original percent saturation by free gas:

$$S_g = V_g/V_t \times 100$$

In determining the free gas saturation as production of the reservoir proceeds, several factors must be considered. If the reservoir pressure has dropped to a value below the saturation pressure, gas in solution in the oil will evolve and become free gas. Some of this evolved free gas will enter the gas-cap, some will be produced, and some will remain in the oil zone in the free state. Each barrel of reservoir oil entering the well will also contain dissolved gas that will be separated from the oil at the surface.

If all gas, free and dissolved, originally in the reservoir is converted into a volume in cubic feet at standard conditions, then:

$$\text{Total gas (SCF)} = G_t = ((V_g/v_o) + Nr_o)$$

After R_a cumulative standard cubic feet of gas have been produced, the volume of gas remaining in the reservoir will be:

$$\text{Remaining gas (SCF)} = (G_t - R_a)$$

Of the gas remaining in the reservoir, r SCF are dissolved in each of the $(N - n)$ barrels of oil remaining in the reservoir so the free gas remaining then will be:

$$\text{Free gas remaining (SCF)} = (G_t - R_a - (N - n)r)$$

If R_1 cumulative standard cubic feet of gas have been injected into the reservoir, then the free gas remaining in the reservoir must be increased by this amount, so:

$$\text{Free gas remaining (SCF)} = (G_t - R_a - (N - n)r + R_1)$$

R_a and R_1 are frequently combined into a single value called the cumulative net gas produced, R_p . $R_p = R_a - R_1$

To reduce the free gas remaining from SCF to barrels at reservoir pressure and temperature, the foregoing equation is multiplied by the gas volume

as the value of α and β are fixed. Then α and β are fixed values
(in general) originally chosen by the user and α represents the original
and β represents the new value.

$$\alpha = \beta + \gamma$$

In general, the law of conservation of probability in the transition
process, which states that the sum of the probabilities of all possible
transitions is a finite value, the original probability, α , is added to the new
value and hence the law of conservation of probability is satisfied. The
new value will be positive, and the sum will be finite. The law
states that the sum of the probabilities of all possible transitions
must still be conserved from the old to the new value.
If the law of conservation of probability in the transition is not
satisfied, it is not a law of conservation of probability.

$$\alpha + \beta = \gamma + \delta$$

Since α and β are finite values, the law of conservation of probability
of the transition in the original state is

$$\alpha + \beta = \gamma + \delta$$

If the law of conservation of probability in the original state is not
satisfied, it is not a law of conservation of probability. The law
states that the sum of the probabilities of all possible transitions

$$\alpha + \beta = \gamma + \delta$$

is finite. The law of conservation of probability in the original state
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sum of the probabilities of all possible transitions is finite.

factor, v , corresponding to the reservoir pressure P . Then:

$$v_g \text{ (bbl)} = (G_t - R_p - (N - n)r)v$$

The free gas saturation, under the new reservoir conditions, is then:

$$s_g = v_g / V_t \times 100$$

3. Determination of Water Saturation

In the establishment of the total pore volume of the reservoir, it is considered that none of the pore space is initially occupied by encroached water. For this reason, the oil-water interface should be located with reasonable accuracy. The amount of connate water occupying pore space in the oil zone and gas-cap zone is determined from core analysis and electric logs. The connate water saturation is then taken as the initial water saturation of the reservoir. It is considered necessary to include this connate water saturation in the calculations, since, if some of it is eventually produced, the decrease in water saturation must be reflected in the trigonic plot. On the other hand, if no connate water is produced and water encroachment is later evident, the subsequent water saturation will be a value higher than the initial saturation which was due solely to the connate water.

During production the degree or amount of water encroachment cannot be readily measured. However, since by definition:

$$s_{og} + s_g + s_w = 100 \text{ per cent}$$

and s_{og} and s_g can be calculated from production data, it follows that:

$$s_w = 100 - (s_{og} + s_g)$$

Furthermore, when the values of s_{og} and s_g are plotted on the trigonic plot, the value of s_w is automatically established.

The establishment of the water saturation, s_w , as indicated above, is all that is necessary for the trigonic plot. However, if it is desired to determine the actual volume, in barrels, of the encroached water, the initial

where γ is the coefficient of the logarithmic function $\gamma = \frac{1}{2}$.

$$p_{\text{sat}}(T) = p_{\text{sat}}(T_0) \exp\left(\frac{h_{\text{vap}}}{R} \left(\frac{1}{T_0} - \frac{1}{T}\right)\right)$$

The true gas saturation, under the new conditions, is given

$$p_{\text{sat}} = p_{\text{sat}}(T) \frac{p}{p_0}$$

3. Determination of water saturation

In the establishment of the total mass values of the components, it is

considered that way of the water vapor is distributed according to molecular weight.

For this reason, the relative humidity should be linked with temperature as

shown. The amount of water vapor occupying each space in the air and

gas-air mass is determined from the relative humidity and relative logs. The amount

water saturation is shown in the initial water saturation of the reservoir.

If in some cases necessary to obtain this amount water saturation in the air

columns, then, it must be to be eventually constant, for example in water

saturation must be indicated in the relative logs. On the other hand, it is

possible that it is not and water saturation is later defined, the water

partial water saturation will be a value higher than the initial saturation with

was the ratio to the initial water.

During production the degree of condensation in water saturation must be

readily accessible. However, since the definition

$$p_{\text{sat}} = p_{\text{sat}}(T) \frac{p}{p_0} = 100 \text{ per cent}$$

and p_{sat} and p can be calculated from the relative logs, it follows that

$$p_{\text{sat}} = 100 \left(\frac{p}{p_0} \right)^{\frac{1}{\gamma}}$$

furthermore, when the values of p_{sat} and p are divided on the relative logs,

the value of γ is automatically established.

The establishment of the water saturation, p_{sat} , as indicated above, is

all that is necessary for the relative logs. However, it is to be noted that

determines the actual values, in terms of the component mass, the initial

and subsequent water saturations are used, since:

$$W_n = (s_w - S_w)V_t$$

W_n in this equation is the volume of the cumulative net encroached water. To obtain the cumulative gross encroached water volume, the cumulative volume of any water produced must be added to W_n , and the cumulative volume of any water injected must be deducted from W_n , so:

$$W = W_n + w_2 - w_1$$

or since:

$$w_2 - w_1 = w_p, \text{ the cumulative net water produced, then:}$$

$$W = W_n + w_p$$

Values for the volume of encroached water are usually calculated by using the Schilthuis material balance equation, or modifications thereof. If such values are available they can be used as a check on the water saturation obtained from the trigonic plot, since:

$$s_w = (V_w + W - w_p)/V_t$$

the following conditions are satisfied:

$$f(x) = x^2 + 2x + 1$$

It is then required to find the value of $f(x)$ at $x = 1$.

Since the function $f(x)$ is a polynomial, it is continuous and differentiable at $x = 1$.

The value of $f(x)$ at $x = 1$ is given by $f(1) = 1^2 + 2 \cdot 1 + 1 = 4$.

Therefore, the value of $f(x)$ at $x = 1$ is 4.

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IV. TRIANGULAR INTERPRETATION OF ACTUAL RESERVOIRS

A. The Schuler Jones Sand Pool

1. General Description and Production History

The Schuler Jones Sand Pool, discovered in September 1937, is located in west central Union County, Arkansas. The reservoir is an anticlinal type trap, approximately four miles long, east and west, and one and one-half miles wide. Maximum closure of the reservoir is 135 feet. Average depth of production is 7,400 feet, with the gas-oil contact at -7,270 feet and the water-oil contact at -7,370 to -7,380 feet.

The reservoir rock is composed of fine to medium size sand grains and is not uniform, but consists of sandstone zones interspersed with shale. The average porosity is 20.2 per cent and the average permeability is 400 millidarcies. Connate water saturation is 35 per cent.

The original volume of the reservoir, as determined from coring and electric logging, is 194,000 acre-feet with approximately 150,000 acre-feet of oil zone and 4,000 acre-feet of gas-cap.

The field was unitised in February 1941 and a gas injection program was started in July 1941. In July 1944 a water injection program was started. From discovery until the start of gas injection the field produced approximately 19 million barrels of oil with the reservoir pressure dropping from 3548 to 1542 psia. From the start of gas injection to March 1950, the field produced approximately 30 million barrels of oil with a drop in reservoir pressure from 1542 to 1432 psia. Careful production and pressure records have been kept on this field and material balance calculations indicate approximately 100 million barrels of stock tank oil originally in place in the reservoir.

THE FEDERAL INVESTIGATION OF ANIMAL WELFARE

1. The Federal Animal Welfare Act

The Federal Animal Welfare Act, 1966, is the primary law...

The Act defines the term "animal" as any mammal, bird, reptile, or amphibian...

The Act also defines the term "cruelty" as the infliction of unnecessary pain...

The Act requires that all animals be treated humanely and with respect for their individuality...

The Act also requires that all animals be kept in clean and sanitary conditions...

The Act further requires that all animals be provided with adequate food and water...

The Act also requires that all animals be provided with adequate shelter...

The Act further requires that all animals be provided with adequate veterinary care...

The Act also requires that all animals be provided with adequate protection from the elements...

The Act further requires that all animals be provided with adequate protection from disease...

The Act also requires that all animals be provided with adequate protection from injury...

The Act further requires that all animals be provided with adequate protection from neglect...

The Act also requires that all animals be provided with adequate protection from abuse...

The Act further requires that all animals be provided with adequate protection from exploitation...

The Act also requires that all animals be provided with adequate protection from cruelty...

The Act further requires that all animals be provided with adequate protection from neglect...

The Act also requires that all animals be provided with adequate protection from abuse...

The Act further requires that all animals be provided with adequate protection from exploitation...

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The Act further requires that all animals be provided with adequate protection from exploitation...

The Act also requires that all animals be provided with adequate protection from cruelty...

The Act further requires that all animals be provided with adequate protection from neglect...

Produced gas has been used exclusively for reinjection, except for a period in 1944-1945 when "make up" gas was imported. During this period more gas was injected than produced, which resulted in a decrease in the cumulative net gas produced for January and July 1945.^{2,3,4}

2. Trigonis Plot of Schuler Jones Sand Pool

Figure 2 is the trigonic plot for the Schuler Jones Sand Pool and covers the period of production from discovery of the pool in September 1937 to March 1950. Reservoir characteristics, fluid characteristics and production data used in calculating the values for the trigonic plot and these calculated values are tabulated in Appendix I.

3. Trigonal Interpretation of the Performance of the Schuler Jones Sand Pool

Point A on figure 2 represents the original saturation condition in the reservoir at time of discovery. This saturation condition was:

Oil and dissolved gas saturation	63.3 per cent
Free gas saturation	1.7 per cent
Water saturation	35.0 per cent

Point B represents the saturation condition in January 1942, six months after gas injection was started. Oil and dissolved gas saturation had dropped to 44.8 per cent, free gas saturation had increased to 19.6 per cent, while water saturation had remained practically constant with a value of 35.6 per cent. Since the volume of the reservoir vacated by the produced oil and dissolved gas had been occupied almost solely by free gas, it is evident that the driving mechanism producing the reservoir between points A and B was a gas drive. The line from A to B closely approximates the situation of an ideal gas drive.

Point C represents the saturation condition at a time between March and September 1947. Between points B and C, both water and free gas saturation increased, indicating a combined water and gas drive as the mechanism producing the reservoir. The trend of the line between points B and C indicates that

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$$\frac{1}{2} \frac{d^2 x}{dt^2} = -kx$$

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the gas drive is slightly predominant over the water drive. The Displacement Index for this interval of production is $1.24/1$.

Point D represents the saturation condition in March 1950. Between points C and D, the water saturation increased while the free gas saturation remained almost constant. This fact and the trend of the line between points C and D indicate that an ideal water drive was the mechanism producing the reservoir.

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100% Oil and
Dissolved Gas

100% Water
B

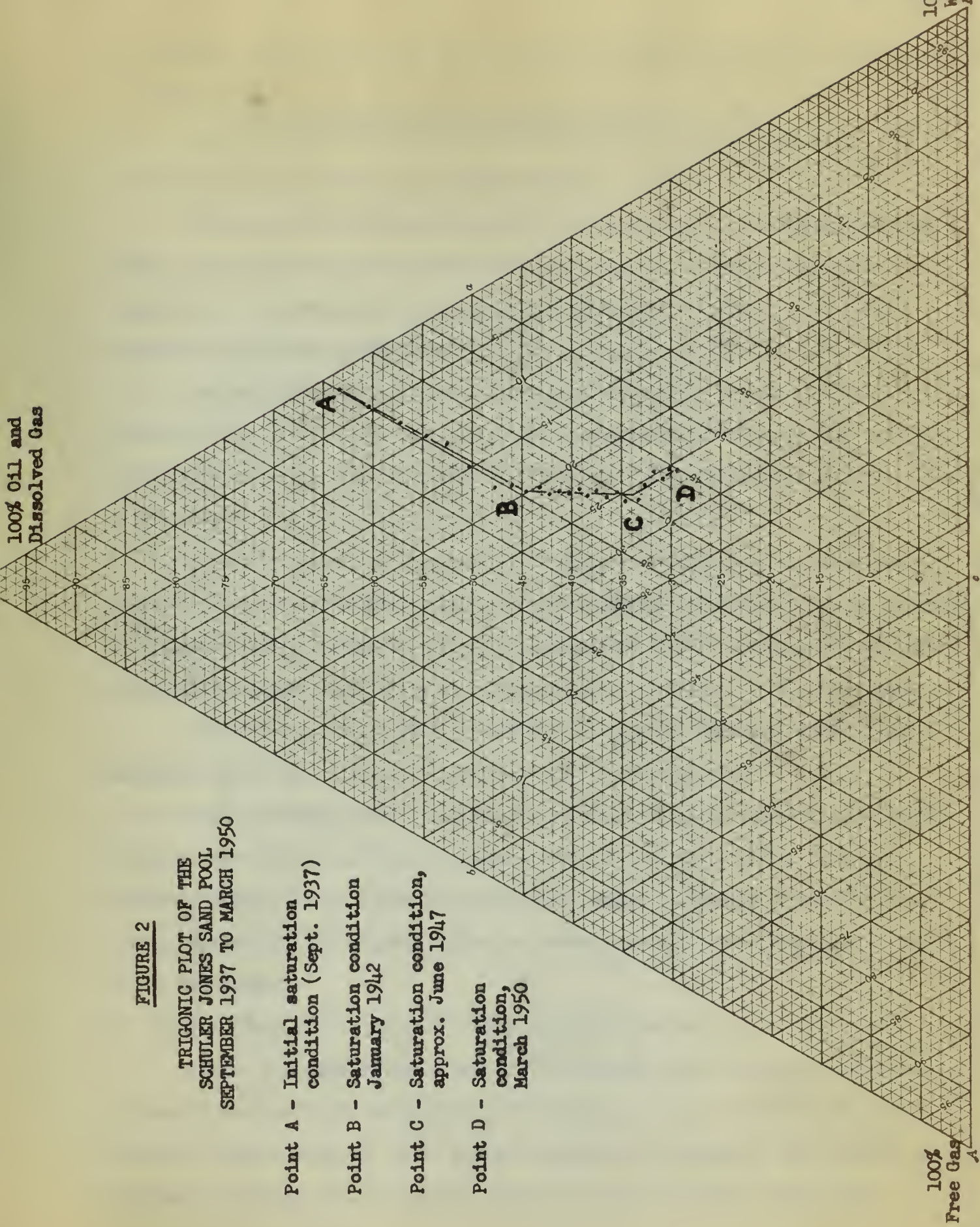


FIGURE 2

TRIGONIC PLOT OF THE
SCHULER JONES SAND POOL
SEPTEMBER 1937 TO MARCH 1950

- Point A - Initial saturation condition (Sept. 1937)
- Point B - Saturation condition January 1942
- Point C - Saturation condition, approx. June 1947
- Point D - Saturation condition, March 1950

100% Free Gas
A

B. The Magnolia Field Reynolds Line Pool

1. General Description and Production History

Engineering data from the Bureau of Mines Report of Investigations 3720 (1943), and factual data from the Arkansas Oil and Gas Commission as given in Pirson⁵ have been used for calculating the values for a trigonic plot of the Magnolia Field Reynolds Line Pool.

The Magnolia Field Reynolds Line Pool, discovered in March 1938, is located in Columbia County, Arkansas. The reservoir is on a symmetrical anticlinal fold, 6 miles long and 1 1/2 miles wide. Maximum closure of the reservoir is 321 feet.

The reservoir rock is an oolitic limestone varying from a porous, highly permeable, sometimes cavernous oolite to dense, granular limestone of low porosity and permeability. Average porosity is estimated at 16.82 per cent,⁵ and average permeability is 1,500 millidarcies. Connate water saturation is 20.0 per cent.

The original volume of the reservoir is 419,550 acre-feet with 345,550 acre-feet in the oil zone and 74,000 acre feet in the gas-cap.

From discovery until June 1948, the reservoir had produced approximately 53 million barrels of oil and 52 billion cubic feet of gas, with a drop in reservoir pressure from 3,480 to 2,818 psia. Volumetric calculations indicate that approximately 244 million barrels of stock tank oil were originally in place in the reservoir.

2. Trigonic Plot of the Magnolia Field Reynolds Line Pool

Figure 3 is the trigonic plot of the Magnolia Field Reynolds Line Pool, and covers the period of production from discovery in March 1938 to June 1948. Reservoir characteristics, fluid characteristics and production data used in calculating the values for the trigonic plot and these calculated values are tabulated in Appendix II.

B. The Specifics of the Study

1. General Overview of the Study

The purpose of this study is to investigate the relationship between the variables of interest. The study is designed to provide a comprehensive overview of the topic and to identify the key factors that influence the outcome. The research is based on a review of the literature and the analysis of data collected from various sources.

The study is organized into several sections. The first section provides a general overview of the study, including the purpose, objectives, and scope. The second section discusses the theoretical framework and the conceptual model. The third section describes the research methodology, including the data sources and the analytical techniques used. The fourth section presents the results of the study, and the fifth section discusses the implications and conclusions.

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3. Trigonal Interpretation of the Performance of the Magnolia Field Reynolds Line Pool

Point A on figure 3 represents the original saturation condition in the reservoir at time of discovery. This saturation condition was:

Oil and dissolved gas saturation	65.9 per cent
Free gas saturation	14.1 per cent
Water saturation	20.0 per cent

Point B represents the saturation condition at approximately June 1944, almost six years after discovery of the reservoir. Oil and dissolved gas saturation had dropped to 54.8 per cent, free gas saturation had increased to 20.3 per cent, and water saturation had increased to 24.9. The increase in both the free gas and the water saturation indicate that a combined water and gas drive was the driving mechanism producing the reservoir during this period. The trend of the line between points A and B further indicates that the magnitude of the gas drive was about equal to the magnitude of the water drive. The Displacement Index for this interval of production is 1.06/1.

Point C represents the saturation condition on June 30, 1948. Between points B and C the water saturation increased while the free gas saturation remained almost constant. This fact and the trend of the line between points B and C indicates that a water drive, approaching the ideal, was the mechanism producing the reservoir. Displacement Index for this interval of production is 1/10.4.

2. Internal Investigation of the Evidence of the Evidence of the Evidence

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Figure 1 represents the original statistical analysis in the

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Figure 2 represents the statistical analysis of approximately 1000 cases

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the fact

100% Oil and Dissolved Gas

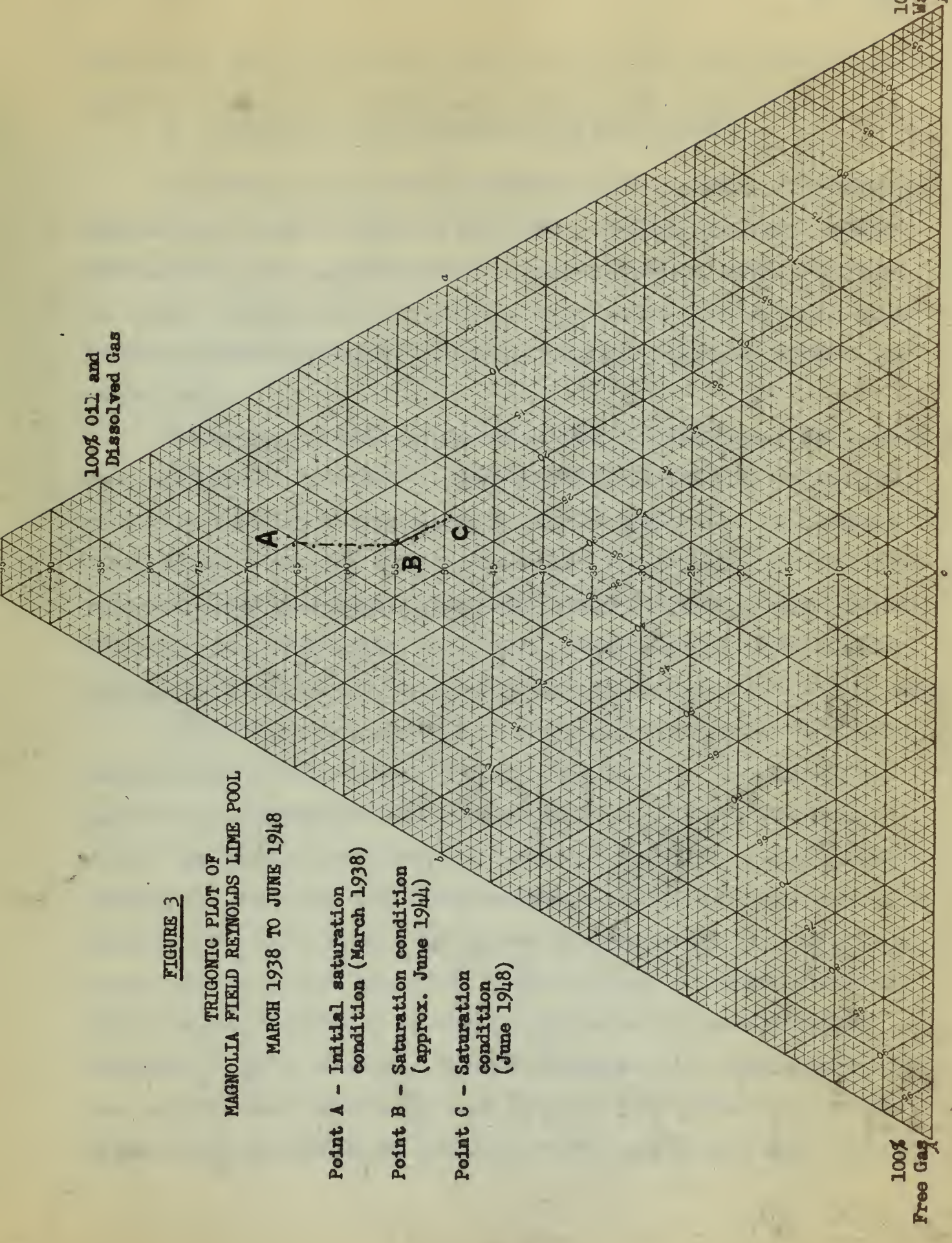
100% Free Gas

FIGURE 3

TRIGONIC PLOT OF
MAGNOLIA FIELD REYNOLDS LIME POOL

MARCH 1938 TO JUNE 1948

- Point A - Initial saturation condition (March 1938)
- Point B - Saturation condition (approx. June 1944)
- Point C - Saturation condition (June 1948)



C. Comparison of the Performance of the Two Reservoirs

The driving mechanism for the initial phase of production of the Schuler Jones Sand Pool (line AB, figure 2) was mainly a dissolved gas drive. This is also indicated by the appreciable drop in reservoir pressure during this phase. The driving mechanism for the second phase of production (line BC, figure 2) was a combined water and gas drive, and for the third phase (line CD, figure 2) was a water drive.

The driving mechanism for the initial phase of production of the Magnolia Field Reynolds Line Pool (line AB, figure 3) was a combined water and gas drive, and for the second phase (line BC, figure 3) was a water drive. The immediate driving effect of the water drive in the Magnolia Field Reynolds Line Pool would indicate a harder water drive, in this pool, than in the Schuler Jones Sand Pool. The higher permeability and the existence of cavernous spaces in the Reynolds limestone would act, in part, to assist in the rapid encroachment of driving water.

During the combined water and gas drive phase and the water drive phase, the performance of both reservoirs was remarkably similar. After the oil and dissolved gas saturation had been decreased by 10 per cent to 12 per cent, by combined water and gas drive, the water drive took over as the driving mechanism producing the reservoir. This change-over from a combined drive to a water drive possibly is due to the increase in the water relative permeability that accompanies the increase in water saturation. However, it must be pointed out that the water saturation indicated by the trigonic plot is not the water saturation throughout the entire reservoir. The water saturation in the portion of the oil zone invaded by water will be very high, while the water saturation in the uninvaded portion and the gas-cap will be due to the connate water only. It is the

high water relative permeability, resulting from the high water saturation in the invaded zone, that assists in making the water drive predominate.

at midday when the light was still shining brightly upon the
the forest and the water in the river below.

The first thing I noticed when I stepped out of the boat
was the smell of the forest. It was a rich, earthy
smell that I had never before. The trees were tall and
straight, their leaves a deep green. The ground was
soft and spongy under my feet. I had never before
felt so at home in a forest.

The sun was shining brightly upon the water, and the
trees were tall and straight. The ground was soft and
spongy under my feet. I had never before felt so
at home in a forest. The water was clear and
shining, and the trees were tall and straight.

The water was clear and shining, and the trees were
tall and straight. The ground was soft and spongy
under my feet. I had never before felt so at home
in a forest. The sun was shining brightly upon
the water, and the trees were tall and straight.

The sun was shining brightly upon the water, and the
trees were tall and straight. The ground was soft
and spongy under my feet. I had never before
felt so at home in a forest. The water was clear
and shining, and the trees were tall and straight.

The water was clear and shining, and the trees were
tall and straight. The ground was soft and spongy
under my feet. I had never before felt so at home
in a forest. The sun was shining brightly upon
the water, and the trees were tall and straight.

V. DISCUSSION

While the trigonic plot will provide a means of interpreting the over-all performance of a producing petroleum reservoir, it has certain definite limitations.

The primary limitation of the trigonic plot is that it will not distinguish of itself between a dissolved gas drive and an expanding gas-cap drive. This limitation applies to both the ideal gas drive situation and to the gas drive portion of the combined water and gas drive situation.

In using the trigonic plot, it must be kept constantly in mind that the saturations given by the plot are the gross saturations for the entire reservoir and are not the saturations in different parts of the reservoir. The trigonic plot does not reveal what portion of the free gas is in the gas-cap and what portion is in the oil zone in the free state. Similarly, the trigonic plot will not reveal how much oil remains in that portion of the reservoir invaded by encroaching or driving water. This is particularly important since it is the oil recovered that pays for the cost of production.

In the development of the trigonic plot as a means of interpreting reservoir performance, a theoretical reservoir having free gas in a gas-cap and a water drive was assumed. The actual reservoirs used for illustration also had gas-caps and water drives. The trigonic plot can be used for a reservoir that has a water drive and no gas-cap, if, at any time during production, free gas is present in the reservoir. Where there is no water drive, the saturation picture on the trigonic plot will follow the ideal gas drive line AB, figure 1.

It should also be pointed out that, in the final stages of primary recovery, where the reservoir pressure is low, the water drive will produce or

Y. ELECTIONS

While the various bills will provide a means of increasing the over-all performance of a production system, it is essential that the various bills be coordinated.

The primary objective of the various bills is that they will be coordinated in such a manner as to provide a consistent and comprehensive program. This includes the need for the various bills to be coordinated in such a manner as to provide a consistent and comprehensive program.

In order to provide for the various bills, it is essential that the various bills be coordinated in such a manner as to provide a consistent and comprehensive program. This includes the need for the various bills to be coordinated in such a manner as to provide a consistent and comprehensive program.

It is the development of the various bills as a means of increasing the over-all performance of a production system, it is essential that the various bills be coordinated in such a manner as to provide a consistent and comprehensive program.

It should also be noted that, in the final stages of development, the various bills will be coordinated in such a manner as to provide a consistent and comprehensive program.

expel free gas as well as oil and dissolved gas. On the trigonic plot, this situation would result in a trend of saturation conditions indicating that the water drive is exceeding the limit established for the ideal water drive.

In respect to the residual oil left by a water drive, it is of interest to note the results obtained in the laboratory by Holmgren⁶ who used gas and water drives on a long core of Nellie Bly sandstone, and then measured the residual oil. Holmgren concluded that: "Maintenance of initial gas saturation by gas injection, together with an increase in water saturation by water input, results in lower final oil saturation." The effects of free gas saturation on oil recovery by water drive has been investigated by Holmgren and Morse⁷, using the long core of Nellie Bly sandstone. They conclude that:

"The production of oil by water flooding can be substantially increased by the maintenance of free gas saturation in the reservoir during the flooding operation. This effect is accomplished by the alteration of oil relative permeability characteristics and the occupation by gas of pore space that would otherwise be filled with residual oil."

If the foregoing conclusions are applied to the trigonic plot of the performance of a reservoir, an indication of ultimate oil recovery can be obtained. That is, if the trigonic plot shows an appreciable free gas saturation during the water drive phase a higher ultimate recovery can be expected than if no free gas were present. However, it must be remembered that the free gas saturation given by the trigonic plot does not distinguish between free gas in the gas-cap and free gas in the oil zone.

It appears then, that, in the case of an established active water drive, it might be desirable to insure the presence of free gas in the oil zone by gradual or periodic flash reduction of the reservoir pressure. This would have the same effect as maintaining, to a degree, a combined water and gas drive in the reservoir.

VI. CONCLUSIONS

It can be concluded that, within its limitations, the trigonic plot of the performance of a producing petroleum reservoir will:

- (a) provide a visual representation of the material balance of the reservoir components;
- (b) indicate the nature of the driving mechanism producing the reservoir;
- (c) indicate the relative magnitudes of the two driving forces when a combined drive mechanism is producing the reservoir;
- (d) indicate the change from one driving mechanism to another;

or, to summarize, will provide the means for making a trigonal interpretation of reservoir performance.

ARTICLE IV

It is the policy of the State to encourage the development of...

The purpose of this article is to provide a framework for...

(a) The State shall encourage the development of...

of the State...

(b) The State shall encourage the development of...

the State...

(c) The State shall encourage the development of...

to provide a framework for...

the State...

(d) The State shall encourage the development of...

the State...

It is the policy of the State to encourage the development of...

the State...

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It is the policy of the State to encourage the development of...

APPENDIX I

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This ensures transparency and allows for easy verification of the data.

Furthermore, it is noted that the records should be kept in a secure and accessible format. Regular backups are recommended to prevent data loss in the event of a system failure or disaster.

The second part of the document outlines the procedures for handling discrepancies. It states that any differences between the recorded amounts and the actual transactions should be investigated immediately. The cause of the error should be identified, and the records should be corrected accordingly.

Finally, the document stresses the need for ongoing training and education for all staff members involved in the accounting process. This helps to ensure that everyone is up-to-date on the latest practices and regulations.

APPENDIX A

This section provides a detailed list of the items included in the accounting records. It includes a breakdown of the various categories of expenses and revenues, along with the corresponding amounts.

The data is presented in a clear and concise manner, allowing for easy comparison and analysis. It also includes a summary of the total figures for each category, providing a high-level overview of the financial performance.

The following table shows the results of the analysis:

Category	Amount
Operating Expenses	\$120,000
Capital Expenses	\$50,000
Revenue	\$200,000
Net Income	\$30,000

The above information is intended to provide a comprehensive overview of the financial data and to assist in the decision-making process. It is subject to change based on future developments and market conditions.

TABLE I

SCHULER JONES SAND POOL CHARACTERISTICS

1. Reservoir Characteristics⁴

Total Reservoir volume	154,000 acre-feet
Original oil reservoir volume	150,000 acre-feet
Original gas-cap volume	4,000 acre-feet
Porosity (average)	20.2 per cent
Connate water saturation	35.0 per cent

2. Fluid Characteristics⁴

Original reservoir pressure	3548 psia.
Original reservoir temperature	198°F.
Original dissolved gas-oil ratio	770 cu. ft. per bbl.
Original formation volume factor	1.452
Original gas volume factor	0.000825

3. Equations from literature⁴ used for determining dissolved gas-oil ratio, formation volume factor and gas volume factor at any pressure P, in lbs. per sq. in. abs., above 300psia

$$r = 0.0334P + 18.65 \text{ cu. ft./cu. ft.}$$

$$B = 8.0 \times 10^{-5}P + 1.168$$

$$v = 0.062P - 4 \text{ in SCF of gas equivalent to one cubic foot of gas at reservoir conditions}$$

4. Volumes used in calculations for trigonic plot based on volumetric calculation from geologic data

V_t	- Total pore volume of reservoir	241,340,000 barrels
V_{OG}	- Pore volume originally occupied by oil and dissolved gas	152,790,000 barrels
V_g	- Pore volume originally occupied by free gas in gas-cap	4,080,000 barrels
V_w	- Pore volume originally occupied by connate water	84,470,000 barrels
N	- Stock tank oil originally in place	105,270,000 barrels
G_t	- Dissolved and free gas originally in place	85.96 billion cu. ft.

TABLE II

PRODUCTION DATA⁴ AND SATURATION CALCULATIONS: SCHULER JONES SAND POOL

End of Month	Reservoir Pressure, P; psia	Cumulative Oil Produced n; 10 ⁶ bbl	(N - n) 10 ⁶ bbl	B	(N-n) B 10 ⁶ bbl	(N-n)B/V _t s _{og} ; %	Cumulative Net Gas Produced R _p ; 10 ⁹ SCF	Dissolved Gas Oil Ratio r; SCF/bbl	(N - n)r 10 ⁹ SCF	$\frac{R_p + (N-n)r}{10^9}$ SCF	$G_t - [R_p + (N-n)r]$ 10 ⁹ SCF	v	$(G_t - [R_p + (N-n)r]) v = v_{g_i}$ 10 ⁶ bbl	$\frac{v_g}{V_t} = s_g\%$	100 - (s _{og} + s _g) s _w ; %
September 1937	3548	--	--	--	--	63.3	--	--	--	--	--	--	--	--	--
July 1938	3153	2.818	102.45	1.420	145.84	60.3	2.59	695	71.20	73.79	12.17	0.00093	11.32	4.7	35.0
January 1939	2813	6.030	99.24	1.393	138.24	57.3	5.87	631	62.62	68.49	17.47	0.00105	18.34	7.6	35.1
July 1939	2533	8.751	96.52	1.371	132.33	54.8	9.22	579	55.89	65.11	20.85	0.00116	24.19	10.0	35.2
January 1940	2318	11.259	94.01	1.353	127.20	52.7	13.17	539	50.67	63.84	22.12	0.00128	28.32	11.7	35.6
July 1940	1978	13.998	91.27	1.326	121.06	50.2	18.63	475	43.35	61.99	23.97	0.00151	36.20	15.0	34.8
January 1941	1658	16.552	88.72	1.301	115.42	47.8	24.97	415	36.82	61.79	24.17	0.00180	43.51	18.0	34.2
July 1941	1542	19.006	86.26	1.291	111.36	46.1	28.74	394	33.99	62.73	23.23	0.00194	45.07	18.7	35.2
January 1942	1524	21.474	83.80	1.290	108.10	44.8	29.33	390	32.68	62.01	23.95	0.00197	47.18	19.6	35.6
July 1942	1510	23.722	81.55	1.289	105.12	43.6	29.79	388	31.64	61.43	24.53	0.00199	48.81	20.2	36.2
January 1943	1497	25.927	79.34	1.288	102.19	42.3	30.05	385	30.55	60.55	25.41	0.00201	51.07	21.3	36.4
July 1943	1490	27.922	77.35	1.287	99.55	41.3	30.21	384	29.70	59.91	26.05	0.00202	52.62	21.8	36.9
January 1944	1496	29.810	75.46	1.288	97.19	40.3	30.26	385	29.05	59.31	26.65	0.00201	53.57	22.2	37.5
July 1944	1496	31.617	73.65	1.288	94.86	39.3	30.48	385	28.35	58.83	27.13	0.00201	54.53	22.6	38.1
January 1945	1489	33.350	71.92	1.287	92.56	38.4	30.42	384	27.62	58.03	27.93	0.00202	56.42	23.4	38.2
July 1945	1498	34.987	70.28	1.288	90.52	37.5	30.37	385	27.06	57.43	28.53	0.00201	57.35	23.8	38.7
March 1946	1488	37.161	68.11	1.287	87.66	36.3	30.51	383	26.09	56.60	29.36	0.00202	59.31	24.6	39.1
August 1946	1494	38.538	66.73	1.287	85.88	35.6	30.56	385	25.69	56.23	29.71	0.00201	59.92	24.7	39.7
March 1947	1471	40.432	64.84	1.286	83.38	34.6	30.85	380	24.64	55.49	30.47	0.00205	62.46	25.9	39.5
September 1947	1461	42.064	63.21	1.285	81.22	33.7	31.38	378	23.89	55.27	30.69	0.00206	63.22	26.2	40.1
March 1948	1454	43.698	61.57	1.284	79.60	32.8	33.17	377	23.21	56.38	29.58	0.00207	61.23	25.4	41.8
September 1948	1474	45.319	59.95	1.286	77.10	31.9	33.81	381	22.84	56.65	29.32	0.00204	59.81	24.8	43.3
March 1949	1429	46.898	58.37	1.282	74.83	31.0	34.57	372	21.71	56.28	29.68	0.00211	62.62	25.9	43.1
September 1949	1437	48.197	57.07	1.283	73.19	30.3	35.23	374	21.34	56.58	29.39	0.00210	61.72	25.3	44.4
March 1950	1432	49.412	55.86	1.283	71.67	29.7	35.30	373	20.84	56.14	29.82	0.00210	62.63	25.9	44.4

TABLE III

CALCULATED SATURATION VALUES USED FOR TRIGONIC PLOT OF
SCHULER JONES SAND POOL

<u>End of Month</u>	<u>S_{og}</u> <u>Per Cent</u>	<u>S_g</u> <u>Per Cent</u>	<u>S_w</u> <u>Per Cent</u>
September 1937 (initial)	63.3	1.7	35.0
July 1938	60.3	4.7	35.0
January 1939	57.3	7.6	35.1
July 1939	54.8	10.0	35.2
January 1940	52.7	11.7	35.6
July 1940	50.2	15.0	34.8
January 1941	47.8	18.0	34.2
July 1941	46.1	18.7	35.2
January 1942	44.8	19.6	35.6
July 1942	43.6	20.2	36.2
January 1943	42.3	21.3	36.4
July 1943	41.3	21.8	36.9
January 1944	40.3	22.2	37.5
July 1944	39.3	22.6	38.1
January 1945	38.4	23.4	38.2
July 1945	37.5	23.8	38.7
March 1946	36.3	24.6	39.1
August 1946	35.6	24.7	39.7
March 1947	34.6	25.9	39.5
September 1947	33.7	26.2	40.1
March 1948	32.8	25.4	41.8
September 1948	31.9	24.8	43.3
March 1949	31.0	25.9	43.1
September 1949	30.3	25.3	44.4
March 1950	29.7	25.9	44.4

THE STATE

OF THE DEPARTMENT OF THE INTERIOR

LAND AND MINERAL OFFICE

<u>Lot No.</u>	<u>Acres</u>	<u>Value</u>	<u>Remarks</u>
100	1.1	1.10	Section 100 (partial)
101	1.1	1.10	Section 101
102	1.1	1.10	Section 102
103	1.1	1.10	Section 103
104	1.1	1.10	Section 104
105	1.1	1.10	Section 105
106	1.1	1.10	Section 106
107	1.1	1.10	Section 107
108	1.1	1.10	Section 108
109	1.1	1.10	Section 109
110	1.1	1.10	Section 110
111	1.1	1.10	Section 111
112	1.1	1.10	Section 112
113	1.1	1.10	Section 113
114	1.1	1.10	Section 114
115	1.1	1.10	Section 115
116	1.1	1.10	Section 116
117	1.1	1.10	Section 117
118	1.1	1.10	Section 118
119	1.1	1.10	Section 119
120	1.1	1.10	Section 120

APPENDIX II

TABLE IV

MAGNOLIA FIELD REYNOLDS LINE POOL CHARACTERISTICS

1. Reservoir Characteristics⁵

Total reservoir volume	419,550 acre-feet
Original oil reservoir volume	345,550 acre-feet
Original gas-cap volume	74,000 acre-feet
Porosity (average)	16.82 per cent
Connate water saturation	20.00 per cent

2. Fluid Characteristics⁵

Original reservoir pressure	3,480 psia
Original reservoir temperature	206°F.
Original dissolved gas-oil ratio	855 cu. ft. per bbl
Original formation volume factor	1.476
Original gas volume factor	0.000895

3. Volumes used in calculations for trigonic plot based on volumetric calculations from geologic data

V_t - Total pore volume of reservoir	547,500,000 barrels
V_{og} - Pore volume originally occupied by oil and dissolved gas	360,700,000 barrels
V_g - Pore volume originally occupied by free gas in gas-cap	77,300,000 barrels
V_w - Pore volume originally occupied by connate water	109,500,000 barrels
N - Stock tank oil originally in place	244,400,000 barrels
G_t - Dissolved and free gas originally in place	295.3 billion cu. ft.

TABLE 1

REVENUE FROM THE SALE OF FEDERAL RESERVE NOTES

1. 1950-1954

1950-1954 1,000,000,000
1951-1952 1,000,000,000
1953-1954 1,000,000,000
Total 3,000,000,000

Total revenue from sale of federal reserve notes 1950-1954 3,000,000,000
Less: Interest on notes 1,000,000,000
Total 2,000,000,000

2. 1955-1959

1955-1959 1,000,000,000
1960-1964 1,000,000,000
Total 2,000,000,000

Total revenue from sale of federal reserve notes 1955-1959 2,000,000,000
Less: Interest on notes 1,000,000,000
Total 1,000,000,000

3. 1960-1964

1960-1964 1,000,000,000
1965-1969 1,000,000,000
1970-1974 1,000,000,000
1975-1979 1,000,000,000
1980-1984 1,000,000,000
Total 5,000,000,000

Total revenue from sale of federal reserve notes 1960-1964 5,000,000,000
Less: Interest on notes 2,000,000,000
Total 3,000,000,000

TABLE V

PRODUCTION DATA AND SATURATION CALCULATIONS: MAGNOLIA FIELD REYNOLDS LIME POOL

<u>End of Month</u>	<u>Reservoir Pressure P; psia</u>	<u>Cumulative Oil Produced n; 10⁶ bbl</u>	<u>(N - n) 10⁶ bbl</u>	<u>B</u>	<u>(N - n) B 10⁶ bbl</u>	<u>(N - n)B/V_t = s_{og}; %</u>	<u>Dissolved gas-oil ratio r; SCF/bbl</u>	<u>(N - n)r 10⁶ bbl</u>	<u>Cumulative Gas Produced R_a; 10⁹SCF</u>	<u>R_a + (N - n)r 10⁹ SCF</u>	<u>G_t - [R_a + (N - n)r] 10⁹ SCF</u>	<u>v</u>	<u>(G_t - [R_a + (N - n)r])v = v_g; 10⁶ bbl</u>	<u>v_g/V_t = s_g %</u>	<u>100 - (s_{og} + s_g) = s_w; %</u>
Initial	3480	--	--	--	--	65.9	--	--	--	--	--	--	--	14.1	20.0
June 1939	3385	1.0	243.4	1.466	356.8	65.2	833	202.8	0.9	203.7	91.6	0.00091	83.4	15.2	19.6
June 1940	3303	7.5	236.9	1.458	345.8	63.1	814	192.8	6.6	199.4	95.9	0.00093	89.2	16.3	20.6
June 1941	3190	14.8	229.6	1.446	332.0	60.6	788	180.9	13.1	194.0	101.3	0.00095	96.2	17.6	21.8
June 1942	3093	21.6	222.8	1.436	319.9	58.4	766	170.7	19.1	189.8	105.5	0.00098	103.4	18.9	22.7
June 1943	3030	27.8	216.6	1.428	309.3	56.5	751	162.7	25.4	188.1	107.2	0.00100	107.2	19.6	23.9
June 1944	2975	33.5	210.9	1.423	300.1	54.8	738	155.6	31.2	186.8	108.5	0.00101	109.6	20.0	25.2
June 1945	2899	38.8	205.6	1.415	289.5	52.9	720	147.3	36.8	184.1	111.2	0.00103	114.5	20.9	26.2
June 1946	2883	43.6	200.8	1.413	283.7	51.8	717	144.1	42.0	186.1	109.2	0.00103	112.5	20.5	27.7
June 1947	2850	48.3	196.1	1.410	276.5	50.5	710	139.2	47.2	186.4	108.9	0.00104	113.3	20.7	28.8
June 1948	2818	52.8	191.6	1.407	269.6	49.2	702	134.5	52.2	186.7	108.6	0.00105	114.0	20.8	30.0

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TABLE VI
 CALCULATED SATURATION VALUES USED FOR TRIGONIC PLOT OF
 MAGNOLIA FIELD REYNOLDS LIME POOL

<u>End of Month</u>	<u>S_{og} Per Cent</u>	<u>S_g Per Cent</u>	<u>S_w Per Cent</u>
March 1938 (initial)	65.9	14.1	20.0
June 1939	65.2	15.2	19.6
June 1940	63.1	16.3	20.6
June 1941	60.6	17.6	21.8
June 1942	58.4	18.9	22.7
June 1943	56.5	19.6	23.9
June 1944	54.8	20.0	25.2
June 1945	52.9	20.9	26.2
June 1946	51.8	20.5	27.7
June 1947	50.5	20.7	28.8
June 1948	49.2	20.8	30.0

TABLE VI

DETERMINATION OF THE EFFECT OF TEMPERATURE ON THE RATE OF

REACTION OF HYDROGEN PEROXIDE WITH FERROUS SULFATE

<u>Rate of Reaction</u>	<u>Time (min)</u>	<u>Rate of Reaction</u>	<u>Time (min)</u>
0.05	1.11	0.20	(Initial) 0.01
0.11	2.22	0.20	0.01
0.16	3.33	1.50	0.01
0.22	4.44	0.00	0.01
0.28	5.55	0.20	0.01
0.34	6.66	0.20	0.01
0.40	7.77	0.20	0.01
0.46	8.88	0.20	0.01
0.52	9.99	0.20	0.01
0.58	11.10	0.20	0.01
0.64	12.21	0.20	0.01
0.70	13.32	0.20	0.01
0.76	14.43	0.20	0.01
0.82	15.54	0.20	0.01
0.88	16.65	0.20	0.01
0.94	17.76	0.20	0.01

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