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AN INVESTIGATION OF THE EFFECT OF ULTRASONIC ENERGY ON THE FLOW OF FLUIDS IN POROUS MEDIA

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CHAPTER I

INTRODUCTION

Man has been familiar with sound since his first entrance on earth many eons ago. However, man has learned, only in comparatively recent years, about a totally new kind of sound ' "silent sound". This very special variety of sound is called "ultrasonics" (beyond sound) and consists of sound waves (physical vibrations of particles of matter) at frequencies above the range of human hearing. Thus, ultrasonics includes all those waves of a frequency of more than approximately 20,000 cycles/sec.[103] This new science may be said to have been known since 1883 when Galton adapted the edge tone generator to determine the upper limit of pitch sensation in human beings.[104]

The study of the scientific principles governing ultrasonics, of the equipment used to generate it, and of its practical applications comprises one of our newest branches of science, the science of Ultrasonics. This field deals both with the effects of mechanical vibrations of ultrasonic waves and with the apparatus used to produce these waves.

The presence of a medium is essential to the transmission of ultrasonic waves.[103] Any material that has elasticity can propagate these waves. The propagation takes the form of a displacement of successive elements of the medium. If the substance is elastic there is a restoring force that tends to bring each element of material back to its original position. Since all such media possess inertia, the particle continues to move after it returns to the position from which it started and finally reaches another different position, past the original one. From this second point it returns to its original position, about which it continues to oscillate with constantly diminishing amplitude. The elements of material will therefore execute different movements or orbits as the wave passes through them. It is the difference in these movements which characterize basic types of ultrasonic waves, but no matter what the wave type, the general properties of ultrasonics remain the same. As the wave travels through the material, successive elements in it experience these displacements, each such element in the wave path moving a little later than its neighbor. In other words, the phase of the wave, or vibration, changes along the path of wave transmission.

Sound waves can be propagated through solids, liquids and gases. In fact, liquids and solids are better conductors of sound than air. Sound travels through air at approximately 1100 feet per second, [108] but moves more than four times faster in water (approximately 4700 feet per second) and approximately fourteen times faster in metals (15,000 feet per second). In general, the more elastic the medium, the greater the velocity of sound in it, and the less power is required to transmit sound energy a given distance. No homogeneous material is an insulator against sound energy.

Ultrasonic energy as applied to solids, liquids and gases can produce desired changes or effects. Some of these effects are:

(a) Cavitation - A formation of bubbles in a liquid during the rarefaction cycle. When the compression occurs, the bubbles implode. During the collapse, tremendous pressures are produced that may reach several thousand atmospheres. Thousands of these bubbles are formed in a small volume of the liquid.

(b) Emulsification - A suspension of fine particles of globules in a liquid which are generally produced by violent agitation. When two immiscible liquids are subjected to intense sound vibration, an emulsion will be formed.

(c) Coagulation - Small particles in smoke, dust and mist agglomerate when the mixtures are subjected to strong sound waves. Intense sound waves have been used to coagulate and precipitate particles in smoke stacks.

(d) Chemical - When high intensity ultrasonic waves are passes through some liquids, reactions that would normally take place are accelerated; in other cases effects are brought about that would normally be absent without ultrasonic vibrations. It is sometimes difficult to determine whether the effects are due to the sound alone or the thermal effects which are a result of the sound energy. Temperature rises of several degrees per minute can be obtained. This heat often obscures the effects which can be attributed to the sound alone. The applications of heating by ultrasonics remain to be seen.

Most of these desired effects will be discussed in more detail in later chapters.

HISTORICAL BACKGROUND

CHAPTER II

Ultrasonics had its beginning in the early part of the twentieth century under the direction of a French scientist, Paul Langevin.[73] The object of his investigation was to determine a device for generating ultrasonic beams for detecting underwater obstacles by means of sound echos.

The transmission and receiving of sound was finally accomplished by means of a new phenomena called the piezo-electric effect (electricity due to pressure), which can be found in crystalized substances such as quartz, rochelle salt and tourmaline crystals.[90]

All the applications of the piezoelectric effect depend on the motor generator action of the crystal. In the crystal resonator, the action drives the crystal itself in mechanical vibration and the mechanical vibration reacts back to control the electrical impedance of the crystal. As an electromechanical transducer, the mechanical stress set-up by the piezoelectric effect drives not only the mechanical elements of the crystal, but also any other mechanical element attached to the crystal surface. Ultrasonic transducers are examples of this use.[90]

By making use of the piezoelectric effects of quartz, Langevin introduced the modern piston transducer. Perhaps the most outstanding advance made by Langevin in this field was his theoretical calculation and experimental verification of the fact that a thin sheet of quartz sandwiched between two steel plates constituted an elector-mechanical resonant system. This discovery made possible a many fold increase (10-25) in amplitude of the steel-quartz-steel structure over that which the same voltage would excite in the quartz alone. The voltages required to drive the quartz alone to a comparable amplitude would be prohibitive and impractical.

The scarcety of piezoelectric quartz and the higher activity of Rochelle salt stimulated scientists to investigate man-made synthetic crystals. Different types of experimentation techniques were developed for utilizing Rochelle salt crystals and in the process much scientific information was accumulated. In the laboratory work with ultrasonic sources in liquids produced the phenomena now commonly associated with ultrasonics, namely standing waves, violent bubbling, and incipient cavitation.

Looking back upon this period (the twenties), it seems as if tools were being assembled and surveys were being made in preparation for a more coordinated scientific effort which was to come. Indeed, the achievements of the thirties in the ultrasonic field represent an intergration of selected processes and techniques of the preceding decade. A variety of transducers were developed. The electrodynamic principle was employed to design a new form of piston transducers. A basis for evaluating the performances of transducers was established, and theoretical predictions for absolute measurements of sound in liquids were implemented by experiment.

REVIEW OF PREVIOUS INVESTIGATORS

CHAPTER III

Various phenomena occur when ultrasonic energy is used. These phenomena will be discussed in detail as they relate to the overall theoretical study of ultrasonic energy. According to an extensive review of the literature, little work, if any, has been conducted or published by the petroleum industry relating ultrasonic energy with the various branches of the industry. Thus, the articles reviewed in this chapter are a composite of theoretical ideas formulated by the various authors. The literature investigation was extensive for the purpose of grasping some background study which would be helpful in relating ultrasonic energy with the flow of fluids in porous media. This chapter covers only the theoretical aspects of ultrasonics; its purpose being to stimulate ideas for future ultrasonic studies for the oil industry.

Ultrasonics breaks down into a number of individual scientific problems and theoretical studies. They are all related to some form of the results of ultrasonic energy, or are studies conducted on the application and generation of ultrasonic energy. The subject matter to be discussed may be conveniently sub-divided as follows:

(1) Sound characteristics

(2) Cavitation

(3) Effects of ultrasonic frequency

(4) Sound adsorption

(5) Emulsification

(6) Scattering of ultrasonic energy

(7) Velocity of sound in various media

(8) Sources of sound in liquids

(9) Temperature and pressure effects

(10) Ultrasoinc transducers and generators

(11) Practical applications

(1) Sound Characteristics - Sound has several important characteristics. It is a wave motion, similar in many respects to light waves, and is propagated with different velocities in different materials.[56] As sound is induced through a material, the motion of the material's particles can be described by the amplitude, frequency, velocity and acceleration with which they move. Because of the elastic properties and the mass of the material in which a sound wave exists, there is a definite amount of energy contained in and being transferred by the sound waves. The term "sound intensity" expresses the energy being transferred through a unit area in unit time by a sound wave.

Depending on the source, a sound wave can spread out like rays from the sun, or be highly confined, like the beam from a searchlight. As with light, sound is transmitted well by some materials and blocked or rapidly decreased in intensity by others. Unlike light, soundwaves must have some physical material in which to exist because they cannot be propagated in a vacuum.

When an ultrasonic beam passing through one medium reaches the boundary of that medium and strikes a dissimilar medium, part of the energy is reflected back through the original medium to the source. The amount of reflection is determined by the nature (specific acoustic impedance) of the two media.[129] The closer the impedance values of the two media, the less reflection occurs and the more energy is transferred from one medium to the other.

(2) <u>Cavitation</u> - In normal circumstances, a liquid will contain many minute nuclei which contain undissolved gas and/or vapor.[30] If the local liquid pressure falls to the vapor pressure, these nuclei will grow in size to become clearly visible cavities.[3] The internal pressures of these cavities will be made equal to the liquid vapor pressure due to the evaporation of some of the liquid into them. If, after a cavity has been formed, the ambient liquid pressure then increases to a value greater than the vapor pressure, the cavity is forced to collapse. Although the typical maximum size of a cavity in water is only of the order of a centimeter, the cavity may collapse with great violence and generate high pressures. Obviously, such collapse may cause enormous mechanical effects, high kinetic energies being concentrated at very small spots.[142] In some liquids, when each of the cavitation bubbles collapse, a shock wave is generated in which the peak pressure can attain values as high as 10,000 atmospheres to 100,000 atmospheres.[46] These pressure waves are then propagated out in the form of a shock wave,[1] and serious damage to nearby solid surfaces may be caused, with small fragments of their material being torn away from them. Such distructive action may, on the other hand, be eminently useful, as in the distruction of liquid born organisms, the production of emulsions and aerosols, the cleaning of parts, and perhaps in some chemical reactions.[50]

It is important to note that the sound intensity, and consequently, the amount of energy required to cavitate a liquid, increases with the external pressure and decreases with an increase in temperature.[44] Furthermore, it varies widely with different liquids. As the temperature is increased on a liquid subjected to sound pressure, agitation appears to increase. The cavitation bubbles grow in size and increase in distribution in a spectacular manner. This does not mean, however, that the sound intensity in the liquid increases.

It can be seen from experiments that cavities tend to appear at the interface of two liquids.[109] The most direct evidence is that when subjecting a two phase system to ultrasonic energy, the formation of gas is seen to be most pronounced at the interface.

True cavitation cannot occur in a pure liquid until the liquid pressure has become sufficiently negative to overcome the forces of natural cohesion. It is well known that degassed liquids can withstand very high negative pressures. But, in a gas filled liquid containing undissolved gas in the form of bubbles, small enough to remain in suspension, these nuclei will expand or contract if the external pressure is made to change. The liquid will then evaporate into the partial void produced.[64]

Although in some cases the gas changes for bubble growth are taken, for simplicity, to be isothermal and those for collapse strictly adiabatic, the true law obeyed by the gas content of the bubble will change continually during the bubble life, being more nearly adiabatic where the bubble volume changes more rapidly. The assumption of adiabatic conditions for the collapse periods implies that the gas temperature will rise to very large values as the radius approaches its minimum. Of course, in practice, the temperature of the bubble surface will be effectively that of the liquid, so that a steep temperature gradient must exist in the gas adjacent to it. How steep it is will depend on how nearly adiabatic the changes are. Since high temperatures are confined to the gas content, the liquid temperature remaining sensibly constant, it seems impossible that heating effects can play an important role in the destructive action by cavitation. However, there is a slow rise in temperature of the liquid as cavitation continues until an equilibrium point is reached.[129]

(3) Effects of Ultrasonic Frequency - The relationship between velocity, frequency and wavelength is as follows:[129]

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}$$

The amount of penetration into a system does not depend upon the frequency of testing except in those cases where the ultrasonic waves are scattered by discontinuities in the material that are of the order of magnitude of the wave length at which the testing is taking place.[103]

When it is desired to obtain a beam of extremely high sound intensity, this is conveniently accomplished with a small radiator operating at high frequency. Similarly, radiators, or sections of cylinders and spheres, produce lines or points of high intensity. Again, the higher the frequency the smaller the radiator needed to obtain the same degree of concentration.

In studying the elastic wave velocities in sedimentary rocks it has been concluded that there was negligible dispersion for rocks at frequencies up to several hundred kilocycles/sec.[95] Present results on igneous and sedimentary rocks confirm and extend this, at least up to five megacycles/sec. The investigation of Amherst sandstone showed that as the weight was increased by adding water to the system, the variation in the natural frequency decreased.[92]

For liquids of low absorption, the magnitude of sound absorption increased with the square of the frequency of vibration, therefore, it is desirable to carry out measurements at the highest possible frequency, in order to insure optimum accuracy.

Results of the absorption coefficient plotted as a function of acoustic pressure for water was found to be dependent upon the frequencies studied, i. e., the absorption coefficient increased, for a given acoustic pressure, as the frequency decreased.[33] For the same intensity, the relative increase of this coefficient is greater among liquids having small absorption coefficients (ethyl and methyl ethers, toluene and water) than in liquids with greater absorption coefficients (transformer oil, glycerine).[34] The relative increase of the absorption coefficient in low viscosity liquids at 1.5 Mc/sec. is much greater than was determined by other authors at higher frequencies.

Work at the Centre National de Recherches at Marseilles has shown that frequencies and the viscosity exert peculiar effects. Some thin oils can emulsify in water at low and not high frequencies, whereas viscous oils do the reverse.[104]

Results indicate that low frequencies (20 to 40 Kc/sec.) produce more intense cavitation and maximum particle displacement.[129] At high frequencies, the cavities formed are smaller, and less energy is stored in each cavity. There is less actual physical movement (particle displacement) for a given power output. More power output is required for equivalent effects as compared to the lower frequencies.

Usually, the lowest frequency suitable for a given application involving cavitation is used because of power considerations. Higher frequencies require more power for an equivalent amount of work performed because of the greater power losses resulting from the higher rate of molecular oscillations. More than ten times as much power is required to make water cavitate at 400 Kc/sec. than at 10 Kc/sec.

(4) Sound Absorption - According to Junt[37], "the basic manifestation of the absorption or attenuation of sound is the conversion of organized systematic motions of the particles of the medium into the uncoordinated random motions of thermal agitation. Various agencies of conversion can be identified as viscosity, heat conduction, or some other mechanism that gives rise to a delay in the establishment of thermodynamic equilibrium; but all are mechanisms of interaction that lead to the same result, namely, that the energy of mass motion imparted intermittently to the medium by the sound source becomes increasingly disordered and unavailable".

Upon conducting experiments of acoustic absorption in sand and soil it was concluded that any transmitted sound travels essentially through the air passages or pores of the sand (that are dry and not saturated).[63] The presence of air is responsible for the high attenuation in a saturated sand. The more air present the greater the attenuation.

In studying the propagation of ultrasonic waves of finite amplitude in liquids, it was stated that there is an increase of absorption with intensity and that this increase is connected, to some extent, with the change of shape of an ultrasonic wave of finite amplitude.

The absorption of sound waves in pure liquids decreased with increasing frequency to some limiting high frequency value.[42] In investigating supersonic absorption in water it was concluded that the acoustic absorption coefficient of water varies directly as the square of the frequency.[122] For liquids of high viscosity, such as castor oil, glycerine, and linseed oil, the temperature and frequency increased as the coefficient of absorption decreased. The value of "α/f^2", where "α" is the absorption coefficient, decreased.[120] Normal alcohols, and highly viscous liquids have the negative temperature coefficients of absorption expected from decreasing viscosity with increasing temperature.[119]

Generally speaking, the amount of absorption is not a problem in any ultrasonic system used for testing, measurement or agitation.[103] However, it is very important in signaling systems where large distances are to be transversed by the ultrasonic wave.

(5) Emulsification - Emulsification may be accomplished with ultrasonic energy. The greatest effect seems to be due to small particles of one liquid, such as water, being forcible propelled into a second one by the vibration.[103] The presence of gas is essential for emulsifying by means of ultrasonics. Pairs of liquids, such as water-paraffin oil, carefully freed of gas and sealed in an evacuated tube, are not emulsified, thus proving that the presence of gases is instrumental for the mechanism of emulsification.[109] Thus, emulsions are only obtained when the conditions are such that cavities are not only produced but also collapsed.

Emulsification by ultrasonics is reduced when hot liquids are used. This is quite contrary to the usual experience in the technique of emulsification. When hydrostatic pressure is applied, the system is no longer saturated as to the gas, thus nuclei, which might have been present, are dissolved and conditions are unfavorable for the production of new ones. Consequently no cavities are formed and emulsification is prevented. However, higher concentrations of dissolved gas may be unfavorable for the production of emulsification, because they have a buffering effect upon the collapse of cavities.

(6) Scattering of Ultrasonic Energy - When ultrasonic energy is transmitted into a medium, what happens to the scattered energy when it encounters obstacles in its path? This question is difficult to answer precisely. It is obvious that in a crowded assembly, further scattering must ensue, and in the limit the sound energy will be diffused instead of being propagated by waves. This means that phase relationships are lost and the radiation becomes incoherent.(104) In general, the total amount of scattered energy will then depend on the population of objects per unit area.

(7) Velocity of Sound in Various Media - An ultrasonic wave being transmitted through a substance may be any of several types. Each type causes a specific movement in the elements of the medium. The paths that the elements follow as they move in response to these waves are called their orbits. These orbits may be essentially parallel to the line of propagation, in which case the wave is longitudinal. On the other hand, they may be executed normal to the direction of propagation; these are called transverse or shear waves. Waves are sometimes derived on the basis of whether or not they change the volume of the material in which they are propagated. If so they are called "waves of dilation" and if not, they are called "waves of distortion". Longitudinal waves travel in liquids, solids or gases and have a high velocity of travel in most media.(103) There are generally three types of ultrasonic velocities. They are:

(a) Phase Velocity - the speed with which a phase is propagated along a wave. Such a wave is not of much practical interest except in theoretical computations.

(b) Group Velocity - velocity with which the envelope of a wave is propagated. The carrier frequency must be high for this condition. This group velocity is most often considered in ultrasonic work. Phase and group velocity may have the same or different values. In the first case, the material is not dispersive, and in the second it is. A material is said to be dispersive when signals of different frequencies travel with different velocities. The weight of evidence so far is that ultrasonic signals are dispersive in solids and liquids.

(c) Signal Velocity - exists only when a medium is dispersive. In such cases different signals seem to travel with different velocities, and the actual speed of travel of a particle signal is its signal velocity. The time of travel may differ with the sensitivity of a receiver, and changing the sensitivity of a particular receiver may change the particular velocity.

The velocity of the wave and that of the individual particles are not the same. In all cases it is the velocity of propagation of the wave that is referred to.

(A) Velocity of Sound in Porous Media - The velocity of sound through porous media is dependent on the nature of the media.[40] Rocks, for example, are characterized not only by their mineral compositon, but by the shape and arrangement of their fundamental particles. The speed of sound through the rock is a function of these characteristics and hence varies in different rocks. Then, too, it varies according to the external pressure imposed upon the rock and the bulk modulus and pressure of the liquid saturating the rock. The speed of sound in a saturated sandstone is lowest when the liquid pressure and the outside pressure on the sandstone system is equal. At constant outside pressure, but decreasing liquid pressure, the speed of sound increases. The most pronounced increase occurs when the liquid pressure decreases from outside pressure to a value of one-half of the outside pressure.

In the study of limestones, it was stated that in general, the increase in velocity with pressure is very rapid at the lower pressures and increases more slowly thereafter.[96] Part of this is undoubtedly due to the closing of the pore space, thus forcing individual crystals into better contact. The effect of temperature is also much larger at the low pressures. Most rocks tend to change somewhat erratically with temperature. This study was conducted both on dry and water saturated samples. In this material the water had increased substantially the velocity at low pressure and reduced the rate of increase with pressure. In the dry core the pulse is traveling alternately through rock and air. With an increase in pressure, the air space is reduced and the velocity is essentially that through solid rock. The actual velocity in this system probably increases more at large pressures due to a decrease of pore space. In the saturated core, the pulse is traveling alternately through rock and water. Water has a much higher velocity than air, hence the initial velocity is higher. An increase in pressure now, however, cannot reduce the pore space and hence the initial velocity increases slowly with pressure. It may also be stated that saturated cores show fairly large decreases in velocity with temperature. This effect is for sandstone. For the limestone, the saturated velocity is smaller at low pressure but increases more rapidly with pressure. This is effectively the opposite of the behavior of the sandstone.

Upon investigation of the absorption of sound by porous materials, it was experimentally determined that the wave length (and the velocity of sound) is considerably smaller than in free air.[(69)]

The propagation of sound through fine grained, high porosity silts and clayey silts is very similar to the propagation of sound through a liquid with suspended particles in it.[(36)] It would appear that when the mineral concentration reaches 23 per-cent (77 per-cent porosity) in a fine grained sediment, the two phase system, i. e., mineral particles-liquid, is no longer a suspension. At that point it starts to assume a structure in which the grain to grain contacts cause the sediment to assume elastic properties which were not present in the suspension. Viscous drag at this concentration is no longer operative, and the sediment assumes a measurable rigidity. At this point the elastic properties, previously either small or absent, become important in the computation of the velocity of sound, and this velocity immediately increases.

At frequencies of 100 cycles/sec. the velocity of propagation of sound in a porous material is about one-third of that for free air, whereas at frequencies in the region above 4000 cycles/sec., the velocity in a Stillite material approaches that in free air.[(72)]

For practically all rocks measured, both igneous and sedimentary, it was found that the velocities measured with decreasing pressures are higher than those measured with increasing pressures.[95] With reference to igneous rocks, an increase in temperature always resulted in a decrease in wave velocities. Several of the dolomites show an increase in wave velocity with temperature up to 100 to 125°C. Further increase in temperature caused a decrease in the wave velocity.

(B) <u>Velocity of Sound in Liquids</u> - When an ultrasonic wave is propagating through a liquid, density gradients are present.[9] As a result the environment of any particular molecule is non-uniform, and its interaction with the other molecules non-isotropic.

For pentane, it was found that the velocity at any pressure, divided by the velocity at atmospheric pressure, increases as the pressure increases, at constant temperature.[28] The velocity varied inversely with temperature at constant pressure.

Studies of the absorption of ultrasonic waves in highly viscous liquids indicate that the velocity of sound in the medium decreased as the temperature and frequency increased.[12] Further tests conducted with mineral oil fractions indicated that the velocity of sound is particularly dependent on the refractive index, and less on the density of the liquids.[31]

(8) <u>Sources of Sound in Liquids</u> - Gas bubbles entrained in water or other liquid can generate large sound pressures in the liquid.[35] Sound can be associated with volume pulsations of the bubbles, and that in these pulsations the bubbles behave like a simple oscillating system with damping. Volume pulsations are excited by enforced changes in the external

or internal pressure on the bubble. Disturbances which change its shape, such as impingement on a rigid surface, if not accompanied by a change in pressure, do not excite volume pulsations and accordingly do not result in sound.

When bubbles entrained in a free stream of liquid flow past a fixed body, the bubbles experience a transient pressure as they move through the hydrodynamic pressure field around the body. The transient pressure causes the bubbles to pulsate and radiate sound. Gas bubbles entrained in water generate sound under a variety of circumstances. However, in all cases the sound is associated with volume pulsations, oscillations in the shape of the bubble resulting in negligible sound pressure.

(9) Temperature and Pressure Effects - At a given temperature and pressure the structure of a liquid has many possible states of packing.[23] The relative concentration in these states are specified by a "degree of order" or "degree of packing". Any variation of this degree of order requires that energy be added or taken from the substance due to the change in potential energy associated with a change of structure. An increase in temperature causes more holes to appear in the liquid. This effect contributes to the thermal expansion coefficient of a liquid. An increase in pressure causes a decrease in the number of holes in the liquid and increases the short range order which leads to a structural contribution to the compressibility.

Changes of static pressure have a profound effect on the cavitation process.[52] Emulsification in oil-water systems increases with pressure from 100 to 1500 mm Hg but decreases above this. The explanation given is that some pressure is necessary to cause efficient collapse of cavitation bubbles, but too high pressure causes the dissolved gases to buffer collapse, or else does not favor the formation of nuclei.

Precise temperature control is difficult to achieve in a liquid undergoing irradiation, because the absorption of many watts of ultrasonic energy represents a heat source of considerable magnitude. In addition to this overall heating, dispersed particles, if present, are raised to a temperature several degrees above the average temperature of the suspensions.

In general, the temperature coefficient of ultrasonic velocity in single liquids is very large, of the order of 0.001 - 0.005 per ^{o}C.[89] When liquids are used in ultrasonic wave propagating devices, this variation of velocity with temperature is large compared to the changes of velocity with the normally encountered changes in frequency, amplitude, or ambient pressure.

The velocity of sound does not change with pressure, but increases in proportion to the square root of the absolute temperature.[104] The absorption decreases as the pressure increases. This is true for gases, except at very low pressures.

(10) Ultrasonic Transducers and Generators - There are a number of ways in which ultrasonic energy may be generated. The method chosen depends upon the power output necessary and the frequency range to be covered. The most common and the simplest method of producing high frequency ultrasonic energy is by the use of magnetostriction or crystal transducers.[103] Magnetostriction is used when frequencies of the order of about 100,000 cycles/sec. are needed, while crystals are used for most

frequencies above that and can be easily driven in the megacycle/sec. range to generate frequencies of as high as about 15 Mc/sec. Much higher frequencies may be obtained by vibrating the crystal at one of its harmonics. If the crystal is ground so that the emitting face is concave, the ultrasonic waves are directed at a point, or focused in the same way that a lens brings light to focus. The ultrasonic energy measured at the focal point of such a crystal is about 150 times that measured at a random sampling of points.(103) A concentration beam would presumably be very valuable for agitational work, where a great amount of ultrasonic output is necessary and where the amount of electrical voltage applied must be limited.

The most common ultrasonic generator used in laboratory experimentation is the piezoelectric type. It converts electrical energy into mechanical vibratory energy by the piezoelectric effect, which causes the material to alternately expand and contract in the presence of an alternating electric field.(90 and 91)

A relatively new material,(56) barium titanate, is now being used as an ultrasonic generator. Compared to quartz, barium titanate has the advantage that lower applied voltages can be used to excite the material.(49) This permits the use of simpler electrical equipment, and considerably reduces insulation problems in constructing a transducer. Its disadvantage, as compared to quartz, is its susceptibility to erosion by cavitation.

(11) Practical Applications of Ultrasonic Energy - Many of the useful applications of sound waves can be thought of as depending on one of two sets of properties.(56) The first set includes those used to move

or agitate a material being treated, usually with great violence, and with large expenditures of energy. The second set centers around those properties used to test a material, without changing its nature or condition.

Neppiras[10] gave an excellent breakdown on the effects and applications of high energy ultrasonics, in tabular form. This author introduced a composite of so much information that it will be presented as a useful reference for future work on ultrasonic energy.

EFFECTS AND APPLICATIONS OF HIGH ENERGY ULTRASONICS

CONTINUOUS PHASE MEDIUM	EFFECTS OF APPLICATIONS	OPTIMUM FREQUENCY (KC/SEC.)	APPROXIMATE ACOUSTIC INTENSITY
	Separation of gas mixtures		
GAS	Production of Aerosols-spraying	10-100	any
	Coagulation of Aerosols	1-25	
	Shaking-mixing-flow-promotion	0-50	any
	Investigation non-linear effects		
SOLID	Destructive testing-fatique-adhesive bonds-wear	any	$10^2 - 10^6$
	Cold welding		
	Machining-drilling-tapping-polishing	20-25	$10^2 - 10^4$

TABLE: 1

EFFECTS AND APPLICATIONS OF HIGH ENERGY ULTRASONICS

CONTINUOUS PHASE MEDIUM	EFFECTS OF APPLICATIONS			OPTIMUM FREQUENCY	APPROXIMATE ACOUSTIC INTENSITY
	Shaking-mixing-flow promotion				
	Thermal effects-therapy			500-2000	0.0-1.5
	Perupitation of hydrosols				
	Cavitation				
	Degassing			0-40	any
	Tensile strengths of liquids				
	Sonoluminescence-sonochemiciluminescence				1.0-5.0
	Hot spot chemistry				1.0-5.0
LIQUID	Fundamental oxidation reactions			500-2000	
	Disruptive	Dispersive	Acceleration of Rate Processes		
	Erosion studies	Emulsification	Chemical reactions		
	Descaling	Dispersing solids	Maturing		
	Thinning	Cleaning fabrics	Surface reactions	5-40	1.0-5.0
	Cell disruption	Degreasing	Diffusion		
	Bactericidal	Cleaning solids	Tanning-dyeing		
	Sterilization	Electrolytic dispersion	Extraction		
	Pasteurization	Grain refinment of metals	Acceleration solution		
	Depolymerization		Emulsion polymerization		

CONTINUATION OF TABLE 1

STATEMENT OF THE PROBLEM

CHAPTER IV

This dissertation has a dual purpose. First and foremost, was experimentally investigate the effects of ultrasonic energy on the secondary recovery mechanism of oil production from a simulated petroleum reservoir in association with a standard secondary recovery mechanism such as water flooding. In future references to this ultrasonic water flood system, the process will be referred to as a "sonic flood", whereas those studies based on straight water floods (used in the investigation only as a comparison of the results obtained with the sonic floods) will be referred to as water floods.

The theoretical research problems to be considered evolve around a basically simple radial flood system composed of one injection well located centrally on the core in which both injected water and ultrasonic energy are simultaneously introduced into the prototype, and two producing wells, located on the periphery of the core.

It is essential in a study of this type to fix certain variables in order to keep the exploratory investigation to a reasonable size. Variables such as fluid injection pressure, fluid saturation, water viscosity, size of the prototype, and composition of the core (permeability, porosity and sand grain diameter) were held constant. The variables considered in the tests were:

(1) Ultrasonic frequencies, ranging from the lowest frequency of 1 Mc/sec. to a maximum frequency to be tested of 5.5 Mc/sec.

(2) Oil viscosity

The effective results of these sonic floods as compared to water floods were compiled based on:

(1) Per-cent recovery of sonic floods as compared to the water floods.

(2) The effect of these floods on such results as:

(a) Instantaneous water-oil ratios

(b) Relative permeability ratios

It is emphasized that this new energy is not limited to only secondary recovery by water flooding. It is theorized that the scope of its application can be foreseen in conjunction with practically any and/or all problems dealing with the recovery of crude oil whether it be primary, secondary or tertiary systems.

Second, it was deemed desirable to investigate the basic characteristics of ultrasonic energy in a type of media typified by oil reservoirs. Although a great deal is known about ultrasonics, much of the information is general and is not suitable for direct application to specific problems. In those cases where it has been applied commercially, success has been achieved more nearly by trial and error than by a direct application of quantitative engineering data.

Ultrasonics would appear to have a reasonable possibility of being a practical means of adding energy to a reservoir - a primary requisite for efficient hydrocarbon recovery. This investigation should provide an insight of value in determination of the potentialities.

DESCRIPTION OF THE APPARATUS

CHAPTER V

The equipment used in this experimental investigation was composed of two main parts:

(1) The equipment to study the effect of ultrasonic energy on the secondary recovery of crude oil from the prototype.

(2) The equipment used to study the phenomena of increased injectivity.

The former included:

(1) Core

(2) Fluid reservoirs

(3) Constant fluid injection rate pump

(4) Ultrasonic transducers (3)

(5) Ultrasonic receiving probe (1)

(6) Ultrasonic generators (2)

(7) Oscilloscope

(8) Vacuum pump

(9) Dessicators (2)

(10) Manometers (2)

(11) Air regulator

(12) Valves

(13) Clock

(14) Burettes

(15) Fittings

Each of the component parts listed can be found schematically combined in the flow diagram, Illustration 1. The elements of the experimental equipment will be discussed separately in the following paragraphs, although the experimental procedure outlining the composite function of the analysis will be described in detail in the next chapter.

(1) Core - The material used in this experiment was Torpedo Sandstone obtained from an outcrop located north of Sand Springs, Oklahoma. It was estimated that a core with a pore volume of approximately 1100 cubic centimeters would be sufficient to obtain the necessary information desired. With this condition placed on the model, small core plugs were cut from the original sandstone sample and porosity tests conducted in order to size the required core system. The average porosity obtained from several tests was 21.4 per-cent. With this value fixed, the core was shaped, the final dimensions being:

thickness = 1.82 inches

diameter = 16.00 inches

Once the desired shape had been obtained, the faces of the core were cleaned by blowing compressed air across the face.

Prior to enclosing the model in Epoxy resin, the following procedure was conducted on the core in order to satisfy the requirement of ideal radial flow conditions. An aluminum band 2.4 inches in width and 52.2 inches long was cut and the ends connected to form a circle with a diameter of 16.25 inches. A strip of 1/8 inch Neoprene rubber tubing was then cut 1.82 inches in width to match the thickness of the core and fitted around the periphery to be held in place with the aluminum band. This gave a tight seal in order to prevent any seepage of sealing agent. A mixture of 10 parts, by weight, of Epon Curing Agent U to 100 parts, by weight, of Epon Resin 820 was mixed and poured over the core and allowed to completely solidify. This procedure was repeated until several layers of resin had accumulated on both faces of the core. The aluminum band and Neoprene tubing were then removed, and inspection of the core revealed that no resin had invaded the periphery protected by the neoprene tubing. The aluminum band was replaced in its original position and sealed to the top and bottom faces of the resin with plastic aluminum fluid cement. This left a 1/8 inch radial drainage around the entire periphery of the core. It was in this drainage that the producing wells were to be drilled in order that ideal radial flooding conditions prevailed.

Another aluminum band was cut to form the outer mold for the prototype system. The core was centered in this mold and Epon Resin was mixed and distributed between the two aluminum bands and over both faces to insure strong bonding of the entire system. After the resin hardened, the outer aluminum band was removed.

Two 1/8 inch holes were then drilled into the annular space at a 180° angle from each other on the bottom face of the core. A portion of this hole was drilled out larger and tapped to take a 1/4 inch NPT fitting. The bottom center face of the core was also tapped for a 1/4 inch NPT fitting. The tope center face of the core was drilled, completely through the resin and the core, with a 1.25 inch (O.D.) diamond drill. This cut was stopped when the drill reached the resin seal at the bottom of the core. A 1.25 (I.D.) lucite cylinder, threaded with NPT threads at the top, was centered on the core over this tap and cemented with Epon Resin.

This cylinder was used to introduce the ultrasonic transducers into the injection well. Another plug was drilled out of the top face of the core at the outer extremities. Like the center drill, it too went through the core and stopped at the resin seal on the bottom of the prototype. This drilled location was 3/4 inch in diameter. On top of this cylinderical hole another lucite cylinder, threaded at the top, was joined to the core with the resin. This location was used to house the receiving probe within the similated formation.

(2) Fluid Reservoirs - The fluid reservoirs (oil, water and pentane), as exemplified in Illustration 1, were lucite cylinders. A copper valve was used to control the flow of fluid from the reservoirs into the flow line leading to the constant injection rate pump.

(3) Constant Fluid Injection Rate Pump - This system was composed of:

(a) A Dayton Power Motor rated at 1/10 horsepower.

(b) A Revco variable speed torque converter Model Number 142-X.

(c) A Zenith pump.

This equipment was connected in series with the fluid reservoirs and prototype and mounted on a stationary board.

(4) Ultrasonic Transducers - The transducer probes were obtained from McKenna Laboratories in Santa Monica, California. The three transducers used were rated at 1 Mc/sec., 3.1 Mc/sec. and 5.5 Mc/sec. and changed RF energy into ultrasonic energy. The generating device in the transducer is a ceramic material called barium titanite. It has the property of electro-striction, i. e., it changes dimensions

in the presence of an electric field. By properly polarizing this ceramic (which was conducted at the suppliers factory) the crystal was made to vibrate at the frequency of the voltage applied between two electrodes placed on opposite faces of the ceramic.

The barium titanate transducers are polarized prior to being mounted in the transducer container. This polarization is the basic mechanism by which the titanate can be made to vibrate. However, this polarization can be removed by allowing the material to get hotter than 125°C. If this happens, the transducer will cease to operate with any efficiency. Depending on the acoustic impedance of the liquid, its specific heat, the amount used, and the time of ultrasonic exposure, a transducer might overheat. The unit has been constructed to operate under most conditions without cooling. The heating of the transducer was not a problem in this investigation because a continuous stream of injection water was flowing around the crystal while in operation. The transducers, however, should never be operated without liquid surrounding the crystal. These transducers were connected to the RF generators by means of coaxial cables furnished by McKenna.

The transducers used in this investigation were cylindrically formed and mounted between cylindrical copper plates. The top portion of the probe was threaded to match the threads on the lucite cylinder which had been previously mounted in the center of the core. Figure 2 illustrates the probe assembly.

(5) Ultrasonic Receiving Probe - The ulstrasonic receiving probe is illustrated in Illustration 3. This probe had a barium titanate crystal mounted on the lower side of the probe similar to the transducer

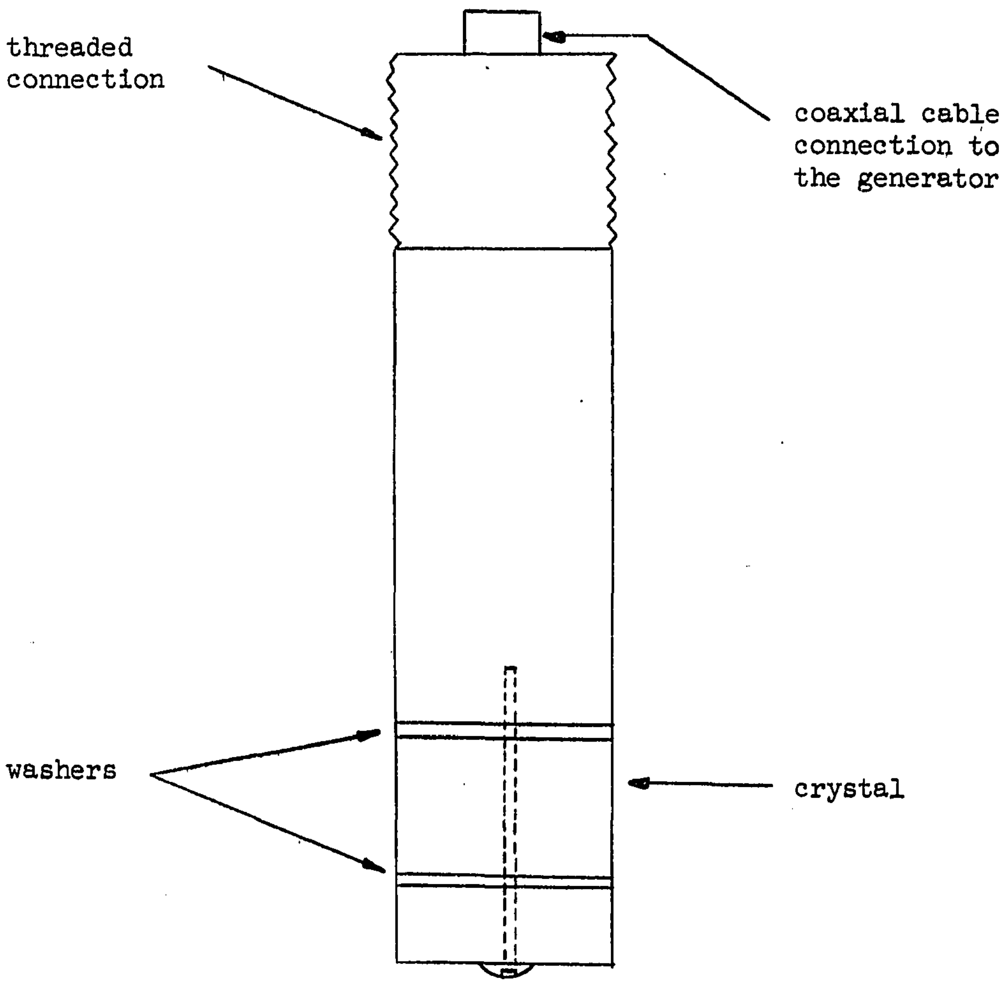


ILLUSTRATION 2

probes. This assembly was threaded at the top and entered the core through the 3/4 inch lucite cylinder located at the outer extremities of the prototype. This probe was connected directly to the oscilloscope by a coaxial cable.

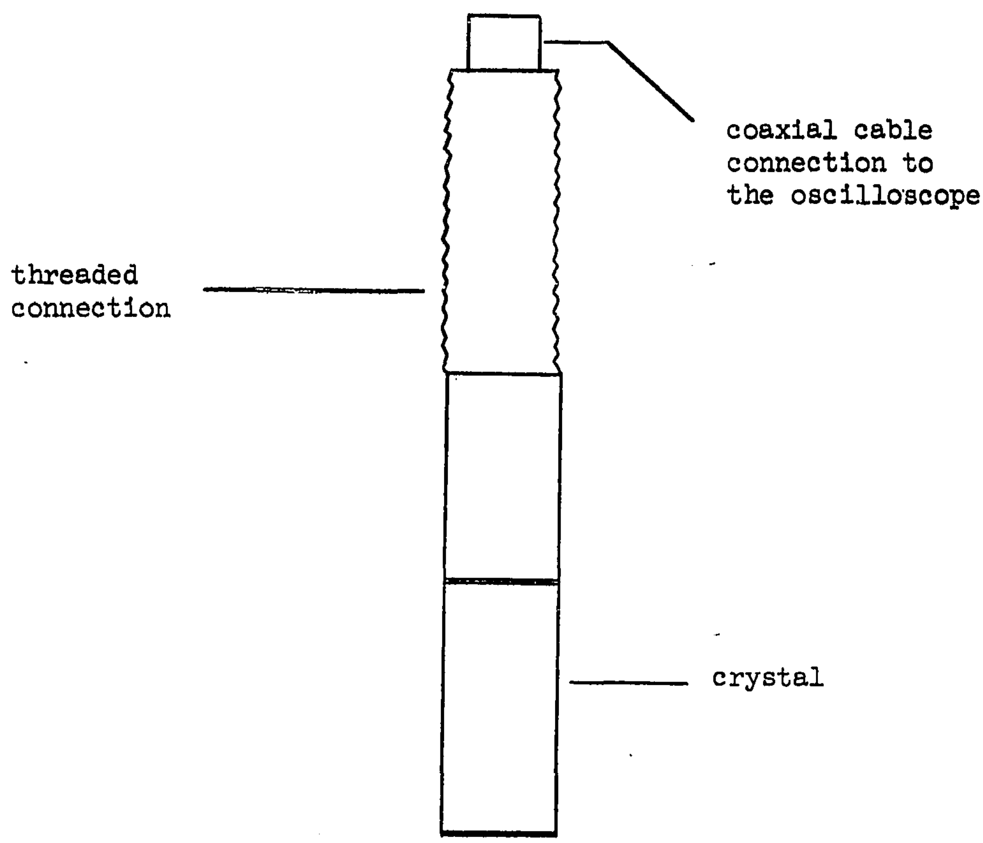


ILLUSTRATION 3

(6) Ultrasonic Generators - Two ultrasonic generators were obtained capable of producing matching frequencies for the three transducers. The ultrasonic generators received were a special purpose liquid load ultrasonic generator designed for laboratory use. One of the generators used previously by J. Sommerfrucht[143] was composed of two separate electronic packages, one operating at 40 Kc/sec. and 1000 Kc/sec. Both electronics were capable of supplying approximately 50 watts of power to the transducers. However, only one transducer could be used at a given time. A second generator was obtained to drive the 3.1 Mc/sec. and 5.5 Mc/sec. transducers.

(7) Oscilloscope - The oscilloscope used was a Tektronix Type 535-A with a Type H plug-in unit. This oscilloscope is considered a wide-range general purpose laboratory instrument. It provides accurate measurements in the Kc/sec. to 15 Mc/sec. range and can be used to measure the voltage of the input waveform by using the calibrated vertical deflection factors of the instrument and associated plug-in unit. The calibrated sweeps of the Type 535-A oscilloscope causes any horizontal distance on the screen to represent a definite known interval of time. Using this feature it was possible to accurately measure the time lapse between two events displayed on the oscilloscope screen.

Another use of this instrument, which was of the utmost importance in this investigation, was its applicability to the measurement of the period (time required for one cycle) of a recurrent waveform. With this information, the frequency, recorded at the pick-up probe position, of the waveform could be determined, since frequency is the reciprocal of the period. With this in mind, it was possible to determine the magnitude of distortion of the waveform emitted from the transducers as the sound progressed through the porous media, and also obtain some indication as to the loss, if any, of magnitude of the waveform which might have transpired across the core between the emitting ultrasonic transducer and the pick-up probe.

The remainder of the equipment is self-explanatory and was added to the system as indicated in Illustration 1.

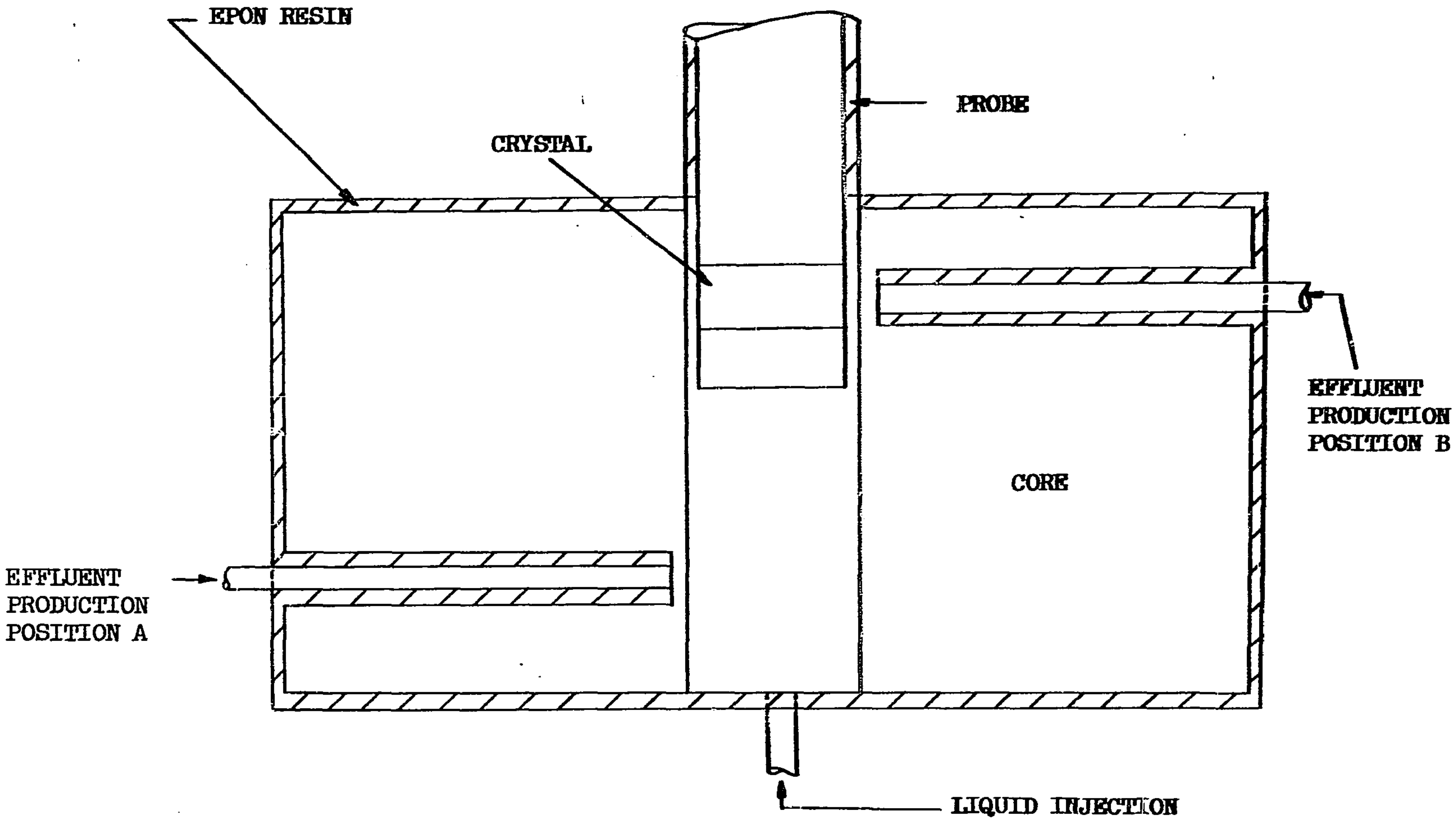
The core used in the injectivity portion of this investigation was formed from the same Torpedo Sandstone used previously. This core had the following dimensions:

Diameter = 12.4 cm

Height = 8.3 cm

This core was completely sealed in Epon Resin. Upon solidification of the sealing agent, a 1.25 inch chamber was drilled through the center of the core up to but not including the bottom face of the resin seal. This cylindrical shaft housed the transducers during the tests. At the bottom center point of the core a 1/8 inch hole was drilled through the sealing material connecting the 1.25 inch center chamber. This 1/8 inch drill was altered at the outer edge of the core for a 1/4 inch fitting and served as the location for the injected fluids.

Two 3/4 inch plugs were drilled out of the side of the core along its periphery up to approximately 3/16 inch from the center shaft. These cuts were made at 180° to each other and in different locations along the vertical height of the core. One location was drilled directly opposite the location of the transducer crystal, while the other, displaced at 180°, was located at some distance below the position of the crystal when fixed in the injection well. These plugs were then filled with Epon Resin. After solidification occurred a 1/8 inch tap was drilled through the resin up to the boundary of the sandstone and resin plug. These 1/8 inch taps were further altered for 1/4 inch fittings at the outer extremities of the core. These drills were made to determine what effect, if any, the emitted ultrasonic energy played with injection of fluids into the surrounding formation directly adjacent to the crystal, and also what effect this energy had on the fluid injection mechanism into the sandstone located below the crystal. These two producing locations were fixed to determine the flow variation from a system of straight water injection as compared to one with a sonic injection mechanism. Illustration 4 displays this core system.



INJECTIVITY CORE

ILLUSTRATION 4

EXPERIMENTAL PROCEDURE

CHAPTER VI

Throughout the discussion of the experimental procedure reference will be made to Illustration 1 in order to display a more realistic description of the method in which the data were obtained.

The oil reservoir was filled with 1500 cc of the oil under investigation, i. e., diesel, core test fluid, and SAE 10 oil. Also at this time 1000 cc of brine was placed in the water reservoir. Oil was then pumped from the oil reservoir through the constant rate injection pump and out through the drain at the bottom of the core. This procedure was conducted to remove any air in the injection line prior to pulling a vacuum on the core. The oil produced from the drain was recorded as the "volume of oil required to flush out air from the lines prior to saturation".

All valve connections surrounding the core were then closed. The receiving probe was fixed in its position in the core along with one of the transducers. The vacuum pump was then connected to the producing outlets and a vacuum was pulled on the core for approximately 14 to 15 hours to insure maximum deletion of air.

Upon completion of the vacuum cycle, oil was pumped into the core. Throughout the saturation cycle a vacuum was continuously pulled at the outlet end of the core. The vacuum pump was removed from the system at breakthrough of the saturating fluid. However, oil was pumped continuously through the core until all 1500 cc had been displaced from the oil reservoir. The produced fluid was collected and recorded as the "volume of oil produced during saturation".

All connections leading to the core were closed, sealing the prototype from the inlet lines. The valve controlling the flow of fluid from the water reservoir was then opened and the constant rate injection pump was started. The oil remaining in the line after saturation was produced, collected (along with any water) and recorded at the drain location. The volume of oil was added to the volume of oil produced to flush the air out of the lines prior to saturation, plus the volume of oil produced during saturation, and this summation subtracted from the original volume of oil in the oil reservoir. The volume of water produced during this step was recorded at the "volume of water required to flush the oil out of the lines". This volumetric balance indicated the volume of oil in the pore spaces of the prototype. Since the original pore volume of the core was known (1244.1 cc) the initial oil saturation could be determined.

Initially, several tests were conducted on the core to determine the percentage recovery of the various oils from the core due to water flooding, corresponding to different initial oil saturations of the core matrix. This information was to be used later as a comparison to the sonic floods tested on these particular oils. It must be emphasized that this dissertation is not designed to study water flooding. The straight water floods were conducted only for a comparison in determining the effects sonic energy contributed to the flow of fluids through a porous media. The procedure used in obtaining the data for water flooding was as follows.

Flooding water, composed of 25,000 ppm salt solution, was forced into the core from the water reservoir at a constant injection pressure, controlled by a manometer located at the inlet position of the core. This pressure was held constant throughout all runs conducted in this experiment. Immediately following the initiation of the flood, the clock was started and the volume of effluent was collected and recorded periodically up to and beyond the point of breakthrough of the water. The run was continued until the volume of cumulative oil and water produced, calculated as a fraction of the pore volume, had reached a value approximating 0.610. At this point the run was terminated. Data were recorded and the following information was obtained:

(a) Time consumed during the run

(b) Instantaneous oil volume produced, cc

(c) Instantaneous water volume produced, cc

(d) Cumulative oil volume produced, cc

(e) Cumulative water volume produced, cc

From these data, the following information was calculated:

(a) Instantaneous water oil ratio

(b) Per-cent recovery of the oil from the core

(c) Reduction in oil saturation

(d) Cumulative effluent produced (i. e., oil and water) as a fraction of the pore volume

(e) Permeability ratio, k_w/k_o

The following procedure was established for obtaining information on the sonic floods. Test floods were conducted using one of the transducers on each oil examined.

The saturation procedure for the various sonic floods duplicated that used for the comparable water floods. The clock was started coincident with the beginning of injection. Upon reassurance that injection fluid surrounded the transducer crystal, which has been previously tuned for maximum output, the generator was started. The tuning of the transducers posed a problem in this investigation and will be discussed in greater detail in a later chapter. The oscilloscope, which had been connected to the receiving probe, was turned on and the following data were periodically recorded.

(a) Time consumed during the run

(b) Instantaneous oil volume produced, cc

(c) Instantaneous water volume produced, cc

(d) Cumulative oil volume produced, cc

(e) Cumulative water volume produced, cc

From this data the following information was calculated:

(a) Instantaneous water-oil ratio

(b) Per-cent recovery of oil from the prototype

(c) Decrease in oil saturation

(d) Cumulative effluent produced calculated as a fraction of the pore volume

(e) Permeability ratios, i. e., k_w/k_o

Information obtained from the oscilloscope was as follows:

(a) Output voltage or amplitude of the transmitted soundwave

(b) Time elapsed between the emmission of the soundwave and the pick-up at the receiving probe location

(c) Output frequency

Tables 2 through 19 list all information obtained in these tests.

Before any particular run could be made the core had to be completely cleaned and dried. Upon completion of any particular run the vacuum pump was connected to the core and a vacuum was pulled. This caused further effluent to be produced, of which water made-up the greatest amount. The vacuum pump was removed from the system when no more fluid was produced from the core.

Pentane was then forced through the core to pick-up the remaining oil in the pore spaces. This was continued until the produced fluid was as "color clear" as the injected pentane. It was felt at this time that all the oil in the core had been essentially removed. This procedure did not however, remove all the water that remained in the system, i. e., the core had a residual water saturation of approximately 40 per-cent. It was then necessary to remove the pentane from the system and further reduce the water saturation to a reasonable value. This was accomplished by blowing dehydrated air through the core and venting the produced gas. Periodic measurements were taken on the produced gas with the use of a wet-test meter. By calculating the pore volume from Boyle's Law, the fluid saturation in the core could be estimated. From 24 to 48 hours were required to reduce the water saturation to a reasonable value. Upon completion of this cleaning cycle, the core was ready for the next test run.

In determining what effect, if any, sonic energy played in increasing the injectivity, the crystal was fixed in the injection well of the injectivity core. Diesel oil was used as the injecting fluid for it was felt a much better basis for conclusions could be drawn from the viscous injection material. The volume of fluid produced from the two producing sites on the core was recorded every minute until approximately ten data points had been obtained. At this time these values were averaged as to the mean fluid being injected into the core. The sonic probe under investigation was turned on and data corresponding to the volume of fluid produced from the two producing locations were recorded. These data were again averaged over ten recorded points obtained, and a mean velocity was procured for the two producing sites.

This same procedure was conducted on all three probes, establishing each time an average velocity with and without the sonic energy. The data obtained from these tests can be found in the appendices and a discussion of the results, plotted on Figures 18, 19 and 20, can be found in Chapter VII.

DISCUSSION OF RESULTS

CHAPTER VII

The results of this experimental investigation of the additional energy supplied to a formation through the use of ultrasonic probes are presented in tabular and graphical form. The data used to obtain the curves referred to in this discussion are found in the Appendix.

Preliminary tests were conducted on small core samples cut from the Torpedo Sandstone to obtain the basic characteristics of the prototype as follows:

(1)	Diameter of the prototype	=	40.7 cm
(2)	Thickness of the prototype	=	4.6 cm
(3)	Initial pore volume of the prototype before drilling the injection well and receiving probe location	=	1289.0 cm
(4)	Diameter of the injection well location	=	3.02 cm
(5)	Diameter of the receiving probe location	=	2.17 cm
(6)	Actual prototype pore volume susceptible to fluid saturation	=	1244.1 cc
(7)	The average air permeability obtained from several core samples	=	313.2 mds

The investigated fluids used in this study were core test, diesel and SAE 10 while the displacing fluid used was 25,000 ppm brine solution. A displacing fluid of this concentration was used in preference to distilled water in order to eliminate swelling of the clay materials. The properties of the fluids used in this study are presented in Table 19 of the Appendix.

Figure 1 illustrates the effect of 1 Mc/sec. sonic flood on the per-cent recovery of core test fluid for two indicated conditions of initial oil saturation, these conditions being 93.8 per-cent and 51.5 per-cent of the pore volume respectively. The straight line portion of the curve represents the production during the initial phase of the flood prior to breakthrough. After water breakthrough the curve rapidly changes slope and eventually approaches the final terminating recovery asymptotically. However, as indicated from the water-oil ratio variations, Tables 6 and 7, the flood based on the higher saturation could have been continued further thereby giving a greater recovery. This flood was continued, beyond the predetermined terminal condition. This was done to reach an equivalent cumulative water-oil ratio with respect to the run conducted on the system containing less initial oil saturation. It can be hypothesized from this test that there is little variation in the recovery values of these two floods and thus indicates that the recovery of sonic flooding is not affected by the initial oil saturation. The values under consideration here are:

(1) At S_{o_i} = 93.8%, the % Recovery = 64.8 with a corresponding Cum WOR = 71.6

(2) At S_{o_i} = 51.5%, the % Recovery = 61.4 with a corresponding Cum WOR = 73.25.

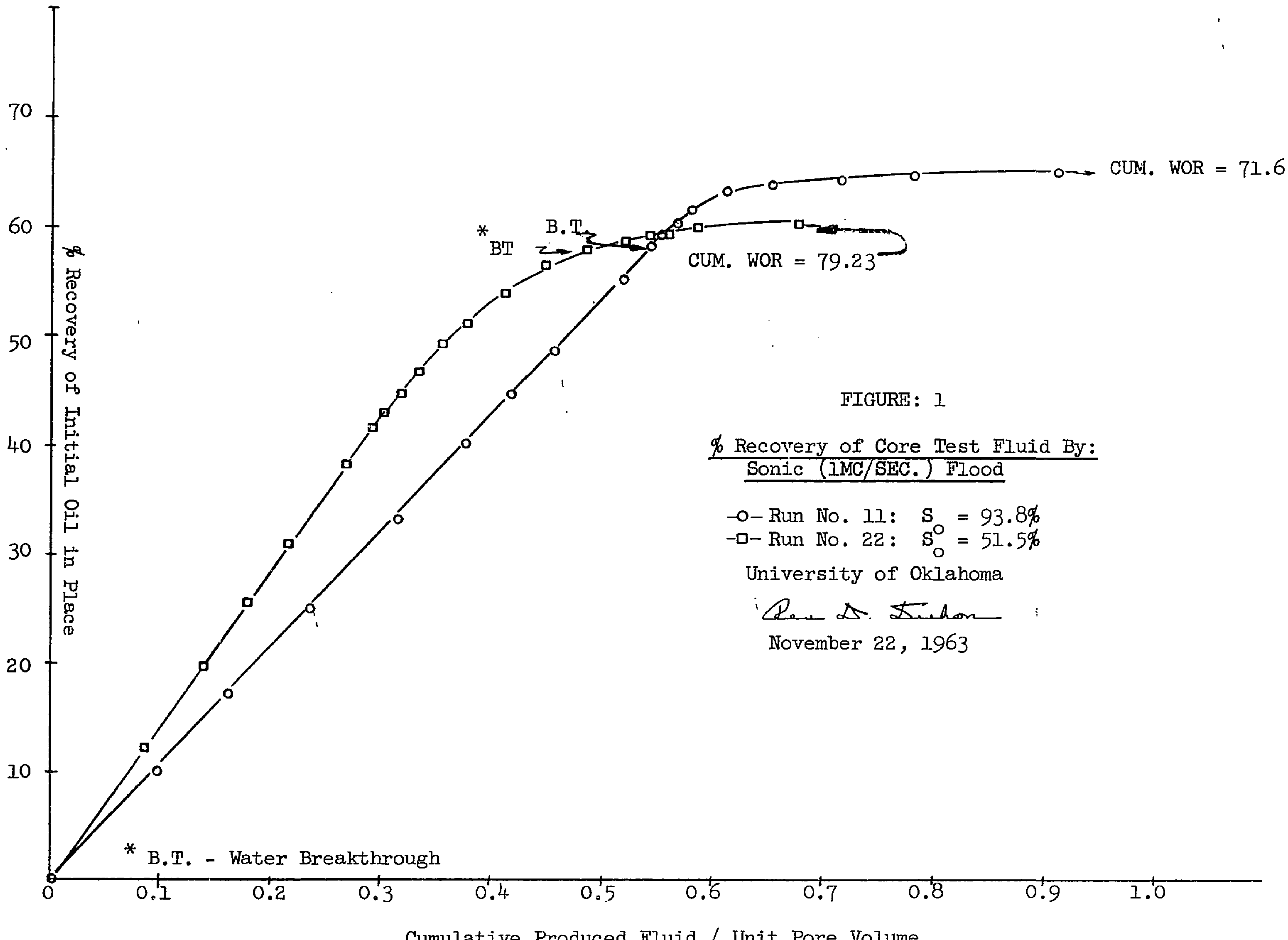


FIGURE: 1

% Recovery of Core Test Fluid By:
Sonic (1MC/SEC.) Flood

-o- Run No. 11: S_o = 93.8%
-□- Run No. 22: S_o = 51.5%

University of Oklahoma

[signature]

November 22, 1963

Figure 2 indicates the effect of a 3.1 Mc/sec. sonic flood on the recovery of diesel. These curves represent conditions of varying original oil saturation, more specifically 66.6 per-cent, 56.8 per-cent and 60.0 per-cent. The recoveries obtained from these tests are:

(1) For S_o = 66.6% the % Recovery = 56.2

(2) For S_o = 56.8% the % Recovery = 56.6

(3) For S_o = 60.0% the % Recovery = 57.5

These values are all within the range of one per-cent recovery at the termination of the flood. However, these tests were conducted under conditions of a range of approximately ten per-cent variation in the oil saturation. The curves again indicate that the ultimate overall per-cent recovery from sonic floods for the tests considered here, are essentially not effected by variation in original oil saturation.

Figure 3 indicates the effect of a 5.5 Mc/sec. sonic flood on diesel oil. Two experimental runs were conducted at this frequency without changing the tuning of the generators. These tests were conducted under experimentally identical conditions. These curves illustrate quite well the reproducibility of experimental results as they practically coincide throughout the entire range of recoveries.

Figures 4, 5, and 6 illustrate a composite configuration of the effects of sonic floods as compared to the recovery by water flooding for the three oils in question. In Figure 4, all tests were conducted at essentially the same oil saturation condition as indicated by the fact that all straight line portions of the curves fall approximately within the same limiting range of both per-cent recovery and cumulative produced fluid/unit pore volume. There is a definite indication of the increase

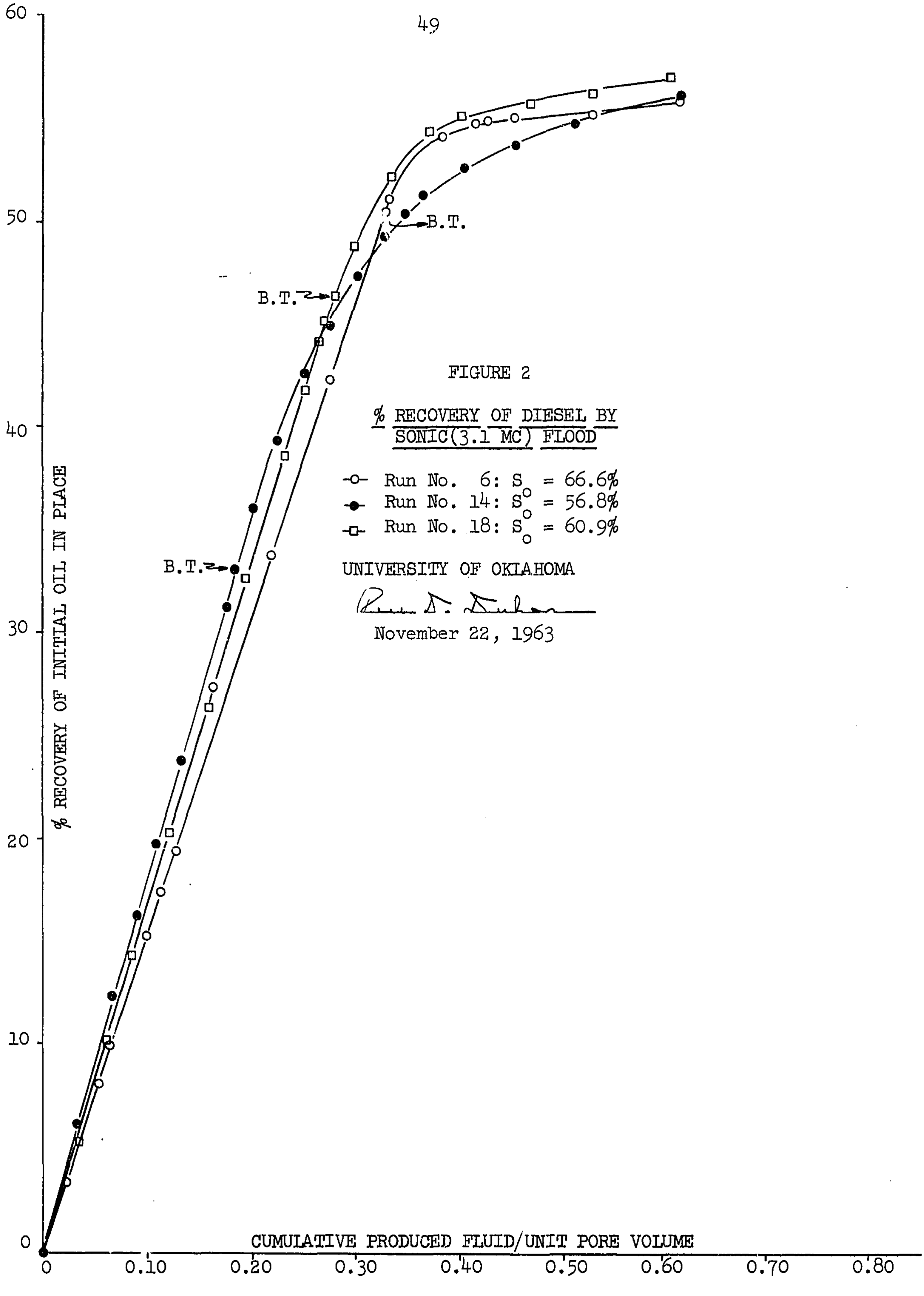


FIGURE 2
% RECOVERY OF DIESEL BY SONIC(3.1 MC) FLOOD
Run No. 6: S_o = 66.6%
Run No. 14: S_o = 56.8%
Run No. 18: S_o = 60.9%
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B.T.
B.T.
B.T.
% RECOVERY OF INITIAL OIL IN PLACE
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME
0
10
20
30
40
50
60
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80

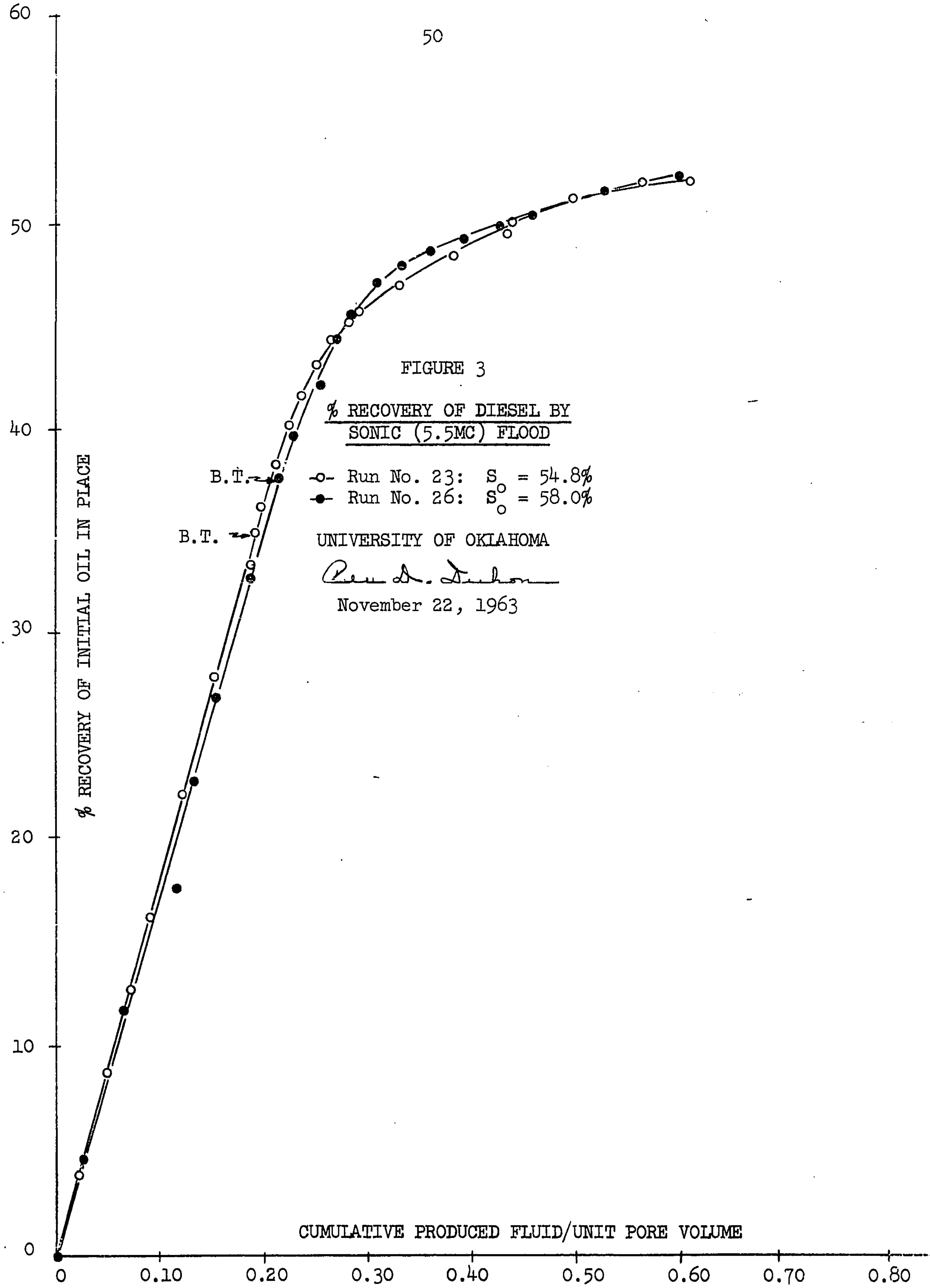

FIGURE 3

% RECOVERY OF DIESEL BY SONIC (5.5MC) FLOOD

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November 22, 1963

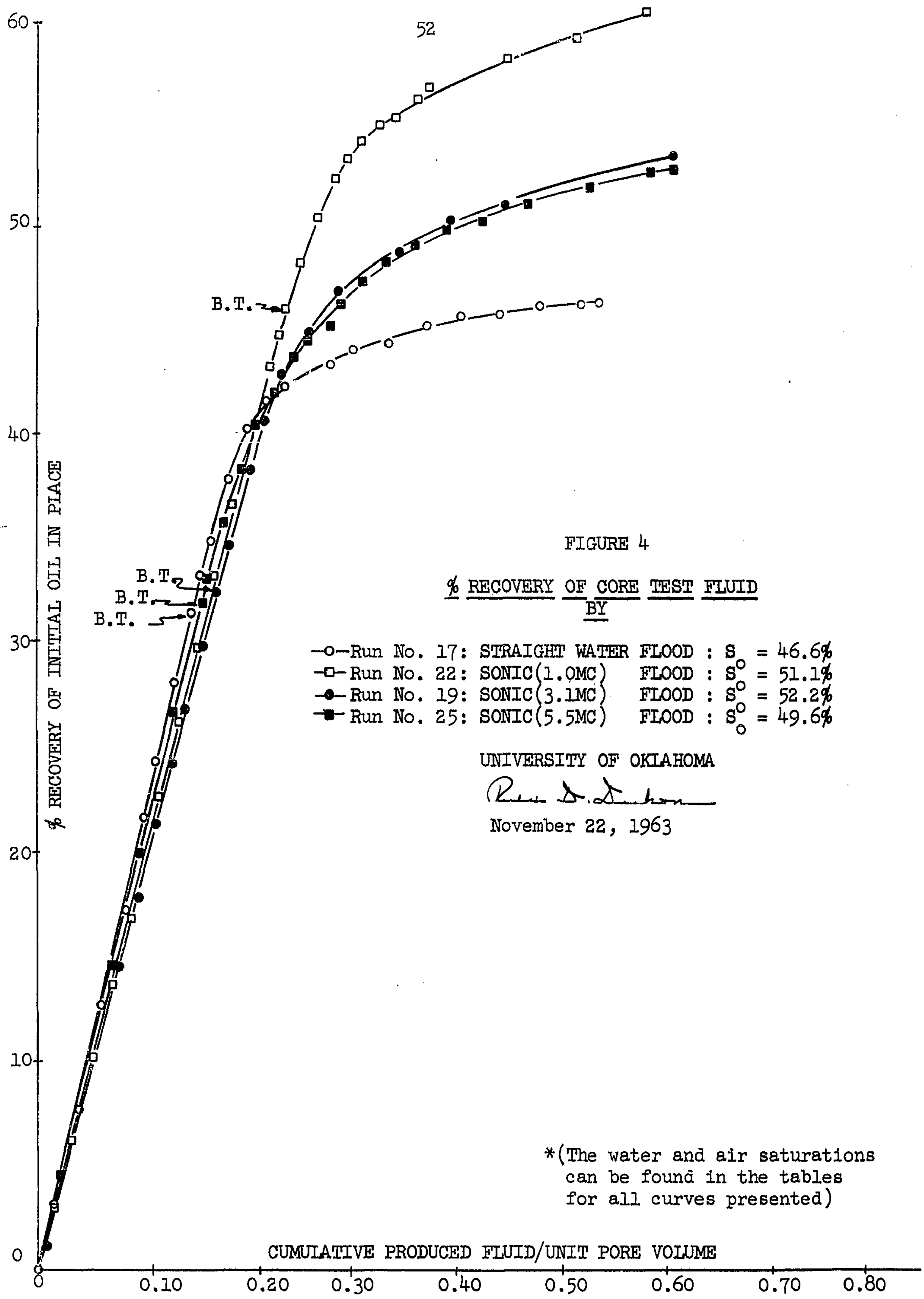
in the per-cent recovery in core test fluid with the use of sonic energy. The recoveries obtained were:

Water Flooding:	Final % Recovery = 46.7
1 Mc/sec. Sonic Flood:	Final % Recovery = 61.4
3.1 Mc/sec. Sonic Flood:	Final % Recovery = 53.9
5.5 Mc/sec. Sonic Flood:	Final % Recovery = 53.1

This shows an additional oil recovery of 14.7 per-cent by the 1 Mc/sec. sonic flood over the water flood and an additional recovery of 7.2 and 6.4 per-cent for the 3.1 Mc/sec. and 5.5 Mc/sec. respectively. As indicated, both the 3.1 Mc/sec. and 5.5 Mc/sec. curves follow approximately the same identical path with only a slight variation in the recoveries, having the 3.1 Mc/sec. sonic flood slightly more efficient than the 5.5 Mc/sec. The following remarks must be injected at this point in order to give some explanation of this result.

A tremendous problem was encountered when the equipment was first obtained. Preliminary tests conducted with the equipment showed that the sonic floods yielded essentially the same recoveries as the water floods. Upon investigation of the equipment, it was noted that the probes were not functioning correctly, regardless of the tedious approach used in tuning the equipment. When placed in a beaker of water, only slight vibrations were noted. Closer investigation showed that energy transmission, which was at a minimum, was being transferred from only a small portion of the crystal face.

Barium titanate crystals are very versatile materials in that they can be shaped to any specification needed for experimentation. Upon examination of the crystals it was found that the thickness of the crystals



60
50
40
30
20
10
0
% RECOVERY OF INITIAL OIL IN PLACE
B.T.
B.T.
B.T.
B.T.
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME
FIGURE 4
% RECOVERY OF CORE TEST FLUID
BY
Run No. 17: STRAIGHT WATER FLOOD : So = 46.6%
Run No. 22: SONIC(1.0MC) FLOOD : So = 51.1%
Run No. 19: SONIC(3.1MC) FLOOD : So = 52.2%
Run No. 25: SONIC(5.5MC) FLOOD : So = 49.6%
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*(The water and air saturations can be found in the tables for all curves presented)

was not perfectly uniform. Inasmuch as the thickness of the material controls the frequency of the waves produced, only portions of the crystal were responding to a certain tuning of the generators. This condition was corrected, but another problem existed with the equipment once a new set of experimental runs was initiated.

There was one and only one position on the tuning knob on the generator that would produce the appropriate pulse to generate the maximum vibrational energy transmitted from the transducer. As the tuning knob could be continually rotated through 360 degrees the position for maximum tuning was extremely difficult to obtain, as just a slight hairline variation in the tuning would produce zero vibrations from the crystal.

As seen from Figures 4, 5, and 6, excellent results were obtained using the 1 Mc/sec. probe. This was the only probe on hand which could be accurately tuned for maximum vibrational transmission. Although the method is simple in theory, it will be stated in the event that it may be of some use in future investigations using this or similar equipment.

A simple transistor radio was accurately tuned to a frequency band of 1000 Kc/sec. and placed near the 1 Mc/sec. crystal. The crystal was then tuned-in and gave maximum visual vibrations in the water when maximum interference was picked-up from the radio.

The tuning of the 3.1 Mc/sec. and 5.5 Mc/sec. transducers was not as easy, as their tuning had to be made on a visible inspection of the vibrations occurring in the water. Although the results obtained from these crystals are positive, there is no concrete evidence that the crystals had been tuned for maximum transmission of energy. It is felt that this is the reason the 3.1 Mc/sec. and the 5.5 Mc/sec. sonic floods in Figures 4 and 6 are not spread out more over a greater pronounced range. It is therefore concluded that the tuning of the transducers is a critical factor in the expected recovery of the displaced materials from the prototype.

Figures 5 and 6 are also composite recovery curves for the straight, 1 Mc/sec., 3.1 Mc/sec. and 5.5 Mc/sec. floods for diesel and SAE 10 oils respectively. They also show this positive effect of additional recovery with associated decreasing frequencies, giving a maximum deviation in recovery for the 1 Mc/sec. sonic flood. The recoveries obtained for the diesel and SAE 10 oils was recorded as follows:

<u>Diesel</u>

Straight water flood:	% Recovery = 50.6
1 Mc/sec. sonic flood:	% Recovery = 60.1
3.1 Mc/sec. sonic flood:	% Recovery = 56.5
5.5 Mc/sec. sonic flood:	% Recovery = 53.1

<u>SAE 10</u>

Straight water flood:	% Recovery = 33.03
1 Mc/sec. sonic flood:	% Recovery = 40.5
3.1 Mc/sec. sonic flood:	% Recovery = 38.6
5.5 Mc/sec. sonic flood:	% Recovery = 38.3

There is a definite indication of increasing recovery with decreasing frequencies for the core test, diesel and SAE 10 oils tested down to the minimum frequency investigated.

Figures 7, 8, and 9 show the effect of sonic floods on the instantaneous water-oil ratio. It may be noted in Figure 7 that after

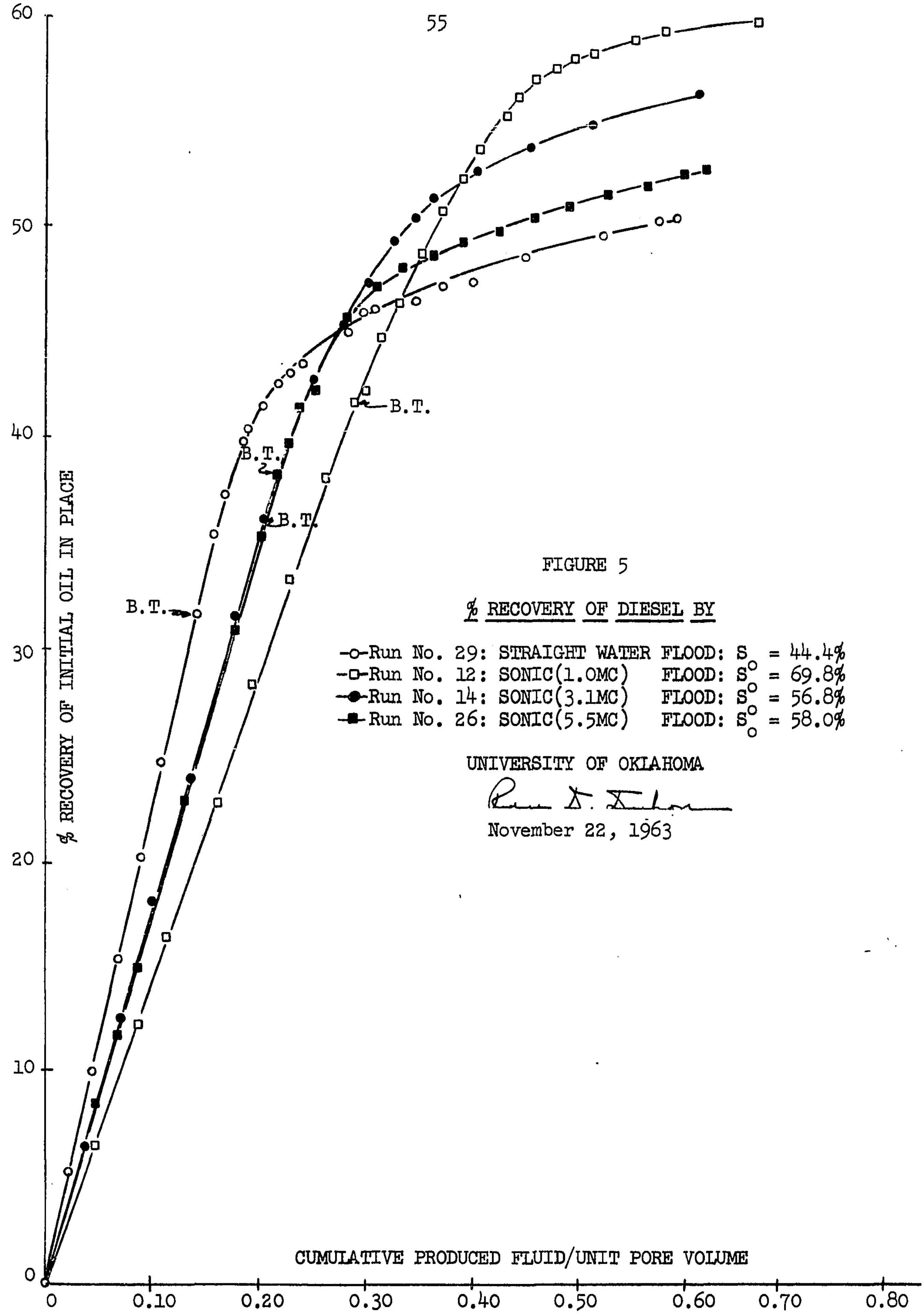

FIGURE 5

<u>% RECOVERY OF DIESEL BY</u>

-o-Run No. 29: STRAIGHT WATER FLOOD: S_o = 44.4%
-□-Run No. 12: SONIC(1.0MC) FLOOD: S_o = 69.8%
-●-Run No. 14: SONIC(3.1MC) FLOOD: S_o = 56.8%
-■-Run No. 26: SONIC(5.5MC) FLOOD: S_o = 58.0%

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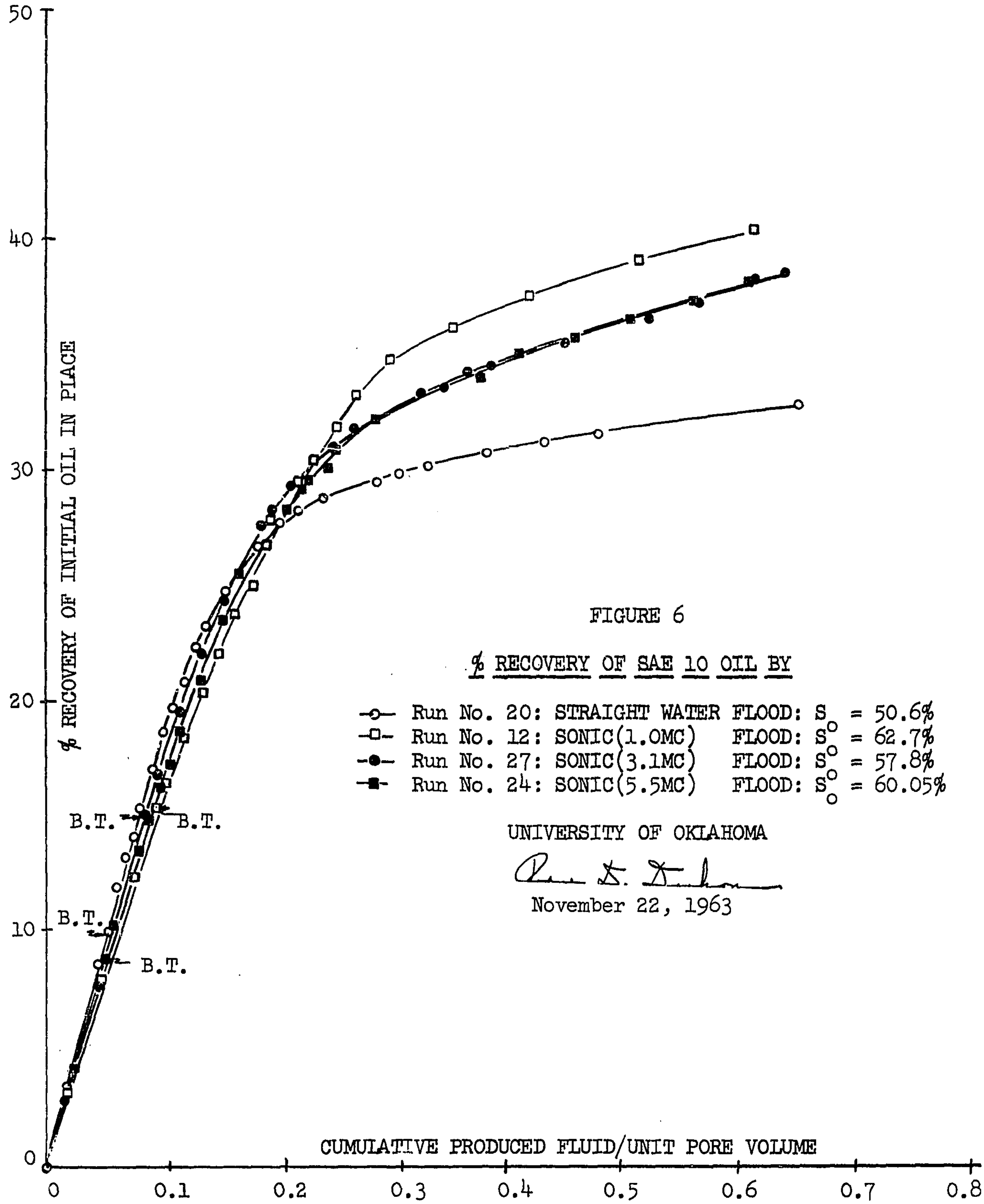
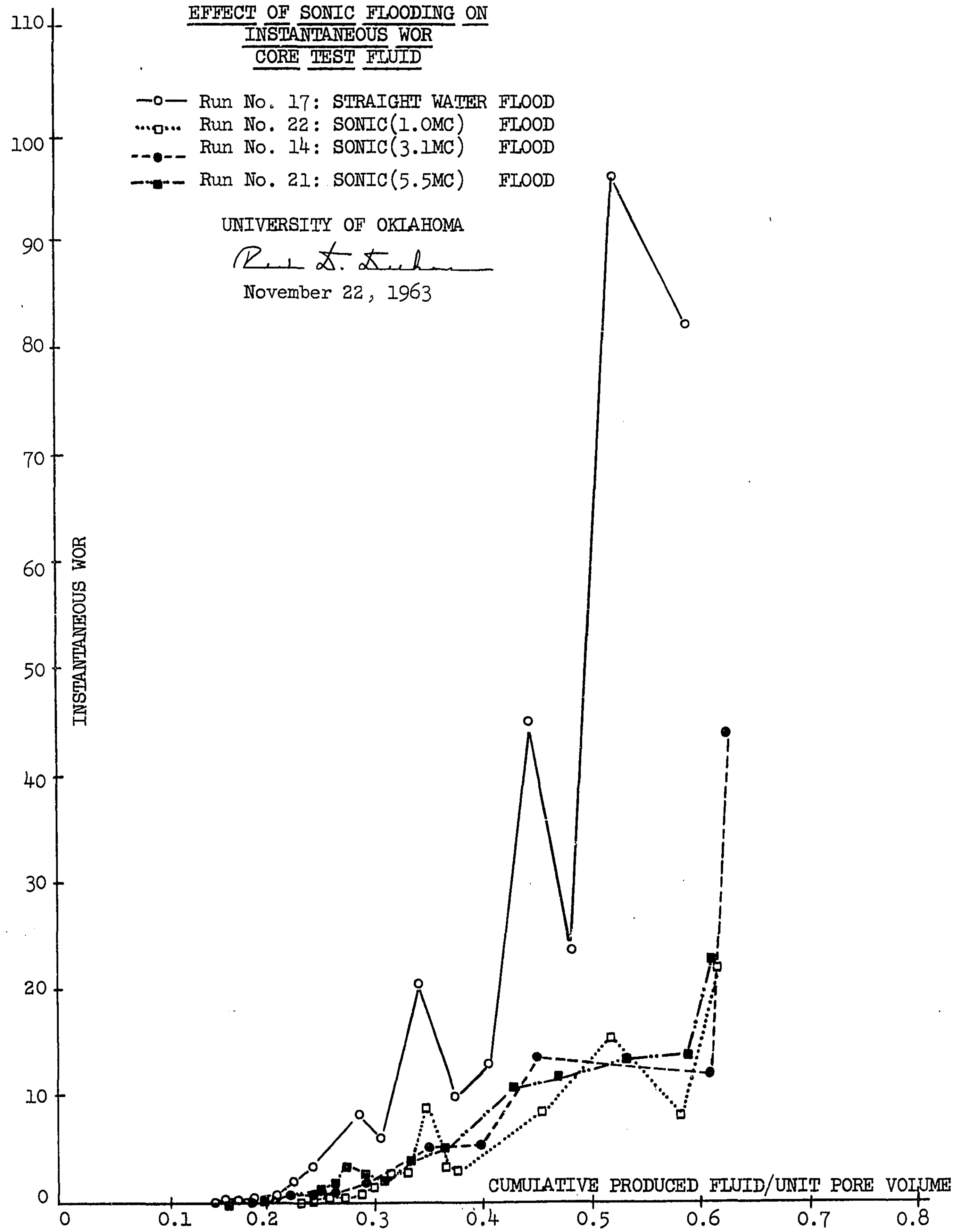


FIGURE 6

% RECOVERY OF SAE 10 OIL BY

FIGURE 7


EFFECT OF SONIC FLOODING ON
INSTANTANEOUS WOR
CORE TEST FLUID
Run No. 17: STRAIGHT WATER FLOOD
Run No. 22: SONIC(1.0MC) FLOOD
Run No. 14: SONIC(3.1MC) FLOOD
Run No. 21: SONIC(5.5MC) FLOOD
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INSTANTANEOUS WOR
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME
0
10
20
30
40
50
60
70
80
90
100
110
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

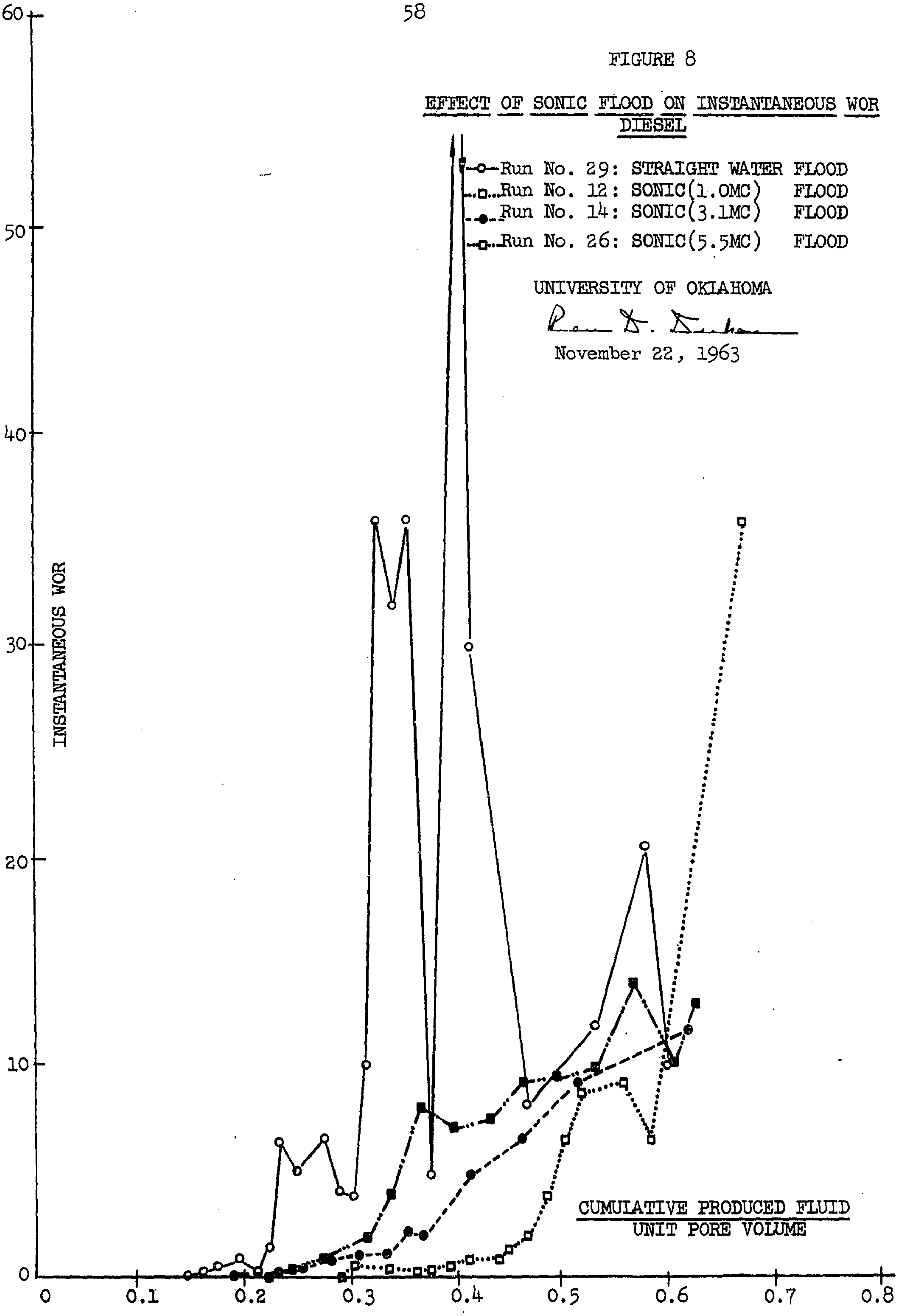
FIGURE 8
EFFECT OF SONIC FLOOD ON INSTANTANEOUS WOR
DIESEL
Run No. 29: STRAIGHT WATER FLOOD
Run No. 12: SONIC(1.0MC) FLOOD
Run No. 14: SONIC(3.1MC) FLOOD
Run No. 26: SONIC(5.5MC) FLOOD
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INSTANTANEOUS WOR
CUMULATIVE PRODUCED FLUID
UNIT PORE VOLUME
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

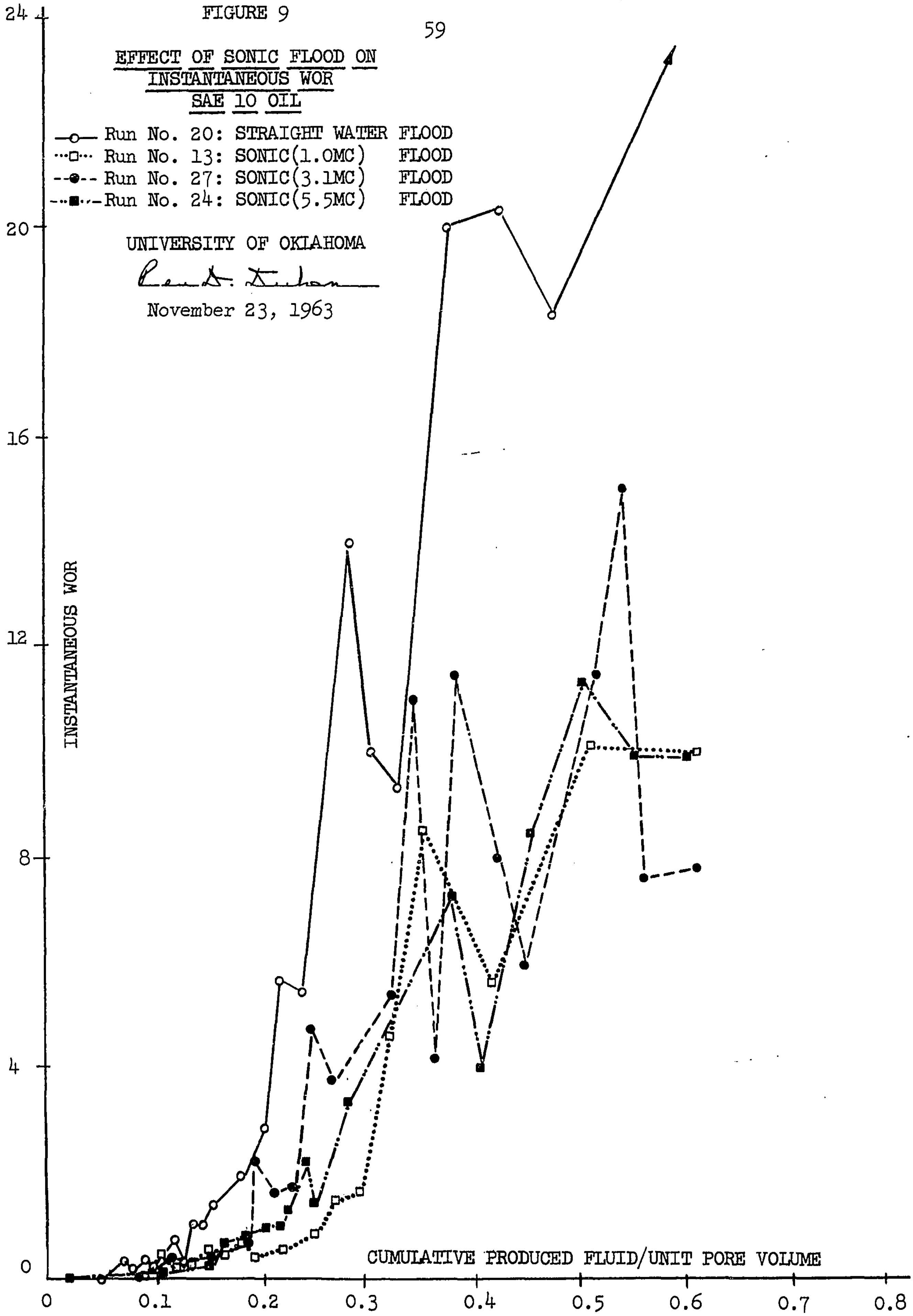
FIGURE 9
EFFECT OF SONIC FLOOD ON
INSTANTANEOUS WOR
SAE 10 OIL
Run No. 20: STRAIGHT WATER FLOOD
Run No. 13: SONIC(1.0MC) FLOOD
Run No. 27: SONIC(3.1MC) FLOOD
Run No. 24: SONIC(5.5MC) FLOOD
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INSTANTANEOUS WOR
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME
0
4
8
12
16
20
24
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

water breakthrough, the instantaneous water-oil ratio curve for the water flood showed drastic increasing and decreasing values. Also, if an average curve was constructed visually through these points it would show a very rapid rise in the water-oil ratios for all oils in question. This rapid rise and fall of the instantaneous water-oil ratio curves for the water floods indicates that water is breaking through some sections in the prototype, which would give the rise in the curve. A drop in the instantaneous water-oil ratio curve indicates that a greater amount of oil is being produced and less water than in the previous data point, indicating a stripping action of various permeable sections within the core. These changes are very pronounced in the cases of the water floods.

A comparison of the results obtained on the instantaneous water-oil ratio curves for the three sonic floods shows a definite decrease in the rise and fall of these curves with an approach towards a smoother curve. It is obviously visible from this graphical presentation, that the general shape of these curves approach that of the water flood curves. Inspection reveals that an association of the rise and fall of the curves, although not as pronounced in the sonic floods, occurs at approximately the same position on the abscissa of the curve. This indicated reduction in the instantaneous water-oil ratio for the sonic floods points out the fact that even though water is breaking through essentially the same permeable zones, the instantaneous volume of water is greatly reduced over that of the water flood even though the cumulative produced fluid/unit pore volume is essentially the same. Thus, it is concluded that more oil is being produced from these zones during the sonic floods. This indicates that there is a more efficient displacement mechanism suggesting:

(a) A more uniform flood front resulting in increased recoveries and/or

(b) A more efficient displacement mechanism within the same area invaded.

Figure 8 illustrates similar results, although there is a marked difference in the spread of the sonic curves, which could be related to the associated spread found on the recovery curves previously mentioned. There is a definite reduction in the sonic flooding effect on the instantaneous water-oil ratio curves. These results indicate that the efficiency is inversely proportional to the frequency of the sonic mechanism-yielding a minimum of recoverable effluent for the straight water flood.

Figure 9 illustrates the remarks previously presented pertaining to the sonic effects on the instantaneous water-oil ratio curves. The curves, however, indicate a less efficient process transpiring in the core, and that more pronounced indications of fingering were observed for this SAE 10 oil.

The conclusion drawn at this point is that the mobility ratio is greatly reduced. The mobility ratio for the floods conducted is defined as follows:

$$\text{Mobility for core test fluid} = \frac{k_o}{\mu_o}$$

$$\text{Mobility for water} = \frac{k_w}{\mu_w}$$

$$(\text{Mobility Ratio})_{\text{core test fluid}} = \frac{k_w}{\mu_w}\,\frac{\mu_o}{k_o} = \frac{\mu_o}{\mu_w}\left(\frac{k_w}{k_o}\right)$$

$$= \frac{1.1230}{0.7781}\left(\frac{k_w}{k_o}\right)$$

$$= 1.443 \ (\frac{k_w}{k_o})$$

(Mobility Ratio)$_{Diesel}$

$$= \frac{2.2370}{0.7781} \ (\frac{k_w}{k_o})$$

$$= 2.87 \ (\frac{k_w}{k_o})$$

(Mobility Ratio)$_{SAE\ 10}$

$$= \frac{28.4200}{0.7781} \ (\frac{k_w}{k_o})$$

$$= 36.6 \ \frac{k_w}{k_o}$$

This mobility ratio is a determining factor in the flow mechanism of oil and water through a porous media. A theoretical maximum recovery occurs when the mobility ratio approaches a minimum value.

Figures 10, 11, and 12 exemplify the produced results on the permeability ratio curves. There is a definite indication that the permeability ratio curves for the sonic floods are greatly reduced with respect to those corresponding to the water floods. This effect has a major bearing on the mobility ratios.

It has been previously assumed in the initiation of these tests, that the viscosities of the various fluids used would be held constant, thus making the mobility ratio completely dependent upon the permeability ratios. Therefore reducing the permeability ratios, as a result of sonic flooding, in effect reduces the mobility ratio, thus effectively increasing the recovered oil.

The question might arise at this time as to the effect sonic flooding had on the viscosity of the displacing and displaced fluids in the core as the flood progressed through the system. Basically, viscosity can be correlated as a function of temperature and pressure. In the system at hand the injection pressure was held constant for each

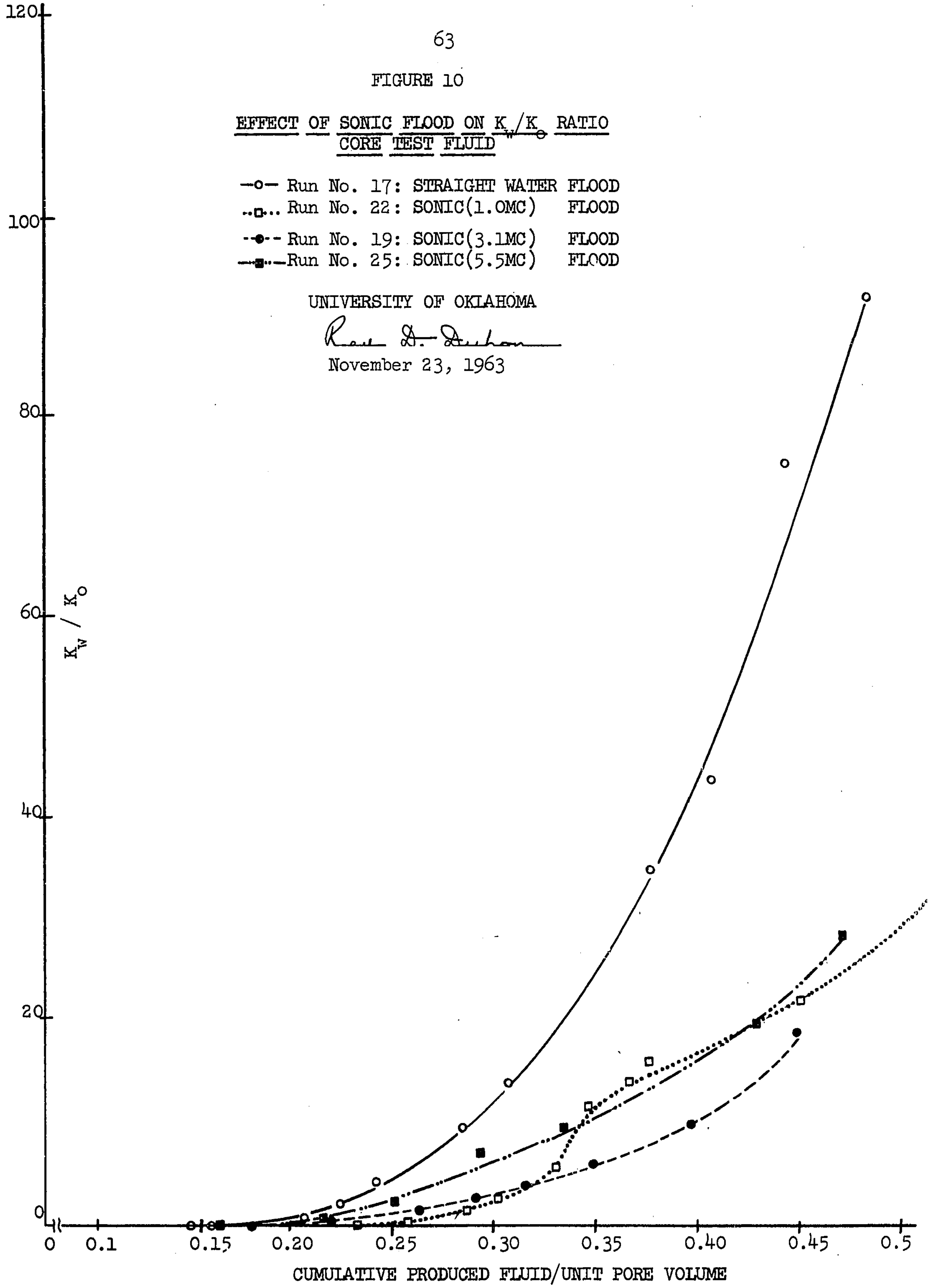

FIGURE 10
EFFECT OF SONIC FLOOD ON K_w/K_o RATIO
CORE TEST FLUID
Run No. 17: STRAIGHT WATER FLOOD
Run No. 22: SONIC(1.0MC) FLOOD
Run No. 19: SONIC(3.1MC) FLOOD
Run No. 25: SONIC(5.5MC) FLOOD
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120
100
80
60
40
20
0
K_w / K_o
0
0.1
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.5
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME

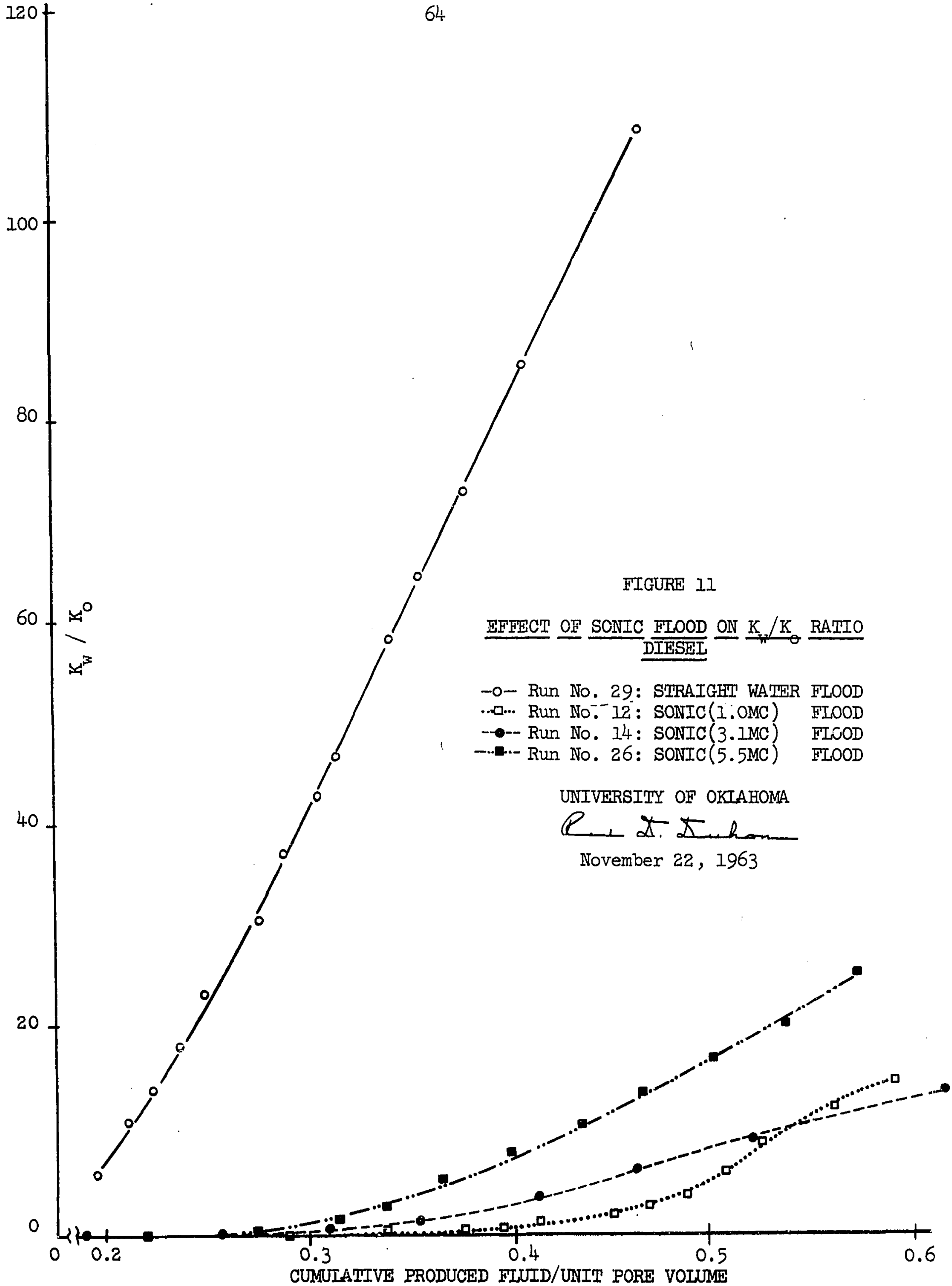
FIGURE 11
EFFECT OF SONIC FLOOD ON K_w/K_o RATIO
DIESEL
Run No. 29: STRAIGHT WATER FLOOD
Run No. 12: SONIC(1.0MC) FLOOD
Run No. 14: SONIC(3.1MC) FLOOD
Run No. 26: SONIC(5.5MC) FLOOD
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K_w / K_o
120
100
80
60
40
20
0
0
0.2
0.3
0.4
0.5
0.6
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME

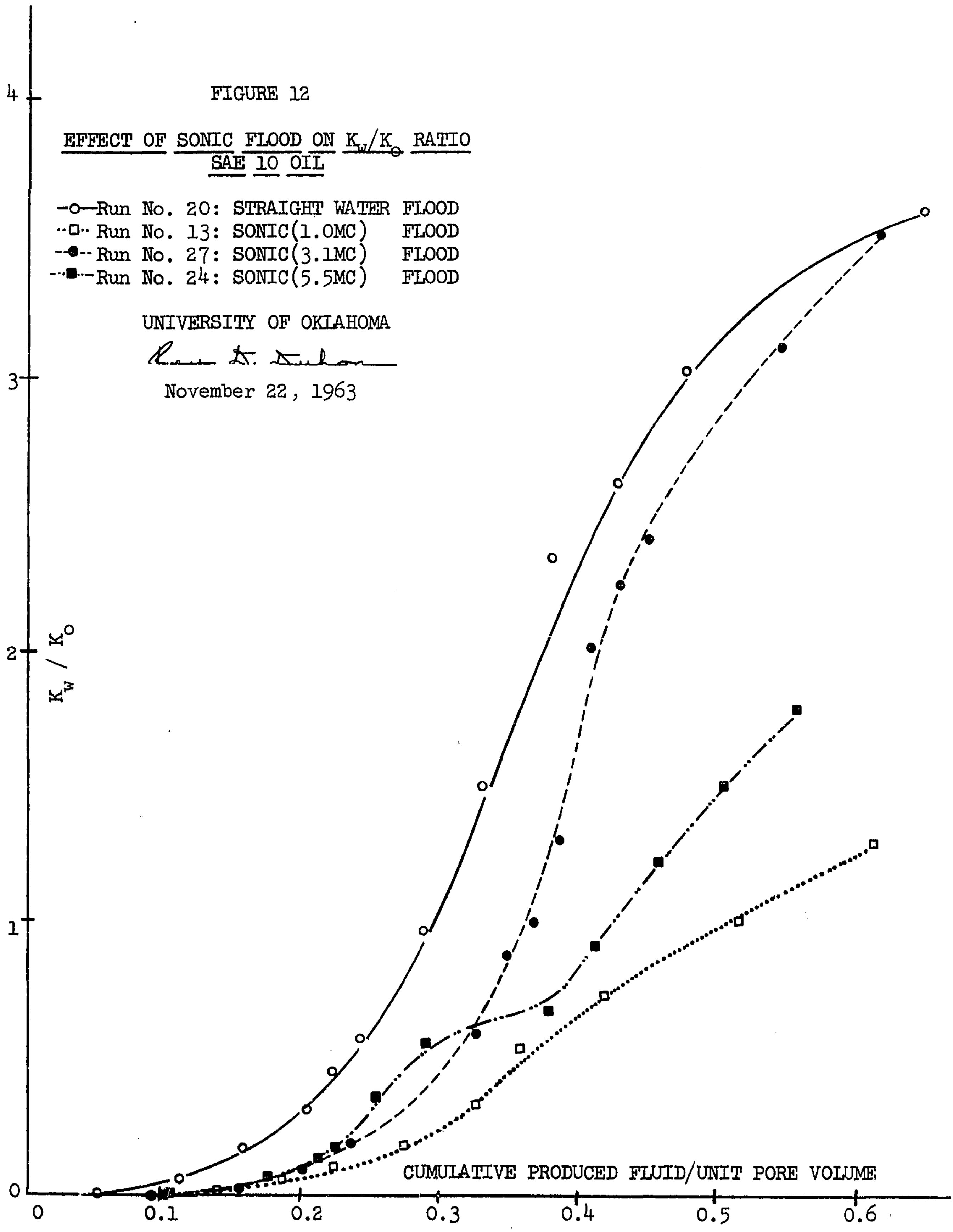
FIGURE 12
EFFECT OF SONIC FLOOD ON K_w/K_o RATIO
SAE 10 OIL
Run No. 20: STRAIGHT WATER FLOOD
Run No. 13: SONIC(1.0MC) FLOOD
Run No. 27: SONIC(3.1MC) FLOOD
Run No. 24: SONIC(5.5MC) FLOOD
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K_w / K_o
CUMULATIVE PRODUCED FLUID/UNIT PORE VOLUME
0
1
2
3
4
0.1
0.2
0.3
0.4
0.5
0.6

individual flood. Assuming only a slight variation in atmospheric pressure, the pressure on the system was essentially constant. This brings up the temperature effects resulting from sonic flooding.

If an ultrasonic probe is placed in a beaker of water an increase in temperature of the water is observed. To preserve the crystal from being ruined due to this temperature change, a continuous stream of liquid should be passes around the crystal, thus reducing these temperature effects. It was felt that this temperature increase might be considered a factor for the increased production found in the tests. A thermometer was therefore placed in the burrette which collected the produced fluid and temperature measurements were recorded. Also, a thermometer was placed near the core in order to determine the room temperature during the flood. Each time a volumetric quantity of effluent was produced its temperature was recorded along with the corresponding temperature of the room. In all cases these temperatures were within $1^{\circ}F$. From this it was felt that the temperature in the system remained essentially constant. Inasmuch as neither temperature nor pressure variations were encountered within the system, the viscosity of the displacing and displaced effluent remained essentially constant, thus making the viscosity ratio constant. It is therefore concluded that the mobility ratio, which in turn effects the recovery, was solely a function of the permeability ratios.

In the case of core test fluid and diesel oil, there is a marked decrease in the permeability ratio, indicating the above results. The permeability ratio for the SAE 10 oil however, did not show this marked variation, thus possibly explaining the lower recoveries obtained from this oil.

Figures 13, 14, and 15 represent the effect of sonic flooding on the recovery mechanism of the oil in question using as a comparative basis the viscosity deviation between the three oils. Tests conducted with the 1 Mc/sec. flood show that the recoverable fluid from the system increases with decreasing viscosities. It is indicated at the end of the curves that there is not a great difference in the recoveries for the diesel and core test fluid however, there is a definite variation between these two fluids and the most viscous fluid tested, that being the SAE 10 oil.

Figure 14, shows the effect of the 3.1 Mc/sec. sonic flood on the three fluids tested. In this case the greatest recovery was obtained with the diesel oil. This deviation in the pattern set forth in the previous curve is most probably due to the tuning effect previously mentioned, whereby maximum vibration was obtained when conducting the diesel oil investigation. Since the viscosity ratio, and hence the mobility, between the diesel and core test oils varied only by a factor of two, assuming similar permeability ratios, it is quite feasible to assume that the recoveries should be within the same range at the termination of the floods. This fact is indicated in these figures as the recoveries of the diesel and core test fluid for the sonic floods are nearly equal. Again, the SAE 10 oil gave the minimum recovery due to the extreme variation in the viscosity of this fluid. Its effect on the mobility ratio is approximately twenty times greater than the other fluids, thus it was expected that the recovery of this oil would be less.

In all systems studied, it was noted that the recoveries increased with decreasing frequencies from 5.5 Mc/sec. to 1 Mc/sec., whereby the 1 Mc/sec. sonic flood gave the maximum recoveries. Conclusions cannot

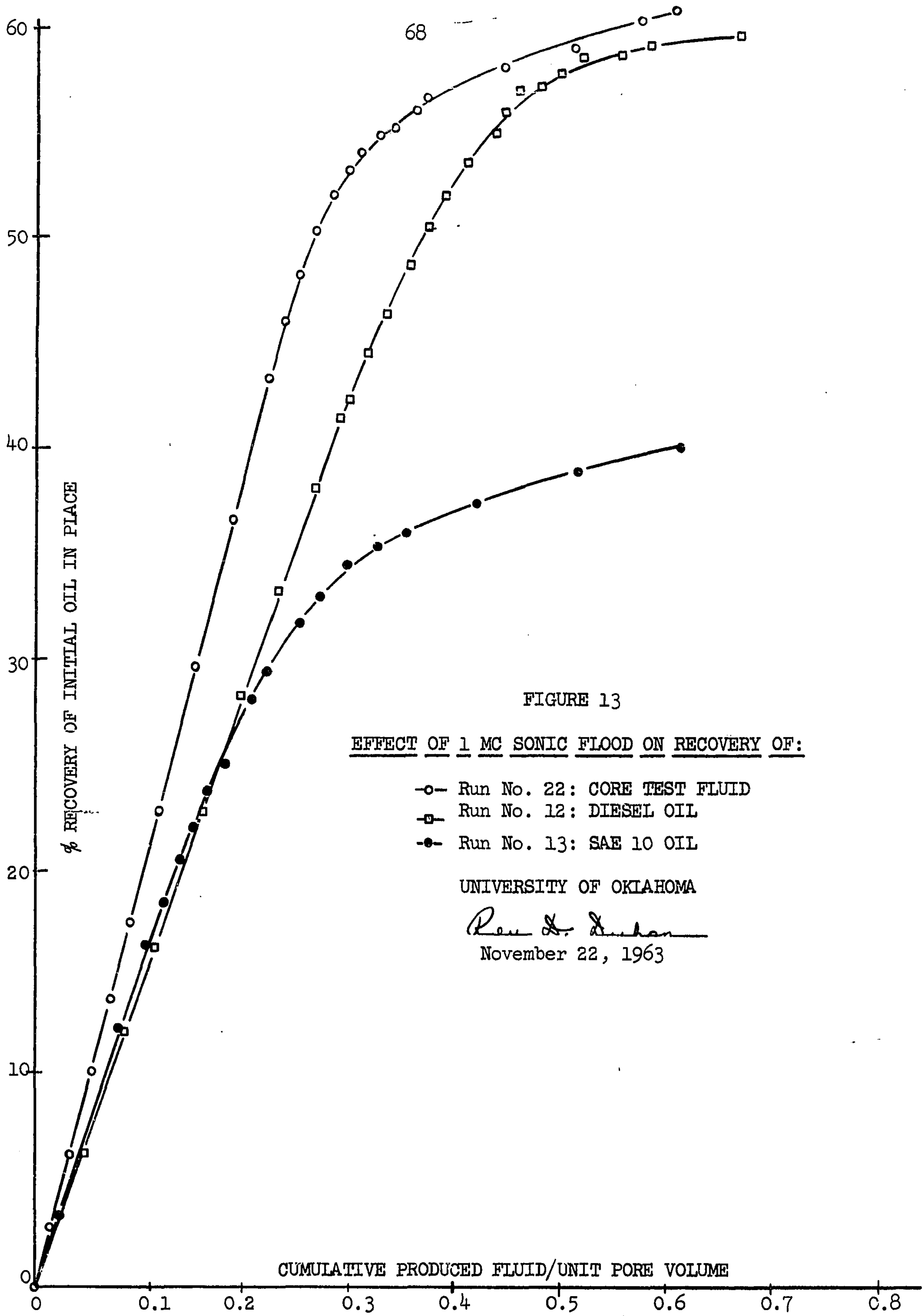

FIGURE 13

EFFECT OF 1 MC SONIC FLOOD ON RECOVERY OF:

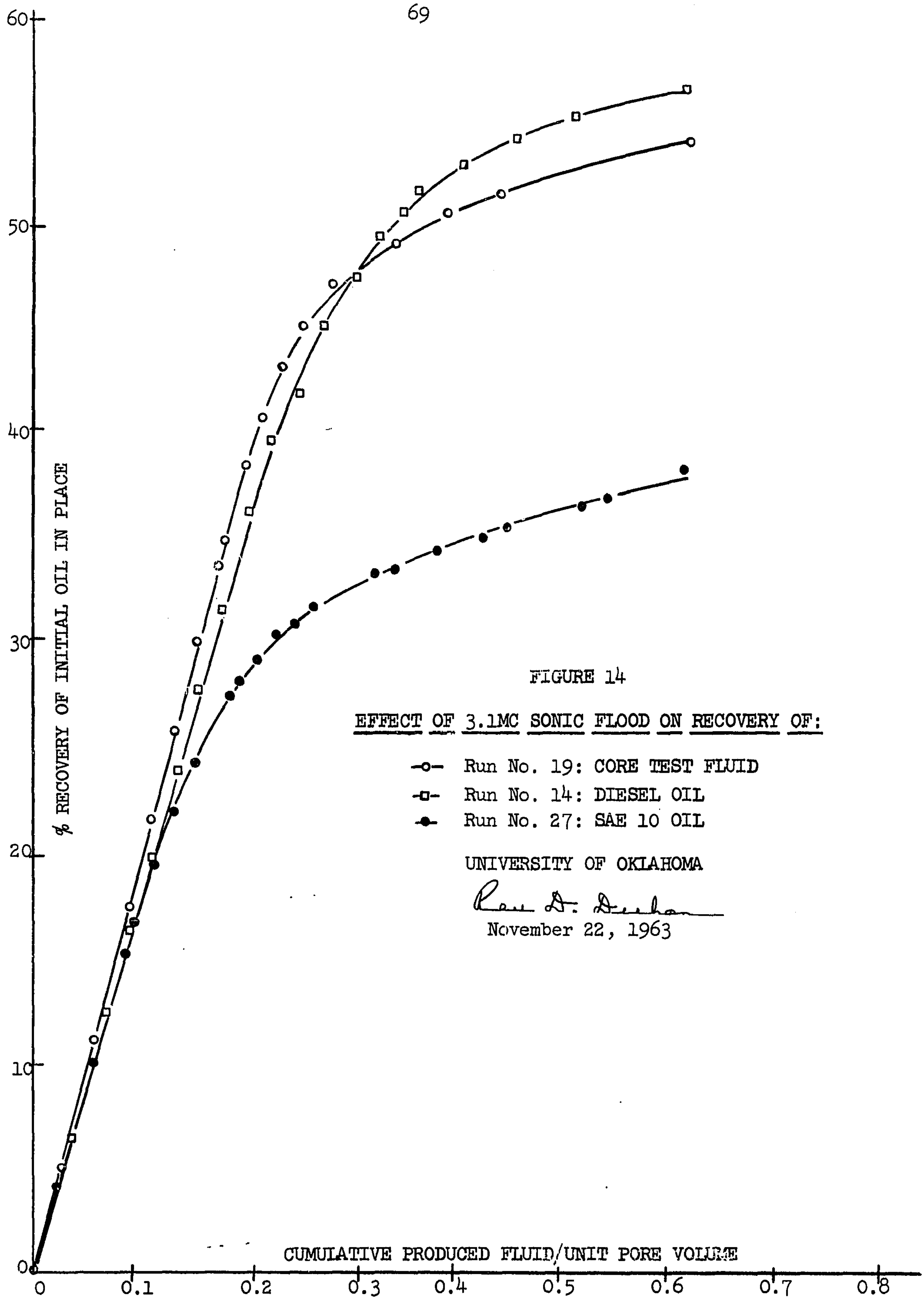

FIGURE 14

EFFECT OF 3.1MC SONIC FLOOD ON RECOVERY OF:

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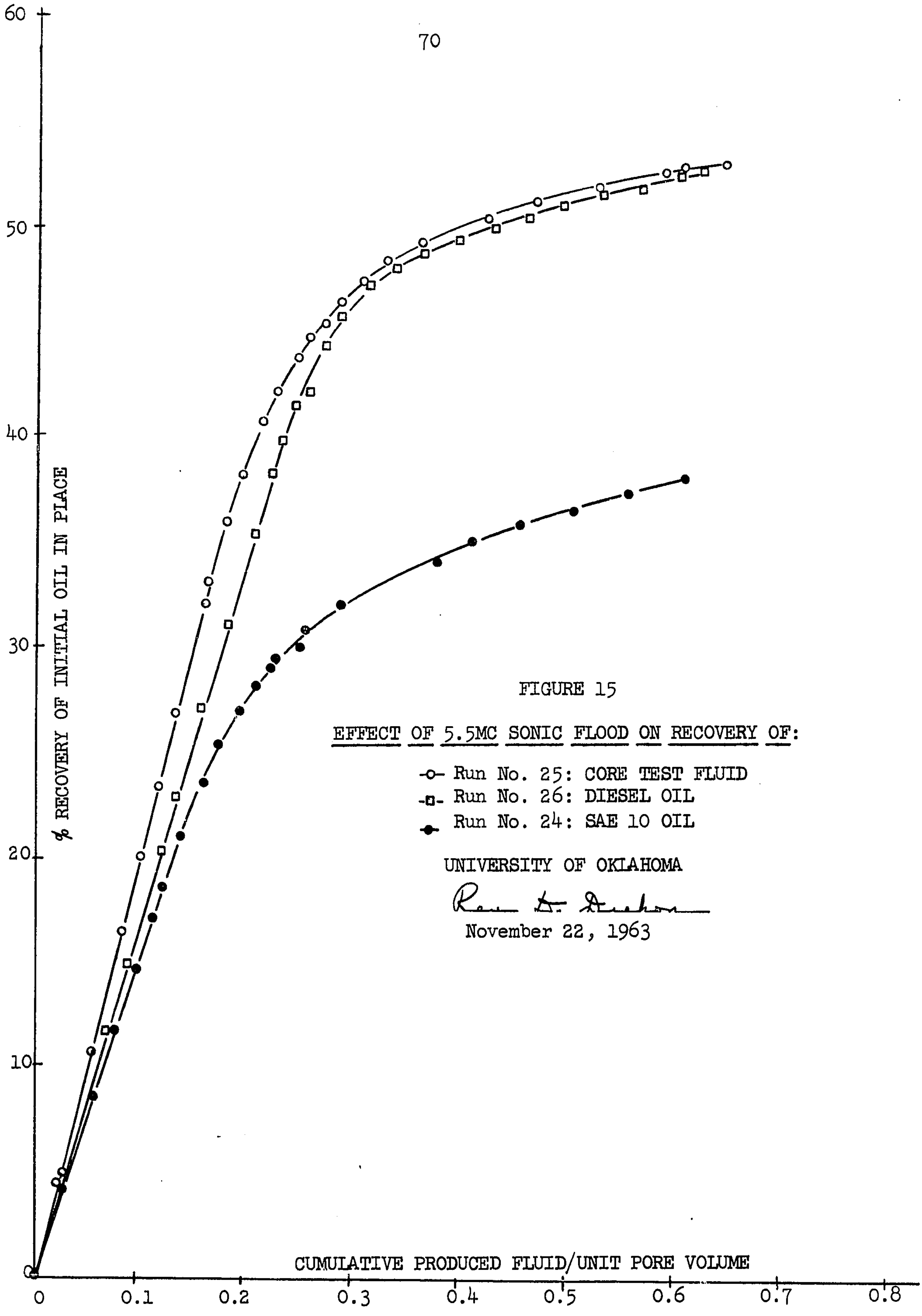

FIGURE 15

EFFECT OF 5.5MC SONIC FLOOD ON RECOVERY OF:

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be drawn beyond the 1 Mc/sec. sonic flood as the equipment necessary to conduct such experimentation was not available. However, since the lowest recoveries in all cases occurred with the straight water flood and the maximum recoveries occurred with the 1 Mc/sec. sonic flood, it is quite feasible that the ultimate sonic flood is not necessarily the 1 Mc/sec. flood, but some frequency between zero sonic flood and the 1 Mc/sec. flood.

Figure 16 illustrates this. These curves have been segmented by lines AB and CD to indicate that this is a region for further investigation. There are definitely no data points to connect the points located on line AB, corresponding to the straight water floods, to data points on line CD, which connects the recoveries of the three fluids at the 1 Mc/sec. sonic flood condition. A straight line has been drawn connecting these points, however whether this is the path or not is questionable. It is quite feasible that the optimum recoveries would be obtained at some frequency between 0 Mc/sec. and 1 Mc/sec., thus indicating that these tests were conducted on the portion of the curve which appears to the right of the peak recovery.

Based on the fluids and the frequencies tested, the 1 Mc/sec. sonic flood definitely indicates an increase in recovery. However, with reference to the SAE 10 oil, the variation in the recoveries between the 1 Mc/sec. and 5.5 Mc/sec. sonic floods is not as pronounced as for the core test and diesel. Thus, it is indicated that essentially one particular frequency will produce approximately the same final recovery.

Figure 17 illustrates a very definite increase in the sweep efficiency of the floods in question. With reference to the core test fluid, this figure illustrates that breakthrough occurs first for the

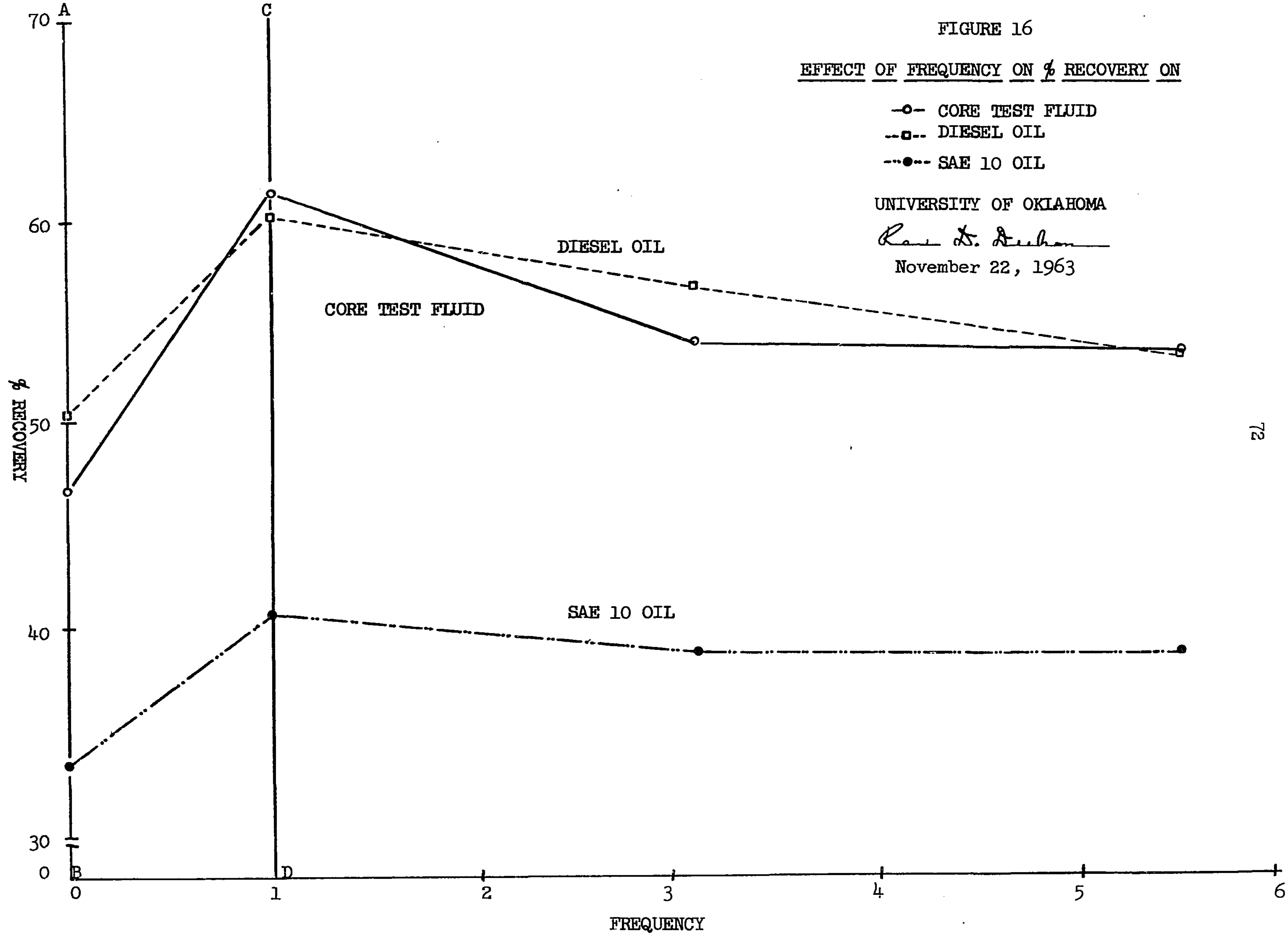
FIGURE 16
EFFECT OF FREQUENCY ON % RECOVERY ON
CORE TEST FLUID
DIESEL OIL
SAE 10 OIL
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DIESEL OIL
CORE TEST FLUID
SAE 10 OIL
% RECOVERY
FREQUENCY
A
B
C
D
70
60
50
40
30
0
0
1
2
3
4
5
6

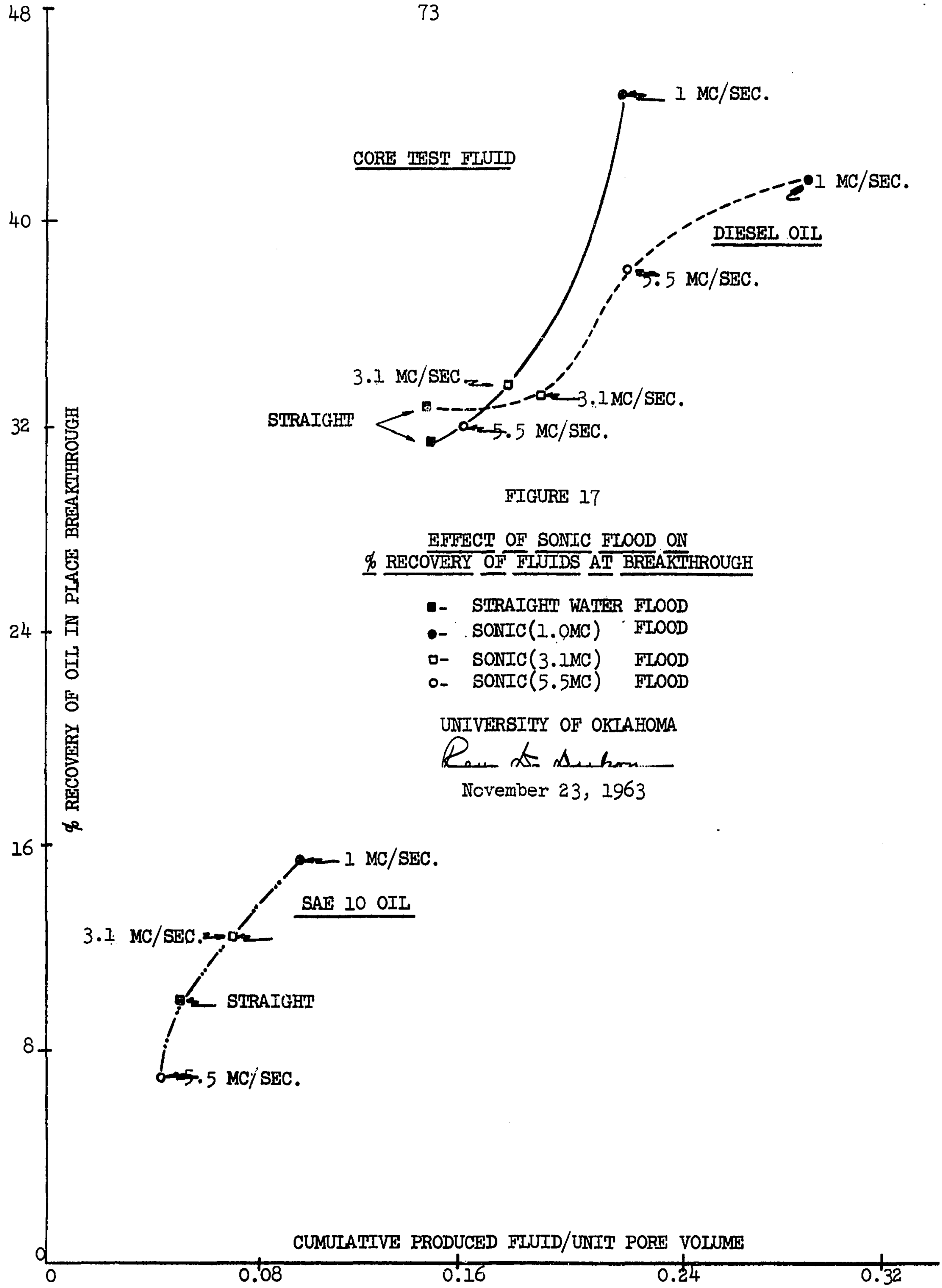

FIGURE 17

EFFECT OF SONIC FLOOD ON
% RECOVERY OF FLUIDS AT BREAKTHROUGH

straight water flood, with the 1 Mc/sec. sonic flood mechanism producing the maximum recovery at breakthrough. This same fact is illustrated for the diesel and SAE 10 oils, although it is indicated that the recovery at breakthrough of diesel for the 3.1 Mc/sec. and 5.5 Mc/sec. are reversed from that of the core test fluid. This variation in results could very well be due to the difficulty in tuning the 3.1 and 5.5 Mc/sec. transducers. There is a definite variation in the results of the breakthrough recoveries based on the SAE 10 oil, in that although the 1 Mc/sec. flood produced the greatest recovery, the 5.5 Mc/sec. flood produced less recovery at breakthrough than the straight water flood. It is felt that the following explanation should suffice for this variation.

It was very difficult to predict the exact time of water breakthrough for the SAE 10 oil as it was so viscous that it produced water from the core even during saturation. This produced water was residual material remaining in the core from the previous run thus making it extremely difficult to predice the exact time of breakthrough. It is felt however, that breakthrough for the 5.5 Mc/sec. sonic flood should actually fall somewhere between the breakthrough recovery points for the straight water flood and the 1 Mc/sec. flood.

The following general remarks pertain to experimentation conducted on the core designed to investigate injectivity. The data obtained for both straight diesel injection (without sonic energy) and with sonic energy for the three probes in question are found in Tables 20, 21, and 22 and are illustrated in Figures 18, 19, and 20. The volumetric flow rates (cc/min.) were obtained from two positions on the core (Illustration 4), one being directly opposite the crystal $(Q_o)B$ and the other displaced below the position of the crystal $(Q_o)_A$.

Figures 18 and 19 indicate that there is definitely an increase in the injectivity, i. e., increased volumetric flow conditions opposite the injection well, with the association of sonic energy. In examination of these figures, it is also noted that the curves corresponding to the volumetric flow rate opposite the crystal is always greater with sonic energy than the curve obtained at position A (below the crystal). Although there is definite indication of increased injectivity below the crystal, the results are not as positive, in that the flow rate shows radical changes sometimes being greater or less than the flow rate without sonic energy. This experimentally proves that injectivity is increased within the injection system of the prototype, and more specifically, more pronounced effects are obtained directly opposite the crystal face. How far down the system from the crystal these same effects could be felt is not known as the thickness of the core was fixed, however, this does bring up a definite area for further investigation. It would be interesting to determine the distance down the injection hole sonic energy would be effective in increasing injectivity of injected displacing fluids. Thus on a scaled model, the exact thickness which could be effectively felt by sonic energy, could be determined and perhaps projected to larger field applications.

The size of the crystal was fixed in this investigation, however it is within the scope of imagination to design larger sonic generating crystals to effectively produce sonic pulses in thicker formations, thus producing similar results obtained in this dissertation.

The results obtained in Figure 20 are rather scattered and no definite conclusions can be reached with this curve. The sporatic

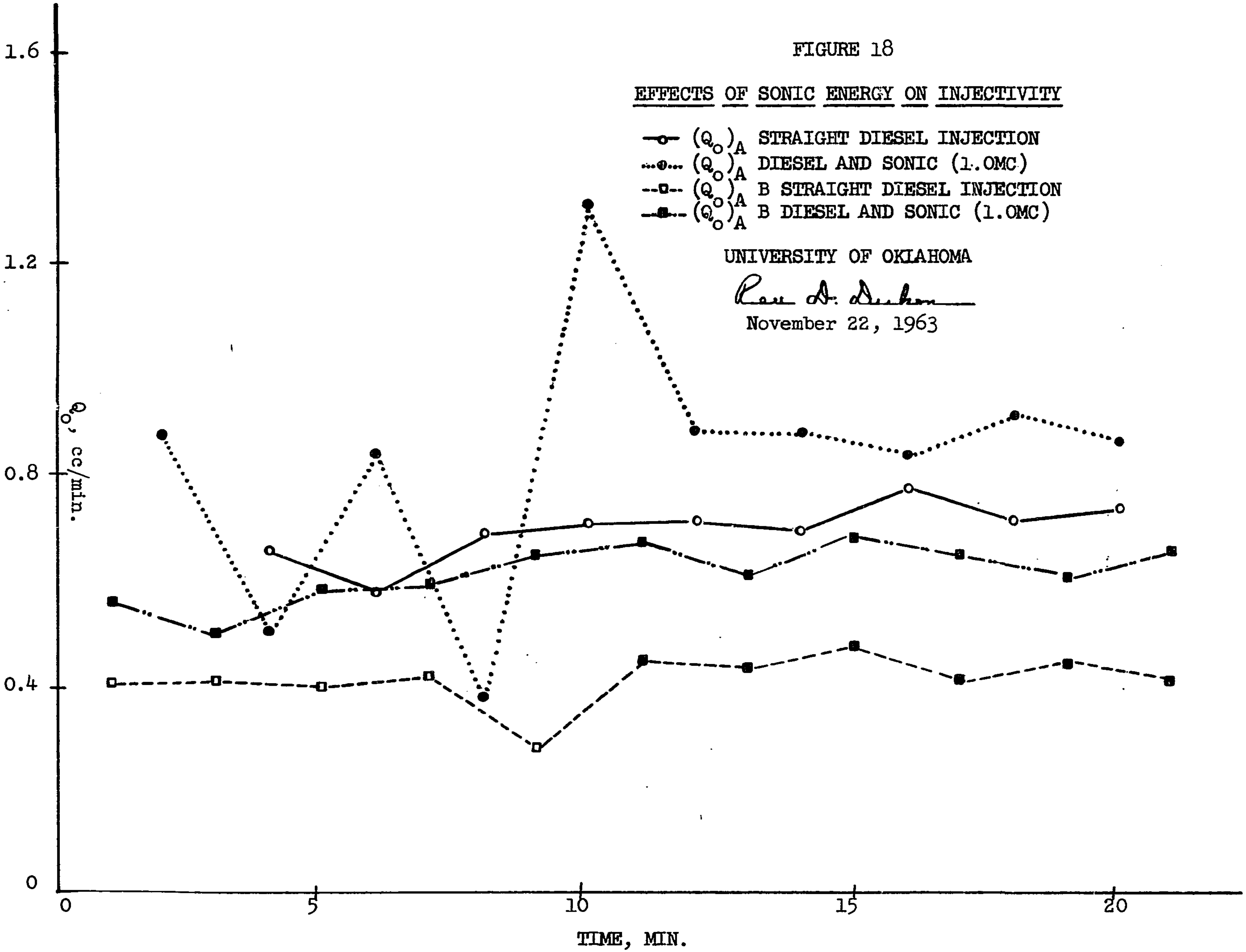

FIGURE 18

EFFECTS OF SONIC ENERGY ON INJECTIVITY

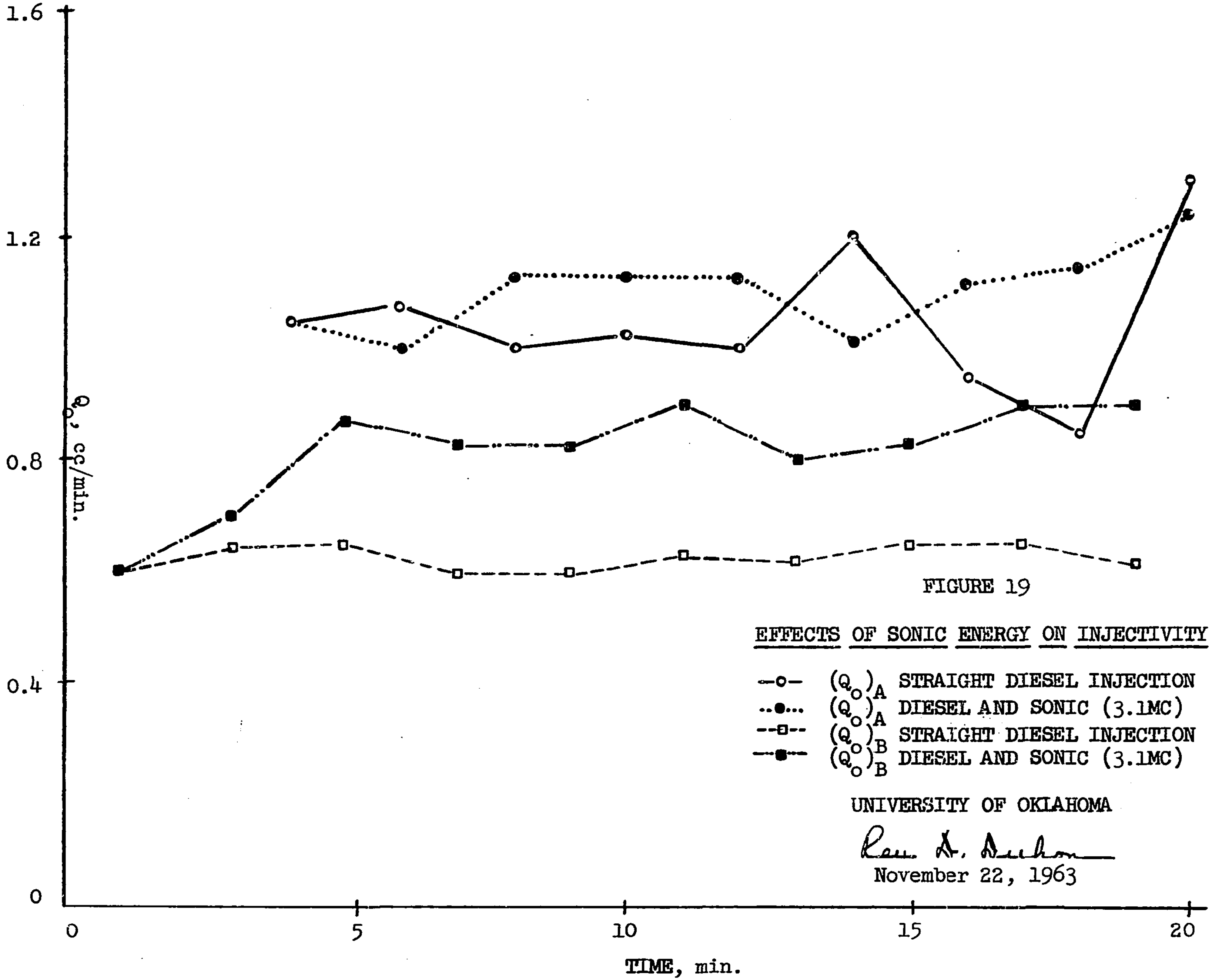

FIGURE 19

EFFECTS OF SONIC ENERGY ON INJECTIVITY

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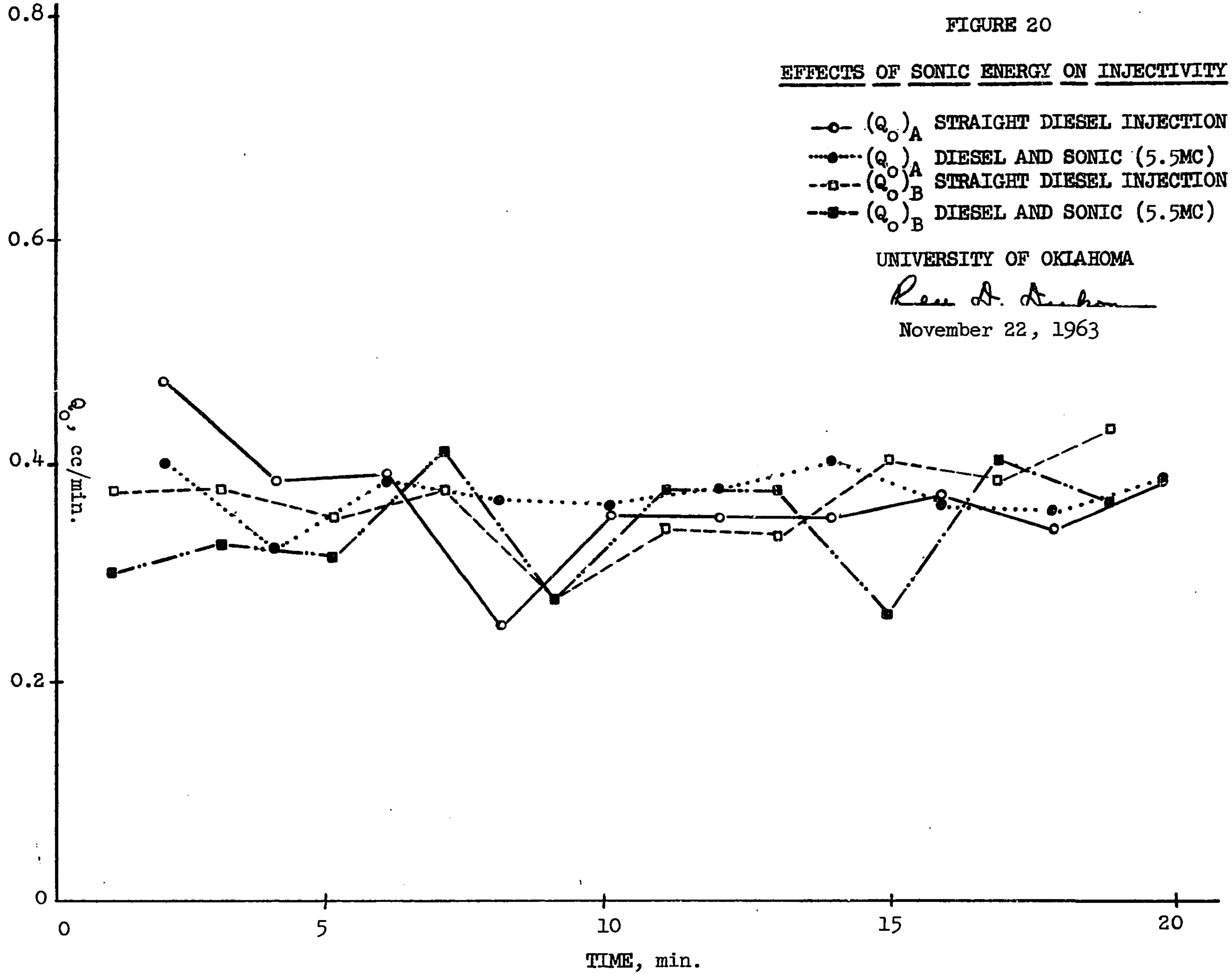


FIGURE 20

EFFECTS OF SONIC ENERGY ON INJECTIVITY

representation of the data is possibly due to the degree of tuning obtained from this 5.5 Mc/sec. transducer.

The results of these figures definitely indicate that there is increased injectivity around the injection well bore, and that this increased injection, although always greater than for conditions without sonic energy, shows a decreasing trend with increasing frequencies.

The information obtained on the oscilloscope pertaining to the sound energy transmitted within the prototype from the emitting to the pick-up position can be found in the Tables in the Appendix. The data indicated that:

(a) A continuous wave train was obtained on the oscilloscope screen which would indicate that no scattering was occurring within this model.

(b) There was no change in frequency between the emitting and pick-up position within the core.

(c) The amplitude of the produced wave for the 1 Mc/sec. sonic probe decreased from the original value obtained at the initiation of the flood up to breakthrough, and then began to increase thereafter. This may be due to the cavitation phenomena occurring at the interface of the displacing and displaced liquids forming a shield type system as the interface or radial boundary increased up to breakthrough. After this point cavitation was reduced and this shielding effect diminished, thus resulting in a rise in the amplitude of the wave.

(d) The amplitude of the waves produced during the 3.1 Mc/sec. and 5.5 Mc/sec. sonic floods remained essentially the same throughout the entire run, with only a small deviation in values scattered throughout the data. Thus, no definite conclusions could be drawn other than perhaps there was no (or little) cavitation occurring within this system which could produce this diminishing effect on the amplitude of the wave prior to breakthrough.

It can be concluded that with increased injectivity and with the other factors presented in this chapter, sonic energy very definitely alters the flow of fluids through porous media. This new applied energy, in association with the other phenomena related to fluid flow through porous media, results in increased recoveries over and above those obtained from a system that was absent of sonic energy.

FACTORS ATTRIBUTED TO THE ADDITIONAL RECOVERY OF OIL BY SONIC FLOODING

CHAPTER VIII

An extensive review of the literature did not reveal any theoretical study pertaining to the association of ultrasonic with the flow of fluids through a porous media. Therefore the following remarks will be purely speculative as to the various conceived factors which play an important part in the additional recovery of oil due to sonic flooding.

As a statement of fact, it was noted throughout these tests that emulsions between the oil and water were not present. As stated by several of the authors quoted in Chapter III, gas, either dissolved or in a free state is essential to the formation of emulsions due to cavitation. Whether gas was present or absent in these tests does not alter the fact that emulsification of the displacing and displaced fluids was not present. It is obvious from the saturations obtained prior to flooding the core, that air was present in the system at the time of the initiation of the flood. Also, the displacing fluid used was not deaerated. Thus, from the study of emulsions prepared with ultrasonics, three possible approaches could be taken based on the absence of emulsions in the effluent. First, there was no cavitation occurring at the interface of the two fluids flowing in the prototype, as cavitation in the presence of air will form emulsions between two immiscible liquids. Second, the pressure on the system was not high enough to collapse the produced cavities which is essential in the formation of emulsions. The third conclusion which could be drawn is that cavitation is occurring at the interface of the two fluids, however, although dissolved gases favor emulsification, high concentrations reduce the emulsification results by cavitation because they have a buffering effect upon the collapse of the cavities, which are essential to the production of emulsions.[109] It is felt that there was an air saturation within the pore structure of the prototype and although the displaced fluid was not saturated with gas as might be encountered in an oil formation, the air saturation was of such magnitude as to prevent emulsification. This may become a problem when transposing this technique to an oil reservoir due to the presence of gas in the displaced fluids, for it has been established that their presence increases the possibility of emulsions. An investigation should be made to determine the critical gas saturation, or gas in solution within a particular crude, to increase the results obtained from the cavitation effects and yet prevent emulsions from forming.

Along these same lines, assuming that the sonic effects do produce emulsions, reference is made to a thesis written by J. Sommerfrucht.[143] In this work, studies were conducted using ultrasonics to break emulsions and it was concluded that at the highest frequency tested (1 Mc/sec.) there was enough energy provided to break emulsions. Considering this conclusion to be valid, it is within the scope of imagination to picture a sonic generator at the surface of a field process supplying energy to the formation to increase oil recovery and also using this same generator in conjunction with some specially designed equipment, the design of which is not within the scope of this investigation, to supply the necessary energy to a transducer within this specific equipment resulting in the breaking-up of any emulsions which might be formed in the formation.

When tuning the crystals for the initiation of any particular test flood in a beaker of water, it was visibly noted that cavitation bubbles were formed within the beaker. The greatest amount of cavities being formed in conjunction with the 1 Mc/sec. transducer. Although there was no apparent method available to note this same condition occurring within the well bore, or point of injection of both water and ultrasonic energy, it is assumed that this condition also existed. It is further assumed, based on work conducted by Bondy, [109] that the formation of cavities were produced at the interface of the displacing and displaced fluids. Upon collapse of these cavities tremendous pressures are produced at the point of contact, and thus pressure waves are sent out into the system. It is postulated that if cavitation occurred at this interface as the flood front moved through the prototype, it attributed to the additional recovery of oil in the following manner:

(1) With such localized pressures acting on a sand surface, i. e., somewhere between 10,000 and 100,000 atmospheres, as recorded in the literature, the pressure may be sufficiently high to separate the sand grains or increase the size of the interconnecting flow channels in the formation to allow the oncoming fluid to enter the pore structure thus forcing the oil out ahead of it. It is stated that obstacles in the path of the wave experience a repulsive force along the direction of propagation due to this radiation pressure.[146] This possibility is quite feasible,

as indicated from the instantaneous water-oil ratio curves. That is to say, more oil is being produced at lower water-oil ratios thus improving the efficiency of the advancing flood front, resulting in flooding out more pore spaces than during the straight water flood.

(2) The pressure waves associated with the collapse of cavities are propagated out in the form of a shock wave.[1] These pressure waves cause serious damage to nearby solid surfaces which they come in contact with causing small fragments of their material to be literally torn away. Since in a well defined porous media there are a massive concentration which can be affected by this pressure wave, it is postulated that the material torn away from the solid surfaces is the oil, which would have otherwise remained trapped within some of the pore spaces. Lord Rayleigh [142] also observed these pressure effects during the collapse of cavities, and stated that these collapses generate enormous mechanical effects, i.e., high kinetic energies being concentrated at very small spots.

(3) Gas bubbles in either a free state or entrained within a fluid can generate large sound pressures in the liquid. Sound can be associated with volume pulsations of the bubble. With these pulsations the bubble behaves like a simple oscillating system. Thus, sound radiated by a bubble must be the result of oscillatory motion of the bubble wall.

The first question which arises is the relative importance of simple pulsations in volume compared to oscillations in the shape of the bubble. The appearance of the bubble wall oscillating in mode corresponding to individual orders of "n" is shown in the following illustration.

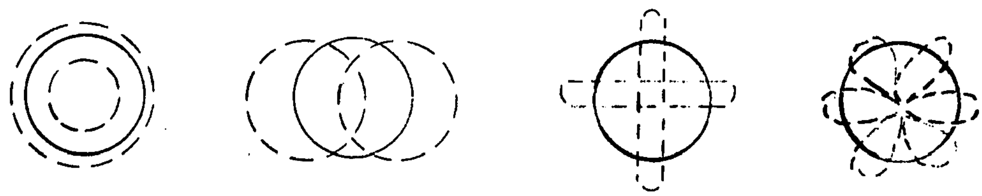


ILLUSTRATION 5

The zeroth mode corresponds to simple volume pulsation, the first mode to translational oscillation, and the higher modes to oscillatory changes in shape of increasing complexity.[35] The zeroth mode involves oscillation of volume with fixed shape, the first mode involves oscillation in position of the center of mass with fixed volume and shape, whereas the higher modes involves oscillations of shape with fixed volume. Appreciable sound is radiated only when the bubble is in volume pulsation. It was also concluded that it does not seem that shape oscillations would ever result in significant sound pressures, except perhaps very close to the bubble, thus only volume pulsations need be considered in calculations of the sound radiated by the bubble.

It is beyond the scope of this investigation to determine bubble oscillations, but it is evident that vibratory motion is transpiring within the prototype due to either the air remaining in the pores prior to saturation or the bubbles of air produced during cavitation. It is postulated that the energy produced due to this vibratory energy from these bubbles would force additional oil from the pore spaces not affected by straight water flooding, possibly due to the shearing of the forces entrapping the oil within the pores.

(4) It has been pointed out in the preceding chapter that additional volumes of fluid could be injected into the formation with the

help of ultrasonic energy, thus increasing the injectivity. If this result is due to the cavitation phenomena produced at the well bore of the injection well, the effects will result in a more uniform flood front initially. As pointed out in the previous chapter, there is a definite indication of reduction in the water-oil ratio and increased sweep efficiency which could be tied in with this effect of increased injectivity, producing a more uniform flooding system at the initiation of the flood. This would reduce bypassing of oil in the formation.

(5) Temperature effects due to cavitation can be ruled out for two reasons. First and foremost, the temperature of the produced fluids was recorded and did not vary with the room temperature. Second, temperature changes are confined to the gas content of the cavity bubble, thus concluding that heating effects are negligible in the destruction action caused by cavitation.[129]

Temperature effects play an important role in the formation of cavities.[44] As the temperature of a cavitating liquid is increased agitation appears to increase. This factor can be tied in with this investigation in that a proposal will be made in Chapter X to consider the effects of similar flood tests conducted under varying temperatures of the displacing fluid. Heat propagation through a formation will definitely increase the recovery of petroleum as indicated by insitu-combustion techniques. Thus, it would be interesting to obtain information correlated to hot water floods in association with sonic energy. By studying a system in which the temperature of the injected fluid was increased, tests could be conducted to determine what effects exist between temperature variation and the cavitation phenomena.

(6) This cavitation phenomana could also explain the results whereby recovery was found to be inversely proportional to the frequency. Investigators have pointed out that the cavitation phenomena decreases with increasing frequency. Thus, if these increased recoveries are dependent upon the formation and collapse of cavities, it would definitely follow that there would be greater residual oil saturation within the core when associated with extremely high frequency sonic floods.

For maximum efficiency in the transfer of energy from a transducer source to the surrounding materials, it has been pointed out that a most important criterion is the matching of the specific acoustic impedances of the two media, since the amount of reflection is determined by this factor. Therefore, the closer the impedance values of the two media, the less reflection occurs and the more transfer of energy from one medium to the other. This is extremely important when requiring a maximum transfer of energy from a transducer to the surrounding medium with a minimum of reflection.

When an ultrasonic wave meets an obstacle, it may be reflected in various ways depending upon both the nature of the obstacle and its size. The action seems to depend upon the relation of the wavelength and the size of the obstacle. If the obstacle is large compared with the wavelength, there is a strong reflected wave that returns from it. A definite shadow is cast behind the obstacle and there may or may not be some diffraction of the wave around its edges. If the obstacle is very small and only a very small fraction of a wavelength, there will be no real reflection and no shadow. The ultrasonic energy seems to pass around the obstacle and come together behind it, passing along as though there were no interference. Of course, if there are enough of these small obstacles, a large portion of the energy may be scattered but there will still be no reflection. The energy will merely disappear inside the piece. One possible explanation of the phenomenon of such reflection is as follows. The wavelength of any ultrasonic vibrational wave represents the distribution of particle displacement within a certain limit, i. e., it represents the amount of compression or expansion in any particular interval of the entire range covered by one wave. The dimensions mentioned so far in the direction parallel to the propagation of the wave. Now, if this same obstacle has a very small cross-sectional area, this smallness coupled with the fact that it has a minute effect on a 1 Mc/sec. wave will give negligible reflection.[103] However, the same small flaw will completely interrupt a high frequency wave over its area and will cause an appreciable reflection. The greater the cross-sectional area of the flaw the more energy it will interrupt and the larger will be the reflected signal. This is possible one explanation as to why the 1 Mc/sec. sonic floods gave better results than at the higher frequencies.

In other words, there are two important factors that influence the reflection. One is the dimension in the direction along the propagation path, the other is the cross-sectional area. It is the dimension along the propagation path that interrupts the wave, but it is the cross-sectional area that determines the amount of reflection.

Wave motion can be plotted or viewed by oscilloscopic means. The figure may be very complex, especially when the particles are being displaced at the same time by more than one wave, very often in different directions. Such an image is referred to as a Lissajous Figure and shows the actual motion of the particle, no matter how many simultaneous forces are acting on it.

The waves produced within the prototype were picked up at the receiving probe location and reproduced on an oscilloscope. The figure represented on the screen of the oscilloscope was a continuous wave train curve. It was as though the sonic energy was being transmitted in a tank-type system without any obstacles deferring its path from the producing transducer to the receiving or pick-up position. It can therefore be concluded that there was no scattering of waves within the formation due to the study of the pictorial representation viewed on the oscilloscope.

Absorption of energy produced from a source transducer is a direct function of the square of the frequency and the viscosity of the medium through which the sound travels, thus the greater the frequency and viscosity the greater the absorption of sound energy, thus relating the decrease in actual recovery with increasing frequencies and the decrease in recovery of the SAE 10 oil. This effect was also observed by Carlin [103] who stated that the loss of ultrasonic energy is due primarily to the viscosity or damping of the medium.

From this discussion, and the results obtained in this investigation, it is concluded that additional energy is being supplied to the formation or prototype in addition to and above the energy generally produced by an approaching displacing fluid, thus resulting in additional recovery by sonic flooding.

FACTORS TO BE CONSIDERED UPON APPLICATION OF SONIC ENERGY TO FIELD OPERATIONS

CHAPTER IX

Sonic energy is merely mechanical or work energy, of unlimited thermodynamic availability in the ideal case, which is transmitted in the form of compressional or other types of elastic waves through fluid or solid matter at a velocity characteristic of the medium.[145] It is important to realize that the nature of sonic energy is not associated with the bulk flow of matter, but with a purely localized motion of matter about a mean position, the disturbance causing the motion of the energy associated with the disturbance are communicated from one layer to the next as the wave progresses. Sonic energy is available energy in the thermodynamic sense, and providing a suitable medium is available, such energy may be a means of adding work into a process or system.

What happens to energy introduced into a system as sonic energy? Sonic energy is mechanical or available energy. When such energy is introduced into a system several things can happen to it.

(a) Alternate regions of adiabatic compression and rarefaction are set-up in the fluid which move out as a wave from the source with a velocity that is characteristic of the elastic properties and density of the fluid surrounding the crystal.

(b) The energy is then absorbed in a number of ways:

(1) Viscous damping - resulting from relative motion between segments of the fluid, degrades some of the available energy to thermal energy.

(2) Conduction of heat - between compressed and rarefied areas results in further loss of available energy.

(c) On meeting the wall of a system, part of the energy of the wave is transmitted through the wall, part absorbed by the wall, and the rest reflected back to the system.

(d) If the amplitude of the pressure variation is great enough, in the case of a liquid, the phenomenon of cavitation occurs. Upon collapse of the voids produced during the initial phases of cavitation, further loss of energy occurs owing to the impact of matter moving at high velocities. Such impact can develop high local energy intensities.

(e) If the fluid in process is a suspension of one phase in another, energy will be absorbed by the drag exerted on the dispersed particles by the localized motion of the continuous phase fluid.

(f) Openings in the system for the feed and withdrawal of fluid in the process provide direct avenues for energy escape, depending on the degree of acoustical baffling designed into the system.

The useful energy in the system at any instant is that represented by the vibratory or wave motion of the material of the system and this wave motion will continue until the available energy is consumed by the effects outlined above.

The question arises now as to what effects this additional energy introduced into the formation has on the variables affecting fluid flow through porous media. Normally these variables are arbitrarily fixed when a field is discovered or at the time secondary recovery operations are considered. The problem arises then to design an engineering process which will ultimately produce the maximum amount of oil in the most economic manner. To do this it is necessary to consider certain variables in such a manner as to obtain this ultimate goal.

It may be noted that one of the primary variables to be considered is the sweep efficiency. Thus increasing this factor will ultimately increase the recovery of oil. As shown from the data, the significant variable changed to increase the sweep efficiency was the permeability ratio. Thus it can be concluded that the sweep efficiency, and thus the recovery, is a direct function of this additional energy introduced into the formation. It can also be concluded that this additional energy does not hinder any of the known factors which effect fluid flow through porous media, but actually adds to the overall contribution of the energy mechanism which produced an efficient process.

It is within the scope of this dissertation to make the following hypothesis pertaining to various factors which could ultimately effect this type of sonic flood. These factors should be considered when making a study of its application to various reservoirs.

(1) Increased Gas Saturation - Increased gas saturation at the initiation of sonic flooding may produce the following effects:

(a) Gas bubbles within the pore structure of the formation may cause additional pulsating energy, thus effectively increasing the expulsion of fluids from these pores.

(b) If the gas saturation is too high, the gas bubbles will have a buffering effect upon the collapse of the cavitation bubbles, thus reducing the effect of cavitation within the system.

(c) If the gas saturation is such that in association with cavitation, emulsions are formed, problems would exist with the emulsified effluent. Thus, studies should be conducted along these same lines to determine the ultimate gas saturation to cause maximum transmission of this energy and yet not produce emulsions.

(2) Dissipation of Energy - The dissipation of energy by internal processes within a sandstone is closely related to the attenuation of a mechanical shock wave travelling through the ground. The damping action of this dissipation will influence the width of the resonance peak of a specimen. It is common practice to express this effect by a function "Q". "Q" is related to the fractional loss of energy per cycle $\Delta W/W$ by the formula

$$\frac{\Delta W}{W} = \frac{2\pi}{Q}$$

Experimental results indicate that any energy loss is practically independent of frequency, although there is a suggestion of a slight increase with frequency particularly at the lower frequencies. Sandstones give the greatest value of $\Delta W/W$ of 0.3 where oolitic and Shelly limestones give $\Delta W/W$ values from 0.1 to 0.15.

The attenuation of waves in fluid saturated porous material may be regarded as the sum of the loss caused by fluid motion and the loss caused by the solid framework, i. e. sloshing and jostline losses. The jostling loss may in turn be regarded as composed of two parts, a dry loss of the solid friction type and a viscous loss resulting from the chemical and physical effects of the fluid on the cementing material of the solid and perhaps within cracks of the grains themselves. The fragmentary results in the literature available indicate that when the rock frame is compressed as it would be in situ, the jostling loss is decreased and is substantially independent of fluid content, independent of pressure, and independent of frequency. Consequently, the variation of the sloshing losses with fluid content and frequency may be used to separate the two type of losses. Only in high permeability rocks do the sloshing decrements appear likely to exceed the jostline ones.[148 and 149]

It is rather widely believed, that attenuation in gas containing sands is qualitatively greater than in the same sands when water saturated. The decrement of water wet sandstones partly saturated with water and gas may be greater than the decrement of the same sand saturated with water provided the frequency is very high. This would tend to be true of high porosity, high permeability formations. At low frequencies, partly saturated sands have lower attenuations than fully saturated sands.

Conclusions drawn from several authors indicate that at high frequencies pulse measurements suggest that certain liquids may increase the rigidity of compacted rocks. In some cases, the logarithmic decrement may be lower when the porous media is fully saturated then under the conditions of partial saturation. At practically all frequencies, the effect of compacting pressure on sloshing decrement is smaller and results only from pressure induced changes in porosity, permeability and elastic constants. For low frequency considerations, at partial saturation of a porous body, the logarithmic decrement may increase as the first power of the liquid saturation.

This dissertation indicates that this sonic energy is energy available over and above the other known factors which influence the recovery mechanism of fluids from a porous media. It is suggested that an extension of this theory be conducted on a pilot study to consider the factors investigated in this dissertation in conjunction with the mentioned factors within this chapter.

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER X

The conclusions reached based on this investigation are:

(1) Additional oil can be expected from a sonic flood, the recovery being inversely proportional to the frequencies tested for the fluids in question.

(2) In sonic floods, the initial oil saturation had no noticeable effect upon the overall recovery.

(3) The results indicate a definite decrease in the water-oil ratios for the sonic floods as compared to the straight water floods, indicating either

(a) a more uniform flood front resulting in increased oil recoveries and/or

(b) a more efficient displacement mechanism within the same area invaded.

(4) There is definite reduction in the permeability ratio curves obtained under the influence of ultrasonics. This effect reduces the mobility ratio and thus increases the recovery expected from a sonic flood over a straight water flood.

(5) No appreciable temperature changes were measured in the effluent during the sonic floods, thus there

was effectively no change in the viscosity ratio of the displacing and displaced fluids at the outlet end.

(6) The expected additional recovery with sonic energy shows an increasing tendency of greater recovery values with decreasing values of the viscosity of the displaced fluids.

(7) Although the 1 Mc/sec. sonic flood produced the maximum recovery in all cases, it does not necessarily follow that this is the optimum frequency for maximum recovery. It is recommended that lower frequencies be tested to determine if some lower frequency will yield additional recovery.

(8) Sonic energy increases the injectivity of a displacing fluid into the surrounding formation.

(9) The contribution of cavitation phenomenon resulting from ultrasonic energy is considered one of the greatest energy effects resulting in the additional recovery.

(10) As increasing temperatures increase cavitation, it is recommended that floods be conducted in conjunction with ultrasonic energy considering variations in injection temperatures of the displacing fluids.

(11) It is postulated at this time that should a flood of this type be conducted on a thick formation of varying permeability streaks, a more efficient injection system could be obtained with a focused transducer operating opposite the zone to be invaded, thus producing a

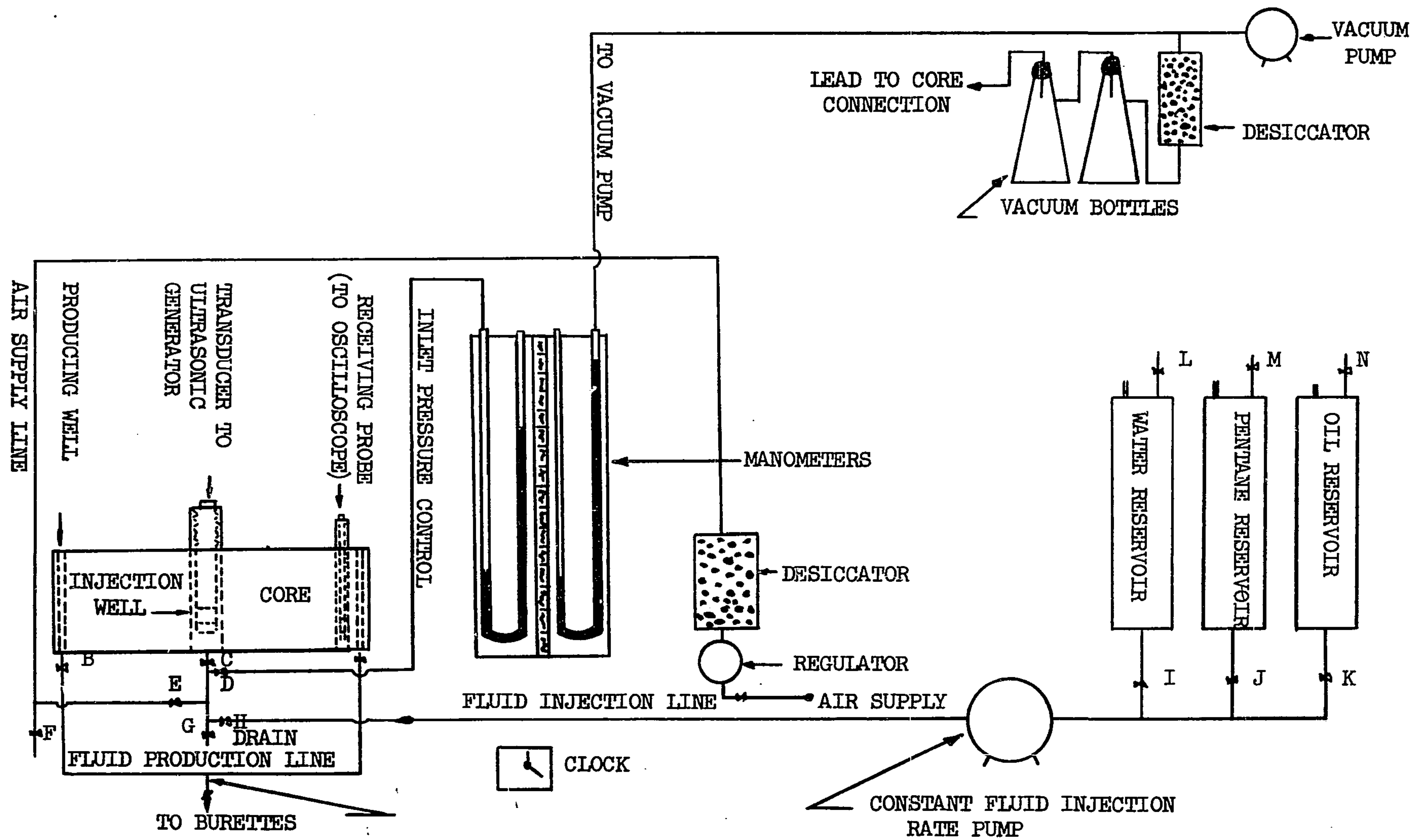
focused driving force to control the injection of the fluids into the zone to be flooded.

(12) The frequency of the emitted wave and that of the wave at the pick-up position within the prototype are the same as indicated from oscilloscopic data.

(13) A well defined continuous wave train was transmitted on the oscilloscope screen indicating that there was no scattering of sound energy in the system.

(14) The amplitude of the produced wave for the 1 Mc/sec. flood decreased from the original value obtained at the initiation of the flood upto breakthrough, and then began to increase thereafter. This indicates that there was absorption occurring within the prototype, however its effect was obviously not enough to hinder the results obtained in the data. The amplitude of the waves produced during the 3.1 Mc/sec. and 5.5 Mc/sec. floods remained essentially constant, with only small deviation in values scattered throughout the data.

APPENDIX



FLOW DIAGRAM

ILLUSTRATION 1

DEFINITIONS

1. Amplitude of Vibration - is the distance that a particle is displaced during the passage of an ultrasonic wave.

2. Wavelength - is the distance between two particles that are at the same point on the wave, i. e., the distance between points of equal phase.

3. Frequency - is the number of vibrations per second.

4. Nodes - are points on the wave where there is no particle motion.

5. Antinodes - are points where there is maximum particle motion.

6. Continuous Wave - is a wave that does not vary in any way during its transmission.

7. Modulated Wave - is a wave that has a continuously changing characteristics.

8. Wave Train - refers to a group of waves that are not followed or preceded by other waves. The individual waves may be identical or different.

9. Attenuation - refers to the loss of energy during the passage of ultrasonic waves.

10. Transducer - is a unit for producing or receiving ultrasonic waves.

11. Wave Motion - can be plotted or viewed by oscilloscopic means. The figure may be very complex, expecially when the particles are being displaced at the same time by more than one wave, very often in different directions.

The following tables represent the data obtained in this study. The run number indicated before each table indicates the exact run as obtained in accumulating the data. Some of the runs were not recorded in this dissertation because of various problems which occurred during the accumulation of data. This will account for the deletion of some of the run numbers and the inconsistency in recording the data pertaining to various runs.

RUN NO. 9

1.	Barametric Pressure = 73.12 cm Hg.	
2.	Vacuum was pulled on the core for 13.25 hours	
3.	Inlet Pressure (Injection) Manometer Readings	= 40.85 cm Hg; 70.9 cm water
4.	Data on Oil:	
(a)	Type of Oil	= core test
(b)	Volume of oil originally in reservoir tank	= 1500.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 22.0 cc
(d)	Volume of oil produced during saturation	= 538.0 cc
(e)	Volume of oil originally in core	= 940.0 cc
5.	Data on Water:	
(a)	Volume of water originally in reservoir tank	= 1000.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 5.0 cc
(c)	Volume of water produced during flooding	= 226.0 cc
(d)	Volume of water produced to clean and drain lines	= 363.6 cc
6.	Original Oil Saturation	= 75.7%
7.	Original Water Saturation	= 0.2%
8.	Original Gas Saturation (Air)	= 17.1%

TABLE: 2 RUN NO. 9

CORE TEST FLUID AND STRAIGHT WATER

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOLUME
	0	0.0	0	0.0	0	0.00	0.00	0.00000
	5	0.0	0	0.0	0	0.00	0.00	0.00000
	10	7.8	-	7.8	-	-	0.83	0.00629
	15	15.8	-	8.0	-	-	1.68	0.01274
	20	33.0	-	17.2	-	-	3.51	0.02580
	25	45.8	-	12.8	-	-	4.87	0.03000
	30	58.0	-	12.2	-	-	6.16	0.04670
	35	71.0	-	13.0	-	-	7.55	0.05720
	40	84.0	-	13.0	-	-	9.93	0.06770
	50	111.8	-	27.8	-	-	11.89	0.09020
	60	139.0	-	27.2	-	-	14.78	0.11200
	70	166.8	-	27.8	-	-	17.72	0.13430
	80	195.0	-	28.2	-	-	20.72	0.15750
	90	223.8	-	28.8	-	-	23.75	0.18050
	100	254.3	-	30.5	-	-	27.08	0.20520
	110	282.5	-	28.2	-	-	30.08	0.22800
	120	312.5	-	30.0	-	-	33.22	0.25200
	130	341.5	-	29.0	-	-	35.28	0.27500
	140	371.0	-	29.5	-	-	39.45	0.29900
	150	402.3	-	31.3	-	-	42.70	0.32400
	160	431.5	-	29.2	-	-	45.90	0.34600
	170	462.0	-	30.5	-	-	48.10	0.37100
BT*	177	481.0	-	19.0	-	-	51.20	0.38700
	180	492.0	-	11.0	-	-	52.20	0.39500
	190	517.0	2	40.0	2	0.05	54.90	0.41600
	200	523.5	43	25.0	41	1.64	55.60	0.45500
	210	529.0	48	5.5	5	0.91	56.20	0.46300
	220	534.0	73	5.0	25	5.00	56.70	0.48700
	230	537.0	100	3.0	27	9.00	57.05	0.51100
	240	538.0	128	1.0	28	28.00	57.25	0.53500
	250	541.0	156	3.0	28	9.33	57.50	0.55500
	260	543.0	188	2.0	28	14.00	57.65	0.58700
	270	545.0	216	2.0	28	14.00	57.90	0.61100
	275	546.4	226	0.4	10	25.00	58.05	0.62000

*BT = BREAKTHROUGH

RUN NO. 17

1. Barametric Pressure = 73.31 cm Hg.

2. Vacuum was pulled on the core for 15.5 hours

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of Oil	= core test
(b)	Volume of oil originally in reservoir tank	= 1428 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 71 cc
(d)	Volume of oil produced during saturation	= 778 cc
(e)	Volume of oiloriginally in core	= 579 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1000 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 102 cc
(c)	Volume of water produced during flooding	= 461 cc
(d)	Volume of water produced to clean and drain lines	= 298 cc

6.	Original Oil Saturation	= 46.6%
7.	Original Water Saturation	= 13.7%
8.	Original Gas Saturation (Air)	= 39.7%

TABLE: 3 RUN NO. 17

CORE TEST FLUID AND STRAIGHT WATER

TIME MIN.	CUM. V_o cc	CUM. V_o cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	K_w/K_o
0	0.0	0	0.0	0	0.00	0.00	0.00000	0.0000
10	16.0	-	16.0	-	-	2.77	0.01285	-
20	30.0	-	14.0	-	-	5.19	0.02410	-
30	45.0	-	15.0	-	-	7.78	0.03620	-
40	60.0	-	15.0	-	-	10.38	0.04820	-
50	74.0	-	14.0	-	-	12.80	0.05950	-
60	87.0	-	13.0	-	-	15.05	0.06980	-
70	101.0	-	14.0	-	-	17.45	0.08120	-
80	114.0	-	13.0	-	-	19.70	0.09610	-
90	126.0	-	12.0	-	-	21.80	0.10100	-
100	139.0	-	13.0	-	-	24.05	0.11180	-
110	152.0	-	13.0	-	-	26.10	0.12210	-
120	164.0	-	12.0	-	-	28.30	0.13180	-
130	175.0	-	11.0	-	-	30.20	0.14080	-
BT 139	183.0	-	8.0	-	-	31.60	0.14710	-
150	193.0	2	10.0	2	0.20	33.40	0.15700	0.1396
160	203.0	4	10.0	2	0.20	35.10	0.16650	0.2792
180	220.0	8	17.0	4	0.24	38.10	0.18350	0.3018
200	235.0	17	15.0	9	0.60	40.50	0.20250	0.7170
220	242.0	31	7.0	14	2.00	41.80	0.21950	2.1000
240	247.0	48	5.0	17	3.40	42.60	0.23700	4.4500
283	253.0	96	6.0	48	8.00	43.70	0.28100	9.9900
300	257.0	120	4.0	24	6.00	44.40	0.30300	14.1700
330	259.0	161	2.0	41	20.50	44.70	0.33800	28.3000
360	263.0	201	4.0	40	10.00	45.50	0.37300	35.3000
390	266.0	238	3.0	37	13.30	46.00	0.40500	44.4000
420	267.0	283	1.0	45	45.00	46.10	0.44200	75.8000
450	269.0	331	2.0	48	24.00	46.50	0.48250	92.4000
480	269.5	379	0.5	48	96.00	46.56	0.52100	158.5000
540	270.5	461	1.0	82	82.00	46.70	0.58900	215.0000

RUN NO. 29

1. Barametric Pressure = 73.7 cm Hg.

2. Vacuum was pulled on the core for 14.85 hours

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of Oil	= Diesel
(b)	Volume of oil originally in reservoir tank	= 1000 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 20 cc
(d)	Volume of oil produced during saturation	= 430 cc
(e)	Volume of oil originally in core	= 550 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1050 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 76 cc
(c)	Volume of water produced during flooding	= 467 cc
(d)	Volume of water produced to clean and drain lines	= 278 cc

6. Original Oil Saturation = 44.4%

7. Original Water Saturation = 26.5%

8. Original Gas Saturation (Air) = 29.1%

TABLE: 4 RUN NO. 29

DIESEL OIL AND STRAIGHT WATER

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	K_w/K_o
0	0.0	0	0.0	0	0.0	0.00	0.0000	0.000
20	29.0	-	29.0	-	-	5.28	0.0233	-
40	40.0	-	11.0	-	-	7.28	0.0321	-
100	65.0	-	25.0	-	-	11.82	0.0522	-
150	85.0	-	10.0	-	-	15.45	0.0683	-
180	97.0	-	12.0	-	-	17.65	0.0780	-
210	112.0	-	15.0	-	-	20.38	0.0901	-
240	123.0	-	11.0	-	-	22.38	0.0990	-
270	137.0	-	14.0	-	-	24.90	0.1100	-
300	150.0	-	13.0	-	-	27.30	0.1208	-
360	175.0	-	25.0	-	-	31.80	0.1406	-
BT 380	181.0	-	6.0	-	-	32.90	0.1455	-
420	196.0	3	15.0	3	0.2	35.60	0.1600	1.045
480	206.0	8	10.0	5	0.5	37.50	0.1722	2.790
552	219.0	15	13.0	7	0.6	39.90	0.1883	5.220
570	223.0	18	4.0	3	0.8	40.60	0.1935	6.260
600	229.0	33	6.0	15	0.3	41.60	0.2108	11.500
630	235.0	41	6.0	8	1.4	42.80	0.2220	14.280
660	237.0	54	2.0	13	6.5	43.20	0.2340	18.800
690	240.0	69	3.0	15	5.0	43.60	0.2480	24.050
720	243.0	89	3.0	20	6.7	44.30	0.2770	31.000
750	248.0	109	5.0	20	4.0	45.10	0.2870	37.900
780	253.0	125	5.0	19	3.8	46.10	0.3040	43.500
810	254.0	135	1.0	10	10.0	46.20	0.3130	47.000
840	254.5	153	0.5	18	36.0	46.30	0.3270	53.300
870	255.0	169	0.5	16	32.0	46.40	0.3410	58.800
900	255.5	187	0.5	18	36.0	46.50	0.3550	65.100
950	260.5	211	5.0	24	4.8	47.40	0.3790	73.500
1013	261.0	247	0.5	36	72.0	47.50	0.4070	86.000
1080	261.2	253	0.2	6	30.0	47.55	0.4130	88.000
1178	268.5	313	7.3	60	8.2	48.80	0.4670	109.000
1320	274.5	385	6.0	72	12.0	49.90	0.5320	135.200
1360	277.5	447	3.0	62	20.7	50.50	0.5820	156.000
1387	278.0	467	2.0	20	10.0	50.60	0.6000	162.500

RUN NO. 20

1. Barametric Pressure = 73.71 cm Hg.

2. Vacuum was pulled on the core for 15.2 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of Oil = SAE 10

   (b) Volume of oil originally in reservoir tank = 1000 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 20 cc

   (d) Volume of oil produced during saturation = 350 cc

   (e) Volume of oil originally in core = 630 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1250 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 51 cc

   (c) Volume of water produced during flooding = 606 cc

   (d) Volume of water produced to clean and drain lines = 292 cc

6. Original Oil Saturation = 50.6%

7. Original Water Saturation = 18.7%

8. Original Gas Saturation (Air) = 30.7%

TABLE: 5 RUN NO. 20

SAE 10 OIL AND STRAIGHT WATER

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	K_w/K_o
	0	0	0.0	0	0.0	0.00	0.00	0.00000	0.00000
	20	9	-	9	-	-	1.43	0.00724	-
	40	22	-	13	-	-	3.41	0.01724	-
	60	35	-	13	-	-	5.56	0.02810	-
	90	55	-	20	-	-	8.74	0.04430	-
BT	102	64	-	9	0.0	-	10.16	0.05150	-
	120	76	0.2	12	0.2	0.02	12.10	0.06120	0.00047
	135	84	2.1	8	1.9	0.24	13.33	0.06920	0.00697
	150	90	4.0	6	1.9	0.30	14.30	0.07550	0.01565
	165	98	5.0	8	1.0	0.13	15.55	0.08200	0.01905
	180	108	8.0	10	3.0	1.00	17.13	0.09320	0.02730
	195	118	10.0	10	2.0	0.20	18.72	0.10290	0.03270
	210	125	13.0	7	3.0	0.40	19.84	0.11100	0.04440
	225	132	18.0	7	5.0	0.70	20.94	0.12064	0.06650
	240	141	21.0	9	3.0	0.30	22.40	0.13020	0.07560
	255	147	27.0	6	6.0	1.00	23.33	0.13980	0.10290
	270	152	32.0	5	5.0	1.00	24.10	0.14790	0.13020
	286	157	39.0	5	7.0	1.40	24.90	0.15750	0.16850
	331	169	62.0	12	23.0	1.90	26.85	0.18580	0.22100
	360	175	79.0	6	17.0	2.80	27.80	0.20400	0.30000
	390	178	96.0	3	17.0	5.70	28.30	0.22000	0.45300
	420	182	118.0	4	22.0	5.50	28.90	0.24100	0.57600
	486	186	174.0	4	56.0	14.00	29.50	0.28900	0.95900
	510	188	194.0	2	20.0	10.00	29.90	0.30700	1.26500
	540	191	222.0	3	28.0	9.30	30.30	0.33200	1.48900
	600	194	282.0	3	60.0	20.00	30.80	0.38300	2.33000
	720	197	343.0	3	61.0	20.30	31.30	0.43400	2.59000
	775	200	398.0	3	55.0	18.30	31.70	0.48100	3.09000
	848	208	606.0	8	208.0	26.10	33.03	0.65400	3.80000

RUN NO. 11

1. Barametric Pressure = 73.69

2. Vacuum was pulled on the core for 18 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of Oil = Core Test

   (b) Volume of oil originally in reservoir tank = 1500 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 17 cc

   (d) Volume of oil produced during saturation = 314.5 cc

   (e) Volume of oil originally in core = 1168.5 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1500 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 49 cc

   (c) Volume of water produced during flooding = 604.2 cc

   (d) Volume of water produced to clean and drain lines = 418 cc

6. Original Oil Saturation = 93.8%

7. Original Water Saturation = -

8. Original Gas Saturation (Air) = 5.2%

TABLE: 6 RUN NO. 11

CORE TEST FLUID AND 1 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOLUME
0	0.0	0.0	0.0	0	0.0000	0.00	0.0000
10	31.0	-	31.0	-	-	2.66	0.0249
20	72.0	-	41.0	-	-	6.18	0.0578
30	116.0	-	44.0	-	-	9.95	0.0933
40	160.0	-	44.0	-	-	13.72	0.1285
50	202.3	-	42.3	-	-	17.32	0.1622
60	248.5	-	46.2	-	-	21.30	0.2000
70	297.5	-	49.0	-	-	25.45	0.2385
80	347.0	-	50.0	-	-	29.70	0.2785
90	396.5	-	49.5	-	-	33.90	0.3185
100	446.0	-	49.5	-	-	38.30	0.3582
105	471.3	-	25.3	-	-	40.30	0.3784
110	497.3	-	26.0	-	-	42.60	0.3835
115	522.1	-	24.8	-	-	44.70	0.4195
120	546.3	-	25.2	-	-	46.70	0.4380
125	571.0	-	24.7	-	-	48.80	0.4575
130	596.0	-	25.0	-	-	51.10	0.4780
135	646.0	-	50.0	-	-	55.30	0.5190
140	669.1	-	23.1	-	-	57.20	0.5370
BT 142	678.8	-	9.7	-	-	58.10	0.5450
145	690.8	0.1	12.0	0.1	0.0083	59.10	0.5540
150	704.3	1.0	13.5	0.9	0.0666	60.30	0.5660
160	718.1	5.0	13.8	4.0	0.2900	61.50	0.5810
170	736.1	30.0	18.0	25.0	1.3900	63.10	0.6150
180	742.1	72.0	6.0	42.0	7.0000	63.50	0.6540
195	745.3	150.0	3.2	82.0	25.6200	63.80	0.7190
210	750.3	226.0	5.0	76.0	15.2000	64.20	0.7840
240	757.3	380.0	7.0	154.0	22.0000	64.80	0.9130
270	763.9	550.2	5.6	170.2	30.3500	65.40	1.0550
280	765.9	640.2	2.0	90.0	45.0000	65.70	1.1300

TABLE: 6 cont. RUN NO. 11

CORE TEST FLUID AND 1 MC/SEC. FLOOD

TIME	TEMP. OF PROD. FLUID	VOLTAGE DISPLAYED	VOLTAGE VOLTS	TIME $(10)^{-6}$ DISPLAYED	TIME $(10)^{-6}$ TIME	FREQUENCY (MC) DISPLAYED	FREQUENCY (MC) FREQ.
0	84.0	2.35	0.0235	1.7	17	9.8	0.98
10	"	"	"	"	"	"	"
20	"	"	"	"	"	"	"
30	"	"	"	"	"	"	"
40	"	"	"	"	"	"	"
50	"	3.20	0.0320	"	"	"	"
60	"	3.40	0.0340	"	"	"	"
70	"	"	"	"	"	"	"
80	84.8	3.70	0.0370	"	"	"	"
90	"	"	"	"	"	"	"
100	"	"	"	"	"	"	"
105	"	"	"	"	"	"	"
110	86.0	"	"	"	"	"	"
115	"	"	"	"	"	"	"
120	"	"	"	"	"	"	"
125	"	4.20	0.0420	"	"	"	"
130	"	"	"	"	"	"	"
135	"	"	"	"	"	"	"
140	"	"	"	"	"	"	"
BT 142	"	"	"	"	"	"	"
145	87.0	"	"	"	"	"	"
150	"	"	"	"	"	"	"
160	"	"	"	"	"	"	"
170	"	"	"	"	"	"	"
180	"	"	"	"	"	"	"
195	"	"	"	"	"	"	"
210	88.0	4.60	0.0460	"	"	"	"
240	"	"	"	"	"	"	"
270	"	"	"	"	"	"	"
280	"	"	"	"	"	"	"

RUN NO. 22

1. Barametric Pressure = 73.37 cm Hg.

2. Vacuum was pulled on the core for 16.75 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of Oil	= Core Test
(b)	Volume of oil originally in reservoir tank	= 1250.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 18.5 cc
(d)	Volume of oil produced during saturation	= 614.0 cc
(e)	Volume of oil originally in core	= 636.0 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1200.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 94.0 cc
(c)	Volume of water produced during flooding	= 379.0 cc
(d)	Volume of water produced to clean and drain lines	= 164.0 cc

6. Original Oil Saturation = 51.5%

7. Original Water Saturation = 24.8%

8. Original Gas Saturation (Air) = 23.7%

TABLE: 7 RUN NO. 22

CORE TEST FLUID AND 1 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
0	0	0	0	0	0.00	0.00	0.0000	80.0
20	20	-	30	-	-	4.72	0.0241	"
30	53	-	23	-	-	8.34	0.0426	"
40	78	-	25	-	-	12.27	0.0626	"
45	89	-	11-	-	-	13.98	0.0715	"
50	101	-	12	-	-	15.90	0.0813	"
55	112	-	11	-	-	17.64	0.0900	90.5
60	124	-	12-	-	-	19.52	0.0997	"
70	146	-	22	-	-	22.95	0.1171	"
80	168	-	22	-	-	26.40	0.1352	"
90	190	-	22	-	-	29.90	0.1530	"
100	212	-	22	-	-	33.35	0.1705	81.5
110	234	-	22	-	-	36.80	0.1880	"
120	258	-	24	-	-	40.60	0.2070	82.0
130	277	-	19	-	-	43.60	0.2230	82.5
BT 135	286	-	9	-	-	45.00	0.2300	83.0
140	294	1	8	1	0.13	46.30	0.2370	"
150	309	6	15	5	0.33	48.60	0.2530	83.3
160	322	12	13	6	0.46	50.70	0.2680	"
170	334	21	12	9	0.75	52.50	0.2850	"
180	341	30	7	9	1.29	53.60	0.2980	83.7
190	346	44	5	14	2.80	54.40	0.3120	"
200	351	58	5	14	2.80	55.20	0.3290	84.0
210	353	76	2	18	9.00	55.50	0.3450	"
220	359	96	6	20	3.34	56.50	0.3650	"
230	362	105	3	9	3.00	57.00	0.3750	"
265	372	190	10	85	8.50	58.50	0.4510	85.5
300	377	258	5	78	15.60	59.30	0.5180	85.8
330	386	340	9	72	8.00	60.70	0.5840	86.0
345	390	379	4	89	22.25	61.40	0.6170	"

TABLE: 7 cont. RUN NO. 22

CORE TEST FLUID AND 1 MC/SEC. FLOOD

TIME	VOLTAGE		$TIME(10)^{-6}$		$(10)^{-6}$ FREQUENCY (MC)	
MIN.	DISPLAYED	VOLTS	DISPLAYED	TIME	DISPLAYED	FREQ.
0	2.60	0.520	1.09	1.09	9.5	0.95
20	2.20	0.440	"	"	"	"
30	"	"	"	"	"	"
40	"	"	"	"	"	"
45	"	"	"	"	"	"
50	2.10	0.420	"	"	"	"
55	"	"	"	"	"	"
60	"	"	"	"	"	"
70	"	"	"	"	"	"
80	"	"	"	"	"	"
90	"	"	"	"	"	"
100	"	"	"	"	"	"
110	"	"	"	"	"	"
120	"	"	"	"	"	"
130	"	"	"	"	"	"
BT 135	2.15	0.430	"	"	"	"
140	"	"	"	"	"	"
150	2.20	0.440	"	"	"	"
160	"	"	"	"	"	"
170	"	"	"	"	"	"
180	"	"	"	"	"	"
190	"	"	"	"	"	"
200	2.23	0.446	"	"	"	"
210	2.30	0.460	"	"	"	"
230	"	"	"	"	"	"
265	2.35	0.470	"	"	"	"
300	"	"	"	"	"	"
330	2.40	0.480	"	"	"	"
345	2.50	0.500	"	"	"	"

RUN NO. 12

1. Barametric Pressure = 73.63 cm Hg.

2. Vacuum was pulled on the core for 13.2 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of Oil	= Diesel
(b)	Volume of oil originally in reservoir tank	= 1500.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 3.5 cc
(d)	Volume of oil produced during saturation	= 626.0 cc
(e)	Volume of oil originally in core	= 870.5 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1250.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 89.0 cc
(c)	Volume of water produced during flooding	= 32.0 cc
(d)	Volume of water produced to clean and drain lines	= 487.0 cc

6. Original Oil Saturation = 69.8%

7. Original Water Saturation = 7.3%

8. Original Gas Saturation (Air) = 22.9%

TABLE: 8 RUN NO. 12

DIESEL AND 1 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
0	0.0	0.0	0.0	0.0	0.00	00.00	0.0000	88.0
20	107.5	-	107.5	-	-	12.35	0.0865	"
30	144.0	-	36.5	-	-	16.56	0.1158	88.5
40	173.0	-	29.0	-	-	19.90	0.1390	"
50	199.6	-	26.5	-	-	22.94	0.1605	"
60	223.0	-	23.4	-	-	25.65	0.1795	"
70	247.0	-	24.0	-	-	28.42	0.1986	"
80	268.5	-	21.5	-	-	30.90	0.2160	"
90	290.0	-	21.5	-	-	33.40	0.2330	"
100	311.0	-	21.0	-	-	35.80	0.2500	89.2
110	333.0	-	22.0	-	-	38.30	0.2670	"
120	354.0	-	21.0	-	-	40.70	0.2840	"
BT 124	363.0	-	9.0	-	-	41.80	0.2910	"
130	372.0	6.0	9.0	6.0	0.67	42.70	0.3040	"
140	391.5	7.5	19.5	1.5	0.08	44.90	0.3200	"
150	407.0	14.0	15.5	6.5	0.42	46.70	0.3380	90.0
160	427.0	20.0	20.0	6.0	0.30	49.10	0.3590	"
170	444.0	26.0	17.0	6.0	0.35	51.00	0.3770	"
180	458.0	34.0	14.0	8.0	0.57	52.60	0.3950	"
190	470.0	44.0	12.0	10.0	0.83	54.00	0.4130	"
200	482.0	55.5	12.0	11.5	0.96	55.30	0.4400	90.7
210	492.0	68.0	10.0	12.5	1.25	56.50	0.4500	"
220	499.0	82.0	7.0	14.0	2.00	57.40	0.4670	"
230	504.0	101.0	5.0	19.0	3.81	57.90	0.4860	"
240	507.0	121.0	3.0	20.0	6.66	58.30	0.5040	"
250	509.3	141.2	2.3	20.2	8.78	58.50	0.5220	91.2
270	514.7	184.8	4.4	43.6	9.93	59.10	0.5610	"
300	519.3	215.2	4.6	30.4	6.62	59.70	0.5890	92.0
330	522.3	323.5	3.0	108.0	36.00	60.10	0.6770	"
345	523.3	359.2	1.0	36.0	36.00	60.20	0.7070	92.8

TABLE: 8 cont.　　　RUN NO. 12

DIESEL AND 1 MC/SEC. FLOOD

TIME MIN.	VOLTAGE DISPLAYED	VOLTS	TIME DISPLAYED	TIME	$(10)^{-6}$ FREQUENCY (MC) DISPLAYED	FREQ.	K_w/K_o
0	2.50	0.0250	0.95	0.95	10.25	1.025	-
20	"	"	"	"	"	"	"
30	2.60	0.0260	"	"	"	"	"
40	2.50	0.0250	"	"	"	"	"
50	1.85	0.0185	"	"	"	"	"
60	"	"	"	"	"	"	"
70	1.80	0.0180	"	"	"	"	"
80	"	"	"	"	"	"	"
90	"	"	"	"	"	"	"
100	"	"	"	"	"	"	"
110	1.50	0.0150	"	"	"	"	"
120	"	"	"	"	"	"	"
BT 124	"	"	"	"	"	"	"
130	1.40	0.0140	"	"	"	"	0.232
140	1.50	0.0150	"	"	"	"	0.259
150	1.60	0.0160	"	"	"	"	0.404
160	1.50	0.0150	"	"	"	"	0.509
170	1.90	0.0190	"	"	"	"	0.632
180	2.00	0.0200	"	"	"	"	0.820
190	2.20	0.0220	"	"	"	"	1.120
200	2.00	0.0200	"	"	"	"	1.453
210	"	"	"	"	"	"	1.890
220	1.70	0.0170	"	"	"	"	2.580
230	1.60	0.0160	"	"	"	"	3.910
240	1.70	0.0170	"	"	"	"	6.230
250	1.90	0.0190	"	"	"	"	9.270
270	"	"	"	"	"	"	12.390
300	1.80	0.0180	"	"	"	"	15.050
330	4.20	0.0420	"	"	"	"	27.600
345	3.50	0.0350	"	"	"	"	40.100

RUN NO. 13

1. Barametric Pressure = 73.17 cm Hg.

2. Vacuum was pulled on the core for 16 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil

(a)	Type of oil	= SAE 10
(b)	Volume of oil originally in reservoir tank	= 1500.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 10.0 cc
(d)	Volume of oil produced during saturation	= 709.3 cc
(e)	Volume of oil originally in core	= 780.7 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1250.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 60.0 cc
(c)	Volume of water produced during flooding	= 451.0 cc
(d)	Volume of water produced to clean and drain lines	= 392.0 cc

6. Original Oil Saturation = 62.7%

7. Original Water Saturation = 23.7%

8. Original Gas Saturation (Air) = 13.6%

TABLE: 9 RUN NO. 13

SAE 10 OIL AND 1 MC/SEC. FLOOD

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
	0	0.0	0.0	0.0	0.0	0.0	0.00	0.0000	80.0
	20	26.0	-	26.0	-	-	3.34	0.0209	"
	40	63.0	-	37.0	-	-	8.07	0.0506	"
	60	98.0	-	35.0	-	-	12.58	0.0783	80.5
BT	73	121.0	-	23.0	-	-	15.50	0.0973	"
	80	130.0	4.0	9.0	4.0	0.45	16.68	0.1078	"
	90	145.0	7.0	15.0	3.0	0.20	18.60	0.1220	81.0
	100	160.0	10.0	15.0	3.0	0.20	20.50	0.1365	"
	110	172.0	16.0	12.0	6.0	0.50	22.10	0.1512	82.0
	120	186.0	22.0	14.0	6.0	0.43	23.90	0.1672	"
	130	196.0	29.0	10.0	7.0	0.70	25.10	0.1810	"
	140	210.0	35.0	14.0	6.0	0.43	27.90	0.1970	"
	150	220.0	41.0	10.0	6.0	0.60	28.20	0.2197	"
	160	230.5	46.5	10.5	5.5	0.52	29.60	0.2225	"
	180	249.0	63.0	18.5	16.5	0.88	31.90	0.2550	"
	200	259.0	78.0	10.0	15.0	1.50	33.30	0.2710	83.0
	220	272.0	99.0	13.0	21.0	1.61	34.90	0.2985	"
	240	278.0	127.0	6.0	28.0	4.67	35.70	0.3260	"
	260	282.0	161.0	4.0	34.0	8.50	36.20	0.3560	83.5
	300	294.0	229.0	12.0	68.0	5.66	37.70	0.4210	84.0
	360	305.0	341.0	11.0	112.0	10.18	39.20	0.5190	"
	410	316.0	451.0	11.0	110.0	10.00	40.50	0.6170	"

TABLE: 9 cont.

RUN NO. 13

SAE 10 OIL AND 1 MC/SEC. FLOOD

	TIME	VOLTAGE		TIME$(10)^{-6}$		FREQUENCY(MC)		K_w/K_o
	MIN.	DISPLAYED	VOLTS	DISPLAYED	TIME	DISPLAYED	FREQ.	
	0	2.10	0.042	1.0	$(10)^{-6}$	10.47	1.047	-
	20	"	"	"	"	"	"	"
	40	1.90	0.038	"	"	"	"	"
	60	1.20	0.024	"	"	"	"	"
BT	73	1.10	0.022	"	"	"	"	"
	80	"	"	"	"	"	"	0.01218
	90	0.90	0.018	"	"	"	"	0.01765
	100	1.25	0.025	"	"	"	"	0.02310
	110	"	"	"	"	"	"	0.03680
	120	1.35	0.027	"	"	"	"	0.04680
	130	1.20	0.024	"	"	"	"	0.06760
	140	"	"	"	"	"	"	0.07930
	150	"	"	"	"	"	"	0.09570
	160	"	"	"	"	"	"	0.11000
	180	1.25	0.025	"	"	"	"	0.13400
	200	1.00	0.020	"	"	"	"	0.17500
	220	"	"	"	"	"	"	0.21900
	240	"	"	"	"	"	"	0.34600
	260	"	"	"	"	"	"	0.57800
	300	0.95	0.019	"	"	"	"	0.73500
	360	1.10	0.022	"	"	"	"	1.01200
	410	2.00	0.040	"	"	"	"	1.28500

RUN NO. 19

1. Barametric Pressure = 73.24 cm Hg.

2. Vacuum was pulled on the core for 15 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm hg; 70.9 cm water

4. Data on Oil:

(a)	Type of Oil	= Core Test
(b)	Volume of oil originally in reservoir tank	= 1500.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 21.0 cc
(d)	Volume of oil produced during saturation	= 829.0 cc
(e)	Volume of oil originally in core	= 650.0 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1099.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 56.5 cc
(c)	Volume of water produced during flooding	= 431.0 cc
(d)	Volume of water produced to clean and drain lines	= 301.0 cc

6. Original Oil Saturation = 52.2%

7. Original Water Saturation = 20.5%

8. Original Gas Saturation (Air) = 27.3%

TABLE: 10 RUN NO. 19

CORE TEST FLUID AND 3.1 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
0	0.0	0.0	0.0	0.0	0.000	0.00	0.0000	84.0
10	13.0	-	13.0	-	-	2.00	0.0105	"
20	33.0	-	20.0	-	-	5.07	0.0265	84.5
30	52.0	-	19.0	-	-	8.01	0.0417	"
40	73.0	-	21.0	-	-	11.24	0.0586	85.2
50	96.0	-	23.0	-	-	14.78	0.0772	"
60	113.0	-	17.0	-	-	17.40	0.0911	"
65	122.0	-	9.0	-	-	18.80	0.0981	86.0
71	132.0	-	10.0	-	-	20.30	0.1061	"
75	140.0	-	8.0	-	-	21.58	0.1125	"
80	150.0	-	10.0	-	-	23.10	0.1205	"
85	159.0	-	9.0	-	-	24.50	0.1279	"
90	168.0	-	9.0	-	-	25.85	0.1350	"
95	177.0	-	9.0	-	-	27.30	0.1422	86.2
100	186.0	-	9.0	-	-	28.60	0.1495	"
105	195.0	-	9.0	-	-	30.10	0.1568	"
110	204.0	-	9.0	-	-	31.40	0.1640	"
115	212.0	-	8.0	-	-	32.70	0.1703	"
BT 119	219.0	-	7.0	-	-	33.70	0.1760	86.4
125	227.0	0.2	8.0	0.2	0.025	34.90	0.1830	"
140	251.0	2.0	24.0	1.8	0.075	38.60	0.2030	"
150	265.0	6.0	14.0	4.0	0.285	40.80	0.2170	87.0
165	280.0	17.0	15.0	11.0	0.734	43.20	0.2390	88.0
180	294.0	30.0	14.0	13.0	0.926	45.20	0.2660	"
200	307.0	52.0	13.0	22.0	1.695	47.20	0.2885	"
240	319.0	112.0	12.0	60.0	5.000	49.10	0.3470	"
270	329.0	164.0	10.0	52.0	5.200	50.70	0.3950	89.0
300	334.0	223.0	5.0	69.0	13.800	51.40	0.4470	"
390	349.5	409.0	15.5	136.0	12.100	53.75	0.6100	"
400	350.0	431.0	0.5	22.0	44.000	53.90	0.6280	88.5

TABLE: 10 cont. RUN NO. 19

CORE TEST FLUID AND 3.1 MC/SEC. FLOOD

TIME MIN.	VOLTAGE DISPLAYED	VOLTS	TIME$(10)^{-7}$ DISPLAYED	TIME	FREQUENCY(MC) DISPLAYED	FREQ.	K_w/K_o
0	1.2	0.06	1.5	3.0	6.95	3.475	0
10	"	"	"	"	"	"	"
20	"	"	"	"	"	"	"
30	"	"	"	"	"	"	"
40	"	"	"	"	"	"	"
50	"	"	"	"	"	"	"
60	"	"	"	"	"	"	"
65	"	"	"	"	"	"	"
71	"	"	"	"	"	"	"
75	"	"	"	"	"	"	"
80	"	"	"	"	"	"	"
85	"	"	"	"	"	"	"
90	"	"	"	"	"	"	"
95	"	"	"	"	"	"	"
100	"	"	"	"	"	"	"
105	"	"	"	"	"	"	"
110	"	"	"	"	"	"	"
115	"	"	"	"	"	"	"
BT 119	"	"	"	"	"	"	"
125	"	"	"	"	"	"	0.01732
140	"	"	"	"	"	"	0.06930
150	"	"	"	"	"	"	0.26700
165	"	"	"	"	"	"	0.77400
180	"	"	"	"	"	"	1.41900
200	"	"	"	"	"	"	2.59500
240	"	"	"	"	"	"	6.05000
270	"	"	"	"	"	"	9.66000
300	"	"	"	"	"	"	19.20000
390	"	"	"	"	"	"	27.62000
400	"	"	"	"	"	"	58.10000

RUN NO. 6

1. Barametric Pressure = 73.31 cm Hg.

2. Vacuum was pulled on the core for 14.75 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of Oil = Diesel

   (b) Volume of oil originally in reservoir tank = 1500.0 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 16.9 cc

   (d) Volume of oil produced during saturation = 665.7 cc

   (e) Volume of oil originally in core = 817.4 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1000.0 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 86.0 cc

   (c) Volume of water produced during flooding = 458.4 cc

   (d) Volume of water produced to clean and drain lines = 324.5 cc

6. Original Oil Saturation = 65.4%

7. Original Water Saturation = 19.8%

8. Original Gas Saturation (Air) = 14.8%

TABLE: 11 RUN NO. 6

DIESEL AND 3.1 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.
0	0.0	0.0	0.0	0.0	0.00	0.00	0.0000
5	29.0	-	29.0	-	-	3.56	0.0233
20	67.0	-	38.0	-	-	8.22	0.0538
25	75.0	-	8.0	-	-	9.18	0.0603
30	82.8	-	7.8	-	-	10.13	0.0656
35	127.0	-	44.2	-	-	15.15	0.1021
45	129.0	-	2.0	-	-	18.18	0.1038
50	144.0	-	15.0	-	-	18.64	0.1158
60	149.0	-	5.0	-	-	19.25	0.1198
70	160.5	-	11.5	-	-	19.65	0.1292
80	185.0	-	15.5	-	-	22.18	0.1455
90	206.0	-	21.0	-	-	25.22	0.1655
100	243.0	-	37.0	-	-	29.80	0.1955
110	278.0	-	35.0	-	-	34.05	0.2238
120	313.0	-	35.0	-	-	38.30	0.2520
130	349.0	-	36.0	-	-	42.75	0.2808
140	386.0	-	37.0	-	-	47.30	0.3108
150	415.0	-	29.0	-	-	50.80	0.3340
BT 152	420.0	-	5.0	-	-	51.50	0.3380
170	444.0	40.0	24.0	40.0	1.67	54.40	0.3890
180	449.8	74.0	5.8	34.0	5.86	55.10	0.4210
190	451.5	83.7	1.7	9.7	5.67	55.20	0.4310
200	453.4	119.0	0.9	35.3	39.30	55.40	0.4590
230	454.8	210.8	2.4	91.8	38.30	55.60	0.5350
234	458.4	313.0	3.6	2.2	0.61	56.20	0.6200

RUN NO. 14

1. Barametric Pressure = 73.59 cm Hg.

2. Vacuum was pulled on the core for 16 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of Oil = Diesel

   (b) Volume of oil originally in reservoir tank = 1500.0 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 43.5 cc

   (d) Volume of oil produced during saturation = 750.0 cc

   (e) Volume of oil originally in core = 706.5 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1000.0 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 78.0 cc

   (c) Volume of water produced during flooding = 374.0 cc

   (d) Volume of water produced to clean and drain lines = 488.0 cc

6. Original Oil Saturation = 56.8%

7. Original Water Saturation = 12.5%

8. Original Gas Saturation (Air) = 30.7%

TABLE: 12 RUN NO. 14

DIESEL AND 3.1 MC/SEC. FLOOD

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
	0	0	0	0	0	0.000	0.00	0.00000	87.0
	10	10	-	10	-	-	1.46	0.00082	"
	20	45	-	35	-	-	6.39	0.00362	"
	30	72	-	27	-	-	10.72	0.05780	"
	40	89	-	17	-	-	12.60	0.07150	"
	50	104	-	15	-	-	14.72	0.08350	"
	60	116	-	12	-	-	16.45	0.09310	"
	70	128	-	12	-	-	18.15	0.10300	88.0
	80	141	-	13	-	-	19.97	0.45400	"
	102	170	-	29	-	-	24.10	0.13650	"
	120	196	-	26	-	-	27.80	0.15750	"
	140	224	-	28	-	-	31.70	0.18000	89.0
BT	147	235	-	11	-	-	33.30	0.18900	"
	160	256	1	21	1	0.048	36.30	0.20600	90.0
	180	280	7	24	6	0.250	39.70	0.23050	"
	200	303	16	23	9	0.391	42.90	0.25600	"
	220	319	30	16	14	0.876	45.20	0.28100	"
	240	336	48	17	18	1.060	47.60	0.30800	"
	260	350	63	14	15	1.070	49.60	0.33200	90.7
	280	358	80	8	17	2.130	50.70	0.35200	"
	300	365	94	7	14	2.000	51.70	0.36900	91.3
	330	374	138	9	44	4.890	53.00	0.41100	"
	360	382	191	8	53	6.630	54.10	0.46100	92.0
	390	389	256	7	65	9.290	55.10	0.51800	"
	450	399	374	10	113	11.800	56.60	0.62200	"

TABLE: 12 cont. RUN NO. 14

DIESEL AND 3.1 MC/SEC. FLOOD

TIME MIN.	VOLTAGE DISPLAYED	VOLTS	TIME$(10)^{-7}$ DISPLAYED	TIME	FREQUENCY(MC) DISPLAYED	FREQ.	K_w/K_o
0	3.5	0.035	1.58	3.16	6.65	3.325	-
10	"	"	"	"	"	"	"
20	"	"	"	"	"	"	"
30	"	"	"	"	"	"	"
40	3.4	0.034	"	"	"	"	"
50	"	"	"	"	"	"	"
60	"	"	"	"	"	"	"
70	"	"	"	"	"	"	"
80	"	"	"	"	"	"	"
102	"	"	"	"	"	"	"
120	"	"	"	"	"	"	"
140	"	"	"	"	"	"	"
BT 147	"	"	"	"	"	"	"
160	"	"	"	"	"	"	0.0167
180	"	"	"	"	"	"	0.1037
200	"	"	"	"	"	"	0.2395
220	"	"	"	"	"	"	0.5440
240	"	"	"	"	"	"	0.6010
260	"	"	"	"	"	"	0.6240
280	"	"	"	"	"	"	1.3620
300	"	"	"	"	"	"	2.0600
330	"	"	"	"	"	"	3.7600
360	"	"	"	"	"	"	6.0600
390	"	"	"	"	"	"	9.3000
450	"	"	"	"	"	"	13.4000

RUN NO. 18

1. Barametric Pressure = 73.5 cm Hg.

2. Vacuum was pulled on the core for 13.5 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of oil = Diesel

   (b) Volume of oil originally in reservoir tank = 1400.0 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 21.5 cc

   (d) Volume of oil produced during saturation = 621.0 cc

   (e) Volume of oil originally in core = 757.5 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1090.0 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 145.0 cc

   (c) Volume of water produced during flooding = 385.0 cc

   (d) Volume of water produced to clean and drain lines = 366.0 cc

6. Original Oil Saturation = 60.9%

7. Original Water Saturation = 15.1%

8. Original Gas Saturation (Air) = 24.0%

TABLE: 13 RUN NO. 18

DIESEL AND 3.1 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
0	0	0	0	0	0.00	0.00	0.0000	84.0
10	15	-	15	-	-	1.99	0.0121	"
20	30	-	15	-	-	3.97	0.0241	85.3
30	48	-	18	-	-	6.35	0.0386	"
45	79	-	29	-	-	10.45	0.0635	86.0
60	109	-	30	-	-	14.42	0.0876	86.2
70	131	-	22	-	-	17.35	0.1052	"
80	154	-	23	-	-	20.40	0.1240	"
90	177	-	23	-	-	23.42	0.1425	87.8
100	201	-	24	-	-	26.60	0.1617	"
110	224	-	23	-	-	29.70	0.1802	89.0
120	248	-	24	-	-	32.80	0.1995	"
130	272	-	24	-	-	36.10	0.2180	"
140	294	-	28	-	-	38.90	0.2360	"
150	318	-	24	-	-	42.10	0.2560	"
160	335	-	18	-	-	44.50	0.2700	89.5
BT 162	343	-	7	-	-	45.40	0.2750	"
170	353	2	10	2	0.20	46.70	0.2850	"
180	371	6	17	4	0.24	49.10	0.3030	"
200	396	25	25	19	0.76	52.50	0.3390	90.0
220	414	51	18	26	1.44	54.80	0.3740	"
240	419	92	5	41	8.20	55.50	0.4110	"
300	425	165	6	73	12.15	56.20	0.4740	"
357	429	237	4	72	18.00	56.80	0.5350	"
390	435	325	6	88	14.67	57.50	0.6100	"
410	442	385	7	60	8.58	58.50	0.6650	"

TABLE: 13 cont. RUN NO. 18

DIESEL AND 3.1 MC/SEC. FLOOD

TIME	VOLTAGE		$TIME(10)^{-7}$		FREQUENCY (MC)	
MIN.	DISPLAYED	VOLTS	DISPLAYED	TIME	DISPLAYED	FREQ.
0	2.100	0.0420	1.5	3	6.85	3.425
10	2.400	0.0480	"	"	"	"
20	2.950	0.0590	"	"	"	"
30	3.250	0.0650	"	"	"	"
45	3.500	0.0700	"	"	"	"
60	3.625	0.0725	"	"	"	"
70	"	"	"	"	"	"
80	"	"	"	"	"	"
90	"	"	"	"	"	"
100	"	"	"	"	"	"
110	"	"	"	"	"	"
120	"	"	"	"	"	"
130	3.750	0.0750	"	"	"	"
140	"	"	"	"	"	"
150	"	"	"	"	"	"
160	"	"	"	"	"	"
BT 162	"	"	"	"	"	"
170	"	"	"	"	"	"
180	"	"	"	"	"	"
200	"	"	"	"	"	"
220	3.875	0.0775	"	"	"	"
240	4.000	0.0800	"	"	"	"
300	4.125	0.0825	"	"	"	"
357	"	"	"	"	"	"
390	"	"	"	"	"	"
410	"	"	"	"	"	"

RUN NO. 27

1. Barametric Pressure = 73.17 cm Hg.

2. Vacuum was pulled on the core for 16.75 hours.

3. Inlet Pressure (Injection)
   Manometer Readings = 40.75 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of oil	= SAE 10
(b)	Volume of oil originally in reservoir tank	= 1000.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 17.0 cc
(d)	Volume of oil produced during saturation	= 281.0 cc
(e)	Volume of oil originally in core	= 719.0 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1000.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 86.0 cc
(c)	Volume of water produced during flooding	= 524.0 cc
(d)	Volume of water produced to clean and drain lines	= 331.5 cc

6. Original Oil Saturation = 57.8%

7. Original Water Saturation = 17.4%

8. Original Gas Saturation (Air) = 24.8%

TABLE: 14 RUN NO. 27

SAE 10 OIL AND 3.1 MC/SEC. FLOOD

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
	0	0	0	0	0	0.0000	0.00	0.0000	80.0
	10	20	-	20	-	-	2.79	0.0161	"
	20	23	-	3	-	-	3.20	0.0185	"
	30	28	-	5	-	-	3.90	0.0225	81.5
	60	56	-	28	-	-	7.80	0.0451	82.2
	75	72	-	16	-	-	10.05	0.0578	82.4
	90	89	-	17	-	-	12.40	0.0715	"
BT	107	109	-	20	-	-	15.15	0.0876	83.0
	120	121	1	12	1	0.0834	16.85	0.0980	83.5
	140	140	5	19	4	0.2110	19.50	0.1165	84.0
	160	159	10	19	5	0.2630	22.10	0.1358	"
	180	176	17	17	7	0.4120	24.50	0.1550	"
	214	199	33	23	16	0.6970	27.70	0.1865	84.5
	225	203	42	4	9	2.2500	28.30	0.1968	85.0
	240	211	55	8	13	1.6270	29.40	0.2130	85.3
	255	219	69	8	14	1.7500	30.50	0.2320	"
	270	223	88	4	19	9.7500	31.10	0.2500	85.5
	285	228	107	5	19	3.8000	31.80	0.2690	"
	330	239	167	11	60	5.4500	33.30	0.3260	86.0
	354	241	189	2	22	11.0000	33.60	0.3460	"
	360	246	210	5	21	4.2000	34.30	0.3670	86.2
	375	248	233	2	23	11.5000	34.50	0.3860	"
	390	249	259	1	26	26.0000	34.70	0.4080	87.0
	405	252	283	3	24	8.0000	35.10	0.4300	"
	420	256	307	4	24	6.0000	35.60	0.4520	"
	465	263	388	7	81	11.5700	36.60	0.5230	86.4
	482	265	418	2	30	15.0000	36.90	0.5480	"
	495	268	440	3	22	7.6700	37.30	0.5680	"
	525	275	495	7	55	7.8500	38.30	0.6180	86.2
	533	277	524	2	39	19.5000	38.60	0.6430	"

RUN NO. 25

1. Barametric Pressure = 73.48 cm Hg.

2. Vacuum was pulled on the core for 14.75 hours.

3. Inlet pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of oil = Core Test

   (b) Volume of oil originally in reservoir tank = 1250.0 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 15.5 cc

   (d) Volume of oil produced during saturation = 617.0 cc

   (e) Volume of oil originally in core = 617.5 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1000.0 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 46.0 cc

   (c) Volume of water produced during flooding = 481.0 cc

   (d) Volume of water produced to clean and drain lines = 400.0 cc

6. Original Oil Saturation = 49.6%

7. Original Water Saturation = 21.2%

8. Original Gas Saturation (Air) = 29.2%

TABLE: 15 RUN NO. 25

CORE TEST FLUID AND 5.5 MC/SEC. FLOOD

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
	0	0	0.0	0	0.0	0.00	0.00	0.0000	81.3
	10	28	-	28	-	-	4.54	0.0225	"
	20	55	-	27	-	-	8.93	0.0442	"
	25	67	-	12	-	-	10.86	0.0538	"
	30	80	-	13	-	-	12.96	0.0643	81.5
	35	91	-	11	-	-	14.72	0.0731	"
	40	102	-	11	-	-	16.52	0.0819	81.8
	50	124	-	22	-	-	20.09	0.0996	82.0
	60	145	-	21	-	-	23.50	0.1165	"
	70	166	-	21	-	-	26.90	0.1335	82.4
	80	187	-	21	-	-	30.30	0.1504	83.0
BT	87	199	-	12	-	-	32.20	0.1600	83.3
	90	205	0.1	6	0.1	0.02	33.20	0.1648	"
	100	223	3.0	18	2.9	0.16	36.10	0.1815	84.0
	110	238	8.0	15	5.0	0.33	38.60	0.1960	84.0
	120	252	14.0	14	6.0	0.43	40.80	0.2138	"
	130	261	24.0	9	10.0	1.11	42.25	0.2290	"
	140	271	35.0	10	11.0	1.10	43.90	0.2460	"
	150	277	46.0	6	11.0	1.84	44.80	0.2590	"
	160	281	59.0	4	13.0	3.25	45.50	0.2730	84.2
	170	287	74.0	6	15.0	2.50	46.50	0.2900	"
	180	294	90.0	7	16.0	2.29	47.60	0.3080	84.4
	195	300	113.0	6	23.0	3.84	48.60	0.3320	85.0
	210	306	143.0	6	30.0	5.00	49.50	0.3610	85.8
	242	312	209.0	6	66.0	11.00	50.50	0.2450	"
	270	317	270.0	5	61.0	12.20	51.40	0.4710	86.0
	300	322	339.0	5	69.0	13.80	52.10	0.2370	"
	330	327	410.0	5	71.0	14.20	52.90	0.5920	"
	340	328	433.0	1	23.0	23.00	53.10	0.6110	"
	348	329	481.0	1	48.0	48.00	53.20	0.6510	"

TABLE: 15 cont. RUN NO. 25

CORE TEST FLUID AND 5.5 MC/SEC. FLOOD

	TIME	VOLTAGE		$TIME(10)^{-7}$		FREQUENCY(MC)		K_w/K_o
	MIN.	DISPLAYED	VOLTS	DISPLAYED	TIME	DISPLAYED	FREQ.	
	0	3.20	32.0	1.8	1.8	5.7	5.7	-
	20	"	"	"	"	"	"	"
	25	"	"	"	"	"	"	"
	30	"	"	"	"	"	"	"
	35	3.10	31.0	"	"	"	"	"
	40	3.20	32.0	"	"	"	"	"
	50	"	"	"	"	"	"	"
	60	"	"	"	"	"	"	"
	70	3.27	32.7	"	"	"	"	"
	80	3.25	32.5	"	"	"	"	"
BT	87	3.30	33.0	"	"	"	"	"
	90	3.38	33.8	"	"	"	"	0.0116
	100	3.40	34.0	"	"	"	"	0.0124
	110	3.38	33.8	"	"	"	"	0.2848
	120	"	"	"	"	"	"	0.5810
	130	"	"	"	"	"	"	1.3500
	140	3.36	33.6	"	"	"	"	2.1100
	150	3.40	34.(	"	"	"	"	3.3800
	160	"	"	"	"	"	"	5.6400
	170	"	"	"	"	"	"	7.3700
	180	"	"	"	"	"	"	8.9600
	195	"	"	"	"	"	"	9.5300
	210	"	"	"	"	"	"	13.0000
	242	"	"	"	"	"	"	20.6400
	270	"	"	"	"	"	"	29.0700
	300	"	"	"	"	"	"	38.6200
	330	"	"	"	"	"	"	48.5000
	340	"	"	"	"	"	"	64.4000
	348	"	"	"	"	"	"	97.6000

RUN NO. 23

1. Barametric Pressure = 73.38 cm Hg.

2. Vacuum was pulled on the core for 15.75 hours

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of oil	= Diesel
(b)	Volume of oil originally in reservoir tank	= 1000.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	= 32.0 cc
(d)	Volume of oil produced during saturation	= 286.0 cc
(e)	Volume of oil originally in core	= 682.0 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	= 1000.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	= 283.0 cc
(c)	Volume of water produced during flooding	= 411.0 cc
(d)	Volume of water produced to clean and drain lines	= 76.0 cc

6. Original Oil Saturation = 54.8%

7. Original Water Saturation = 21.4%

8. Original Gas (Air) Saturation = 23.8%

TABLE: 16 RUN NO. 23

DIESEL OIL AND 5.5 MC/SEC. FLOOD

TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
0	0	0.0	0	0.0	0.00	0.00	0.0000	84.5
10	27	-	27	-	-	3.96	0.0217	85.0
15	45	-	18	-	-	6.60	0.0362	"
20	61	-	16	-	-	8.95	0.0490	85.2
25	75	-	14	-	-	11.01	0.0603	"
30	88	-	13	-	-	12.93	0.0707	85.7
35	100	-	12	-	-	14.68	0.0804	"
40	112	-	12	-	-	16.45	0.0902	86.0
50	134	-	12	-	-	19.65	0.1075	"
60	154	-	20	-	-	22.60	0.1240	"
70	173	-	19	-	-	25.40	0.1390	86.2
80	192	-	19	-	-	28.20	0.1543	86.4
90	211	-	19	-	-	30.95	0.1695	"
100	229	-	18	-	-	33.60	0.1840	86.8
BT 106	240	-	11	-	-	35.22	0.1930	87.0
110	248	1.0	8	1.0	0.13	36.40	0.2000	88.0
120	262	3.5	14	2.5	0.18	38.50	0.2130	"
130	275	8.0	13	4.5	0.35	40.40	0.2280	88.2
140	285	14.0	10	6.0	0.60	41.80	0.2405	"
150	294	22.0	9	8.0	0.89	43.30	0.2540	89.0
160	304	30.0	10	8.0	0.80	44.60	0.2683	"
170	309	42.0	5	12.0	2.40	45.40	0.2825	89.0
180	313	54.0	4	12.0	3.00	45.90	0.2950	"
210	322	95.0	9	41.0	4.55	47.20	0.3350	"
240	332	149.0	10	54.0	5.40	48.70	0.3865	90.7
270	339	209.0	7	60.0	8.57	49.80	0.4410	91.8
300	344	271.0	5	62.0	12.40	50.50	0.4940	92.0
330	351	337.0	7	66.0	9.44	51.50	0.5530	"
360	356	411.0	5	74.0	14.80	52.30	0.6160	"

TABLE: 16 cont. RUN NO. 23

DIESEL OIL AND 5.5 MC/SEC. FLOOD

TIME MIN.	VOLTAGE DISPLAYED	VOLTS	TIME $(10)^{-7}$ DISPLAYED	TIME	FREQUENCY (MC) DISPLAYED	FREQ.
0	4.15	41.5	1.8	1.8	5.75	5.75
10	"	"	"	"	"	"
15	4.00	40.0	"	"	"	"
20	"	"	"	"	"	"
25	"	"	"	"	"	"
30	"	"	"	"	"	"
35	"	"	"	"	"	"
40	"	"	"	"	"	"
50	"	"	"	"	"	"
60	"	"	"	"	"	"
70	"	"	"	"	"	"
80	"	"	"	"	"	"
90	"	"	"	"	"	"
100	3.90	39.0	"	"	"	"
BT 106	"	"	"	"	"	"
110	"	"	"	"	"	"
120	3.95	39.5	"	"	"	"
130	4.00	40.0	"	"	"	"
140	"	"	"	"	"	"
150	"	"	"	"	"	"
160	"	"	"	"	"	"
170	"	"	"	"	"	"
180	"	"	"	"	"	"
210	"	"	"	"	"	"
240	"	"	"	"	"	"
270	"	"	"	"	"	"
300	"	"	"	"	"	"
330	4.10	41.0	"	"	"	"
360	"	"	"	"	"	"

RUN NO. 26

1. Barametric Pressure = 73.44 cm Hg.

2. Vacuum was pulled on the core for 13.75 hours

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

   (a) Type of oil = Diesel

   (b) Volume of oil originally in reservoir tank = 1000.0 cc

   (c) Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum = 19.0 cc

   (d) Volume of oil produced during saturation = 260.0 cc

   (e) Volume of oil originally in core = 721.0 cc

5. Data on Water:

   (a) Volume of water originally in reservoir tank = 1000.0 cc

   (b) Volume of water produced to flush oil from injection lines leading to the core prior to flooding = 46.0 cc

   (c) Volume of water produced during flooding = 401.0 cc

   (d) Volume of water produced to clean and drain lines = 416.0 cc

6. Original Oil Saturation = 58.0%

7. Original Water Saturation = 17.5%

8. Original Gas Saturation = 24.5%

TABLE: 17 RUN NO. 26

DIESEL OIL AND 5.5 MC/SEC. FLOOD

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
	0	0	0	0	0	0.000	0.00	0.0000	84.0
	10	34	-	34	-	-	4.72	0.0253	"
	20	62	-	32	-	-	8.61	0.0498	"
	30	85	-	23	-	-	11.80	0.0682	"
	40	108	-	23	-	-	15.00	0.0869	"
	50	128	-	20	-	-	17.78	0.1290	"
	60	148	-	20	-	-	20.55	0.1190	84.2
	70	166	-	18	-	-	23.05	0.1335	"
	85	196	-	30	-	-	27.20	0.1575	"
	105	225	-	29	-	-	31.20	0.1810	"
	110	237	-	12	-	-	32.90	0.1905	"
	120	256	-	19	-	-	35.50	0.2060	"
	130	272	-	16	-	-	37.80	0.2180	"
BT	135	277	-	5	-	-	38.40	0.2220	"
	140	288	1	11	1	0.091	39.95	0.2320	"
	150	300	5	12	4	0.333	41.70	0.2450	84.7
	160	312	11	12	6	0.500	42.30	0.2590	85.0
	170	321	19	9	8	0.890	44.60	0.2730	86.0
	180	331	27	10	8	0.800	45.90	0.2880	"
	200	342	48	11	21	1.910	47.40	0.3140	"
	220	348	71	6	23	3.840	48.30	0.3370	"
	240	352	103	4	32	8.000	48.90	0.3660	86.2
	260	357	139	5	36	7.200	49.60	0.3990	"
	280	361	177	5	38	7.600	50.10	0.4325	"
	300	365	214	4	37	9.250	50.70	0.4650	"
	320	369	252	4	38	9.500	51.30	0.4990	86.7
	340	373	292	4	40	10.000	51.80	0.5350	87.0
	360	376	334	3	42	14.000	52.20	0.5710	"
	380	380	375	4	41	10.250	52.80	0.6080	"
	390	382	401	2	26	13.000	53.10	0.6290	"

TABLE: 17 cont. RUN NO. 26

DIESEL OIL AND 5.5 MC/SEC. FLOOD

	TIME	VOLTAGE		$TIME(10)^{-7}$		FREQUENCY(MC)		K_w/K_o
	MIN.	DISPLAYED	VOLTS	DISPLAYED	TIME	DISPLAYED	FREQ.	
	0	3.80	38.0	1.8	5.7	5.7	5.7	-
	10	"	"	"	"	"	"	"
	20	4.00	40.0	"	"	"	"	"
	30	"	"	"	"	"	"	"
	40	4.05	40.5	"	"	"	"	"
	50	"	"	"	"	"	"	"
	60	4.13	41.3	"	"	"	"	"
	70	"	"	"	"	"	"	"
	85	4.14	41.4	"	"	"	"	"
	105	"	"	"	"	"	"	"
	110	4.18	41.8	"	"	"	"	"
	120	"	"	"	"	"	"	"
	130	"	"	"	"	"	"	"
BT	135	"	"	"	"	"	"	"
	140	"	"	"	"	"	"	0.0316
	150	"	"	"	"	"	"	0.1472
	160	"	"	"	"	"	"	0.3210
	170	4.20	42.0	"	"	"	"	0.5960
	180	"	"	"	"	"	"	0.8750
	200	4.29	42.9	"	"	"	"	1.5400
	220	4.40	44.0	"	"	"	"	2.8700
	240	4.38	43.8	"	"	"	"	5.6600
	260	4.35	43.5	"	"	"	"	8.1800
	280	4.23	42.3	"	"	"	"	10.7700
	300	4.38	43.8	"	"	"	"	14.0100
	320	4.21	42.1	"	"	"	"	17.3200
	340	4.30	43.0	"	"	"	"	20.8000
	360	4.38	43.8	"	"	"	"	25.6200
	380	4.40	44.0	"	"	"	"	29.2000
	390	"	"	"	"	"	"	33.7000

RUN NO. 24

1. Barametric Pressure = 73.43 cm Hg.

2. Vacuum was pulled on the core for 12.5 hours

3. Inlet Pressure (Injection)
   Manometer Readings = 40.85 cm Hg; 70.9 cm water

4. Data on Oil:

(a)	Type of oil	=	SAE 10
(b)	Volume of oil originally in reservoir tank	=	1000.0 cc
(c)	Volume of oil produced to flush air from injection lines leading to the core prior to pulling a vacuum	=	17.0 cc
(d)	Volume of oil produced during saturation	=	236.0 cc
(e)	Volume of oil originally in core	=	747.0 cc

5. Data on Water:

(a)	Volume of water originally in reservoir tank	=	1000.0 cc
(b)	Volume of water produced to flush oil from injection lines leading to the core prior to flooding	=	47.0 cc
(c)	Volume of water produced during flooding	=	477.0 cc
(d)	Volume of water produced to clean and drain lines	=	211.0 cc

6. Original Oil Saturation = 60.05%

7. Original Water Saturation = 17.40%

8. Original Gas Saturation (Air) = 22.55%

TABLE: 18 RUN NO. 24

SAE 10 OIL AND 5.5 MC/SEC. FLOOD

	TIME MIN.	CUM. V_o cc	CUM. V_w cc	INST. V_o cc	INST. V_w cc	INST. WOR	% RECOVERY	CUM. PROD. FLUID/UNIT PORE VOL.	TEMP. OF PROD. FLUID
	0	0	0.0	0	0.0	0.000	0.00	0.0000	90.0
	15	19	-	19	-	-	2.55	0.0153	90.2
BT	25	32	-	13	-	-	4.28	0.0257	"
	40	53	0.4	21	0.4	0.019	7.10	0.0429	"
	50	67	1.1	14	0.7	0.050	8.97	0.0548	90.8
	60	77	3.0	10	1.9	0.190	10.31	0.0643	91.0
	70	89	4.0	12	1.0	0.083	11.92	0.0747	"
	80	101	5.0	12	1.0	0.083	13.53	0.0852	91.2
	90	111	6.0	10	1.0	0.100	14.85	0.0940	"
	100	121	7.0	10	1.0	0.100	16.20	0.1030	"
	110	129	8.0	8	1.0	0.125	17.28	0.1103	"
	120	140	9.0	11	1.0	0.091	18.75	0.1198	92.0
	140	157	14.0	17	5.0	0.296	21.05	0.1375	"
	160	176	20.0	19	6.0	0.316	23.60	0.1575	"
	180	191	31.0	15	11.0	0.735	25.60	0.1705	"
	200	202	40.0	11	9.0	0.818	27.05	0.1945	"
	220	211	49.0	9	9.0	1.000	28.30	0.2090	"
	245	218	59.0	9	10.0	1.011	29.20	0.2220	"
	260	221	63.0	3	4.0	1.335	29.60	0.2280	"
	280	225	72.0	4	9.0	2.250	30.10	0.2480	"
	300	231	81.0	6	9.0	1.500	30.90	0.2510	92.2
	350	241	115.0	10	34.0	3.400	32.30	0.2860	"
	428	255	217.0	14	102.0	7.290	34.10	0.3790	92.0
	450	263	249.0	8	32.0	4.000	35.20	0.4110	"
	480	269	300.0	6	51.0	8.500	36.00	0.4570	"
	510	274	359.0	5	57.0	11.400	36.70	0.5070	91.2
	540	280	417.0	6	60.0	10.000	37.50	0.5600	91.0
	570	286	477.0	6	60.0	10.000	38.30	0.6130	"

TABLE: 18 cont. RUN NO. 24

SAE 10 OIL AND 5.5 MC/SEC. FLOOD

TIME MIN.	VOLTAGE DISPLAYED	VOLTS	TIME $(10)^{-7}$ DISPLAYED	TIME	FREQUENCY (MC) DISPLAYED	FREQ.	K_w/K_o
0	3.40	34.0	1.8	1.8	5.7	5.7	-
15	3.55	35.5	"	"	"	"	"
BT 25	3.30	33.0	"	"	"	"	"
40	3.40	34.0	"	"	"	"	0.000523
50	"	"	"	"	"	"	0.001889
60	"	"	"	"	"	"	0.007100
70	3.50	35.0	"	"	"	"	0.009360
80	3.60	36.0	"	"	"	"	0.011620
90	3.65	36.5	"	"	"	"	0.014400
100	3.60	36.0	"	"	"	"	0.017100
110	"	"	"	"	"	"	0.020500
120	"	"	"	"	"	"	0.023000
140	"	"	"	"	"	"	0.031100
160	"	"	"	"	"	"	0.039700
180	3.80	38.0	"	"	"	"	0.060100
200	"	"	"	"	"	"	0.082200
220	"	"	"	"	"	"	0.109200
245	3.75	37.5	"	"	"	"	0.137000
269	4.00	40.0	"	"	"	"	0.173500
280	"	"	"	"	"	"	0.235000
300	4.10	41.0	"	"	"	"	0.276500
350	"	"	"	"	"	"	0.369000
428	"	"	"	"	"	"	0.568000
450	"	"	"	"	"	"	0.677000
480	"	"	"	"	"	"	0.910000
510	"	"	"	"	"	"	1.220000
540	"	"	"	"	"	"	1.492000
570	"	"	"	"	"	"	1.769000

TABLE: 19

FLUID PROPERTIES

FLUID SAMPLE	TIME SEC.	CONSTANT CS/SEC	KINEMATIC VISCOSITY, CS	FLUID DENSITY	ABSOLUTE VISCOSITY, CPS.
WATER	195.6	0.003633	0.7106	1.0105	0.7781
CORE TEST FLUID	413.0	0.003633	1.5004	0.7484	1.1230
DIESEL	106.0	-	-	0.8261	2.2370
SAE 10	130.1	0.253800	33.0190	0.8608	28.4200

TABLE: 20

INJECTIVITY DATA

TIME	STRAIGHT						1 MC/SEC.					
	CUM. $(V_o)_A$	CUM. $(V_o)_B$	INST. $(V_o)_A$	INST. $(V_o)_B$	INST. $(Q_o)_A$	INST. $(Q_o)_B$	CUM. $(V_o)_A$	CUM. $(V_o)_B$	INST. $(V_o)_A$	INST. $(V_o)_B$	INST. $(Q_o)_A$	INST. $(Q_o)_B$
MIN.	cc	cc	cc	cc	cc/min	cc/min	cc	cc	cc	cc	cc/min	cc/min
0	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.000	0.000
1	-	0.80	-	0.80	-	0.400	-	1.10	-	1.10	-	0.550
2	0.80	-	0.80	-	0.80	-	1.75	-	1.75	-	0.875	-
3	-	1.60	-	0.80	-	0.400	-	2.08	-	0.98	-	0.490
4	2.10	-	1.30	-	0.65	-	2.75	-	1.00	-	0.500	-
5	-	2.38	-	0.78	-	0.390	-	3.23	-	1.15	-	0.575
6	3.24	-	1.14	-	0.57	-	4.40	-	1.65	-	0.825	-
7	-	3.20	-	0.82	-	0.410	-	4.40	-	1.17	-	0.585
8	4.60	-	1.36	-	0.68	-	5.13	-	0.73	-	0.365	-
9	-	3.75	-	0.55	-	0.275	-	5.69	-	1.28	-	0.640
10	6.00	-	1.40	-	0.90	-	7.75	-	2.62	-	1.310	-
11	-	4.62	-	0.87	-	0.435	-	7.00	-	1.32	-	0.660
12	7.40	-	1.40	-	0.70	-	9.50	-	1.75	-	0.875	-
13	-	5.47	-	0.85	-	0.425	-	8.28	-	1.28	-	0.640
14	8.77	-	1.37	-	0.685	-	11.25	-	1.75	-	0.875	-
15	-	6.40	-	0.93	-	0.465	-	9.62	-	1.34	-	0.670
16	10.20	-	1.43	-	0.765	-	12.90	-	1.65	-	0.825	-
17	-	7.20	-	0.80	-	0.400	-	10.90	-	1.28	-	0.640
18	11.60	-	1.40	-	0.700	-	14.70	-	1.80	-	0.900	-
19	-	8.07	-	0.87	-	0.435	-	12.20	-	1.20	-	0.600
20	13.05	-	1.45	-	0.725	-	16.40	-	1.70	-	0.850	-

STRAIGHT:

$(Q_o)_{A_{avg}}$ = 0.656cc/min.

$(Q_o)_{B_{avg}}$ = 0.405cc/min.

1 MC/SEC.:

$(Q_o)_{A_{avg}}$ = 0.823cc/min.

$(Q_o)_{B_{avg}}$ = 0.638cc/min.

TABLE: 21

INJECTIVITY DATA

TIME	STRAIGHT						3.1 MC/SEC.					
MIN.	CUM. $(V_o)_A$ cc	CUM. $(V_o)_B$ cc	INST. $(V_o)_A$ cc	INST. $(V_o)_B$ cc	INST. (Q_o) cc/min	INST. $(Q_o)_B$ cc/min	CUM. $(V_o)_A$ cc	CUM. $(V_o)_B$ cc	INST. $(V_o)_A$ cc	INST. $(V_o)_B$ cc	INST. $(Q_o)_A$ cc/min	INST. $(Q_o)_B$ cc/min
0	0.00	0.00	0.00	0.00	0.000	0.000	0.00	0.00	0.00	0.00	0.000	0.000
1	-	1.20	-	1.20	-	0.600	-	1.20	-	1.20	-	0.600
2	1.50	-	1.50	-	-	-	1.40	-	1.40	-	-	-
3	-	2.30	-	1.10	-	0.650	-	2.60	-	1.40	-	0.700
4	3.60	-	2.10	-	1.050	-	3.50	-	2.10	-	1.050	-
5	-	3.40	-	1.10	-	0.650	-	4.35	-	1.75	-	0.875
6	5.75	-	2.15	-	1.075	-	5.50	-	2.00	-	1.000	-
7	-	4.60	-	1.20	-	0.600	-	6.00	-	1.65	-	0.825
8	7.75	-	2.00	-	1.000	-	7.75	-	2.25	-	1.125	-
9	-	5.80	-	1.20	-	0.600	-	7.65	-	1.65	-	0.825
10	9.80	-	2.05	-	1.025	-	10.00	-	2.25	-	1.125	-
11	-	7.06	-	1.26	-	0.630	-	9.45	-	1.80	-	0.900
12	11.80	-	2.00	-	1.000	-	12.25	-	2.25	-	1.125	-
13	-	8.30	-	1.24	-	0.620	-	11.05	-	1.60	-	0.800
14	14.20	-	2.40	-	1.200	-	14.27	-	2.01	-	1.005	-
15	-	9.60	-	1.30	-	0.650	-	12.80	-	1.75	-	0.825
16	16.10	-	1.90	-	0.950	-	16.50	-	2.23	-	1.115	-
17	-	10.90	-	1.30	-	0.650	-	14.60	-	1.80	-	0.900
18	17.80	-	1.70	-	0.850	-	18.78	-	2.28	-	1.140	-
19	-	12.13	-	1.70	-	0.850	-	18.78	-	1.80	-	0.900
20	20.40	-	2.60	-	1.300	-	21.25	-	2.47	-	1.235	-

Straight:

$(Q_o)_{A_{avg}} = 1.050$ cc/min.

$(Q_o)_{B_{avg}} = 0.607$ cc/min.

3.1 MC/SEC.:

$(Q_o)_{A_{avg}} = 1.1$ cc/min.

$(Q_o)_{B_{avg}} = 0.845$ cc/min.

TABLE: 22

INJECTIVITY DATA

TIME MIN.	CUM. $(V_o)_A$ cc	CUM. $(V_o)_B$ cc	INST. $(V_o)_A$ cc	INST. $(V_o)_B$ cc	INST. $(Q_o)_A$ cc/min	INST. $(Q_o)_B$ cc/min	CUM. $(V_o)_A$ cc	CUM. $(V_o)_B$ cc	INST. $(V_o)_A$ cc	INST. $(V_o)_B$ cc	INST. $(Q_o)_A$ cc/min	INST. $(Q_o)_B$ cc/min
0	0.00	0.00	0.00	0.00	0.000	0.000	0.00	0.00	0.00	0.00	0.000	0.000
1	-	0.75	-	0.75	-	0.375	-	0.60	-	0.60	-	0.300
2	0.85	-	0.85	-	0.475	-	0.80	-	0.80	-	0.400	-
3	-	1.50	-	0.75	-	0.375	-	1.25	-	0.65	-	0.325
4	1.62	-	0.77	-	0.385	-	1.45	-	0.65	-	0.325	-
5	-	2.20	-	0.70	-	0.350	-	1.88	-	0.63	-	0.315
6	2.40	-	0.78	-	0.390	-	2.20	-	0.75	-	0.375	-
7	-	2.95	-	0.75	-	0.375	-	2.70	-	0.82	-	0.410
8	2.90	-	0.50	-	0.250	-	2.93	-	0.73	-	0.365	-
9	-	3.50	-	0.55	-	0.275	-	3.25	-	0.55	-	0.275
10	3.60	-	0.70	-	0.350	-	3.65	-	0.72	-	0.360	-
11	-	4.18	-	0.68	-	0.340	-	4.00	-	0.75	-	0.375
12	4.30	-	0.70	-	0.350	-	4.40	-	0.75	-	0.375	-
13	-	4.75	-	0.67	-	0.335	-	4.75	-	0.75	-	0.375
14	5.00	-	0.70	-	0.350	-	5.20	-	0.80	-	0.400	-
15	-	5.55	-	0.80	-	0.400	-	5.27	-	0.52	-	0.260
16	5.74	-	0.74	-	0.370	-	5.92	-	0.72	-	0.360	-
17	-	6.30	-	0.75	-	0.375	-	6.07	-	0.80	-	0.400
18	6.42	-	0.68	-	0.340	-	6.63	-	0.71	-	0.355	-
19	-	7.16	-	0.86	-	0.430	-	6.79	-	0.72	-	0.360
20	7.10	-	0.68	-	0.380	-	7.40	-	0.77	-	0.385	-

$(Q_o)_{A_{avg}}$ = 0.347cc/min.

$(Q_o)_{B_{avg}}$ = 0.405cc/min.

$(Q_o)_{A_{avg}}$ = 0.823cc/min.

$(Q_o)_{B_{avg}}$ = 0.638cc/min.

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