THE EFFECT OF INTERNAL COMBUSTION ENGINE OPERATION

UPON THE VISCOMETRIC PROPERTIES OF POLYMER THICKENED

MULTI-VISCOSITY CRANKCASE OILS

BY

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ABSTRACT

The effects of engine mileage upon the viscometric properties of seven different brands of multi-viscosity engine oils were examined by subjecting each brand of oil to an average of 1500 miles of service in the crankcases of different passenger cars.

Oil samples were taken every 500 miles after the oil was put in the crankcase. The control oil sample was taken from a can of oil at the time the oil was put in the engine.

The viscosity indices and kinematic viscosities at $100^\circ F$ and $210^\circ F$ were calculated for each sample of oil. The percent change in viscosity index and kinematic viscosity for each sample of each brand was calculated relative to the control's viscosity index and kinematic viscosity. The viscosity index, and kinematic viscosities of each brand's samples were plotted as a function of mileage.

All of the oils showed a decrease in kinematic viscosity at $210^\circ F$. Some of the oils showed a decrease in kinematic viscosity at $0^\circ F$. The viscosity index change varied from sample to sample of the same brand. The viscosity index increased for some brands and decreased for others. Six out of seven oils no longer qualified as the original SAE rating of the oil.

APPROVAL OF THESIS

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PREFACE

In order to modify engine oil's natural viscosity change with temperature, many modern engine oils include the addition of a very high molecular weight polymer. This polymer is added to the base engine oil in certain critical proportions. The purpose of this viscosity index improver is to make the single weight base engine oil exhibit temperature-viscosity characteristics unlike those of the unmodified base oil. It then becomes possible for one oil to have a viscosity at one temperature while the viscosity at another temperature is not the same as that of the same oil before the index improver was added. This enables the modified oil to be less dependent upon the operating temperature extremes which the oil is subjected to in the normal lubricating process.

Basically, all the viscosity index improver does is to make the base oil thicker at high temperatures than the unmodified base oil. This proves to be very important if we examine the oil in the crankcase of the ordinary internal combustion engine. In the middle of the winter, the temperature in the crankcase of a cold engine may reach several degrees below zero, while the temperature in the crankcase and oil, after the engine is fully warmed up, may reach over 350°F.[1] If a single weight engine oil is used

1."Oil For Your Car, At Last The True Story", Popular Science, September 1967, Volume 191, Number 3, page 67

in the crankcase, it must be thin enough at the low temperatures to limit the battery drain during engine cranking. This thin oil, at the higher temperatures of the fully warmed up engine, might be too thin to effectively prevent, or limit, the amount of oil consumption. If the oil is too thin at the higher temperatures, it might not provide the proper lubrication and possibly ruin the engine in a short period. If an oil with the viscosity index improver is used, the viscosity at the low temperature is low enough so that the battery drain is minimized, and the viscosity of the oil at the higher temperature is high enough to minimize the oil consumption rate and provide proper lubrication.

The best way to examine the mechanics of the polymer in the oil is to imagine the oil to be composed of little spheres. The long chain polymer, in the cold weather, coils up into little balls and offers a minimum resistance to the motion of the oil's molecules (spheres). However, there is a definite increase in the viscosity relative to the unmodified base oil.[2] Meanwhile, at the higher temperatures, the polymer uncoils and forms a long, snakelike chain that retards the free motion of the oil molecules much more than if the base oil did not have the polymer added. This is how one

2."Lubricating Oil Additives; How They Act", Battele Technical Review, Oct. 1967, Volume 16, No. 10, page 9

oil can have its temperature-viscosity relationship varied.

During the flow of the oil through the engine's passages and through areas of very high pressures such as cams, lifters, and rockers, the polymer is subjected to some very high shearing forces, and the final result is that many of the long chain polymers are broken or sheared into many smaller length polymers.[3] These smaller length polymers still form small spheres at low temperatures to reduce only slightly the viscosity of the oil. At the higher temperatures, the now smaller polymer chains don't increase the viscosity as much as the original long chain polymers. This means that the oil will now be thinner at high temperatures. It is very possible for the oil consumption rate to increase as compared to the initial oil before the polymer broke.

The oils that contain these polymers usually cost more than single weight oils. If the polymers break, the V.I. improved oil might be no better than an ordinary single weight oil.

3. "Additives; Their Role In Industrial Lubrication", Humble Oil and Refining Company, Lubetext DG-2K, Printed Feb. 1967

A temporary change in the viscosity index of an oil could be the result of the orientation of the polymer in the oil. If the long chain polymers should align themselves such that their axes are parallel to the planes formed by the oil molecules, then the polymer will offer little resistance to the motion of the molecules. If the polymer should be aligned in such a way that its axis is perpendicular to the planes of the oil molecules, then the maximum resistance will be exhibited. A condition where the minimum resistance is noticed, but only as a result of the orientation of the polymer and not as a result of the breaking of the chains is known as a temporary change in index.

Messrs. West and Selby, in their report entitled "The Effect of Engine Operation on The Viscometric Properties of Multigraded Engine Oils" reported that all of the oils they tested showed a permanent viscosity loss in a period equivalent to 385 miles. Their results were based upon test stand engines which ran at given speeds for times equivalent to 385 miles of driving. The loss in viscosity of the oils was attributed to the viscosity index improver polymer's break-down due to the shearing the oil is subjected to.

This test was started because the writer was curious to see what would happen to similar multi-viscosity oils

used in engines used in every day driving. The test period
was increased to 1500 miles, which was the practical time
limit imposed by the completion of this report.

to the two women in my life;

my loving wife Rose Marie,

my lovely daughter Janine.

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F = the force applied to shear a fluid or move an object in contact with the fluid

g = the acceleration due to gravity in cm/sec^2

h = the seperation distance of two planes

k = the pressure coefficient of viscosity

H = kinematic viscosity of 100 index oil at $100^{o}F$

L = kinematic viscosity of 0 index oil at $100^{o}F$

$K.V._{210}$ = kinematic viscosity at $210^{o}F$

N = the exponent which raises the value of $K.V._{210}$ to equal the ratio of H toU.

P = pressure

r = radius of balls used in the Hoeppler Falling Ball viscometer

S_b = the specific gravity of the ball used in the Hoeppler Falling Ball Viscometer

S_f = the specific gravity of the fluid used in the Hoeppler
Falling Ball Viscometer

T = temperature degrees Rankine

V.I. = viscosity index for indices less than 100

V.I.$_e$ = viscosity index for indices greater than 100

V_b = the velocity of the ball in the Hoeppler Falling Ball
viscometer

Z_o = the kinematic viscosity of the fluid at atmospheric
pressure

Z_p = the kinematic viscosity of the fluid at pressure "P"
in pounds per square inch

V = the velocity of the moving plane in Newton's model

η = the absolute viscosity of the fluid

ρ = the mass density of the fluid

ν = the kinematic viscosity of the fluid

INTRODUCTION

To completely understand the significance of this report, it becomes necessary to review certain principles properties and definitions which will prove to be useful in the balance of this report on engine lubricating oils. The very first and most important area to cover describes the most important property of the lubricating oil: viscosity.

Webster's New World Dictionary defines viscosity as "the internal fluid resistance of a substance caused by molecular attraction which makes it resist a tendency to flow". For any given fluid, according to the above definition, the viscosity, or resistance to flow, will be a function of the molecular properties of that fluid.

Although the concept and understanding of molecules and atomic arrangements is relatively new, the development of the model for viscosity analysis and the critical parameters is not new. In 1668, Sir Isaac Newton developed and defined the theory which is still used today.[1]

Newton constructed a system, or model, composed of a fluid placed between two flat, paralled plates; the bottom

1."Lubrication-Viscosity", Texaco Incorporated, Volume 52, Number 3, page 21

plate remained stationary while the top plate moved with a velocity "V" under the action of the applied force "F". The seperation distance between these plates, or planes, was called "h". The area of the plane in contact with the fluid was defined as "A".[2]

Newton defined the fluid as being composed of very tiny spheres which form the fluid layers. (Figure I) He also stated that the layer of fluid in contact with the planes "wets" the planes and thus becomes fixed to the planes. In this way, the very top plane or layer of the fluid's spheres moves with a velocity "V" relative to the bottom stationary plane of the fluid's spheres.

He went further to define the Shear Stress as being the ratio of the applied force "F" to the area of the plane in contact with the fluid "A". Shear Strain Rate was defined as the velocity of the top plane divided by the plane's seperation distance "h". The Rate of Shear was defined as the ratio of a given fluid plane's velocity to the distance that plane lies from the bottom or stationary plane. The Rate of Shear is sometimes represented by the letter "R" and is called the Velocity Gradient.

From this model, Newton deduced that the Velocity Grad-

2."Lubrication-Viscosity", Texaco Incorporated, Volume 52, Number 3, Page 23
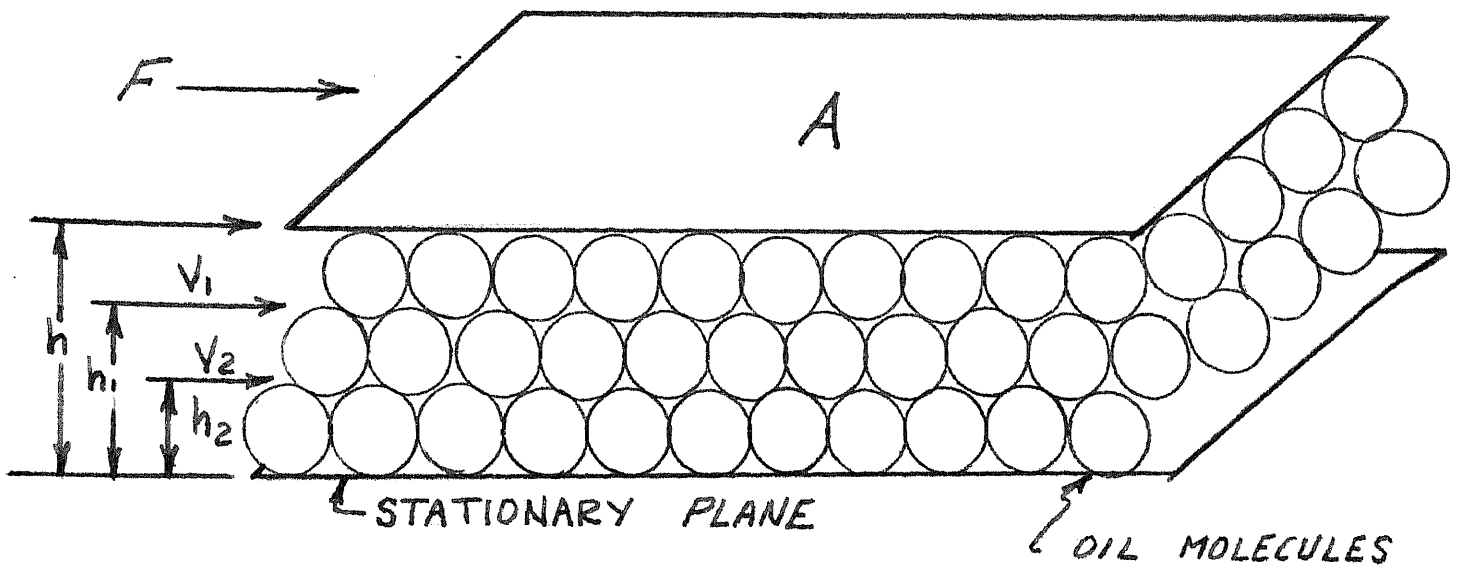
Figure 1. Newton's model showing those parameters which Newton stated influenced the measurement of viscosity.

ient for any given fluid would be constant as long as the fluid flow remains laminar, or smooth parallel flow of the fluid's planes. A constant Velocity Gradient means that the velocity of any given fluid plane will be a function of the fluid plane's perpendicular distance from the stationary plane. If the Velocity Gradient happens to be taken relative to a fluid plane that is also moving, the velocity in the equation is taken as the relative velocity and the distance of seperation is taken as the distance between the two planes.

The most important result of Newton's investigation is that he deduced that the force required to maintain a given constant velocity of the moving plane is proportional to the area of the plane and the Rate of Shear. In equation form, Newton's deduction takes the form

$$(1) \qquad\qquad F = (AV/h) \times \eta$$

where the factor "η" is called the coefficient of absolute or dynamic viscosity, or simply viscosity. Thus, viscosity could be measured if the other four variables could be measured. It is based upon the above equation that viscosity is defined and measured. Rearranging equation (1) yields

$$(2) \qquad \eta = \frac{\text{Shear Stress}}{\text{Rate of Shear}} = \frac{F/A}{V/h}$$

The units for viscosity as defined by Newton will depend upon which system the parameters are measured in. In the Metric (centimeter, gram, second) system, the Shear Stress has the units of dynes per square centimeter. The Rate of Shear has the units of reciprocal seconds (seconds^{-1}). The resulting unit of viscosity is called the "poise" in honor of Dr. J. Poiseuille who studied fluid flow in capillaries. Because the poise is a large number, a centipoise, or one-hundredth of a poise is used.

In the English (foot, pound, second) system, the Shear Stress has the units of pounds per square inch. The Rate of Shear has the units of reciprocal seconds. This resultant unit of viscosity is called a "reyn" in honor of Osborne Reynolds who studied fluid flow and was instrumental in many of the fluid flow principle's development. The unit of one-millionth of a reyn is called a Newton in honor of Sir Isaac Newton.

The equivalence of the English and Metric system's measurements for the absolute viscosity "η" is given by the equality;

(3) 10^6 Newtons = 68,950 Poise = 6,895,000 centipoise = 1 Reyn

Looking at Newton's equation (1), it implies that when-
ever a force exists in a similar system as he defined
(Figure 1) a definite velocity or Rate of Shear will exist
no matter how small. These fluids which have a Shear Stress
directly proportional to the Rate of Shear will have viscosity
which will remain constant at a given temperature and pressure
Thus, if either the Rate of Shear or the Shear Stress, or
both should change, the viscosity would remain constant.
A fluid which exhibits this property is called a Newtonian
fluid. For this type of fluid, the plot of Shear Stress
versus Rate of Shear will be a straight line with the inter-
cept at the origin on the axes. The slope of this line, in
the proper units, will be the absolute viscosity "η". An
example of such a fluid is engine oil.

On the other hand, a fluid which does not shear or
move until a definite Shear Stress other than zero is
applied is called a Plastic Solid. The critical stress
needed to cause the fluid to just move or shear is called
the Yield Value. Once the fluid shears, the Shear Stress will
be proportional to the Rate of Shear just as if it were New-
tonian. If a plot is formed, the slope of the line rep-

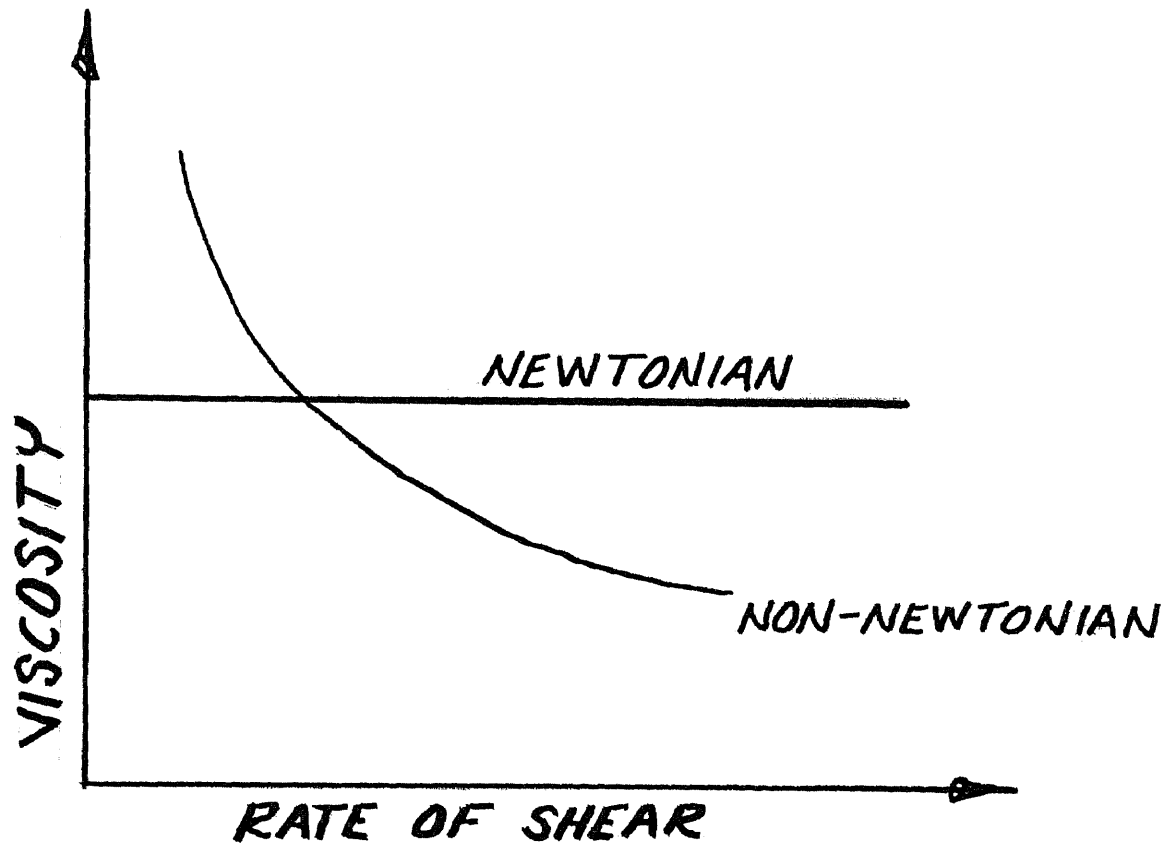Figure 3. A representation of the effect of a varying shear
rate upon the viscosity of the Newtonian and non-Newtonian
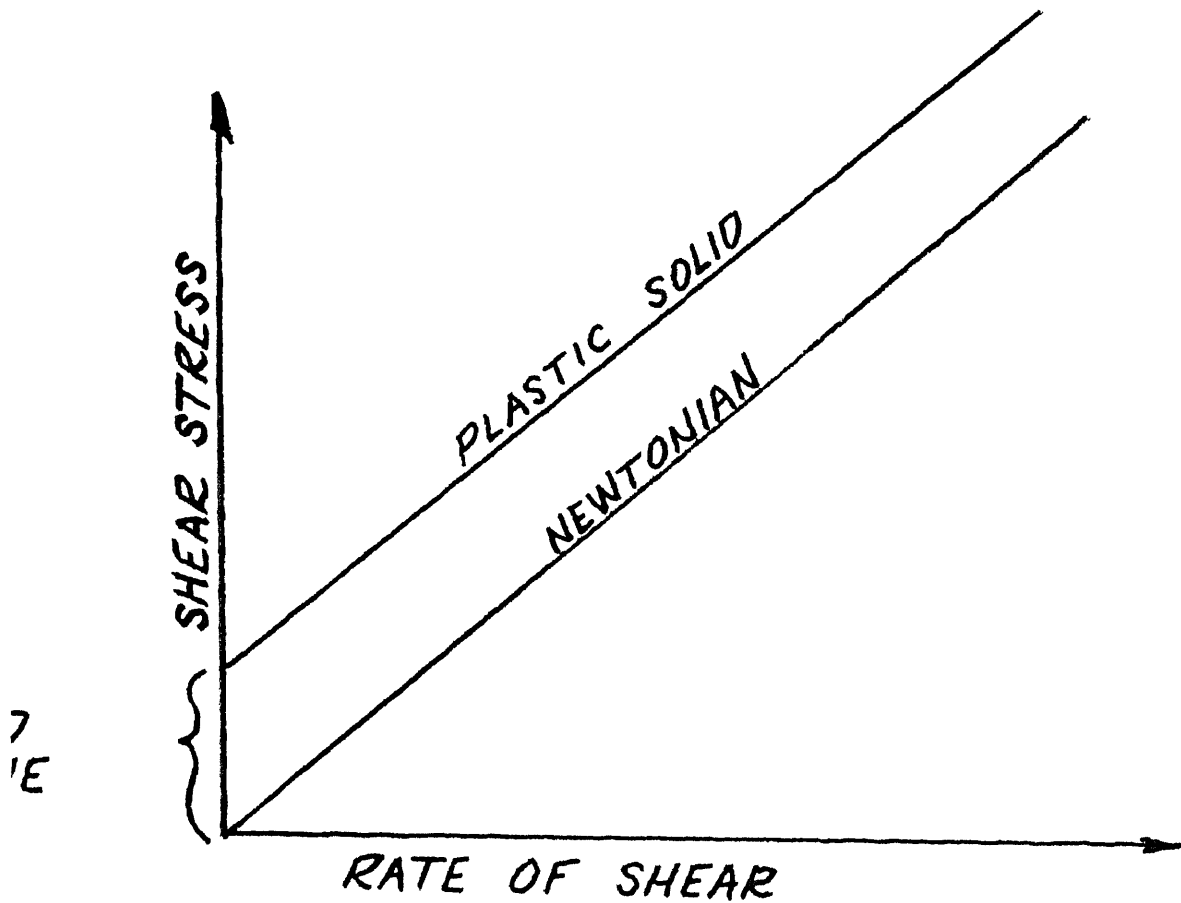fluids.

Figure 3A. A comparison of the Newtonian and Plastic Solid's
reaction to a given shear stress. Note that the Plastic
Solid does not have a rate of shear until the yield
value is reached. After the yield value is passed, the
Plastic Solid reacts as a regular Newtonian fluid.

resenting the shear stress versus the rate of shear for the

Plastic Solid will be linear, but the intercept will be at

the Yield Value of the shear stress. The slope of this line,

in the proper units, will be the absolute viscosity. For all

shear stresses above the Yield Value, the fluid will be-

have like a Newtonian fluid. (Figure 3) An example of such

a fluid is automotive oil that is heavy in paraffins at a

low temperature below the waxy pour point.

Directly opposite the Newtonian fluid is the non-New-

tonian fluid. This fluid possesses a viscosity which is de-

pendent upon the rate of shear, and as a result, the "appar-

ent" viscosity is meaningful only when the rate of shear

at which the viscosity is measured is also given. Examples

of such fluids are butter and hypoid greases.

Although the viscosity mentioned so far has been

called absolute or dynamic viscosity, another commonly used

viscosity is called the "kinematic" viscosity. Kinematic

viscosity is the ratio of the absolute viscosity to the

fluid's mass density "ρ".[3] The unit for kinematic vis-

cosity is called a Stoke while one-hundredth of a Stoke

is called a centistoke. The mass density of the fluid

3."Lubrication-Viscosity", Texaco Incorporated, Volume 52,
    Number 3, page 27

measured at the temperature of the fluid at which the viscosity is measured.

Parameters Which Affect Viscosity

Now that a basic understanding of viscosity has been established, the parameters which affect the viscosity will be investigated. The most important parameter in the study of viscosity is temperature.[4]

As the temperature of the fluid is increased, the viscosity of the fluid will decrease. An elementary way to envision this is to recall that Newton's model defined the fluid as being composed of tiny spheres. As the temperature increases, these tiny spheres tend to vibrate more energetically than at lower temperatures. The spheres (molecules) average distance from another adjacent sphere will increase, and thus the molecular attraction will decrease. When a shear stress is impressed upon the fluid, the spheres offer less resistance to the stress and the net result is that the fluid flows easier.

As the temperature is decreased, the opposite reaction takes place. The molecules of the fluid vibrate less and the molecular attraction increases because the molecules

4. Fuller, Dudley D., "Theory and Practise of Lubrication For Engineers", John Wiley and Sons Inc., 1956, Third Printing

are closer together at any given time. The shear stress
required to produce a given rate of shear is greater than
the stress required to produce an identical rate of shear
in the same fluid at a higher temperature.

An equation which gives the relationship between the
temperature and viscosity of oils is given as

$$(4) \qquad \log_{10}\log_{10} (\nu + 0.8) = \eta\log_{10}T + C$$

where "ν" is the kinematic viscosity and "T" is the ab-
solute temperature in degrees Rankine. "C" and "η" are
constants dependent upon the oil.

Another parameter which affects the viscosity, but not
as markedly as the temperature, is the pressure.[5] At very
high pressures in the order of several thousand pounds per
square inch, the viscosity varies considerably. An em-
pirical equation of the form

$$(5) \qquad Z_p = Z_o e^{kP}$$

5. "Lubrication-Viscosity", Texaco Incorporated, Volume 52,
   Number 3, page 41

where;

Z_p = the absolute viscosity at the given pressure "P"
in pounds per square inch

Z_o = the absolute viscosity at atmospheric pressure

k = the pressure coefficient of viscosity, a constant
for a given oil

A comparison of the effect upon oil's viscosity due
to the temperature and pressure can be seen if it is
realized that a 500 psi pressure increase has the same
effect in magnitude, but opposite in direction, as an in-
crease in temperature of 2°F.[6]

Hydrocarbon oils, when exposed to nuclear radiation,
show an increase in viscosity. The change in viscosity will
depend upon the type of oil, the dosage of radiation and the
type of radiation. Paraffinic oils have a greater change
for a given dose of radiation than napthanic oils. Syn-
thetic oils will generally suffer a greater increase than
natural oils. Oils with viscosity index improvers will show
a decrease in viscosity for low radiation doses, but with
higher doses, the viscosity will increase to several times
the original viscosity.[7]

6. "Lubrication-Viscosity II", Texaco Incorporated, Volume 47,
   February 1961, Number 2, page 22
7. Ibidem., page 23

Principal Methods of Viscosity Measurement

There are eight different systems used to measure the viscosity of fluids. The following will describe each system and explain the principles of each system.

1) The time required for a given quantity of the fluid to flow through a calibrated orifice at a given temperature under the action of gravity is referred to as the Time of Flow system.

2) The torque exerted upon a disc which rotates in the fluid, or the torque needed to rotate a cylinder in the fluid is referred to as the Torque system.

3) The torque exerted upon a disc suspended in a rotating cup of the fluid is another type of Torque system.

4) The rotational speed of a disc or cylinder driven in the liquid by a known constant torque is known as the Rotational Speed system of measurement.

5) The time of fall of a ball or sphere through the liquid is called the Time of Fall measurement.

6) The time required for an air bubble to rise through the fluid is used to measure viscosity of fluids.

7) The rate of damping of an induced ultrasonic wave

in the fluid yields an answer proportional to the viscosity
of the fluid.

8) The pressure drop of the fluid through a capillary
can be measured to give the value of the viscosity.

In all eight of the above systems, because the temperature
of the fluid is so important, the temperature must be care-
fully controlled so that an accurate and reproducible reading
can be taken. The temperature of the fluid must be stated
with the viscosity reading.

The principal system used for measuring the viscosity
of oils in the United States is the Saybolt Universal system.
The viscometer consists of a flask which has a .4823 inch
diameter by .0695 inch long orifice at the bottom. A
sample of the oil which is 60 ml. in volume is heated to a
given temperature by a bath which surrounds the flask. The
oil is usually measured at either $100^{\circ}F.$ or $210^{\circ}F.$ The time
required for the sample to flow through the orifice into a
receiving beaker under the orifice of the flask is measured.
The time, in seconds, is called the Saybolt Seconds-Universal.
Because the time of flow of a given volume is measured, the
Saybolt system incorporates the Time Of Flow system.

The Couette Viscometer incorporates the Torque system

described in system (2) and (3) above. A small specimen of the fluid is placed in the annulus between two concentric cylinders. The fluid is heated to the final temperature of measurement by a circulating bath system in the casing of the outer cylinder. The outer cylinder is then rotated at a given speed while the torque exerted on the inner, stationary cylinder is measured. With a given inner and outer cylinder diameter and temperature, quite a large range of viscosities can be measured. The rotational speed of the outer cylinder determines the speed "V" while the area of the cylinder defines the area "A". The clearance between the two cylinders determines the value of "h". The Couette Viscometer can measure the viscosity of both Newtonian and non-Newtonian fluids.

The Hoeppler Falling Ball Viscometer incorporates principle number (5) where the absolute viscosity of the fluid is measured by the velocity of a falling ball as it falls a given distance in the fluid at a given temperature. The governing equation for the absolute viscosity as measured in this system is given as:

(6)
$$\eta = \frac{2(S_b - S_f)gr^2}{9V_b}$$

where

S_b = the specific gravity of the ball at the fluid test
temperature

S_f = the specific gravity of the fluid at the test temp-
erature

g = the acceleration of gravity in cm/sec^2

r = the radius of the ball in centimeters

V_b = the velocity of the ball as it falls a given dis-
tance in the fluid in cm/sec.

The use of different size balls and different specific
gravities of the balls enables the use of this system to be
used for measuring large varieties of fluids and viscosities.
Once again, the temperature of measurement must be carefully
controlled and stated in the results.

Summarizing briefly, viscosity is the most important
property of oils. Temperature and pressure are the two
most important parameters which affect the viscosity.
Nuclear radiation affects the viscosity, but this is usually
in isolated cases where there is radiation in large amounts.

Fluids which have a viscosity which is independent of the applied shear stress are called Newtonian fluids while those that have viscosities which are a function of the rate of shear are called non-Newtonian fluids.

For all viscosity measurements in the many different systems, the temperature at which the viscosity is measured must be carefully controlled and stated in the results. For non-Newtonian fluids, the rate of shear must also be given.

OIL

Oil is the greatest natural resource man has. With it, and the present technology, man has been able to virtually eliminate friction, provide power to drive machinery, provide light and heat, formulate and develop plastics and medicines as well as other countless uses.

Crude oil took many millions of years to form. Initially, the bodies of prehistoric animals and plants fell into existing bodies of water, or fell onto land that was eventually covered with water. Many layers of these plants and animal bodies were covered over with sand, mud and silt. The upheavals of the earth during its early stages pushed many of these stratified layers deep into the bowels of the earth. Under the constant action of heat, chemical action and enormous pressures, the hydrocarbon crude oil was formed.

The surrounding mud, silt and sand, under the same heat, pressure and chemical action eventually solidified into rock. This rock trapped the oil below the surface of the earth. Some of the rock was porous and permitted some of the oil to ooze to the surface of the earth. The non-porous rock formed solid enclosures which the oil couldn't penetrate. For most of the relatively short time man has been on this earth, the

only oil used was that oil that managed to migrate to the
surface of the earth.

In 1859, Colonel Edwin Drake used a rather crude
piece of equipment to go down to where the oil lies; be-
low the surface of the earth. Using a device similar to
the present day pile drivers, he continuously smashed
a hard steel bit down through the rock until the oil
was reached. The oil thus found was taken from the well
by the natural pressure of the oil pocket. This method of
getting the oil continued to be popular until 1901 when the
more effective rotary drilling was used.

Basically, rotary drilling rigs twist a hardened steel
bit into the rock while pressure is applied to the drill bit
to increase the rate of travel into the rock. To keep the
tool bit cool, a special mud is pumped down the hollow
drill bit shaft that supprts and drives the drill bit. The
mud then flows up to the surface and carries the cuttings
to prevent the hinderance of the bit. The mud that solid-
ifies on the wall of the bored hole provides a degree of
support to prevent the collapse of the hole. Once the oil
is reached, the natural pressure of the oil forces the oil
up the drilled hole.

The art of drilling has advanced to such a state that
"directional" drilling is not uncommon. This type of drilling
sends the drill bit down into the earth at some angle diff-
erent than ninety degrees. This permits the oil under un-
accessible areas to be reached without drilling directly over
the oil pocket. This type of drilling is very important
if oil is suspected under a city or otherwise difficult
area.

Offshore drilling is finding its place in the oil
producing systems of today. Since water covers over two-
thirds of the earth's surface and because there is land
under the water, the elimination of this land would have
proven to be wasteful.

Methods used in off-shore drilling vary according to
the position of the well. For relatively shallow drilling,
barges are sunk and the drill rig is built upon the defunct
barge. For deep water drilling, multi-million dollar ped-
estals are built to support the oil rigs many feet above the
surface of the water at the high water mark. Storms at sea
demand that the pedestals be built ruggedly and must be made
to house the crews, machinery and supplies. There are oil
wells in existence today that are over six-hundred feet above
the bottom of the ocean.

With all the modern advances and technology involved in the drilling and location of oil, only one out of eight oil wells produce oil.[1]

Crude Oil Refining

The refining process starts with a huge heat exchanger called a pipe still. Here, heat is applied very rapidly to the crude oil as the oil flows whrough the still. In this still, non-lubricating segments of the crude oil such as gas, gasoline and kerosene and light fuel oil are removed. The rest of the crude oil is called reduced crude because the above segments were removed.

The reduced crude goes to another still where the oil is fractioned into different grades or bodies of motor lubricating oils, namely; light, medium and heavy. A residual oil, heavy in asphalt and petrolatum, is another product of this still. This residual is further processed until the asphalt and petrolatum are removed. The residual oil is then used for purposes other than motor oil.

The motor oil, although distilled, still retains some undesireable impurities such as wax and substances of a

1. "Oil In Depth", American Oil Company, Torchlight Series

highly unstable nature.

The waxes in the motor oil can be effectively removed by one of two ways. The first method is called a propane dewaxing system. Cold, liquid propane is purged through the oil and any wax in the oil solidifies. This solid wax is then filtered out of the oil. The second method uses solvents such as methyl ethyl ketone (MEK) or toluene. The solvents dissolve the wax. The solvent system is as effective as the propane system except it does not involve the low temperature and high pressure associated with the propane system.

Filtering is the principle system used to rid the oil of the other impurities. Finely ground clay is mixed with the oil and left in the oil for some time to allow the clay to absorb the impurities. The "dirty" clay is then removed from the oil by centrifugal filtration. In a modificaion of this system, the oil is forced through beds of clay where the impurities are filtered out in a continuous operation.

Improving Oil's Properties With Additives

Although the motor oil is fully refined at this stage, it is still not perfectly suited for many of the functions that a modern engine demands. High compression engines

turning high RPM's demand that the oil provide oxidation
resistance, prevent foaming, keep engine parts clean, pre-
vent corrosion and effectively lubricate the engine in the
areas of extremely high pressures. The oil must also serve
as a heat transfer medium for cooling the engine. To pro-
vide these properties, additives must be used.

Humble Oil defines an additive as "a chemical added
in small quantities to a petroleum product to enhance,
rather than alter certain desirable properties".[2] The
action of the additive, in general, is on a molecular
level. Almost all of the additives in use are either polar
compounds, polymers or compounds containing sulphur, phos-
phorous or chlorine in active form.

Polar compounds are molecular structures which ex-
hibit a positive charge on one end and a negative charge
on the other end. Because of this, the molecule has the
ability to orient itself in the same way that a compass
needle does. Certain polar compounds have a very strong
attraction for metal surfaces and cling to the metal in a
preferred alignment due to the charges of the compounds.

2."Additives: Their Role in Industrial Lubrication", Humble
    Oil and Refining Company, Lubetext DG-2K, Printed Feb-
    ruary 1967, page 1

Polarity may also create a difference in the chemical properties of the compound. One end of the compound might be water soluble while the other end might be oil soluble.

A polymer is created by the linking of many molecules to form one molecule of high molecular weight. Thus, one long molecule is formed where the individual component's identity is not lost.

Compounds containing active ingredients form a reaction with a base metal or oil to provide extended lubricating properties.

Oxidation is a chemical reaction in which oxygen combines with certain materials. All oils oxidize to some extent. The by-product of the oil's oxidation can be organic acids such as organic peroxides as in the case of oxidized paraffinic oils. Oxidized aromatic oils produce sludge. Napthanic oils produce both sludge and acid when they oxidize. The acid produced is harmful to non-ferrous metals found in engine bearings. The sludge tends to increase the viscosity of the oil and thus limit the oil flow and lubricating properties. The sludge also gums

up the vital engine parts. The rate of oxidation is quite
high in the base oil, and as the temperature of the oil
increases, the rate of oxidation increases. The acid by-
products stimulate further oxidation to yield a potential
chain reaction in the crankcase.

An additive known as an oxidation inhibitor reacts
with the by-product of the initial oxidation-organic per-
oxide. The additive has a strong affinity for this peroxide
and reacts with the peroxide to form a harmful compound.
By removing the peroxide, the rate of oxidation is greatly
reduced and the catalytic peroxides are readily neutralized.

Another type of oxidation inhibitor coats the metals
in the engine that would normally be attacked. These add-
itives are the "compound" type in which certain active ele-
ments in the compound react with the metal to protect the
metal. Some metals, when they oxidize, produce products
which also increase the rate of oxidation. If these metals
are protected from oxidizing, the catalytic by-products
will be removed.

When an engine oil becomes contaminated with water,
rust can start on the metallic surfaces of the engine unless
an additive is placed in the oil that can prevent the oil

from allowing the water to come in contact with the engine surfaces in free form.

Polar compounds added to the oil can form a soluble water-oil mixture and prevent the water from getting on the engine surfaces, or the compound can cling to the metal so strongly that no water can touch bare metal. If there should happen to be water on the surface at the time, the additive will displace the water from the surface due to its strong affinity for the metal.

Corrosion is defined as the gradual deterioration of non-ferrous metals. As noted previously, oxidation by products attack non-ferrous metals. An anti-oxidation additive, to some extent, is also a corrosion inhibitor. Most corrosion inhibitors form a chemical reaction with the metal and physically protect the metal by providing a tough, inert film.

The ability of oil to hold water in suspension is called the emulsibility of the oil. A polar compound which has the property of being oil soluble on one end and water soluble on the other end is the principal type of emulsifying additive. The polar compound links the water

on the one end of the compound and the other end links the
water. The oil and water are not usually mutually soluble.
Because this additive keeps the oil free of "free" water,
rust can not form. The water, if it is kept in suspension,
will be removed during the oil change.

Oil that does not retain water in suspension is said
to be demulsible. Oils used for steam turbines and other
steam equipment must be demulsible so that the condensed
steam can be drawn off of the oil in the oil sump. Because
there is free water in the oil, a rust prevetative must be
added to the oil.

At certain low temperatures, many oils will not flow.
The temperature at which an oil will no longer flow is
called the "pour point". There are two different reasons
why the oil won't flow at these temperatures.

If the oil is principally napthanic, the viscosity
of the oil will increase to such a level that free flow is
prevented. This pour point is the result of the temperature-
viscosity properties of the oil.

In paraffinic oils at low temperatures, wax crystals
in the oils congeal and link together like fingers to phy-
sically prevent the oil from flowing. This temperature for

this oil is called the "waxy" pour point. The waxy pour
point is always reached before the viscosity of the oil is
so high that the oil can not flow. Once the waxy mass is
broken by brief agitation, the oil will flow until the
temperature is reached at which the viscosity of the oil
is too high to flow.

Most of the wax is removed from the oil at the ref-
inery, however, some wax is deliberately left in the oil
to increase certain lubricating properties of the oil. This
is especially true of the paraffinic oils. A high molecular
weight polymer additive prevents the full growth of the
wax fingers and thus the interlacing network is not given
the chance to completely form. This pour point depressant
will lower the pour point only until the oil is too thick
to flow because of its natural increase in viscosity due
to low temperatures.

All oils tend to entrap air due to the natural
churning of the oil by the equipment it is lubricating.
The amount of air held in the oil, and the amount of foam,
will determine if an anti-foam agent is needed. Heavy oils
will tend to hold more air, and more foam, than thin oils
because of the heavy oil's increased surface tension.

When too much air is present in the oil, sometimes oil is replaced by air in the lubricating process. Air is not an acceptible lubricant in engines, expecially high speed engines. Too much foam can cause oil sumps to overflow, and if pumps are used to distribute the oil, vapor lock and cavitation can occur.

The use of medium molecular weight silicone polymers as an additive proves to be a very effective anti-foam agent. The polymer attacks the surrounding oil around the bubble and reduces the surface tension of the oil. The air bubble then rises to the free surface of the oil where it is easily broken due to the low tension of the oil skin.

Detergent-dispersants are used not only to clean an engine's parts, but it also prevents impurities from getting on the engine. The detergent part of the additive will remove sludge that is already on the engine. The dispersant will keep this dirt in solution in the oil and take the dirt with it in the oil change. The detergents are made of metallic soaps with polar attraction for the solids in the oil. Because of the polar properties of the additive, the oil's emulsibility is improved.

In today's modern high speed, high compression engines, high pressures are developed in the bearings, cams and cam-

shafts, rocker arms and lifters. Incomplete lubrication
might result if an extreme pressure (EP) additive is not
used in the oil.

Complete fluid film lubrication depends upon the
moving object's ability to "pull" oil into the region
of high pressure.[3] This oil film seperates the objects
and prevents wear and heat build up. However, if the
motion of the object is not fast enough, or not uniform,
not enough oil will be pulled into the high pressure re-
gion to provide the adequate seperation. This seperating
film does not exist upon the object's surface if the ob-
ject has not been used for a while. Upon start-up of the
object, there isn't any fluid film to prevent metal to
metal contact until the proper oil pressure could be
built up. For a slight period of time the engine compon-
ents will have metal to metal contact, and during this
time, wear is accelerated.

To prevent metal to metal contact upon start-up, or
sporadic motion of the object, or possibly from the in-
ability of the object to form a complete oil film due to
the rupturing of the oil film, a polar type additive is

3. "Principles of Lubrication", Humble Oil and Refining
   Company, Lubetext DG-5A, Printed April 29, 1963, page 7

placed in the oil. Some of these additives have a very strong affinity for the metal surfaces and plate themselves to these surfaces. The compound then holds some of the oil on the surfaces and provides lubrication in the form of a high strength, continuous thin film. Polar additives are also used to increase the film strength of the base oil so that the film won't rupture under boundary lubrication. This property is especially useful in heavy, reciprocating machinery.

Polar additives employ physical and chemical protection for the critical parts. Some additives use only physical protection. In the abscence of a lubricating film, microscopic welding and rupturing of the asperities on the surface results. The physical additive under the very high local temperatures of this microscopic welding, melts before the metal's asperities do. The two surfaces then slide over each other using the melted additive as a lubricant.

Thus it can be seen that the use of additives in the oil does indeed enhance the basic properties of the oil.

VISCOSITY INDEX

As mentioned earlier in this report, all oils will show an increase in viscosity for a decrease in temperature. As the temperature increases, the oil's viscosity will decrease. Many oils that have the same viscosity at a given low temperature will not have the same viscosity at a given higher temperature. The rate at which an oil's viscosity will change with temperature is known as the Viscosity Index of the oil. An oil that varies very little with a change in temperature is said to have a high V.I. while an oil that changes alot with a temperature change is known as a low V.I. oil.

West coast narthanic oils were known to have a very large variation in viscosity for a given temperature range, and for this reason this oil was arbitrarily assigned the index number of zero (0). In contrast, East coast paraffinic oil was assigned an index number of 100 because this oil showed a slight viscosity change for a given temperature change. The work of Dean and Davis in 1928 defined how any oil could be classified as to how much its viscosity would change with a certain temperature change.[1,2]

1. "Lubrication-Viscosity", Texaco Incorporated, Volume 52, Number 3, page 38
2. "New Viscosity Index System For Lubricating Oils",ASTM D2270

Dean and Davis stated that if the viscosity-temperature properties of both the one-hundred index oil and the zero index oil were known, the V.I. of any other oil could be determined by comparing the oil's properties with that of the known V.I. oils. (Figure 4) The equation below is used to find the V.I. of the unknown oil

$$(7) \qquad \text{VISCOSITY INDEX} = \frac{L - U}{L - H} \times 100$$

where

L = the viscosity (kinematic) of the zero V.I. oil at $100^{\circ}F$

H = the viscosity (kinematic) of the one-hundred V.I. oil at $100^{\circ}F$

U = the kinematic viscosity of the unknown V.I. oil at $100^{\circ}F$

In choosing the values of the zero and one-hundred V.I. oil, the viscosity of all three oils must be the same at $210^{\circ}F$. Thus, in order to determine the V.I. of any oil, the kinematic viscosity of that oil must be known at 100° and $210^{\circ}F$. The V.I. system is useless if the above condition is not met.

This system for finding the viscosity index of an oil was so well accepted that the American Society for Testing and Materials (ASTM) accepted the system as standard and

"0" V.I. (L)

UNKNOWN V.I.

"100" V.I. (H)

L

U

H

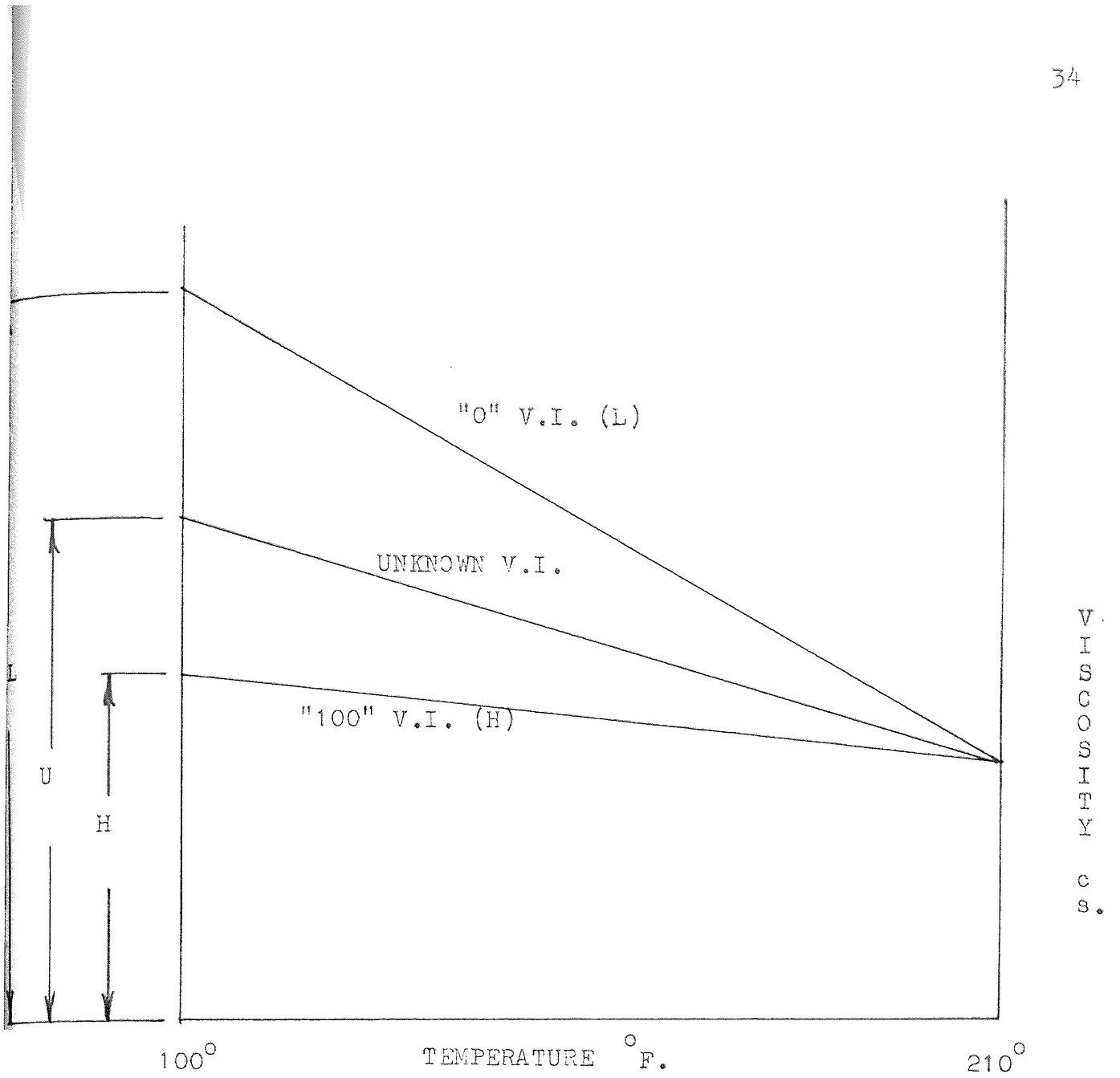100°   TEMPERATURE °F.   210°

VISCOSITY cs.

FIGURE 4. A plot showing the representation of the
equation used in determining the Viscosity Index of
an unknown V.I. oil. Note that all three oils have
the same viscosity (kinematic) at 210°F

assigned it their number D567 which is still used in industry.

However, the system had several drawbacks in it, namely:

a) the system did not hold true for light oils with a kinematic viscosity below eight centistokes at 210°F

b) the whole system was based upon arbitrary standards based upon the numbers zero and one-hundred. These standard numbers are no longer suitable for many blended oils and synthetics.

c) the viscosity index of a blend consisting of different V.I. oils could not be determined from the weighted average of the components.

d) an oil with exceptionally good temperature-viscosity properties will have a viscosity index which is a function of the oil's viscosity. An oil with an infinite V.I. (one that does not show any change in viscosity with a change in temperature) will have a certain kinematic viscosity at 210°F. The "L" and "H" values are fixed once the viscosity of the unknown oil is determined. If the oil in question has a different kinematic viscosity at 210°, then the"L" and "H" values would also be different. In this way, the viscosity index of the oil could range from 100 to 350
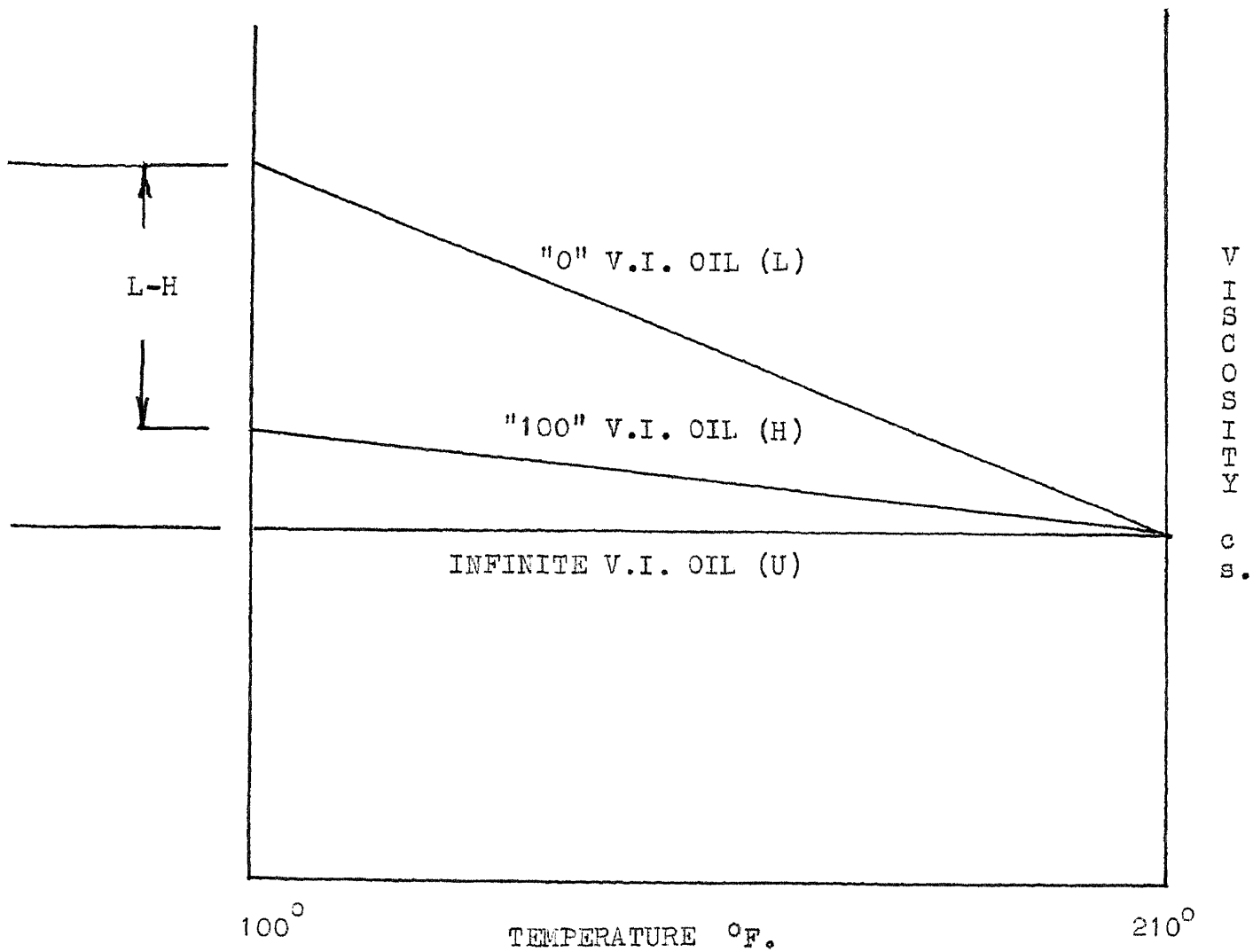
FIGURE 5. A plot showing how it is possible for an oil to have a Viscosity Index greater than 100. The viscosity at 210° will determine the value of the V.I. of the oils. For this viscosity, the viscosity of the "L" and "H" oils are fixed, thus the Unknown oil will have a V.I. that is a function of its viscosity at 210°.

if the system of Dean and Davis is used to calculate the viscosity index.[3] (Figure 5)

e) two different oils with identical viscosity indices in the range of 150 could have the same kinematic viscosity at 100° but with different kinematic viscosities at 210°F. All oils with a viscosity index of 150 could be represented by a line constructed by joining points that represent the kinematic viscosities at 100° and 210° of each oil. The ordinate of this plot would be the kinematic viscosity of the oils at 100° while the abscissa would be the kinematic viscosity at 210°F. The line thus formed would not be linear, but it would have a maximum point. After this maximum point, the line decreases in such a way that a horizontal line from the ordinate intercepts the line in two places. This horizontal line represents a given kinematic viscosity at 100°F. The fact that this line intercepts the plot in two places illustrates the fact that there are two values of viscosity at 210° for a 150 V.I.

Because the inconsistencies and drawbacks of this ASTM standard D567 were recognized, a desire for a more uniform standard was voiced by many companies. As a result of lobbying at the Third and Fourth World Petroleum Congresses

3."Lubrication-Viscosity", Texaco Incorporated, Volume 52, Number 3, page 38

KINEMATIC VISCOSITY @ 210°F cs.
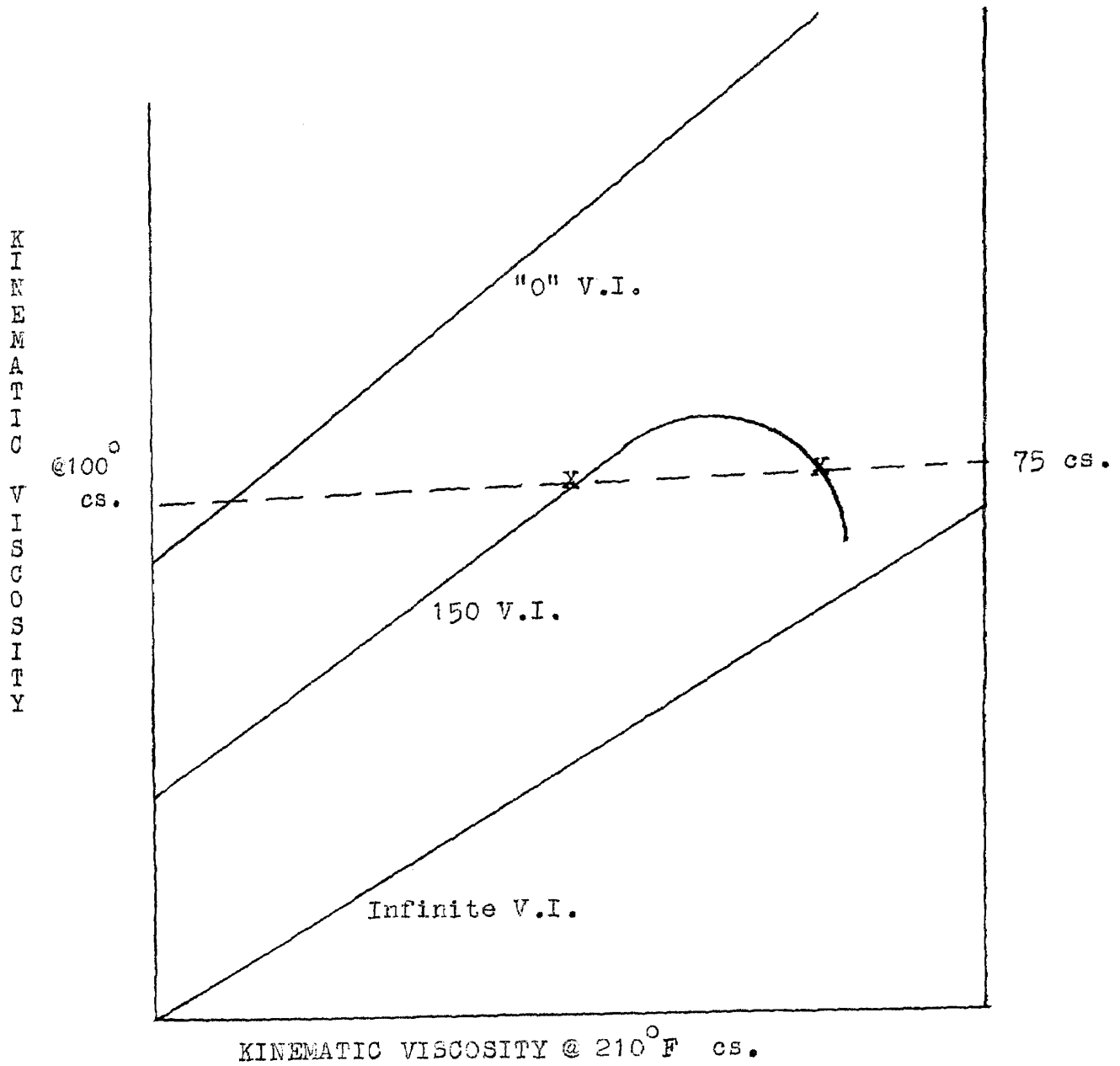
FIGURE 6. This illustration shows how two oils with the same V.I. have different viscosities at 210° and identical viscosities at 100°. The infinite V.I. oil has equal viscosities at 100° and 210°F.

in 1951 and 1955, and under the sponsorship of the ASTM, standard D2270 was developed and finally accepted in 1964.[4] This new standard is identical to D567 for indices below and including values of 100, which was one of the initial requirements in the development of D2270. For those values of the index above 100, the transition from the old to the new standard was made smooth and continuous. The new standard was also developed so that it would be easy to use. When industry finally accepts standard D2270, it is probable that D2270 will replace D567.[5]

Standard D2270 consists of two parts: Part A is for indices less than or equal to 100, Part B is for those oils that have indices greater than 100. Part A is identical to the old ASTM D567. Part B consists of equations

$$(8) \qquad (K.V._{210})^N = \frac{H}{U}$$

Solving for "N" yields;

$$(9) \qquad N = \frac{\log H - \log U}{\log K.V._{210}}$$

4. "New Viscosity Index System For Lubricating Oils", ASTM standard D2270
5. Ibidem.

Solving for the value of the viscosity index;

$$(10) \qquad V.I._{210} = \frac{(antilog\ N) - 1.0}{.0075} + 100$$

where;

K.V.$_{210}$ = the kinematic viscosity of the unknown oil
at $210^\circ F$.

H = the kinematic viscosity at 100° of an oil having
a 100 index by the ASTM D567 and having the same
viscosity at 210° as the unknown oil

U = the kinematic viscosity at 100° of the unknown oil

N = the exponent required to raise the viscosity of
the oil at 210° to equal the ratio of the "H"
and "U" viscosities

V.I.$_{210}$ = the viscosity index "extended" (100 or more)

If the kinematic viscosity at 210° is greater than 75.0
centistokes, the value of "H" can be obtained from;

$$(11) \qquad H = 0.19042Y^2 + 12.968Y - 101.8$$

where;

Y = the kinematic viscosity of the oil at 210°

There are four ways to obtain the viscosity index from
the kinematic viscosity data at 100° and 210°F. The first
system is incorporated in the ASTM "Viscosity Index Tables
Calculated From Kinematic Viscosity" (Data series number
DS-39). This is a book which contains complete viscosity
tables from 2.00 to 75.0 centistokes at 210° to enable
viscosity indices to be calculated from zero (0) to up
to 300.

The common log-log sliderule is used to calculate the
viscosity index of the unknown oil in the second system. The
results are accurate to within one V.I. unit.

The third method involves logarithmic calculations
where the "L" and "H" values of the viscosity of the un-
known oil at 210° are taken from Table I of ASTM standard
D2270. The "H" value is the "L" value minus the value of
"D" in this table. The rest of the calculations are straight
forward and involve the use of equations (9) and (10).

The last and most popular system consists of using
charts supplied by ASTM D2270. A sloping line is drawn be-
tween two vertical scales which are calibrated in units os
centistokes at 210°F. A third scale, calibrated in units of
centistokes at 100°F is located in such a position that when
a horizontal line is drawn from the value of the unknown

oils viscosity, it will intersect the sloping line drawn
at the value of the viscosity at 210° right above a hor-
izontal scale calibrated to yield the viscosity index
representative of the unknown oil. A particular use of
this chart is that the viscosity of a given V.I. oil at
either 100° or 210° can be found if only one of the vis-
cosities is known.

The desire for an oil with an improved temperature-
viscosity relationship has been recognized for a long time.
In 1867, just two years after the Civil War, a United States
patent was issued to Messrs. Eames and Seely for their "im-
proved compound" oil. The compound consisted of rubber, a
light hydrocarbon fraction and a fixed fatty oil which,
according to the developers, would "increase the oil's
fluidity at low temperatures while at the usual summer
heat, the body of the oil is increased".[6]

Polymer blending has been used to improve the temp-
erature-viscosity relationship in engine oils since the 1930's.
The typical polymer consists of very high molecular weight
long chain polymers. The molecular weight usually ranges
from 5,000 to 20,000 while some polymers may hit values

6. "Lubrication-Viscosity I", Texaco Incorporated, Number 1.
    Volume 47, January 1961, page 40

as high as 700,000. The principal types of polymers used today are butene polymers, polymethylacrylates and nitrogen containing polymers polyisobutylene and polyalkylatyrene

During this time from the 1930's to the present, the state of the art of this polymer blending has advanced to such a degree that it now becomes possible to create an oil that has a predetermined viscosity at 210° or $0^\circ F$. Thus, if a certain viscosity base oil is chosen, a given amount of a certain polymer can be added such that the resulting oil will have a viscosity identical to the predetermined viscosity. This means that the viscosity can be made to order on blended oils.

Because these polymer-blended multi-viscosity oils have become more and more popular, and because these oils have unusual viscometric properties for a given temperature range, it became necessary to standardize how these oils would be designated so that different brands of the same standard designation would produce oils that have the same properties at the same temperature. Generally speaking, single weight oils have numbers which designate the viscosity of the oil as measured at $210^\circ F$, however, the numbers are not the numerical values of the viscosity at $210^\circ F$. An oil with the designation SAE 30, as determined by the

Society of Automotive Engineers, will have a kinematic
viscosity greater than 9.6 cs. but less than 12.9 cs. at
210°F. As long as the oil's viscosity at 210° is between
the limits just mentioned, the oil is called an SAE 30
weight oil. If the kinematic viscosity is less than 9.6
but greater than 5.7 cs., it is called an SAE 20 oil.
(Table I)

An oil that has an absolute viscosity of greater
than 1200 cp. but less than 2400 cp. at 0°F is desig-
nated as a 10W oil. The letter "W" refers to the fact that
the viscosity is measured at 0°F. This suffix can be un-
derstood to mean "winter" because it is primarily for this
season that these low viscosity oils are needed. It should
be noted that the viscosity mentioned is not kinematic,
but rather centipoise. The kinematic viscosity in centi-
stokes is usually reserved for those oils that do not have
the suffix "W".

As mentioned previously, the two standard temperatures
used to measure the viscosity of the oils are 100° and 210°F.
The value of the viscosity at 0°F is obtained by interpro-
lation of the data for the oil at the two standard temper-
atures above. This is the reason that the viscosity of the
"winter" oil is given in absolute terms. The mass density
of the oil will change as the temperature is decreased.

TABLE I

SAE VISCOSITY NUMBERS FOR CRANKCASE OILS

SAE cosity mbers	Viscosity Units	Viscosity Range $0^\circ F$		$210^\circ F$	
		MIN ___ MAX		MIN	MAX
5W	Centipoise	less than 1200			
	Centistokes	1300			
	Saybolt Seconds	6000			
10W	Centipoise	1200 [a] less than 2400			
	Centistokes	1300 2600			
	Saybolt Seconds	6000 12000			
20W	Centipoise	2400 [b] less than 9600			
	Centistokes	2600 10500			
	Saybolt Seconds	12000 48000			
20	Centistokes			5.7	less than 9.6
	Saybolt Seconds			45	58
30	Centistokes			9.6	less than 12.9
	Saybolt Seconds			58	70
40	Centistokes			12.9	less than 16.8
	Saybolt Seconds			70	85
50	Centistokes			16.8	less than 22.7
	Saybolt Seconds			85	110

(a) Minimum viscosity at 0° may be waived provided the viscosity at 210° is not below 4.2 cs. (40 SUS)

(b) Minimum viscosity at $0^\circ F$ may be waived provided the viscosity at 210° is not below 5.7 cs. (45 SUS)

The absolute viscosity and the mass density both increase, but not in the same proportion. An interprolation of the data in kinematic terms would be incorrect because the mass density is assumed to change the same amount or percentage as the absolute viscosity.

CONCLUSION

All of the engine oils the writer tested, without exception, suffered a permanent loss in viscosity during the test period of approximately 1500 miles. These losses ranged from a minimum loss of 25% to a maximum of 49% at 100°F. while the losses at 210° ranged from a minimum of 1.1% to a maximum of 47.7%. The viscosity indices of these oils varied from a maximum loss of 36% to a gain of 65%.

Only two samples of Rotunda 6000 Mile engine oil were used in this report. The first sample was taken from a new can of the engine oil as purchased from a Ford dealer. The second sample was taken from the crankcase of a 1967 Ford during its first oil change at 3000 miles. The oil showed a viscosity loss of 1.6% at 100° and a similar loss of 20.5% at 210°F. The viscosity index decreased 23.9% during the 3000 mile test period. Because only two samples were used for this test, a completely accurate conclusion can not be stated because it is not known how intermediate samples taken at 500 mile-intervals would have tested.

Sinclair's Dyno Supreme showed a permanent viscosity loss of 40.6% at 100° and a loss of 11.6% at 210°F. The viscosity index increased a total of 59.6% during the 1617 mile test period.

Shell Oil's _Super Shell_ showed a net permanent viscosity loss of 42.1% and 47.7% at 100° and 210° respectively. The viscosity index decreased 20.3%.

Mobil's _Special_ suffered a loss in viscosity of 25.2% at 100° and 29.3% at 210°. The viscosity index showed a net decrease of 10% based upon the original virgin oil sample.

American Oil Company's _Super Permalube_ had a viscosity loss of 34.6% at 100° after 2000 miles of use. The loss at 210° was only 1.10%. The viscosity index increased a total of 40% during this period. The viscosity loss at 1500 miles was 38.4% at 100° and 3.30% at the higher temperature. The slight increase in viscosity at 2000 miles could have come from the contamination normally found in the oil as the mileage on the oil increases.

Veedol' s multigrade engine oil showed a loss in viscosity of 49% at 100° and 15.3% at 210° after 1706 miles. The viscosity index increased 65.5% relative to the virgin oil sample.

Super Blend, Quaker State's multigrade engine oil, had a loss in viscosity of 30.6% at 100° after 475 miles of use. At 1075 miles, the viscosity increased until the net loss in viscosity, relative to the unused virgin sample, was only 1.0%.

The viscosity loss at 210° and 475 miles was 46.5% and increased until the final viscosity at 1075 miles was measured at 30.8%. This increase in viscosity between 475 miles and 1075 miles probably resulted from the accidental addition of one quart of SAE 30 engine oil to the crankcase in the period between the above mileages. The results at 1075 miles at both the measurement temperatures are not considered representative of the original oil. The viscosity index, however, showed a decrease of 34.1% at 475 miles and a net decrease of 36% at 1075 miles.

As evidenced in this report, the evaluation of an engine oil's performance based upon the viscosity index alone can be misleading. A viscosity index increase could result from a loss in the oil's viscosity providing the viscosity decrease at 210° is greater than the decrease in viscosity at 100°F.

Based upon the oil's extrapolated viscosity at 0°F. and the measured viscosity at 210°F., it was found that;

Rotunda 6000 Mile engine oil still qualified as a 10W-30 engine oil after 3000 miles of use. This conclusion is based upon two samples that were taken 3000 miles apart.

Dyno Supreme, Sinclair's brand of multigrade engine oil qualified as 5W-30 engine oil instead of the original 10W-20-30.

Mobil's Special qualified as 5W-20 instead of its original specification of 10W-30.

Shell's Super Shell had a final rating of 5W-20 instead of the original 10W-20W-30.

American's Super Permalube fulfilled the requirements for a 5W-30 engine oil compared to its original 10W-30.

Veedol filled the requirements as a 5W-30 engine oil instead of the original 10W-20W-30.

Quaker State's Super Blend failed to meet its original low temperature requirement of a 10W oil, but it did meet the 30 weight specification at 210°. The final designation was 5W-30. This oil had a mixture of regular SAE 30 engine oil and the original 10W-20W-30 oil.

Throughout all the tests on these oils, the rate of oil consumption did not appear to be any more, or any less, than the oil consumption rate of single weight engine oil.

From a practical viewpoint, it appears that it would be wise to use the multiviscosity engine oils in the colder winter months where the low viscosity of these oils permits low cranking energy and battery drain. In the warmer summer months, a single weight engine oil of high enough viscosity to provide proper lubrication should be used.

A low viscosity oil is not needed in the summer months, but the high temperature viscosity is needed to provide adequate lubrication.

Some automobile manufacturers recommend 6000 miles between oil changes. Based upon the results of this test, the viscosity might be too low at 6000 miles if a multi-viscosity oil is used. Because the mileage involved was only 1500 miles, a definite statement can not be made as to where the line should be drawn concerning permissible time between oil changes and the time at which risks are being taken. The writer feels that a 2000 to 3000 mile interval should not be exceeded. Additives are depleted as a function of time, and the only way to replace these additives is to replace the oil with new oil.

The color of the oil is not a good means to determine when crankcase oil should be changed. Many oils at 1000 miles looked as "bad" as oils taken at 1500 miles. None of the oils were gritty or contaminated. Once foreign bodies are felt in the oil, regardless of when the oil was changed last, the oil should be changed.

Several oil companies recommend that oil should be changed every 3000 miles or 60 days based upon depletion of additives and increase in the acidity of the oil.

RECOMMENDATIONS

The writer realizes that for future tests of this nature to be more meaningful, the test period should be extended and more oils should be tested. It would be interesting to see how single weight engine oils perform under the same conditions.

If any more tests on multi-viscosity oils are performed, it is recommended that samples of the oils be taken at 500 mile intervals up to 4000 miles. At this mileage, more information could be gained regarding long range results of the effect upon the viscosity and extraprolated results at 6000 miles would be more meaningful.

Contaminants in the oil at higher mileages might increase the viscosity of the samples. Filtering the oil prior to viscosity measurements should remove most of the solids and sludge found in the higher mileage oils.

Viscosity change is just one part of the total change in the oils' properties as a function of mileage. Additives are also depleted as time goes on, but it is not known at what rate these additives are lost. Based upon this, and several oil company's reports, the oil in the crankcase

should be changed every 3000 miles or 60 days, whichever comes first.

Many garage men report that the rate of oil consumption of multi-viscosity oils increases as time and mileage increases. One mechanic reported that he added one quart of the same multi-viscosity oil to his car after 1200 miles and another quart 900 miles later. With this in mind, it would be interesting to see if the oil consumption rate for multi-viscosity engine oils is lower, higher or equal to single weight engine oils.

APPENDIX

OILS INVESTIGATED

1) Mobil Oil's Mobil Special 10W-30

   1966 Chevrolet Impala 250 cubic inch 6 cylinder engine

2) Quaker State's Super Blend 10W-20-30

   1957 Ford Fairlane 8 cylinder engine

3) Sinclair Oil's Dyno Supreme 10W-20W-30

   1964 Rambler Classic 135 horsepower 6 cylinder engine

4) American Oil's Super Permalube 10W-30

   1960 DeSoto 361 cubic inch 8 cylinder engine

5) Shell Oil's Super Shell 10W-20W-30

   1961 Rambler American 6 cylinder engine

6) Rotunda 6000 Mile Oil 10W-30

   1967 Ford Galaxie 500 289 cubic inch 8 cylinder engine

7) Veedol 10W-20-30

   1963 Rambler American 6 cylinder engine

APPARATUS

1) Adjust-A-Volt Isolated Variable Transformer

2) Daytronic Differential Transformer Plug In Type 60

3) Fisher Unitized Bath Control, Model 33, Fisher Scientific Company

4) Philadelphia Micro-Set Thermomoeter, range $-27^{\circ}F$ to $127^{\circ}F$

5) Rao Couette Viscometer Model B4, Rao Instrument Co. Inc.

6) Moseley Autograf, Model 135A, X-Y Recorder

7) Servo Amplifier Controller, Model R5A66, Rao Instrument Co. Inc.

8) Westphal Specific Gravity Balance, Henry Troemmer Inc.

9) "Time-It!" Precision Timer, Precision Scientific Co. Inc.

10) Chromalox Hot Plate, Edwin L. Wiegand Co., 2000 watts Variable Input

11) Pipette Viscometer Number 128, Orifice factor = .306 DuPont Photo Products Research Lab

12) Mercury bulb thermometer, $-20^{\circ}C$ to $+200^{\circ}C$

SAMPLE CALCULATION

VISCOSITY INDEX

Using the data presented for Super Shell at 1500 miles

$$V_{100} = 35.7 \text{ cs. @ } 100°F$$

$$V_{210} = 7.97 \text{ cs. @ } 210°F$$

From ASTM standard D2270-64, we get the value for "H" for the following viscosities at $210°F$

H = 63.84	V_{210} = 8.00
H = 62.62	V_{210} = 7.90

Interprolating for "H" at the viscosity of 7.97 cs. @ $210°$

$$H = 63.47 \qquad = 7.97$$

Substituting into the equation

$$(V_{210})^N = \frac{H}{U}$$

Solving for the value of "N" using the data above

$$7.97^N = \frac{63.47}{35.70} = 1.78, \therefore \; N = 0.278$$

Substituting the value of "N" thus found into the equation

$$VI_e = \frac{(\text{antilog N}) - 1.0}{.0075} + 100.0$$

$$VI_e = \frac{(1.900) - 1.00}{.0075} + 100.0$$

$$VI_e = \frac{0.900}{.0075} + 100.0 = 120.0 + 100.0$$

$$VI_e = \underline{220.0} \quad \text{Answer}$$

MILEAGE	VISCOSITY @100°	PERCENT LOSS
0	66.1	---
500	63.5	39.3
1000	45.8	30.7
1500	40.7	38.4
2000	43.2	34.6

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	13.68	---
500	13.79	.11
1000	10.58	3.10
1500	10.38	3.30
2000	12.58	1.10

OIL TYPE
AMERICAN

	ABSOLUTE VISCOSITY (centipoise)	SPECIFIC GRAVITY	KINEMATIC VISCOSITY (centistokes)	TEMP (°F.)
0	57.2	.865	66.1	100
0			13.68	210
500	55.0	.868	63.5	100
500	. .		13.79	210
000	40.0	.873	45.8	100
000			10.58	210
500	35.7	.876	40.7	100
500			10.38	210
000	37.8	.877	43.2	100
2000			12.58	210

OIL TYPE: AMERICAN

MILEAGE	$V_0°$ (SUS)	$V_{100}°$ (C.S.)	$V_{210}°$ (C.S.)	H	N	V.I.	% CHANGE (V.I.)
0		66.1	13.68	141.7	.290	227	
							+5.28
500		63.5	13.79	143.4	.310	239	
							+6.16
1000		45.8	10.58	96.1	.314	241	
							+18.00
1500		40.7	10.38	93.4	.354	268	
							+40.00
2000	1700	43.2	12.58	125.2	.420	318	

VISCOSITY INDEX

KINEMATIC VISCOSITY

V.I.

100°F

210°F

MILEAGE

AMERICAN

62
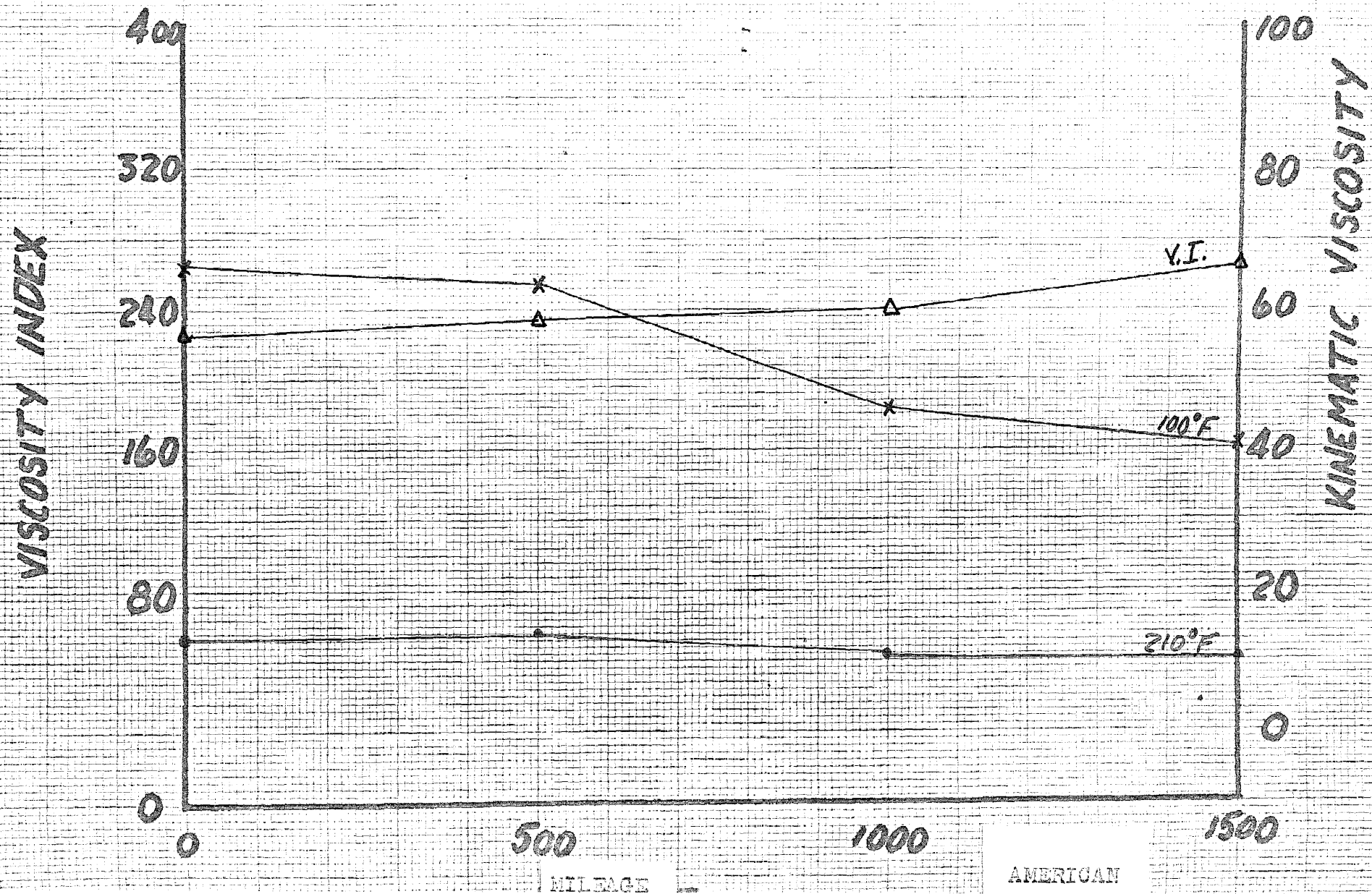
OIL: SUPER PERMALUBE
MILEAGE: 0
VISCOSITY: 66.1 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X 10⁻²

63
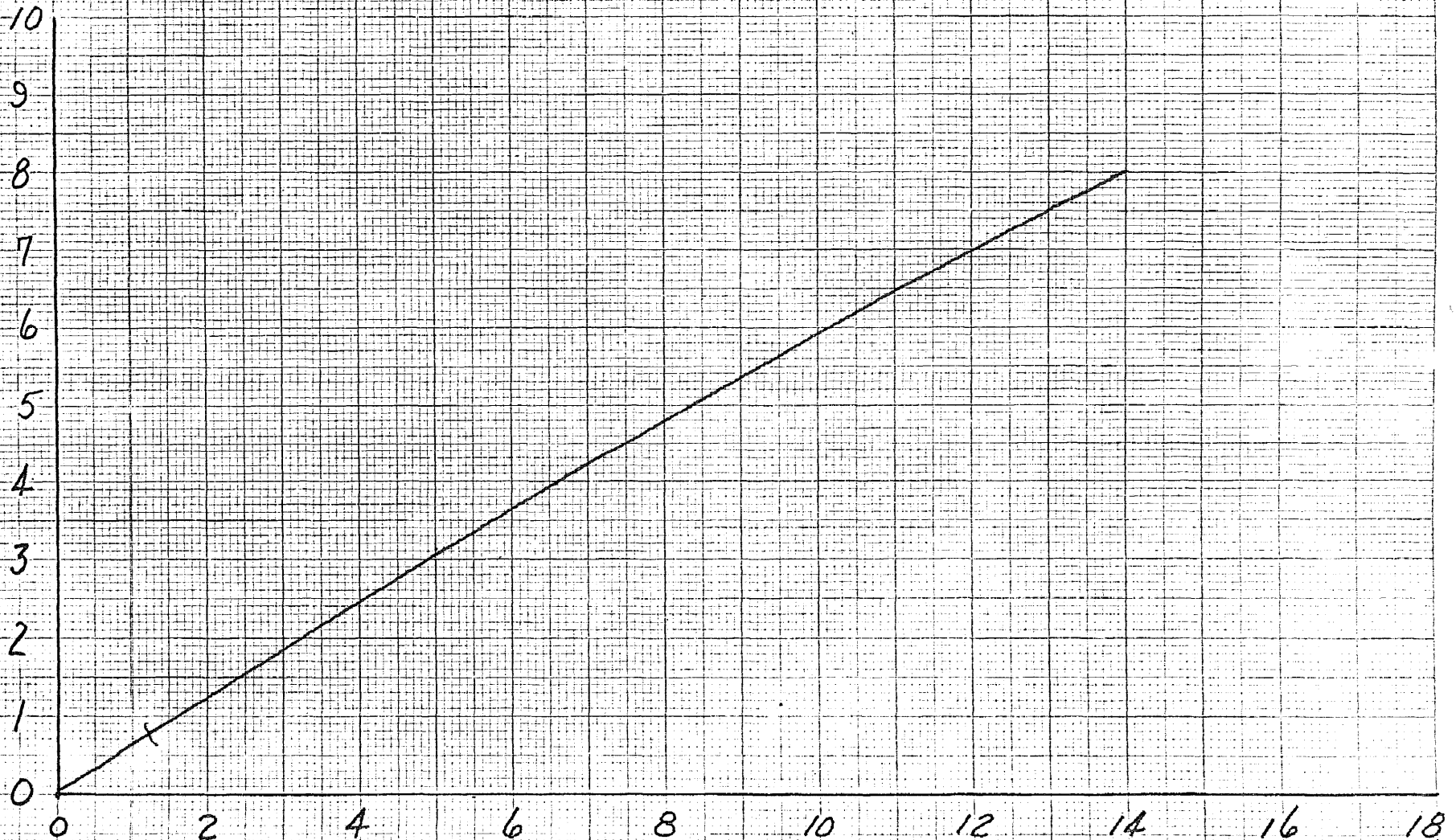
OIL: SUPER PERMALUBE
MILEAGE: 500
VISCOSITY: 63.5 cS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²

64
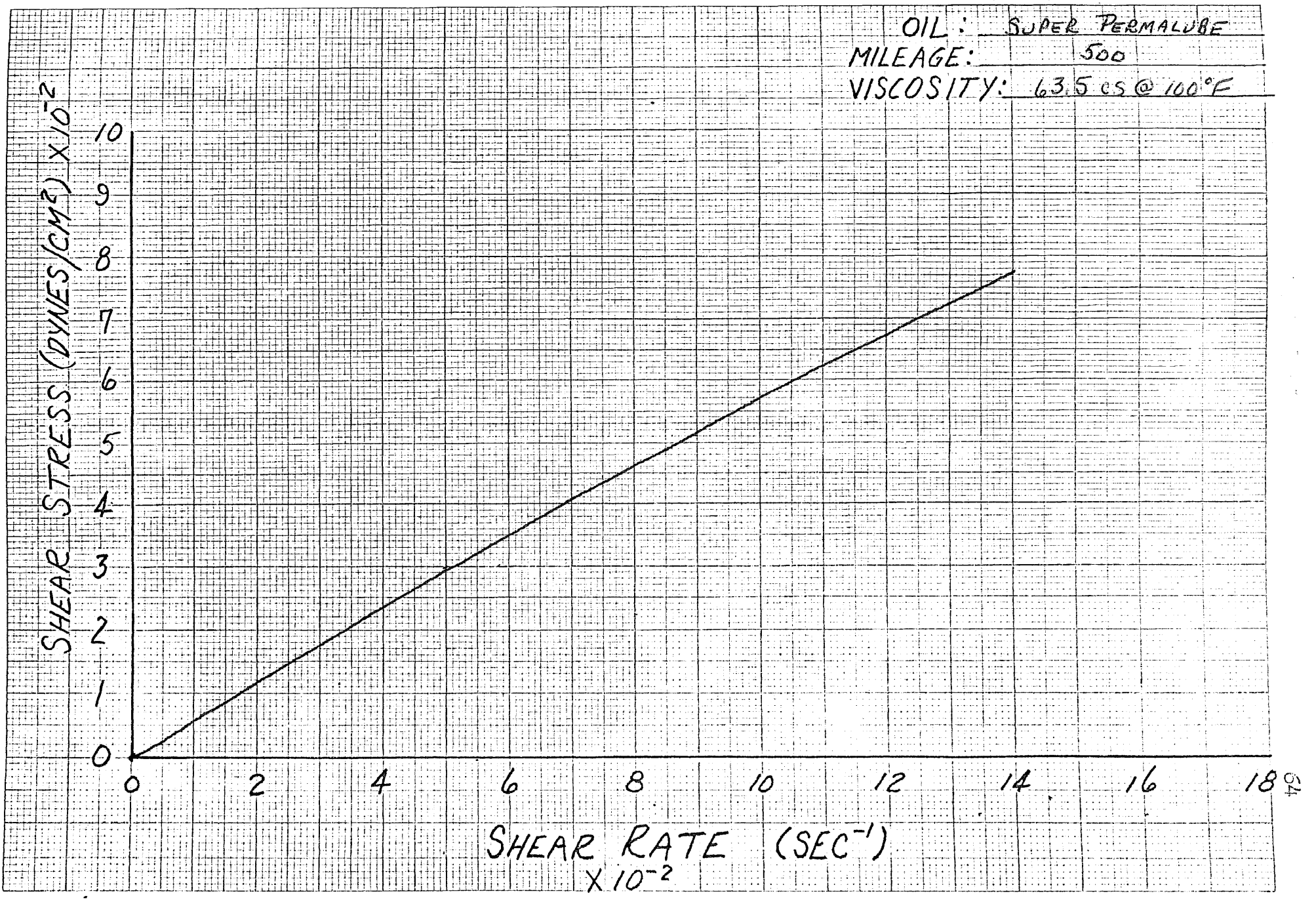
OIL: SUPER PERMALUBE
MILEAGE: 1000
VISCOSITY: 45.8 cs @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²

65
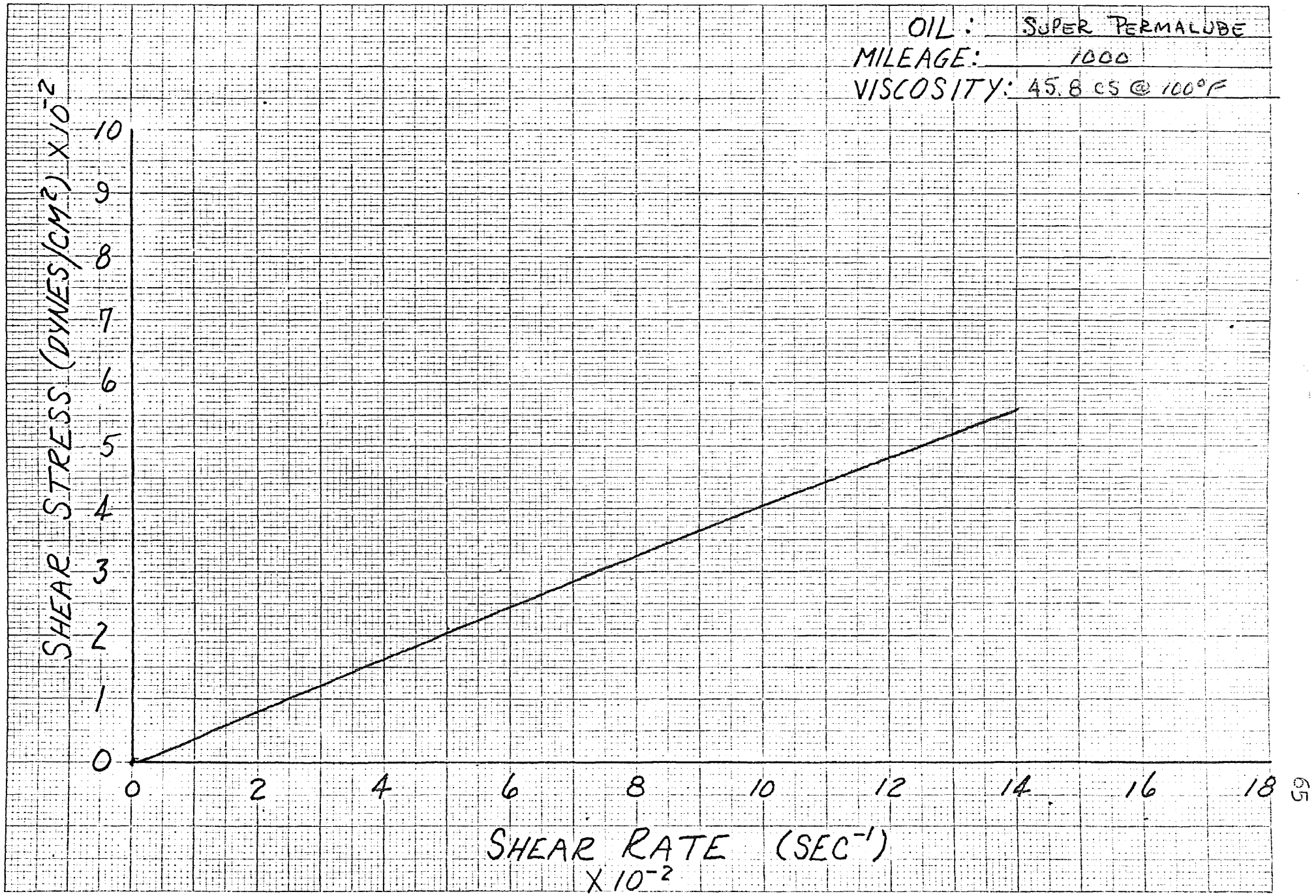
OIL: SUPER PERMALUBE
MILEAGE: 1500
VISCOSITY: 40.7 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²
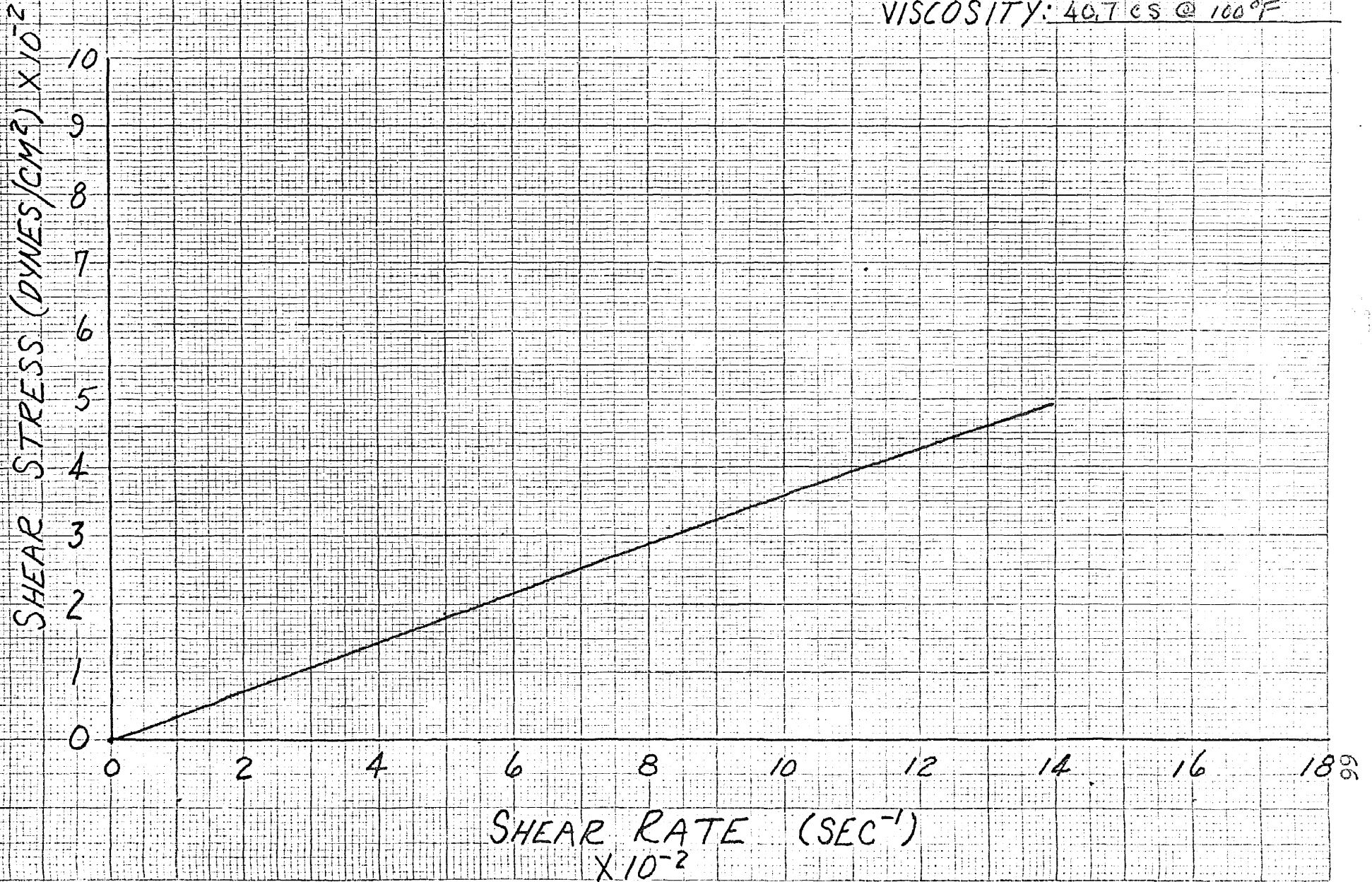
OIL: SUPER PERMALUBE
MILEAGE: 2000
VISCOSITY: 43.2 cs @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²
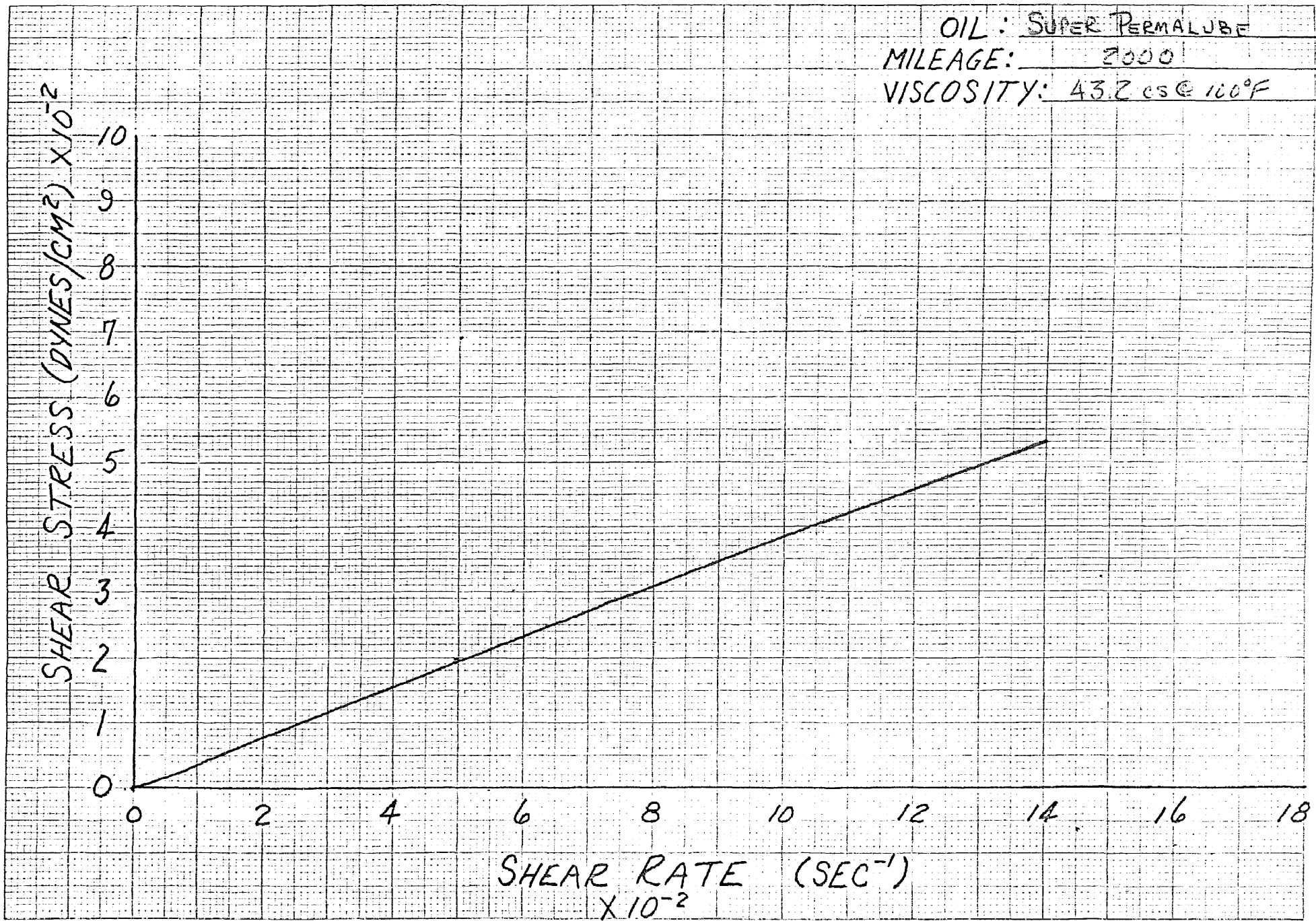
MOBIL

MILEAGE	VISCOSITY @100°	PERCENT LOSS
0	54.3	---
563	47.5	12.5
1075	41.5	23.6
1545	40.6	25.2

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	13.89	---
563	11.98	13.8
1075	11.78	15.2
1545	9.82	29.3

OIL TYPE
MOBIL SPECIAL

AGE	ABSOLUTE VISCOSITY (centipoise)	SPECIFIC GRAVITY	KINEMATIC VISCOSITY (centistokes)	TEMP ($^\circ$F.)
0	47.3	.870	54.3	100
0			13.89	210
563	41.5	.873	47.5	100
563			11.98	210
1075	36.4	.877	41.5	100
1075			11.78	210
1545	35.8	.881	40.6	100
1545			9.82	210

OIL TYPE: MOBIL

EAGE	$V_0°$ (SUS)	$V_{100}°$ (C.S.)	$V_{210}°$ (C.S.)	H	N	V.I.	% CHANGE (V.I.)
0		54.3	13.89	144.9	.371	280	
							− 4.00
63		47.5	11.98	116.4	.361	273	
							+ 10.00
075		41.5	11.78	113.6	.408	308	
							− 10.00
45	2400	40.6	9.82	87.0	.332	253	

VISCOSITY INDEX

KINEMATIC VISCOSITY

V.I.

100°F

210°F

MOBIL

MILAGE

400

320

240

160

80

0

0

500

1000

1500

100

80

60

40

20

0

71
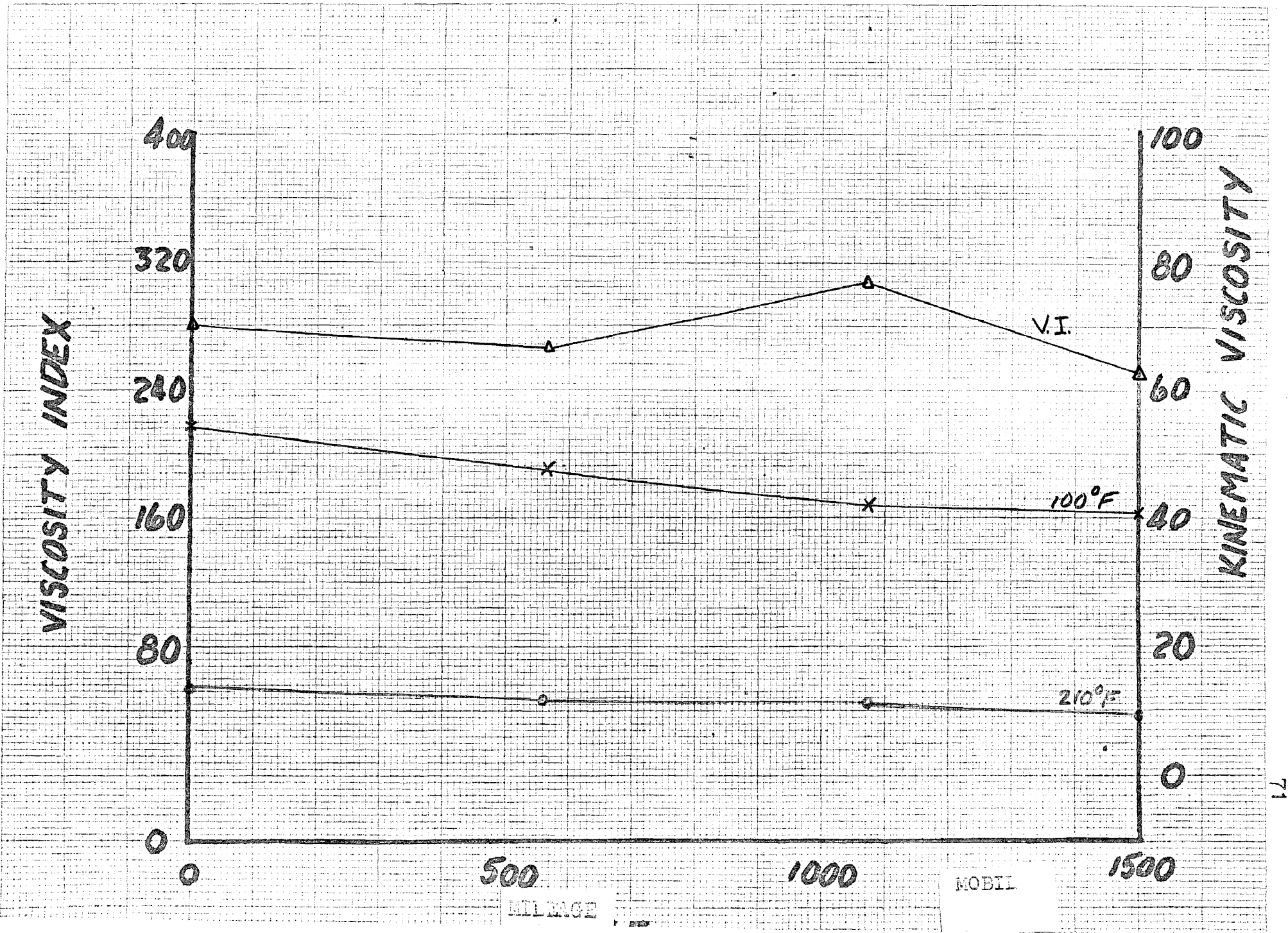
OIL: MOBIL SPECIAL
MILEAGE: "0" MILES
VISCOSITY: 54.3 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X 10⁻²

SHEAR RATE (SEC⁻¹)
X 10⁻²
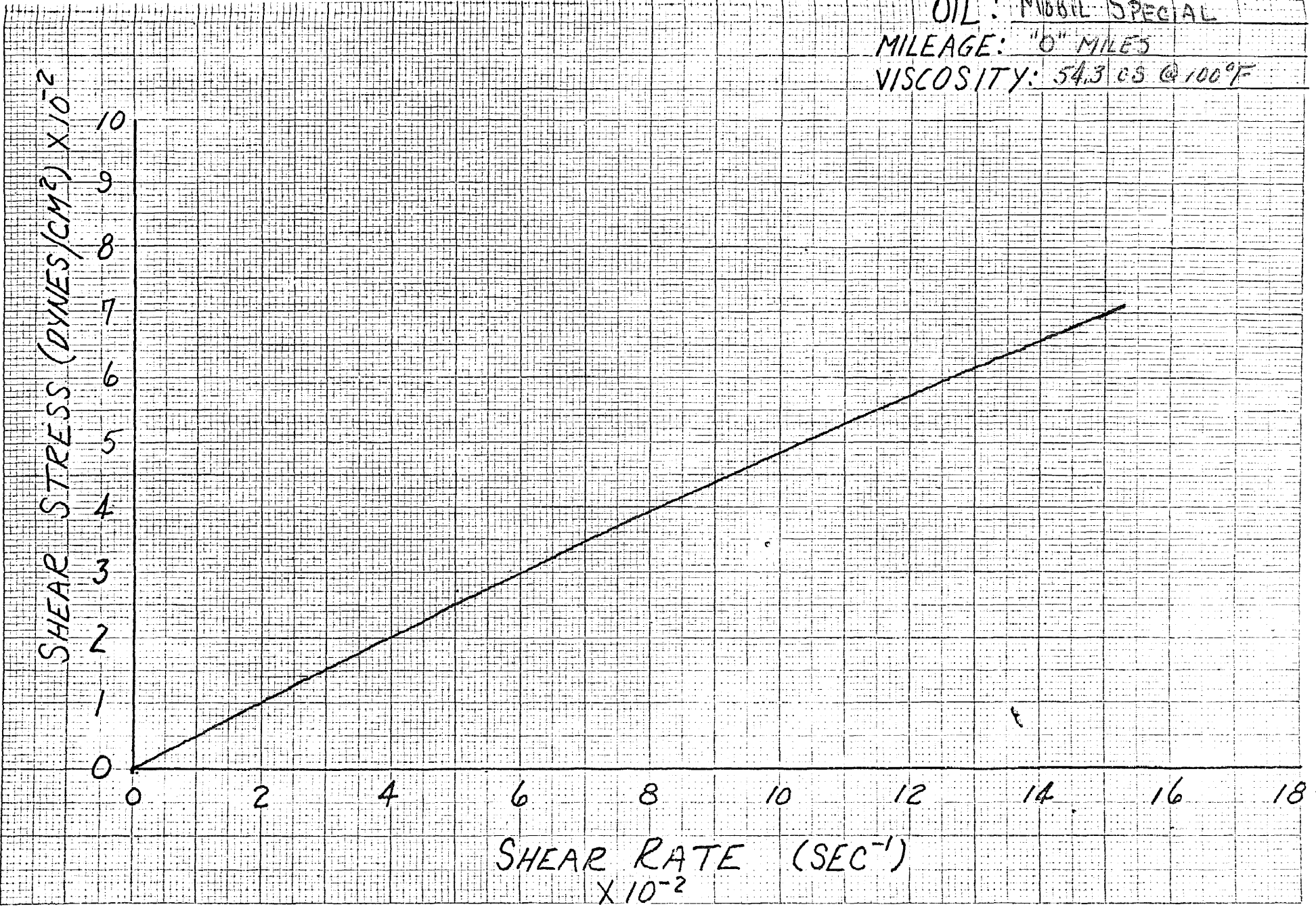
OIL: MOBIL SPECIAL
MILEAGE: 563
VISCOSITY: 475 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²
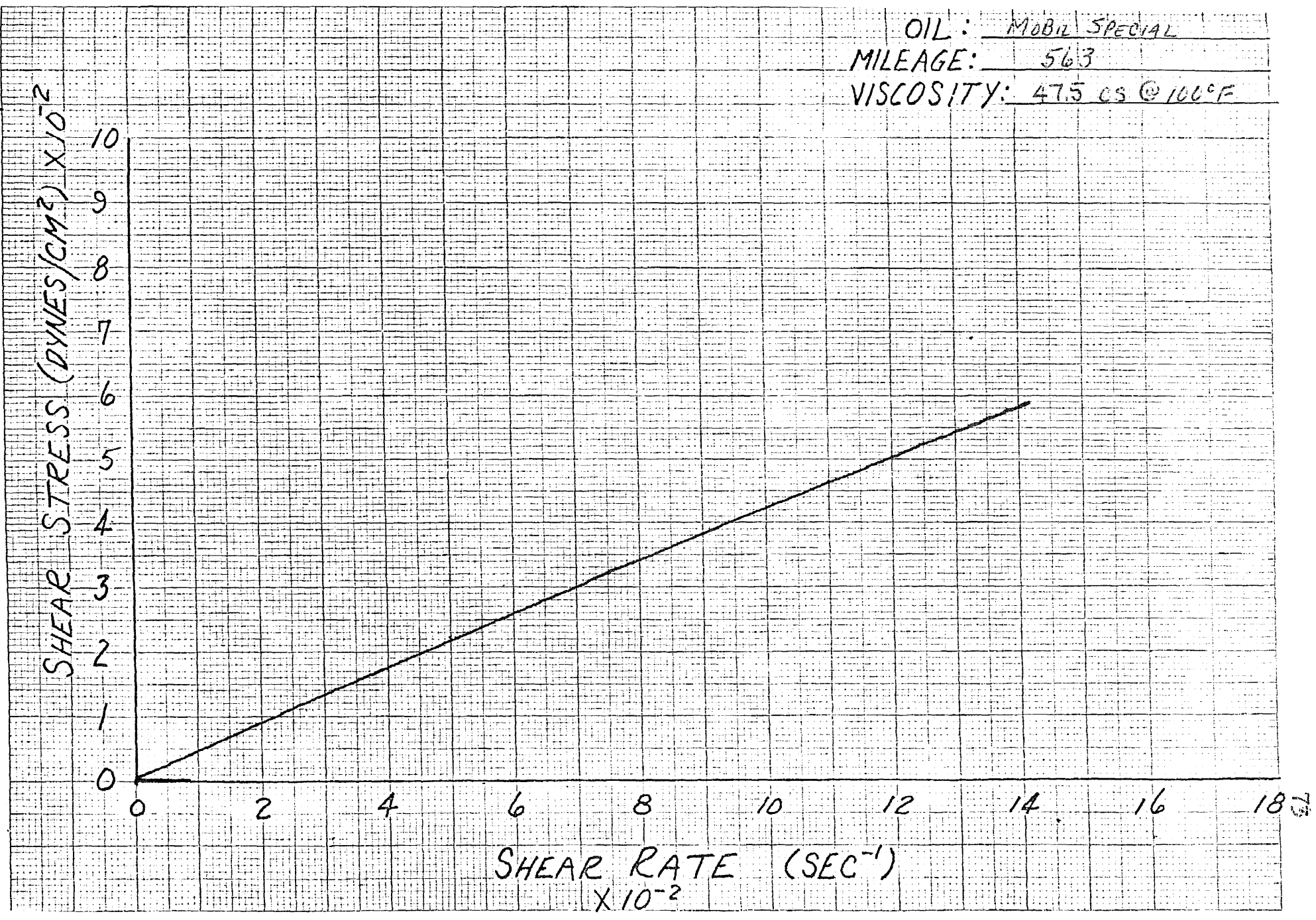
OIL: MOBIL SPECIAL
MILEAGE: 1050
VISCOSITY: 41.5 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²

74
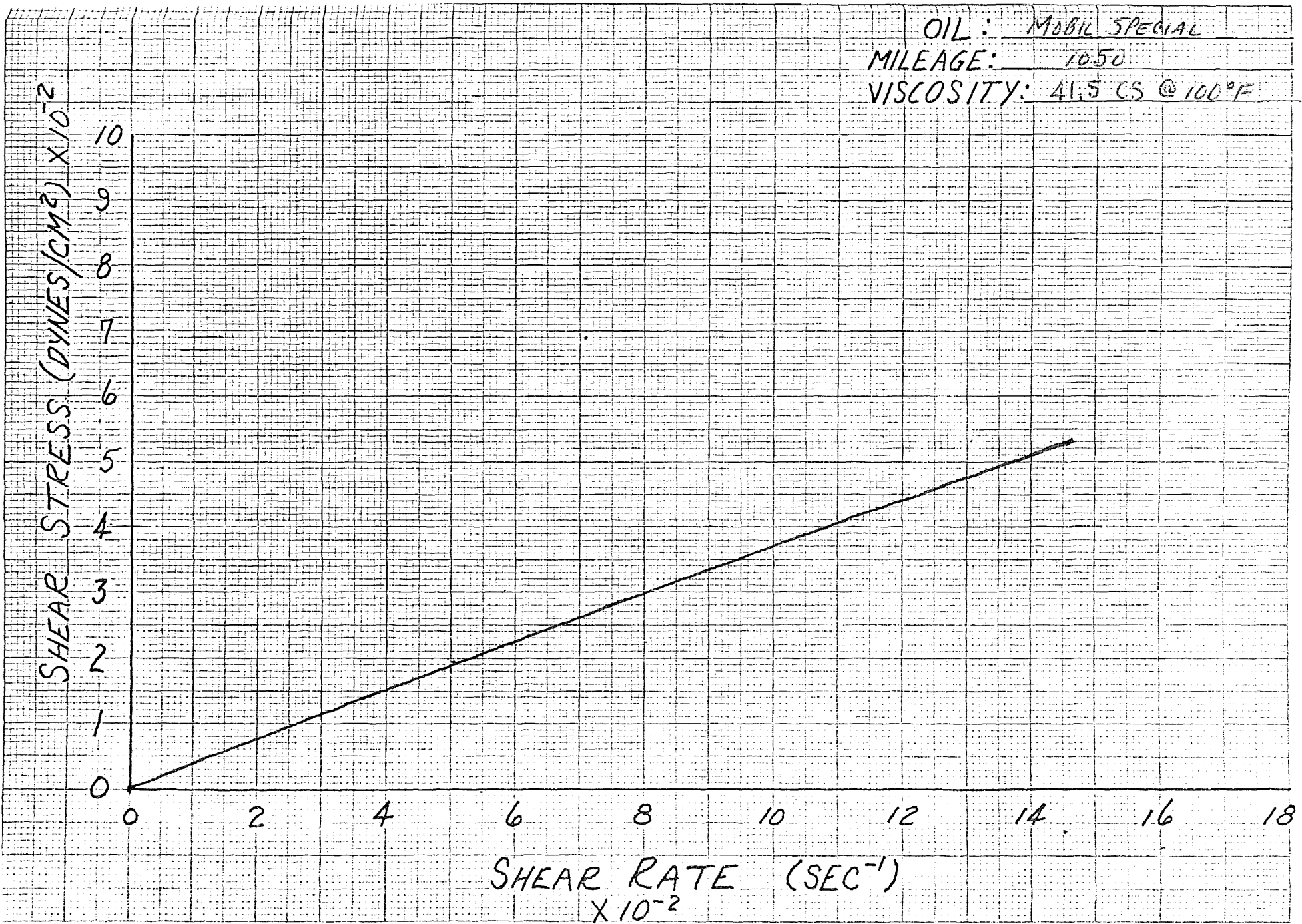
OIL: MOBIL SPECIAL
MILEAGE: 1545
VISCOSITY: 40.6 cs @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²
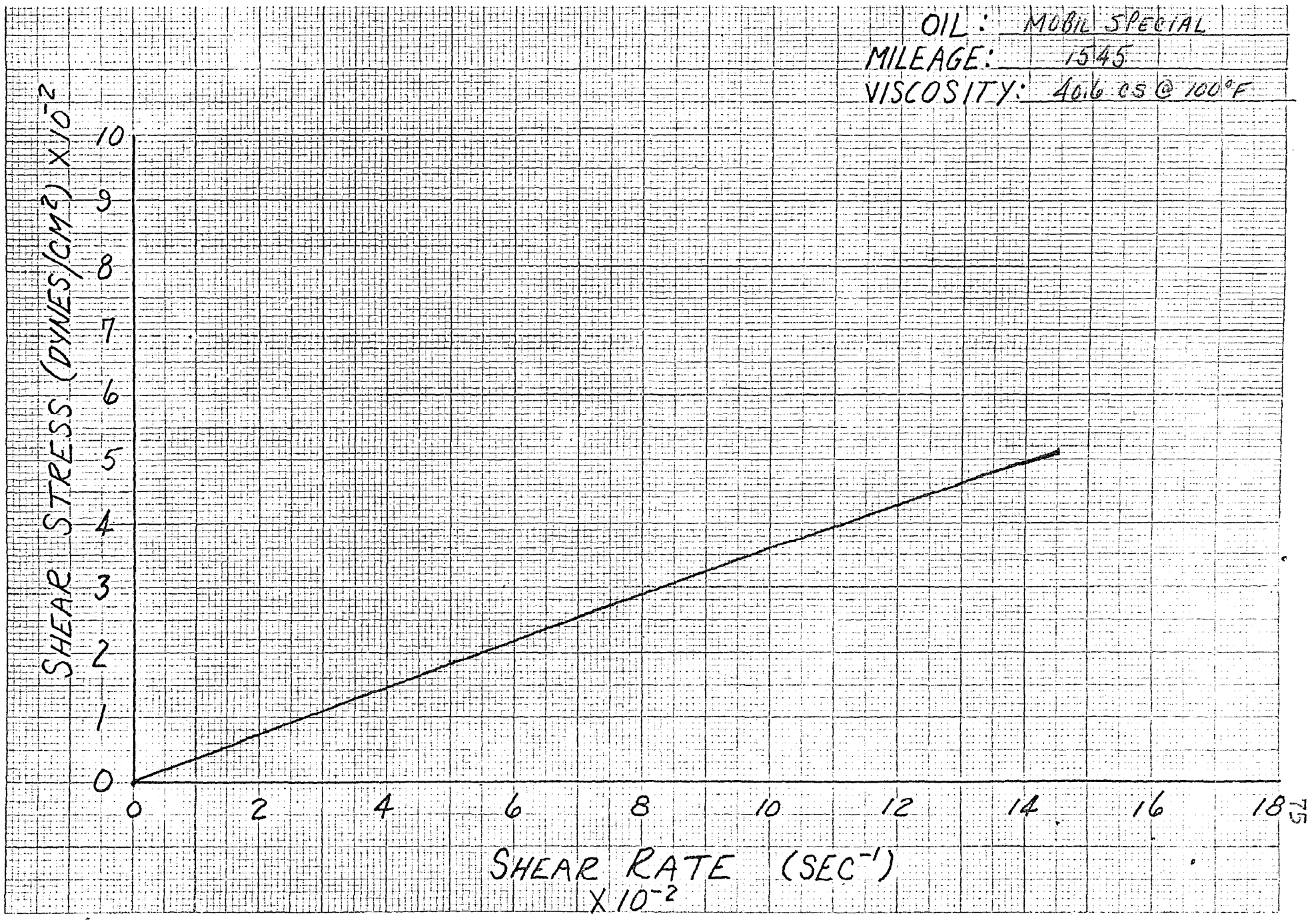
QUAKER STATE

MILEAGE	VISCOSITY @100^a	PERCENT LOSS
0	55.2	---
475	38.3	30.6
1075	55.7	1.0

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	1 5.3	---
475	8.18	46.5
1075	10.58	30.8

QUAKER STATE

MIL	ABSOLUTE VISCOSITY (centipoise)	SPECIFIC GRAVITY	KINEMATIC VISCOSITY (centistokes)	TEMP (°F.)
0	47.8	.866	55.2	100
0			15.29	210
475	33.1	.864	38.3	100
475			8.18	210
1075	47.3	.867	55.7	100
1075			10.58	210

OIL TYPE: QUAKER STATE

EAGE	$V_0°$ (SUS)	$V_{100}°$ (C.S.)	$V_{210}°$ (C.S.)	H	N	V.I.	% CHANGE (V.I.)
0		55.2	15.29	166.9	.405	305	
							− 34.1
175		38.3	8.18	66.1	.261	209	
							− 36.0
075	1700	55.7	10.58	96.1	.234	195	

VISCOSITY INDEX

KINEMATIC VISCOSITY

400

320

240

160

80

0

0

500

1000

1500

MILEAGE

QUAKER STATE

100

80

60

40

20

0

X 100°F

V.I.

210°F

79
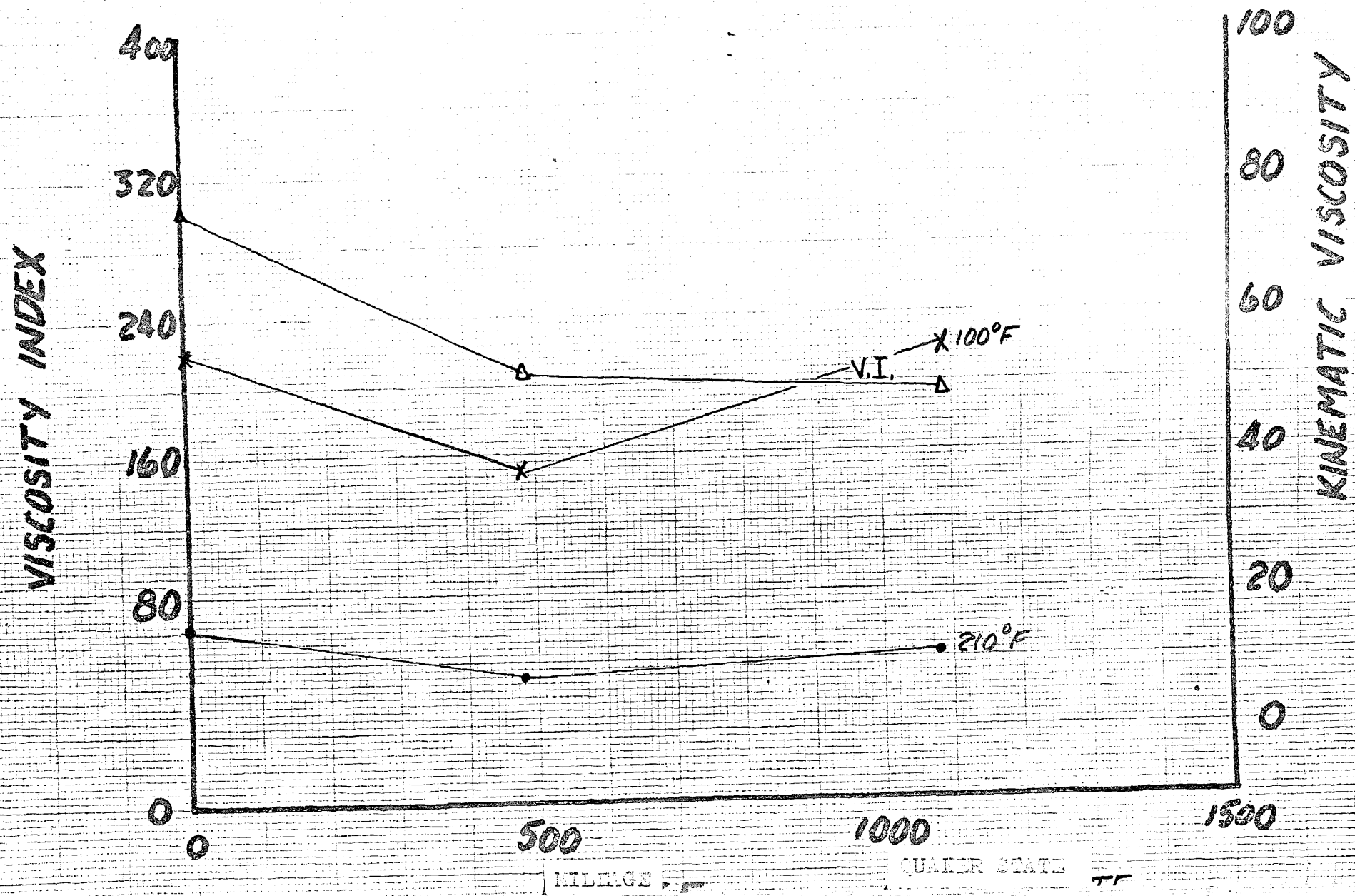
OIL: QUAKER STATE
MILEAGE: "0" MILES
VISCOSITY: 55.2 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²
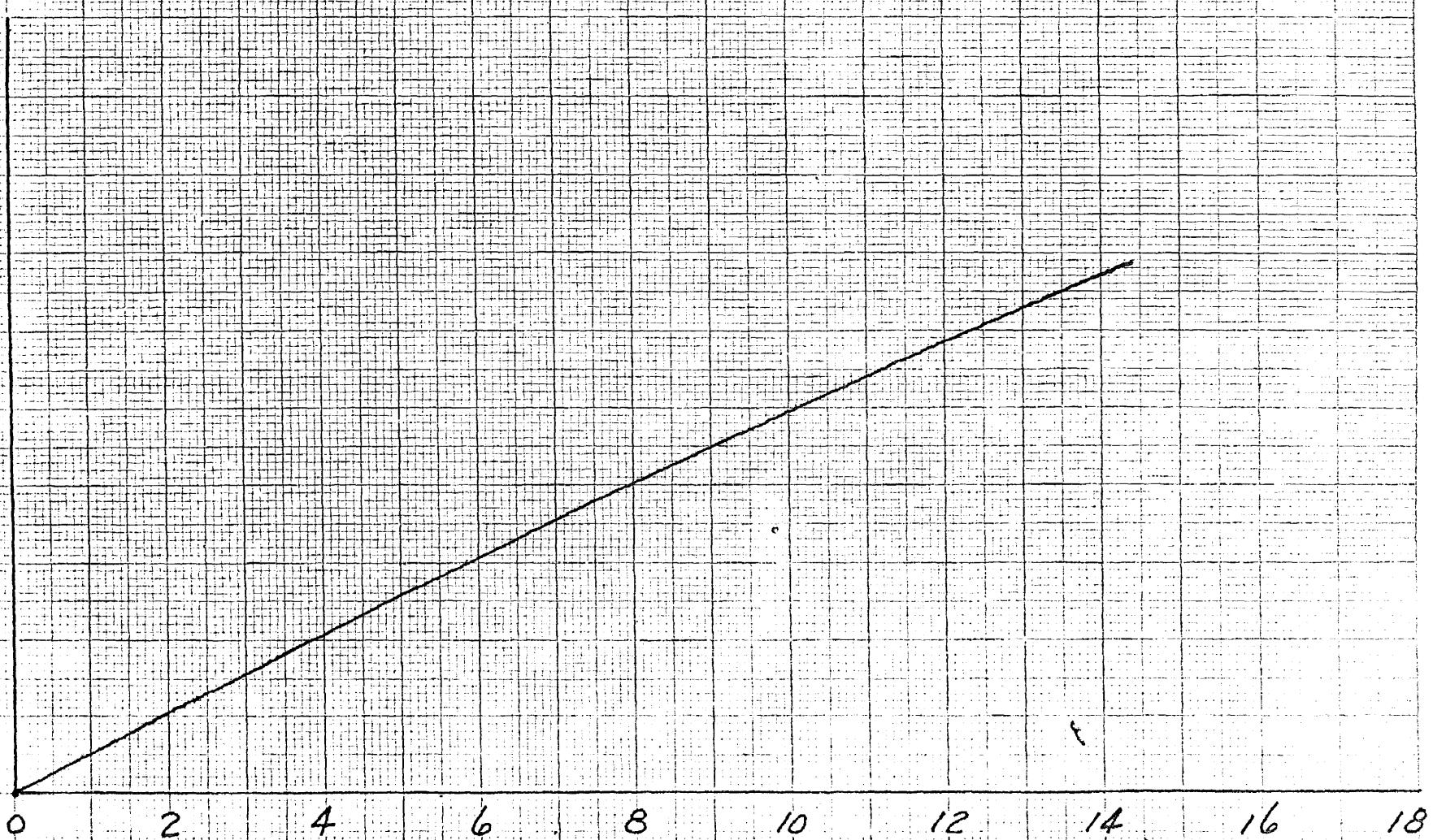
OIL: QUAKER STATE
MILEAGE: 475
VISCOSITY: 38.3 CS @100°F

SHEAR STRESS (DYNES/CM²) $\times 10^{-2}$

SHEAR RATE (SEC⁻¹) $\times 10^{-2}$

81
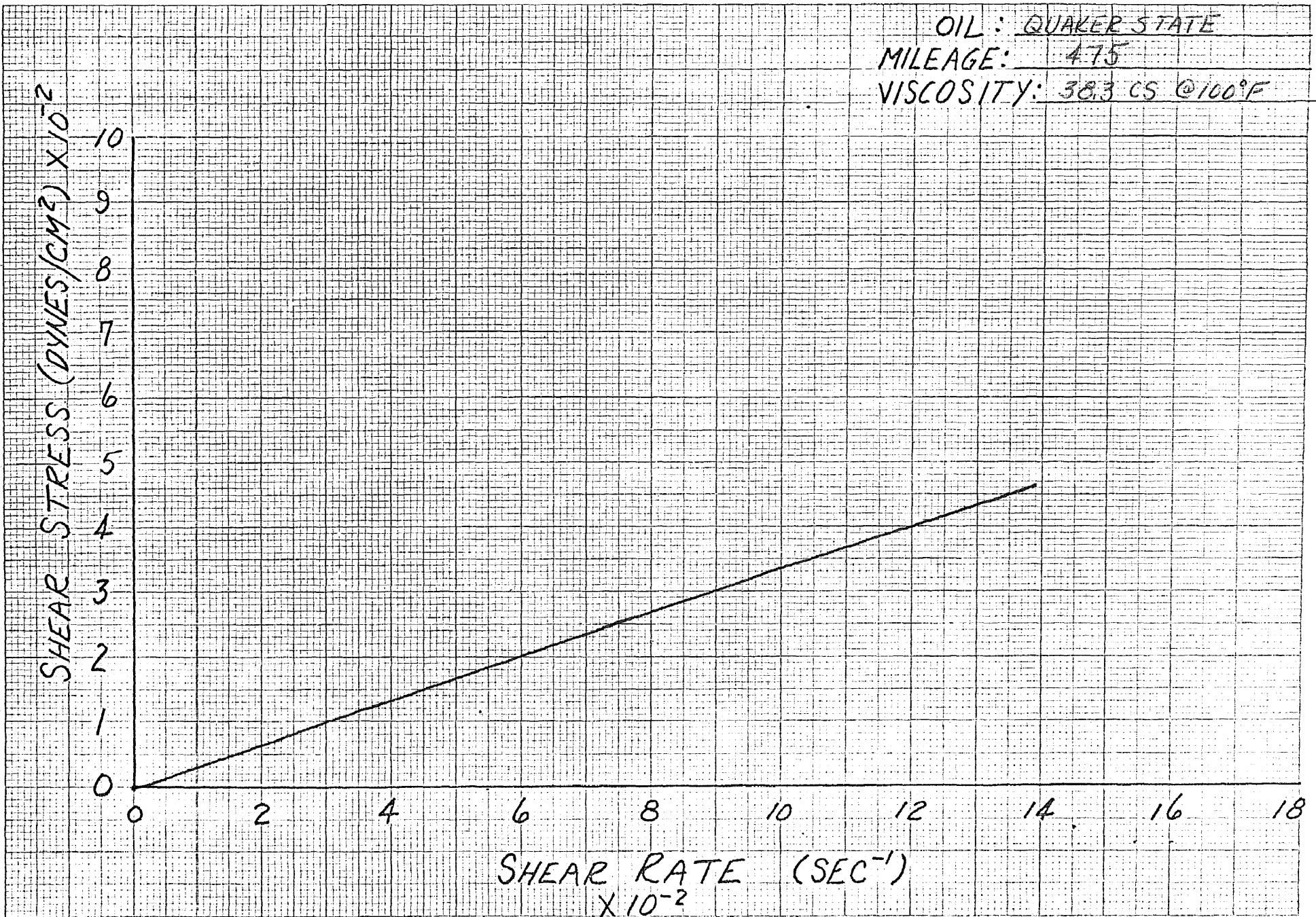
OIL: QUAKER STATE
MILEAGE: 1075
VISCOSITY: 5.57 cs @ 100°F

98
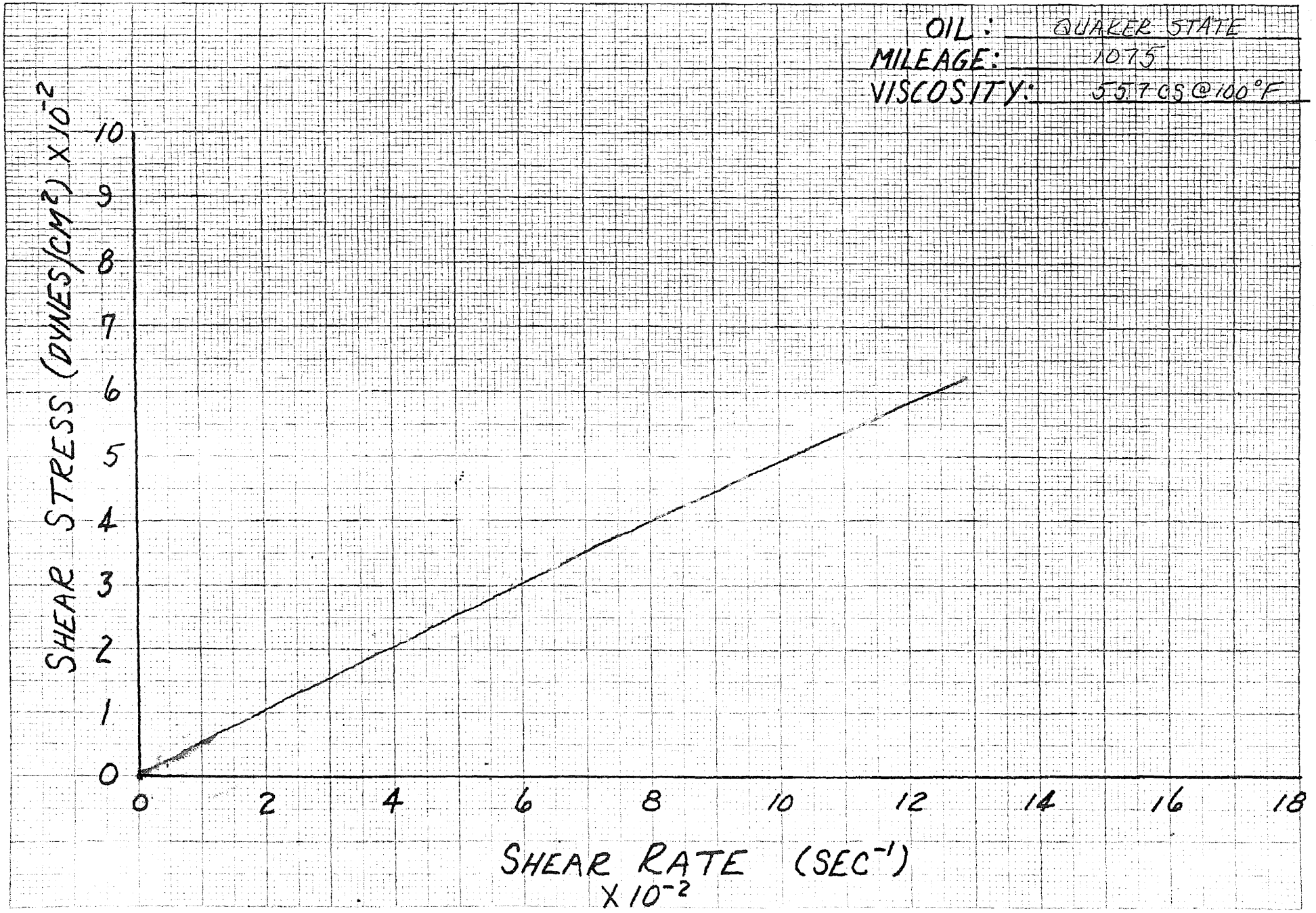
ROTUNDA

MILEAGE	VISCOSITY @100°	PERCENT LOSS
0	60.8	---
3000	60.7	1.6

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	1 4.69	---
3000	11.68	20.5

OIL TYPE
ROTUNDA

L	ABSOLUTE VISCOSITY	SPECIFIC GRAVITY	KINEMATIC VISCOSITY	TEMP
	(centipoise)		(centistokes)	(°F.)
	52.2	.859	60.8	100
			14.69	210
00	53.5	.882	60.7	100
00			11.68	210

OIL TYPE: <u>ROTUNDA</u>

EAGE	$V_0°$ (SUS)	$V_{100°}$ (C.S.)	$V_{210°}$ (C.S.)	H	N		V.I.		% CHANGE (V.I)
)		60.8	14.69	157.3	.354		268		
									-23.90%
000	6500	60.7	11.68	112.2	.250		204		

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²
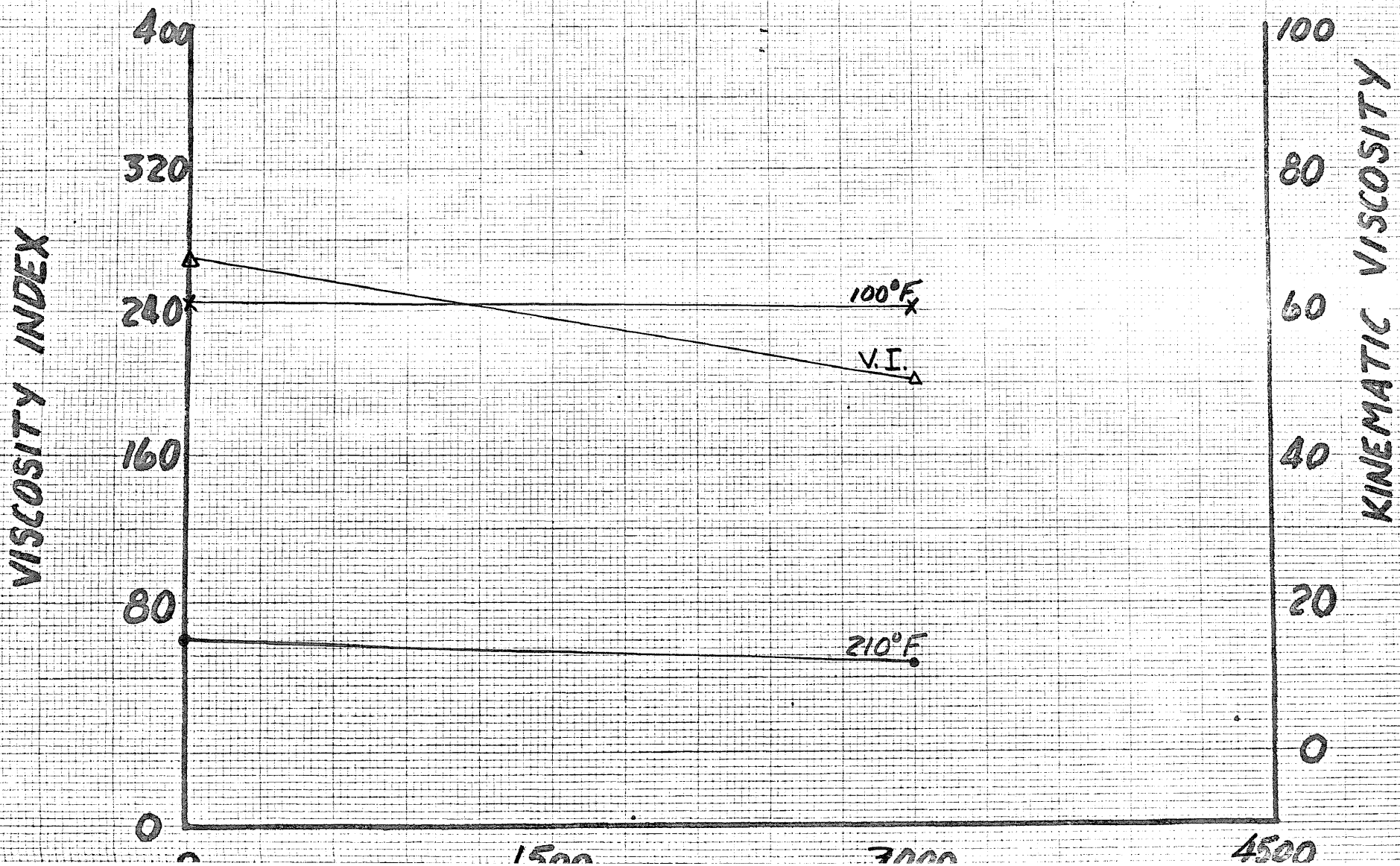
OIL: ROTUNDA
MILEAGE: 0
VISCOSITY: 60.8 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE ('SEC⁻¹)
X 10⁻²
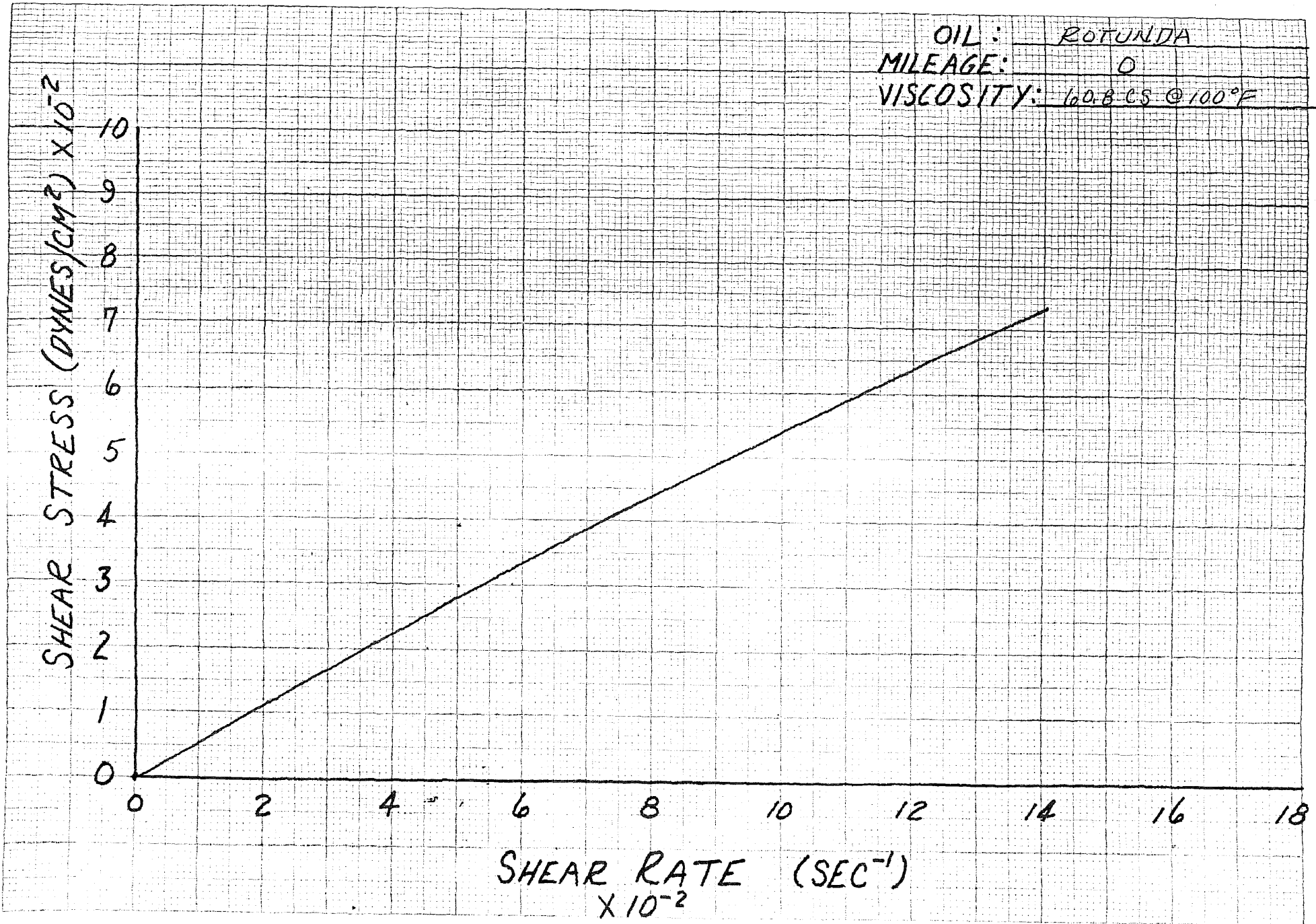
OIL: ROTUNDA 6000 MILE
MILEAGE: 3000
VISCOSITY: 60.7 CS @ 100°F
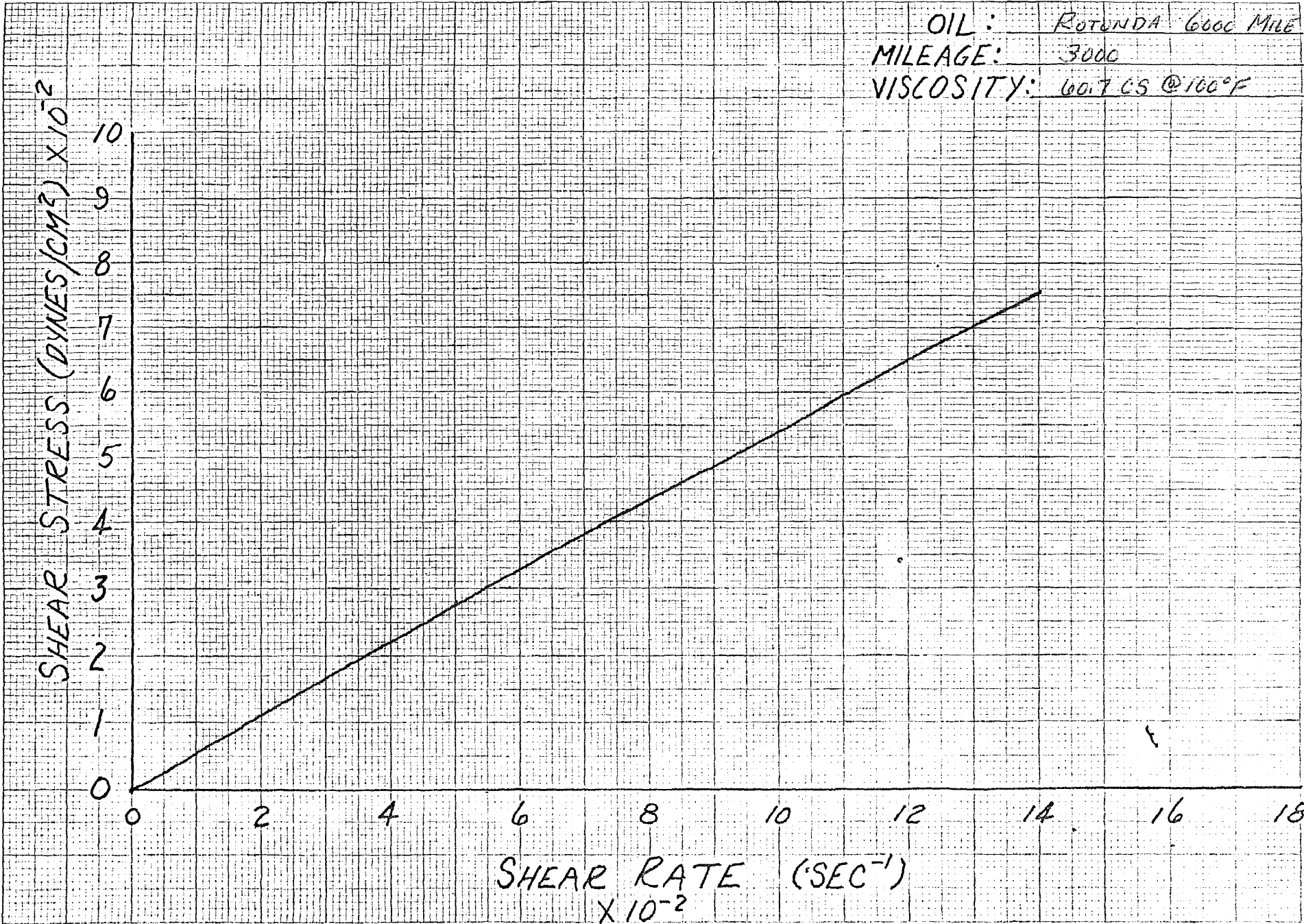
SHELL

MILEAGE	VISCOSITY @100°	PERCENT LOSS
0	61.7	---
500	39.3	36.3
1000	32.3	47.7
1500	35.7	42.1

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	15.30	---
500	9.62	37.1
1000	10.18	33.4
1500	7.97	47.7

OIL TYPE
SHELL

EL	ABSOLUTE VISCOSITY	SPECIFIC GRAVITY	KINEMATIC VISCOSITY		TEMP
	(centipoise)		(centistokes)		(°F.)
0	53.6	.869	61.7		100
0			15.3		210
500	34.6	.880	39.3		100
500			9.62		210
1000	28.2	.874	32.3		100
1000			10.18		210
1500	31.4	.881	35.7		100
1500			7.97		210

OIL TYPE: SHELL

EAGE	$V_0°$ (SUS)	$V_{100}°$ (C.S.)	$V_{210}°$ (C.S.)	H	N	V.I.	% CHANGE (V.I.)
0		61.7	15.3	167.0	.364	276	
							-7.25
500		39.3	9.62	84.4	.336	256	
1000		32.3	10.18	90.7	.445	338	
							-20.30
1500	3000	35.7	7.97	63.6	.278	220	

VISCOSITY INDEX

400

320

240

160

80

0

KINEMATIC VISCOSITY

100

80

60

40

20

0

V.I.

100°F.

210°F.

500   1000   1500
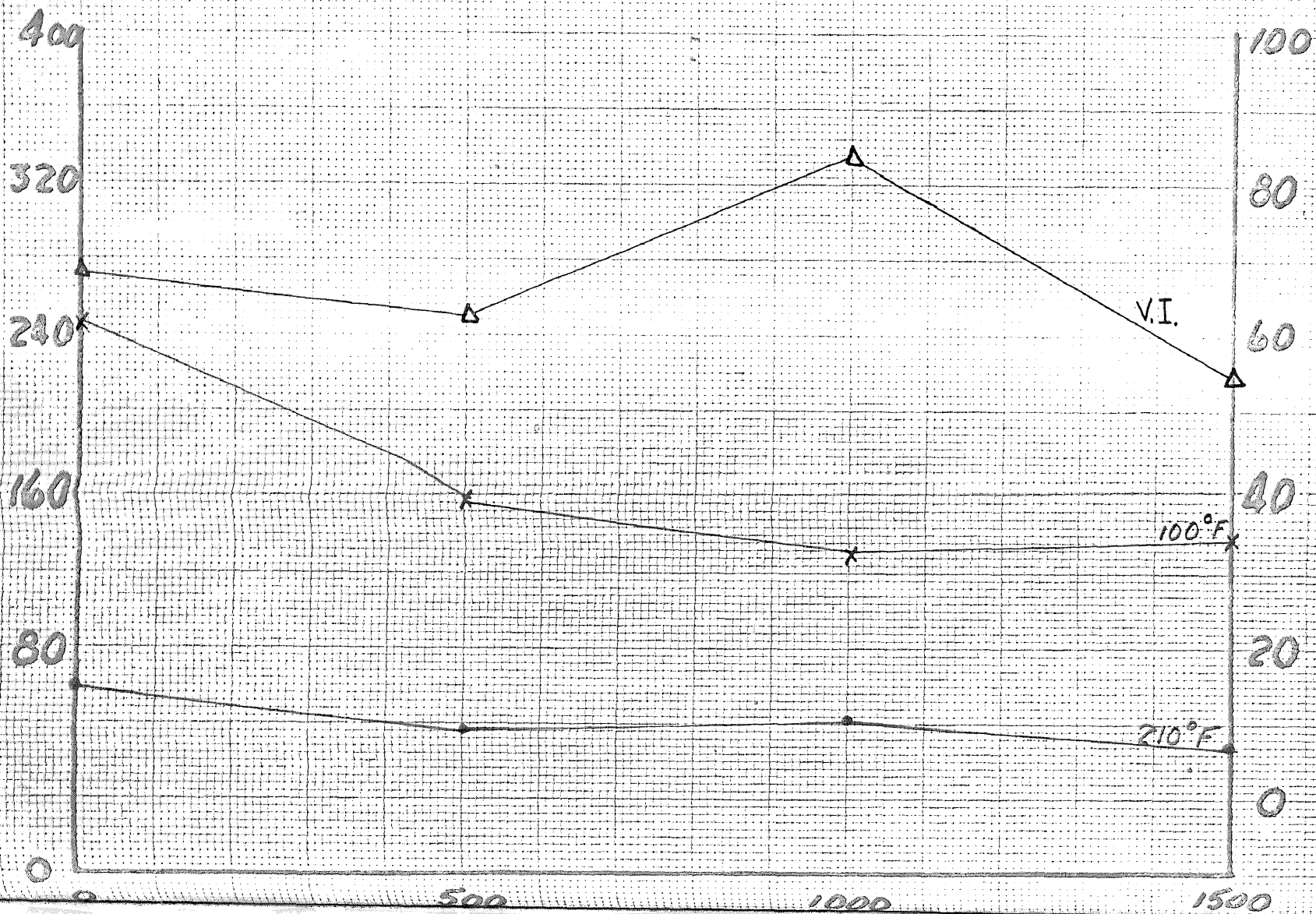
OIL: SUPER SHELL
MILEAGE: 0
VISCOSITY: 61.7 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²

109
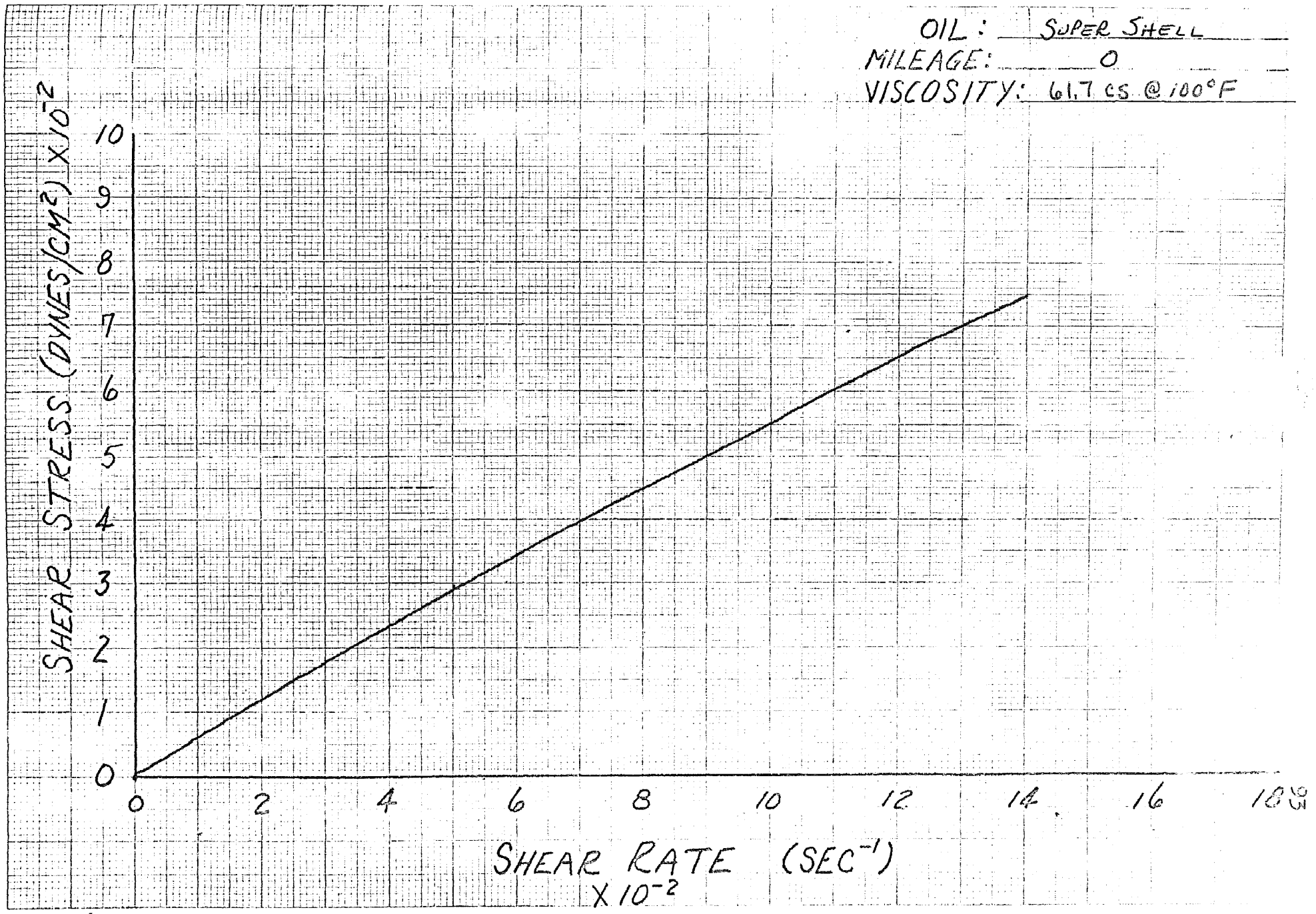
MILEAGE: 500 MILES
VISCOSITY: 39.3 cs @ 100°F

SHEAR STRESS (DYNES/CM²) × 10⁻²

SHEAR RATE (SEC⁻¹) × 10⁻²

94
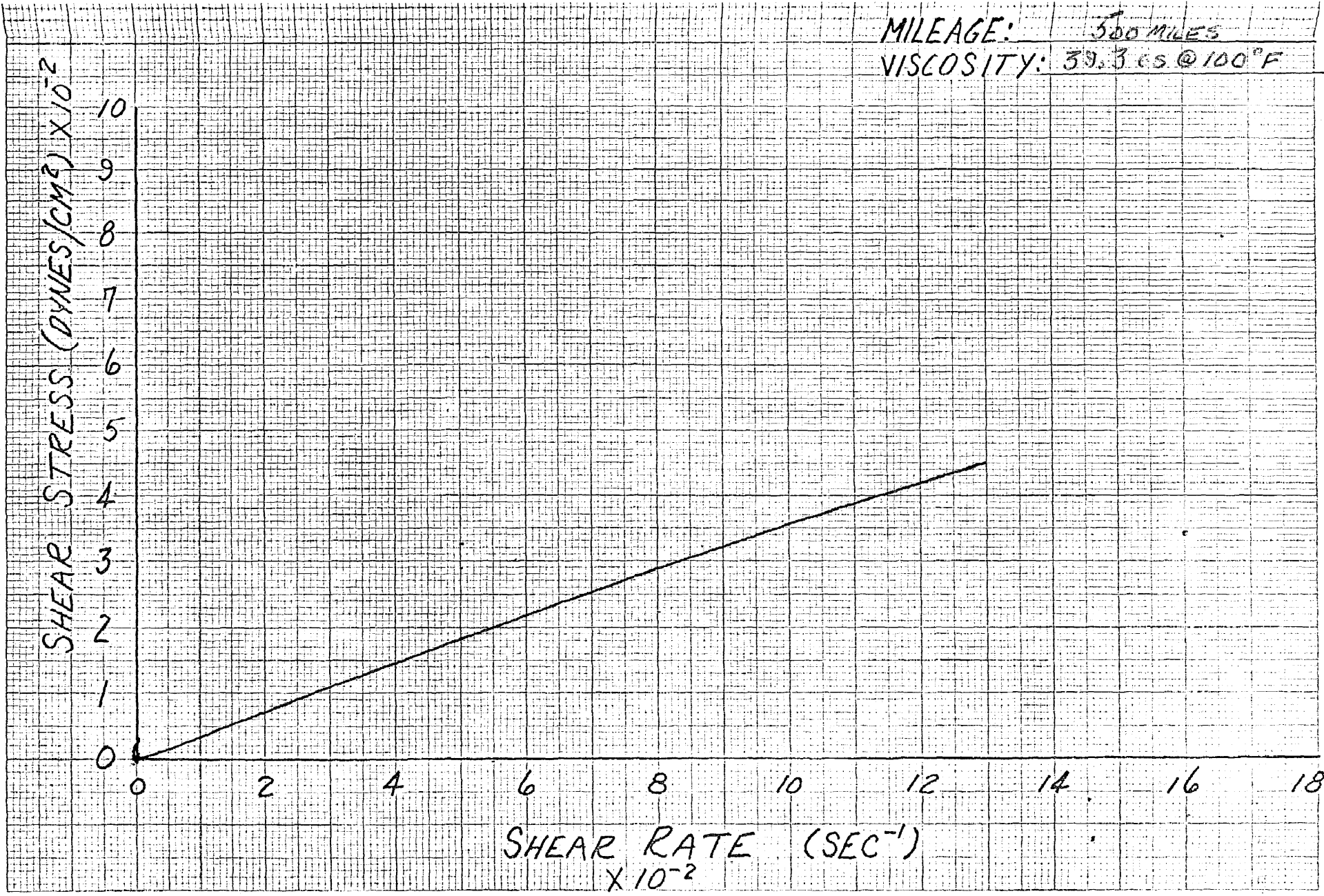
OIL: SUPER SHELL
MILEAGE: 1000
VISCOSITY: 32.3 cs @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²
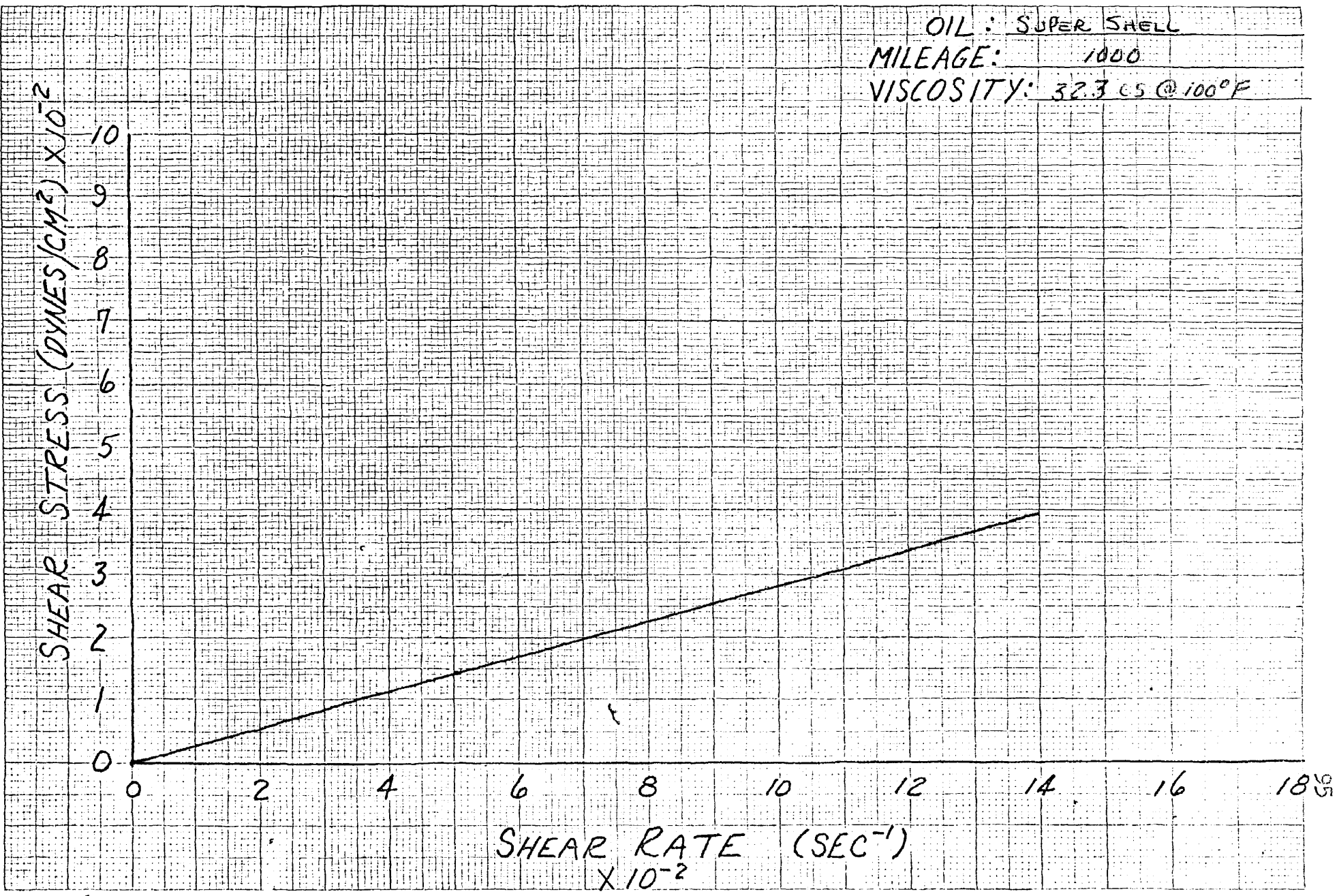
OIL: SUPER SHELL
MILEAGE: 1500
VISCOSITY: 35.7 cs @ 100°F

Y-axis: SHEAR STRESS (DYNES/CM²) ×10⁻²

X-axis: SHEAR RATE (SEC⁻¹) ×10⁻²
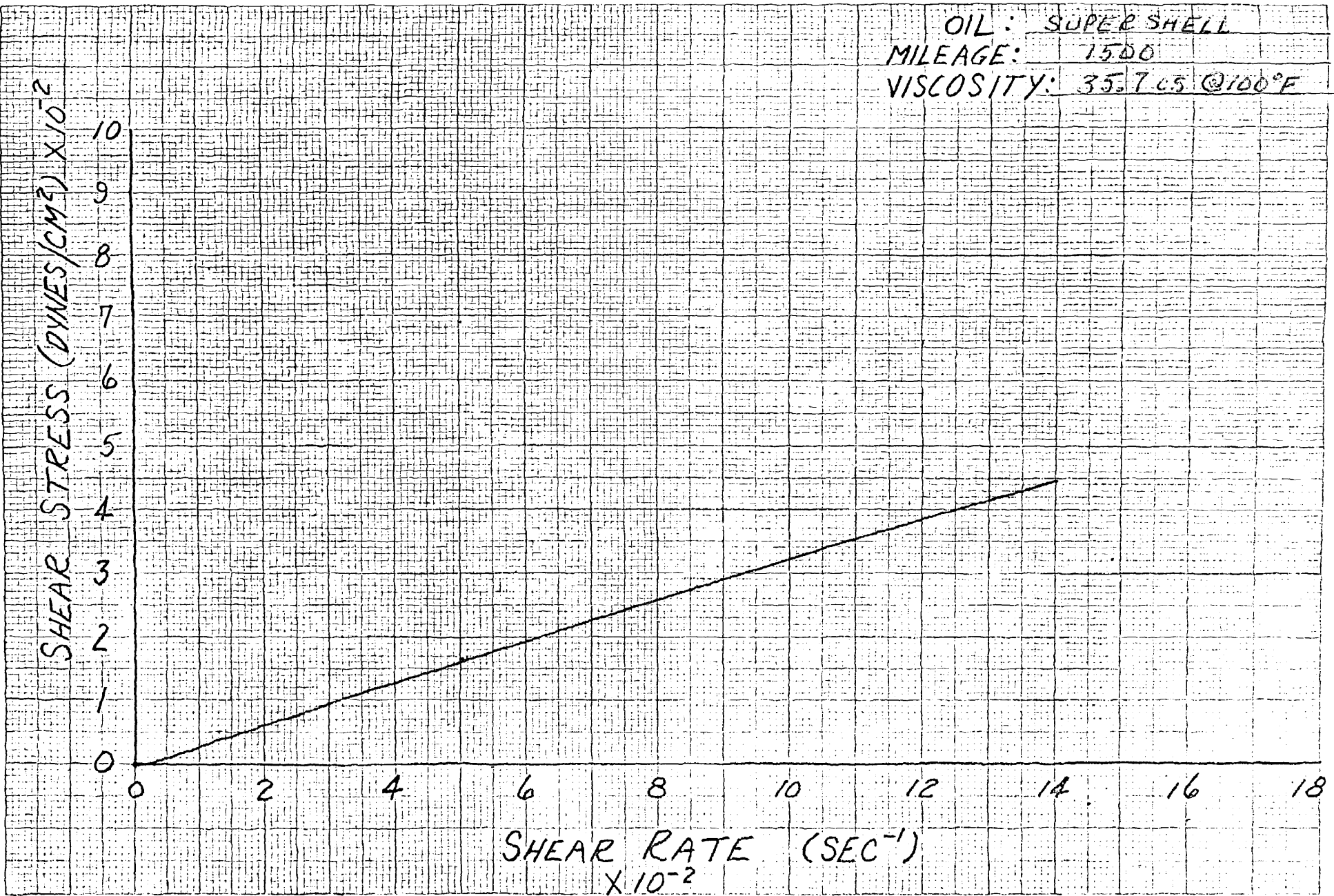
SINCLAIR

MILEAGE	VISCOSITY @100°	PERCENT LOSS
0	48.6	---
400	43.5	10.5
987	32.9	32.3
1617	28.8	40.6

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	10.68	--
400	10.38	2.8
987	9.23	13.6
1617	9.64	11.6

OIL TYPE
SINCLAIR

	ABSOLUTE VISCOSITY (centipoise)	SPECIFIC GRAVITY	KINEMATIC VISCOSITY (centistokes)	TEMP (°F.)
0	42.1	.865	48.6	100
0			10.68	210
400	37.7	.867	43.5	100
400			10.38	210
887	28.6	.869	32.9	100
887			9.23	210
617	25.0	.870	28.8	100
617			9.64	210

OIL TYPE: SINCLAIR

EAGE	$V_0°$ (SUS)	$V_{100°}$ (C.S.)	$V_{210°}$ (C.S.)	H	N	V.I.	% CHANGE (V.I.)
0		48.6	10.68	97.4	.292	228	
							+ 9.20
100		43.5	10.38	93.4	.326	249	
							+31.10
87		32.9	9.23	79.3	.396	299	
							+59.60
617	800	28.8	9.64	84.6	.475	364	
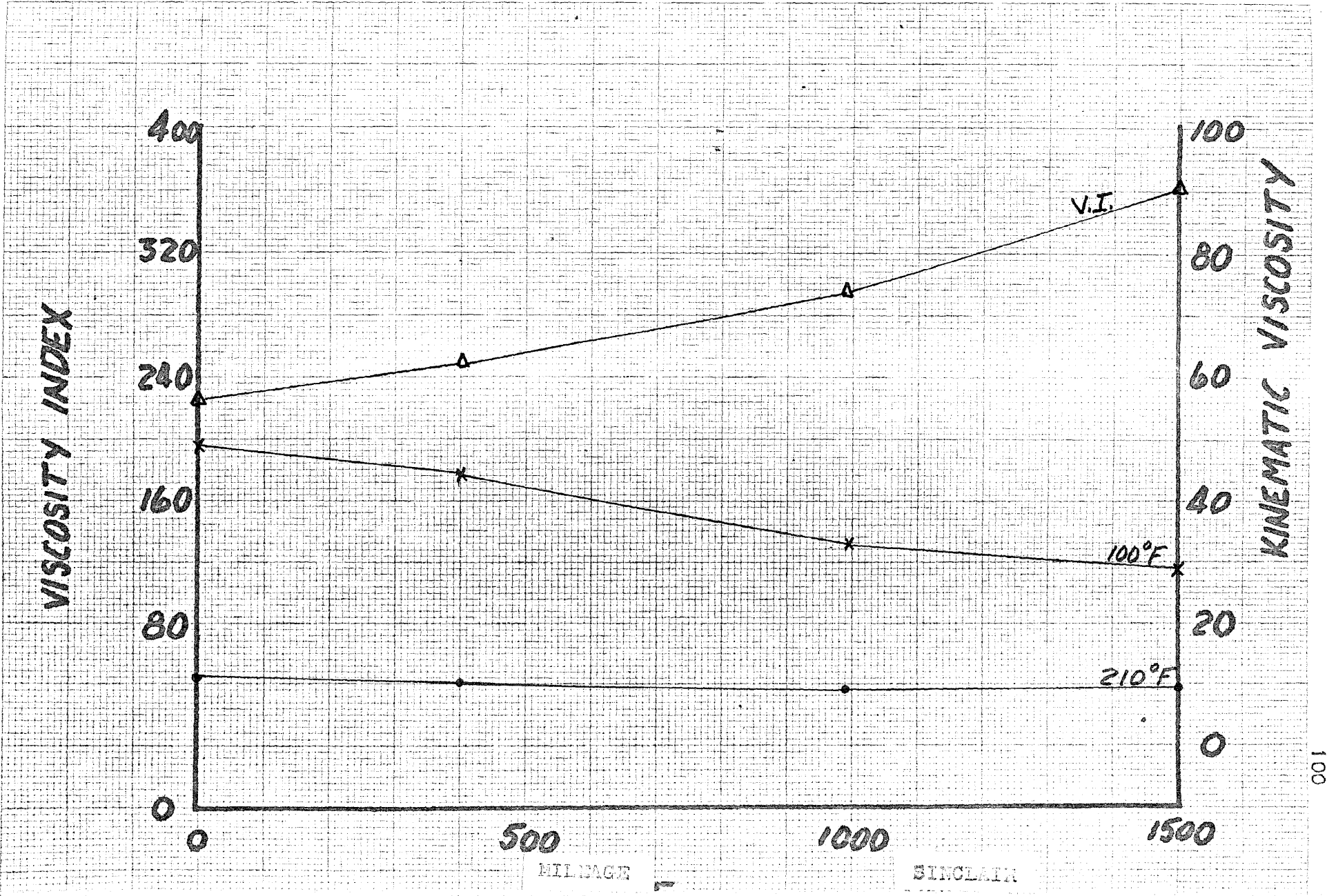
OIL: SINCLAIR DYNO SUPREME
MILEAGE: "0" MILES
VISCOSITY: 48.6 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X 10⁻²

SHEAR RATE (SEC⁻¹) X 10⁻²

101
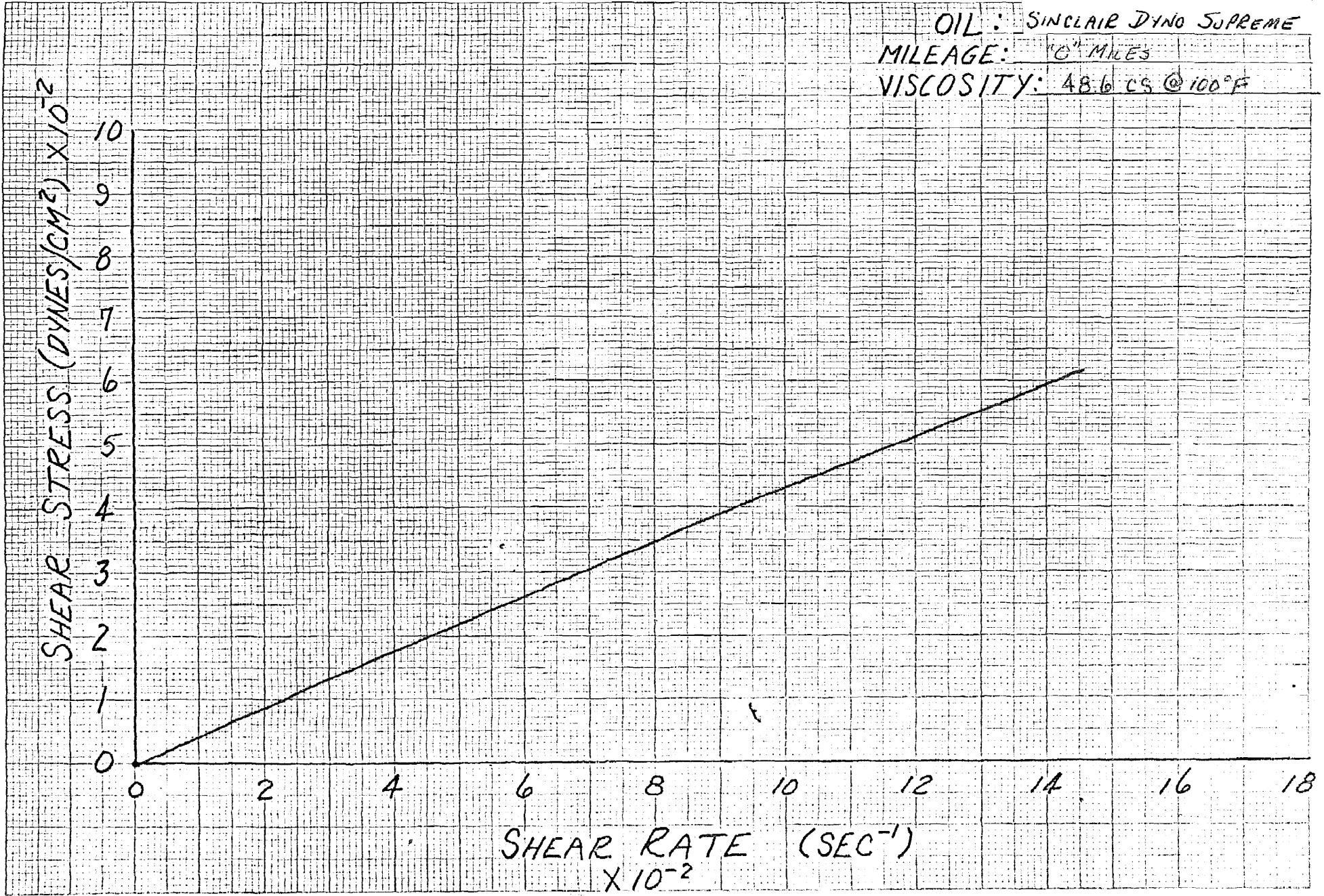
OIL: SINCLAIR DYNO SUPREME
MILEAGE: 400
VISCOSITY: 43.5 CS @ 100°F

SHEAR RATE (SEC⁻¹) ×10⁻²

SHEAR STRESS (DYNES/CM²) ×10⁻²

102
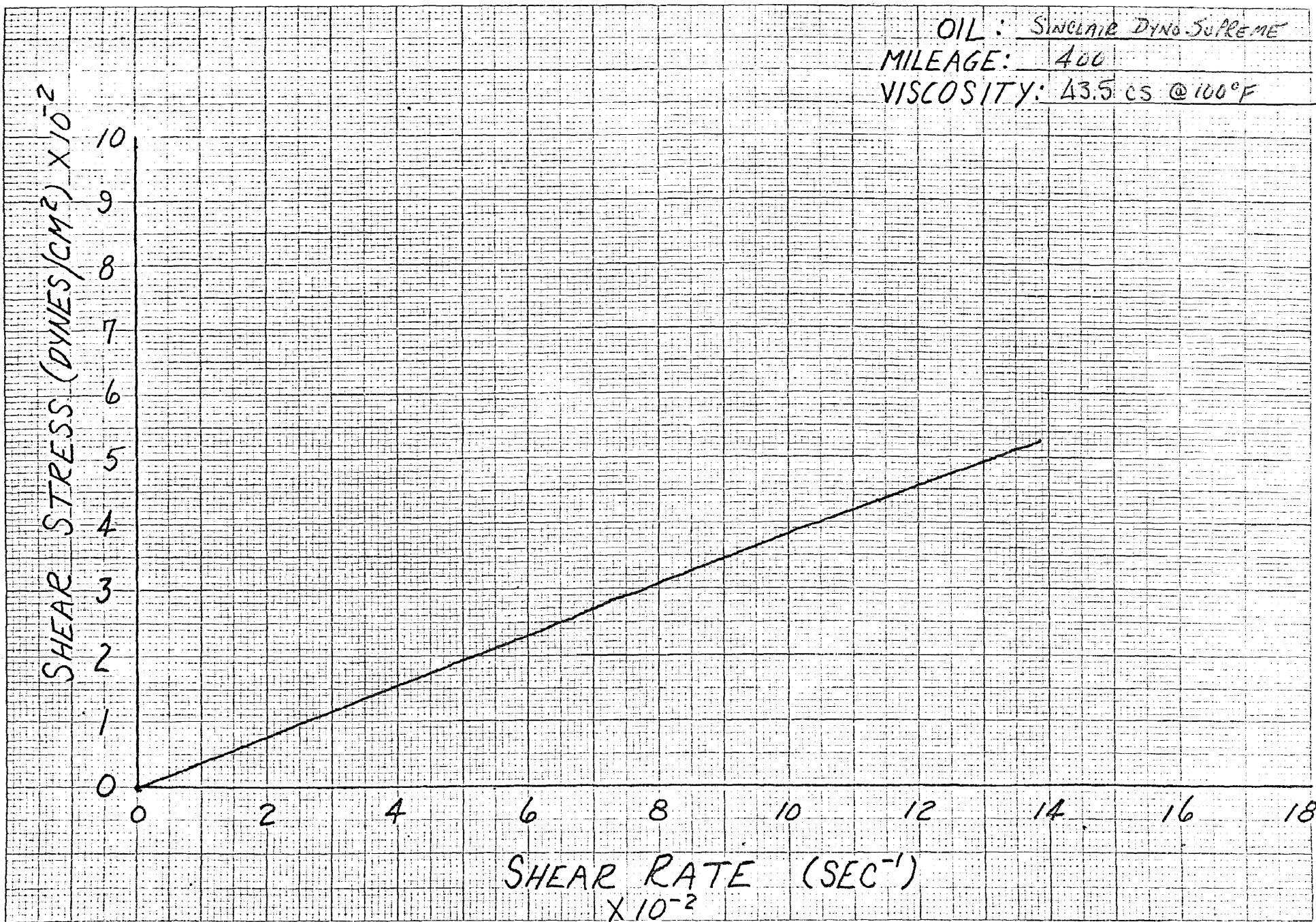
OIL: DYNO SUPREME
MILEAGE: 987
VISCOSITY: 32.9 CS @ 100°F

SHEAR STRESS (DYNES/CM²) ×10⁻²

SHEAR RATE (SEC⁻¹)
×10⁻²

103
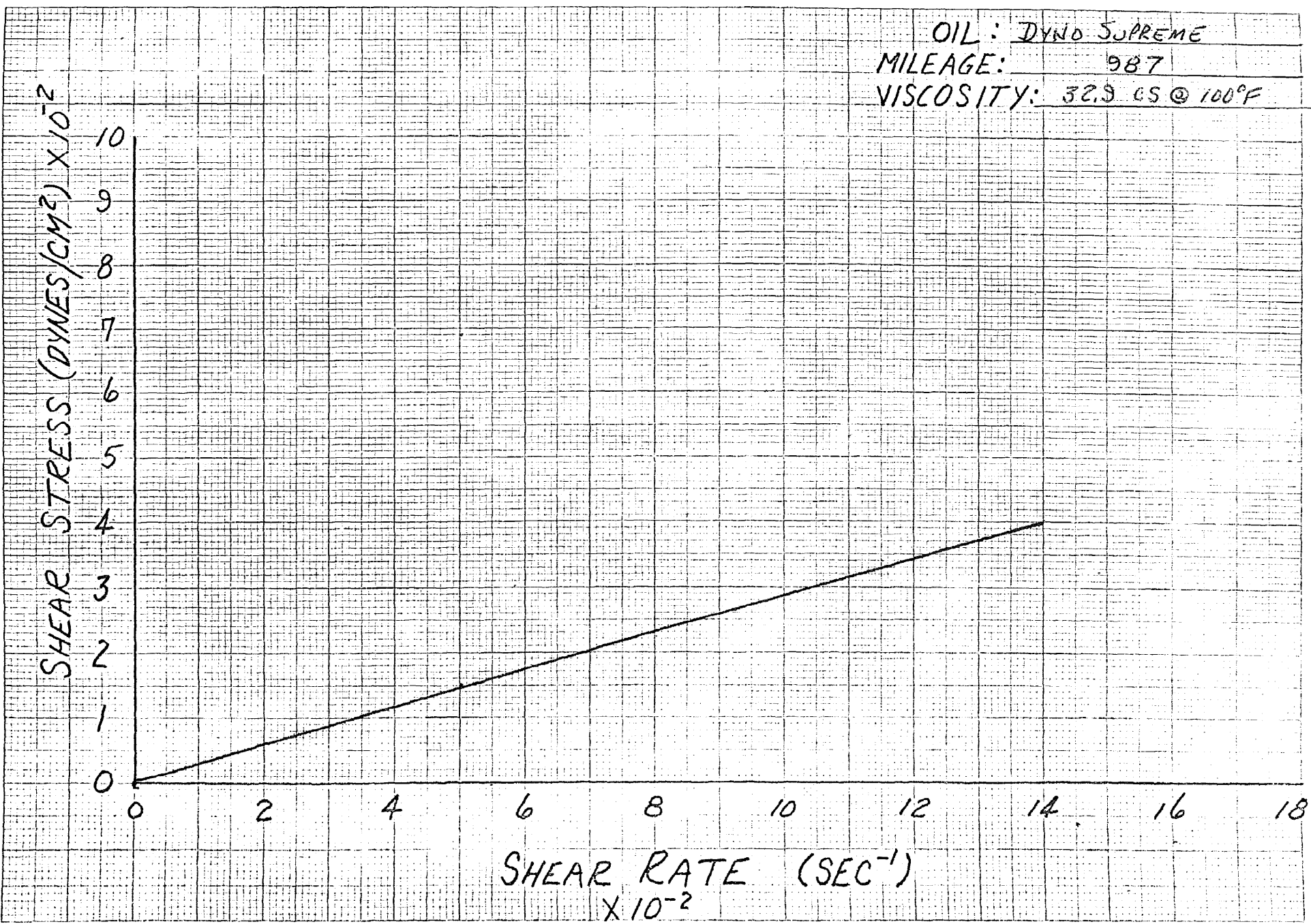
OIL: DYNO SUPREME
MILEAGE: 1617
VISCOSITY: 28.8 CS @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²

104
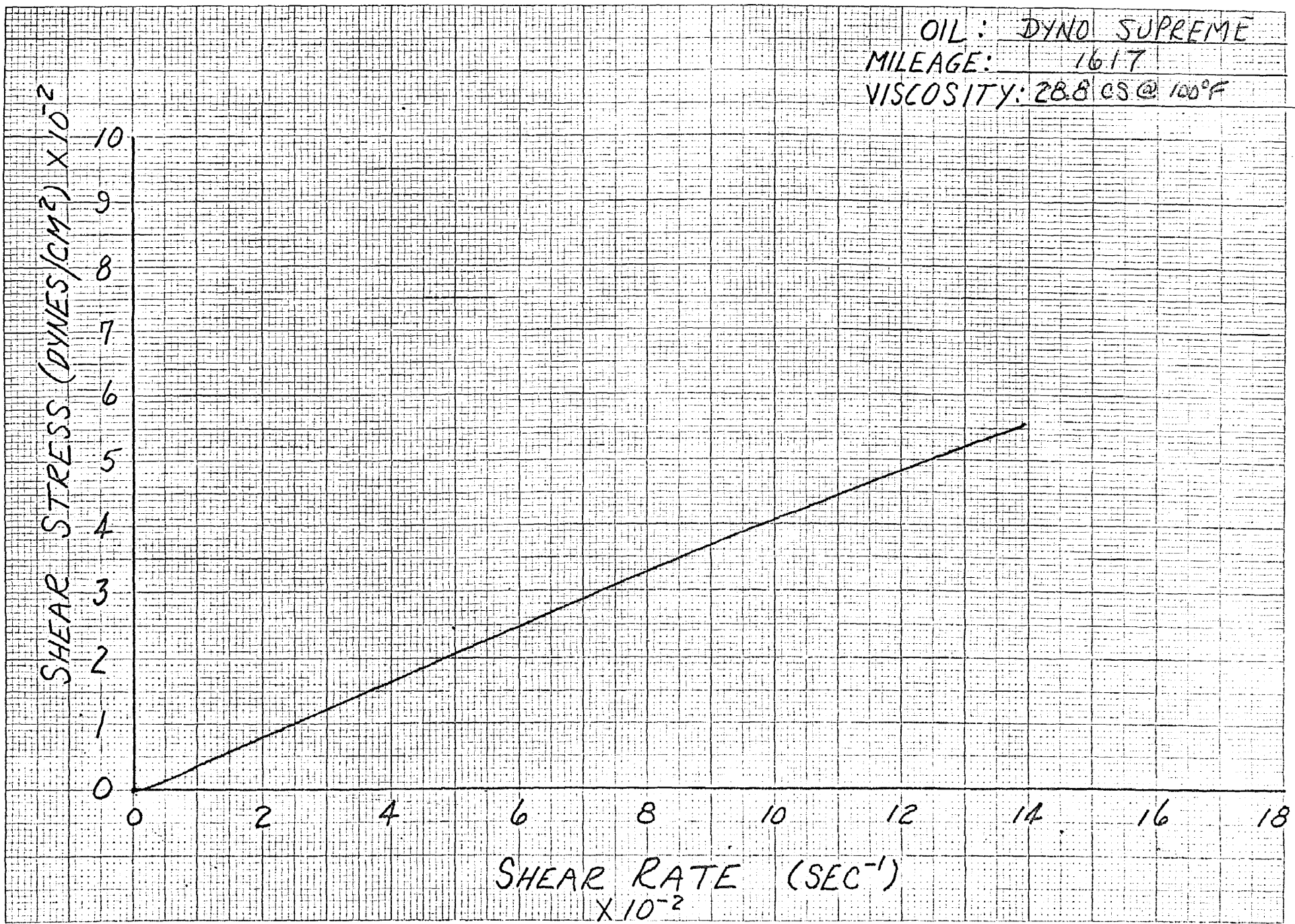
VEEDOL

MILEAGE	VISCOSITY @100°	PERCENT LOSS
0	87.6	---
523	57.8	34.0
1126	32.1	63.4
1706	44.6	49.1

MILEAGE	VISCOSITY @210°	PERCENT LOSS
0	12.38	---
523	11.88	4.04
1126	7.37	40.5
1706	10.48	15.3

VEEDOL

...ERAGE	ABSOLUTE VISCOSITY (centipoise)	SPECIFIC GRAVITY	KINEMATIC VISCOSITY (centistokes)	TEMP ($^\circ$F.)
0	75.7	.865	87.6	100
0			12.38	210
523	50.0	.867	57.8	100
523			11.88	210
1126	28.3	.870	32.1	100
1126			7.37	210
1706	39.3	.880	44.6	100
1706			10.48	210

OIL TYPE: <u>VEEDOL</u>

MILEAGE	$V_{0°}$ (SUS)	$V_{100°}$ (C.S.)	$V_{210°}$ (C.S.)	H	N	V.I.	% CHANGE (V.I.)
0		87.6	12.38	122.2	.134	148	
							+48.60
523		57.8	11.88	115.0	.278	220	
							+49.30
126		32.1	7.37	56.2	.280	221	
							+65.50
1706	1100	44.6	10.48	94.7	.320	245	

VISCOSITY INDEX

KINEMATIC VISCOSITY

V.I.

100°F

210°F

MILEAGE

VEEDOL

108
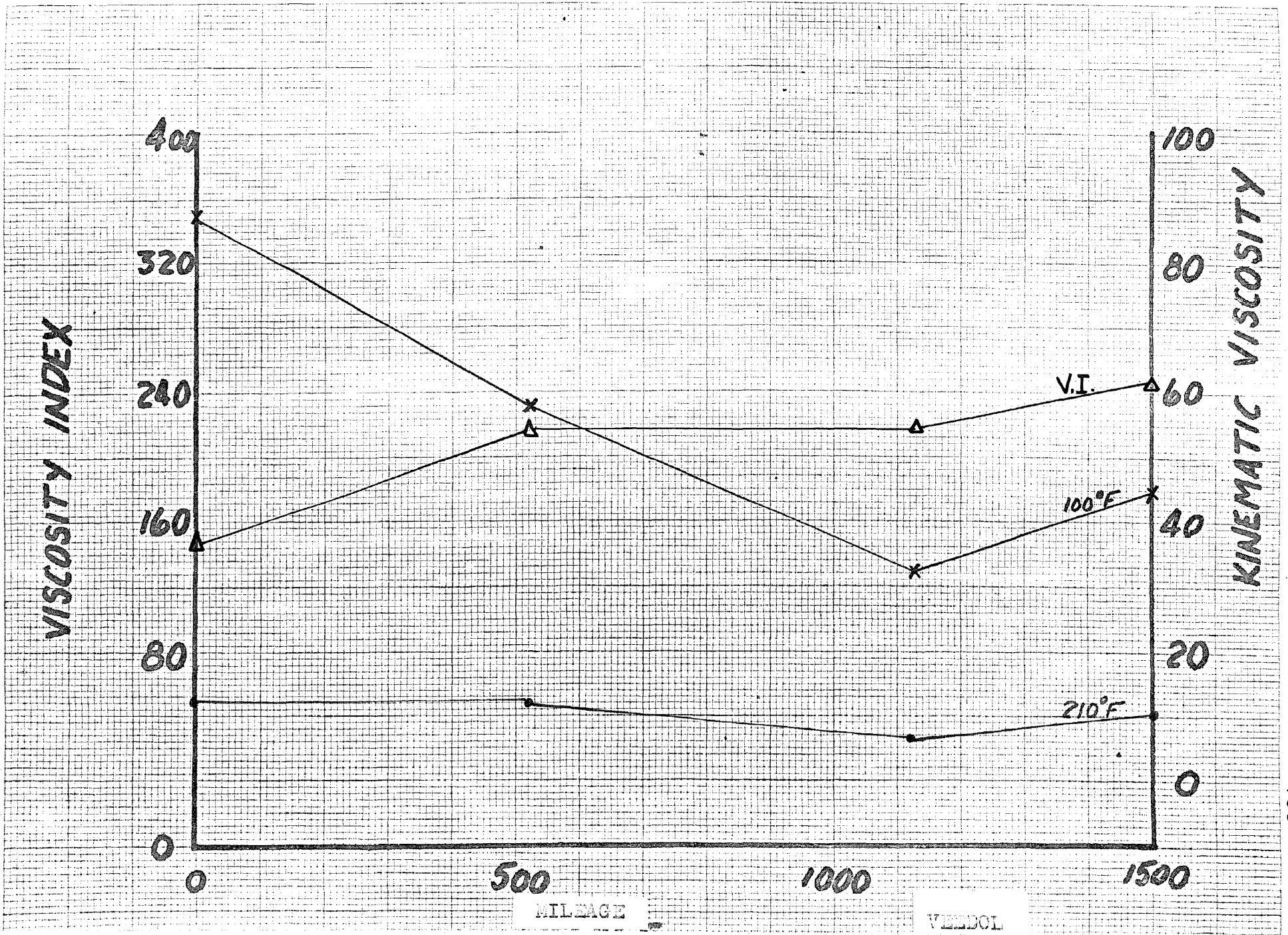
OIL: VEEDOL
MILEAGE: 0
VISCOSITY: 87.6 cs @ 100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹) X10⁻²

109
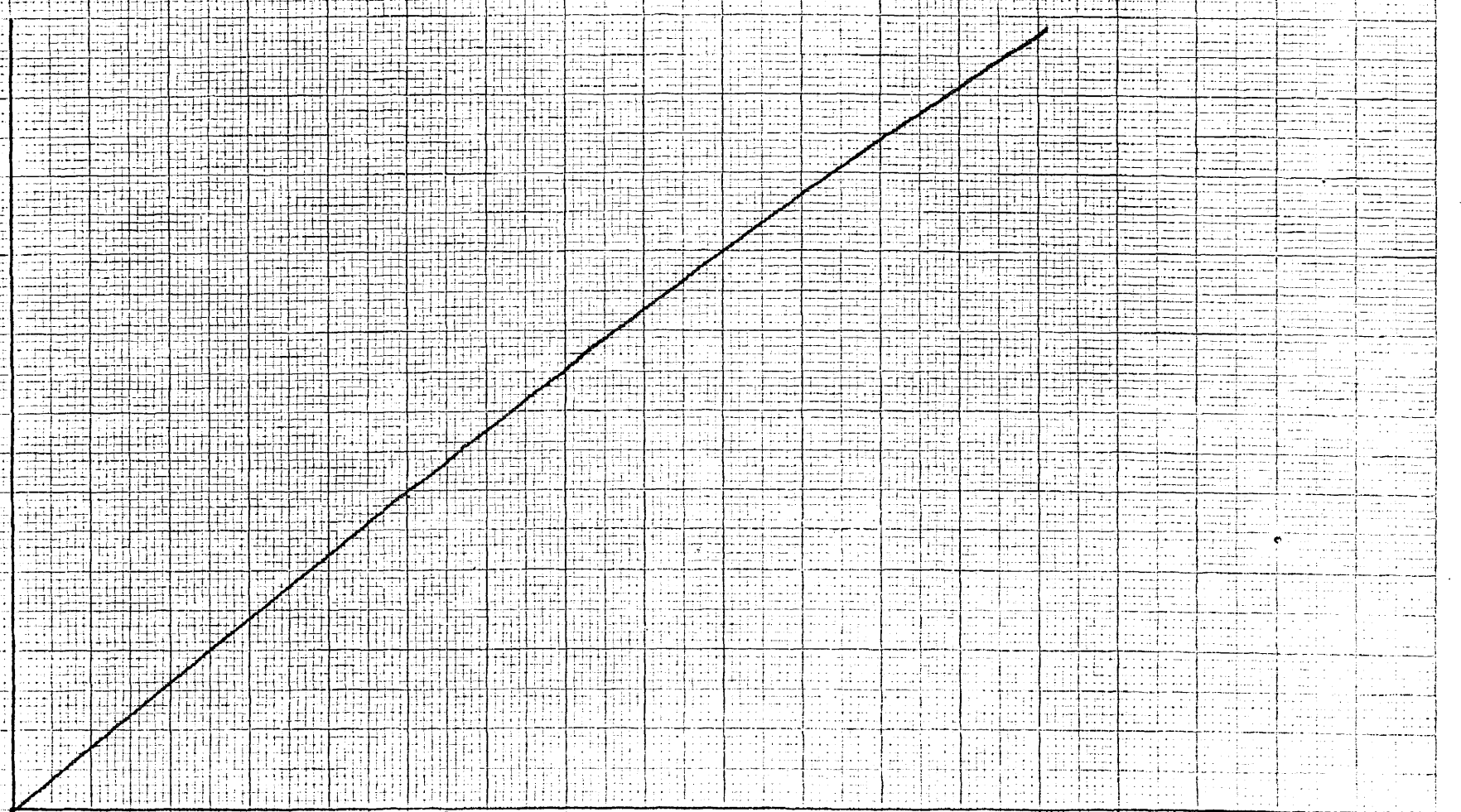
OIL: VEEDOL
MILEAGE: 523
VISCOSITY: 578 CS @100°F

SHEAR STRESS (DYNES/CM²) X10⁻²

SHEAR RATE (SEC⁻¹)
X10⁻²

OIL: VEEDOL
MILEAGE: 1126
VISCOSITY: 32.1 cs @100°F

SHEAR STRESS (DYNES/CM²) X 10⁻²

SHEAR RATE (SEC⁻¹) X 10⁻²
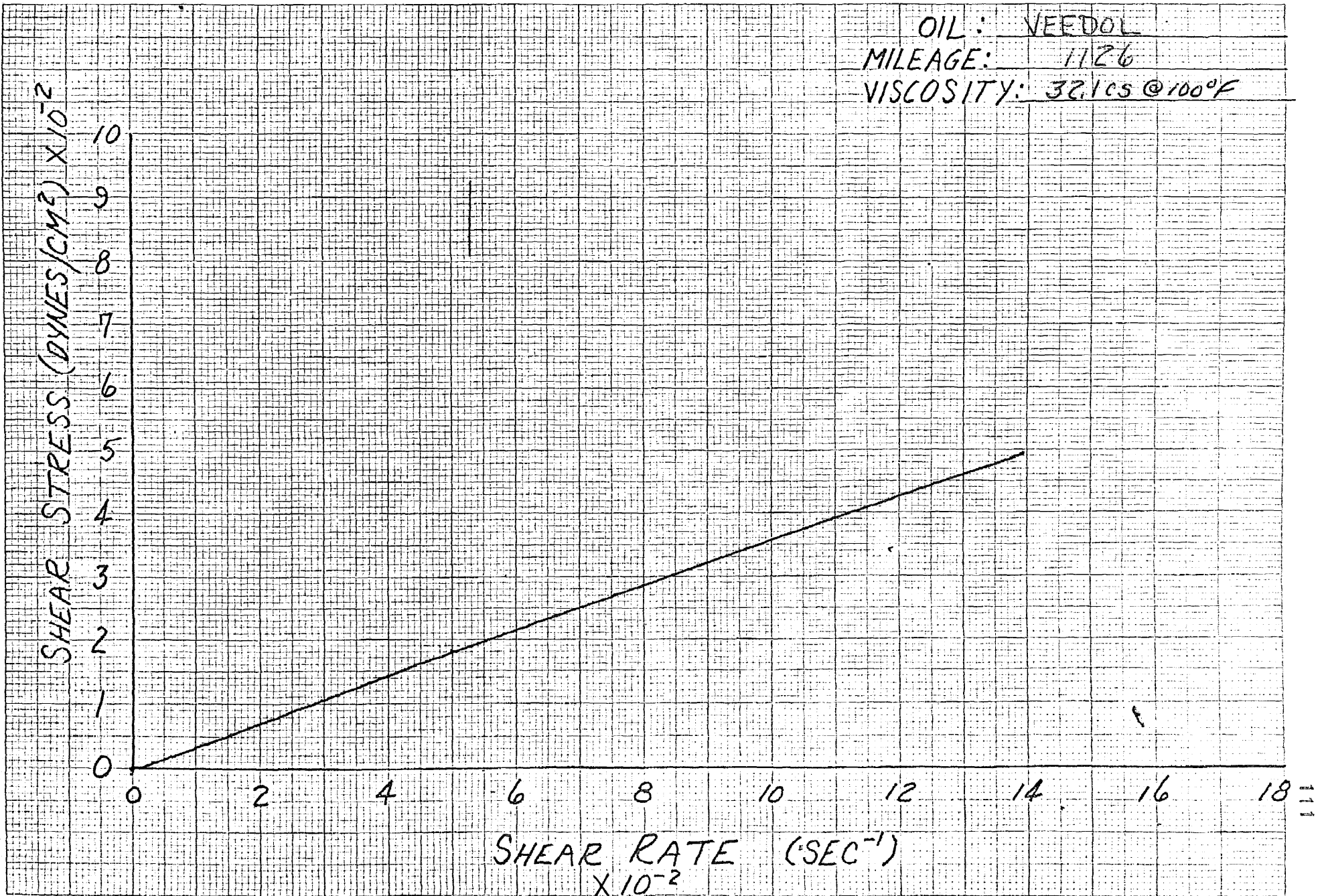
OIL: VEEDOL
MILEAGE: 1706
VISCOSITY: 44.6 cs @ 100°F

SHEAR STRESS (DYNES/CM²) X 10⁻²

SHEAR RATE (SEC⁻¹)
X 10⁻²
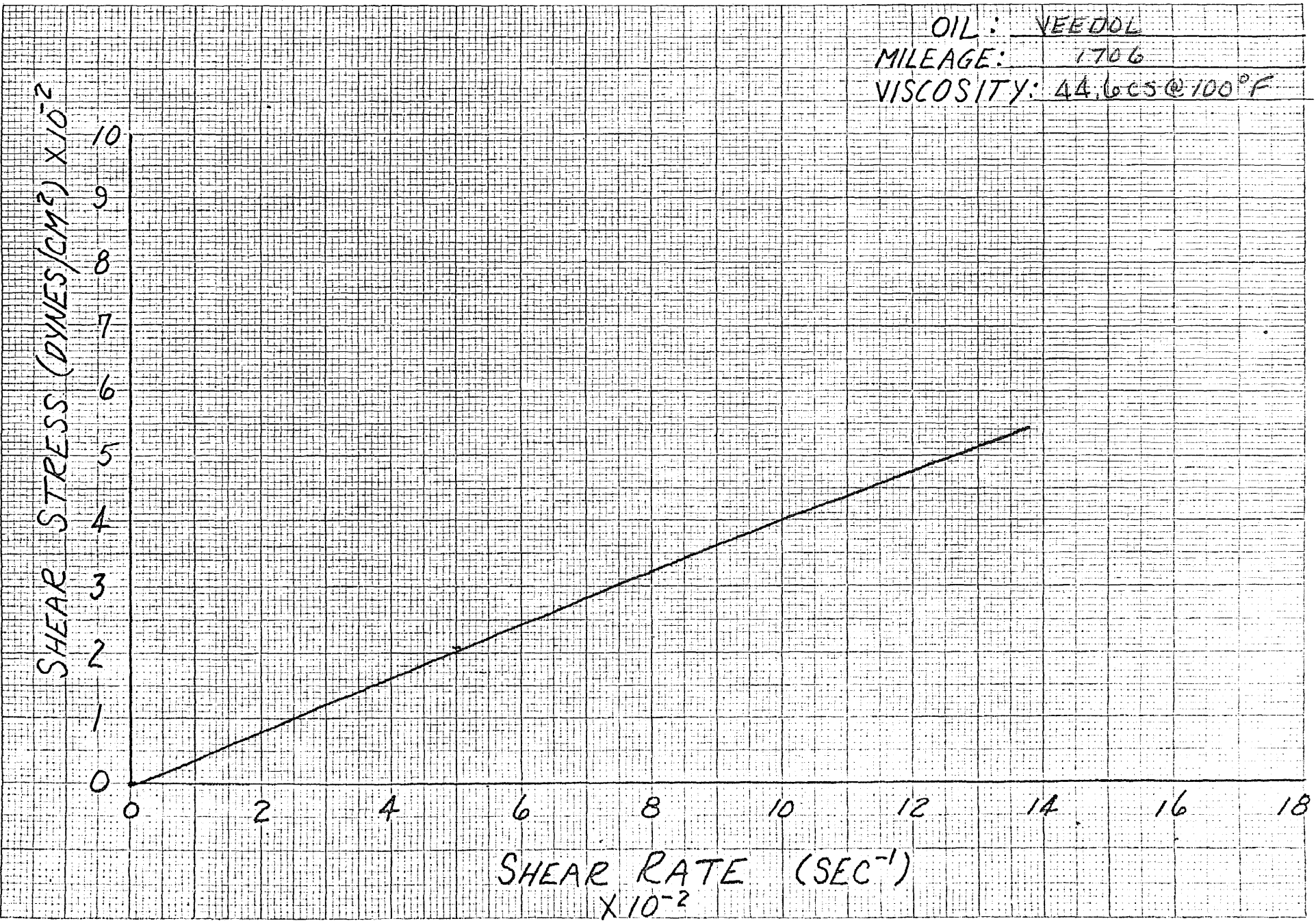
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