EFFECT OF SERVICE ON AUTOMOBILE CRANKCASE OILS

A THESIS

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By

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C O N T E N T S

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INTRODUCTION

The average motorist has a very vague idea, if any, of the actual changes that take place in the crankcase oils during service. He merely in most cases takes the service station attendants word for the condition of the oil, or changes it according to the speedometer reading regardless of the amount of oil he may have added during a number of miles of operation. This is without a doubt a very fine example of false economy. The service station attendant is anxious to sell oil, and in many cases may make unwittingly false statements from a lack of knowledge, or he may knowingly make false statements in order to make a sale to an uninformed motorist.

Much effort has been spent in an endeavor to establish some reliable criterion for judging the life of crankcase oils. Numerous tests have been made by reliable investigators as to changes which crankcase oils undergo in service. Many of these tests have simply been of a general nature, determining the changes which occur in general physical and chemical properties of the oils. Other tests have been attempts, however, to establish a relation between some particular laboratory test or tests and the performance of an oil in service. The effect of service on the general properties of an oil are pretty well established. Efforts ,however, to establish a relation between service performances and laboratory tests have met with little if any success. Large samples of oil are required in order to make the many oil tests. This would necessitate a large withdrawal of oil from the crankcase and, thereby greatly reduce the apparent mileage due to "sweetening". Consequently, certain tests were decided upon which it was thought would give the most significant information about the various changes that do occur in a crankcase oil during service.

There has been considerable work done on this problem, but to the authors knowledge no conclusive information or correlation of the various papers has been accomplished.

REVIEW OF LITERATURE

In starting an engine in cold weather it may be necessary to supply more than ten times the normal amount of fuel in order to obtain sufficient fuel vapor to form a combustible mixture. The average carburetor, when choked, will supply a mixture ratio less than about one and one-quarter pounds of air per pound of gasoline (1.25 to 1), if the fuel is all vaporized. Now, if the temperature is so low that only one-tenth of the gasoline is vaporized when the carburetor is choked , the resulting mixture ratio supplied to the cylinders will be 1.25 to 1/10, or as conventially expressed 12.5 to 1, which is just rich enough to start the motor.

The unvaporized fuel dilutes the oil, and an enormous amount of dilution will occur under such conditions if the engine is started frequently without being operated for a period long enough for the temperature to reach such a value that a considerable portion of the diluent is eliminated. The foregoing suggests that in service dilution may be reduced by: (1) reducing time required to bring engine up to normal operating temperatures; (2) operating with high temperatures of the cylinder walls; (3) reducing time of operation with rich mixtures; (4) operating with oil at high temperatures; (5) providing adequate ventilation in the crankcase. The effective life of an oil may be impaired by operation at extremely high temperatures, and increasing ventilation of the crankcase may afford a better opportunity for dirt to enter and contaminate the oil. The foregoing suggestions indicate what is possible rather than what is desirable.

Sparrow and Eisinger[1] have stated, that if the temperature of the oil film upon the cylinder walls is below the dew point of the fuel-air ratio, any vapor striking this film will, ofcourse , remain liquid.

The extremely high rate of dilution which occurs in cold weather during the starting and warming up period is because that the fuel-air ratio required is very high. The rate of dilution increases with an increase in fuel-air ratio, and the changeis , in most instances, directly proportional to the change in this ratio.

Barnard[2] has shown that: (1) road tests under ordinary conditions in which wear is estimated from the oil analysis, although indicating increased wear with dilution, are inconclusive because of settling of the metallic particles; (2) liability to increased wear caused by excessive amounts of suspended matter is considerably lessened by this settling; (3) as shown by dynamometer tests, rate of wear increases with dilution. Furthermore, rate of wear increases much more rapidly than dilution and, above a dilution of 10to 15 percent, percentage increases in wear is much greater than the percentage of dilution.

Pidgeon and Tester[3] have concluded from their tests that the percentage of dilution in an oil reaches an approximately constant value for any particular engine. The point of maximum dilution and minimum viscosity is reached in about the first 400 miles of service.

Wilson and Wilkin[4] have shown that: (1) dilution does approach an equilibrium condition under reasonably constant operating conditions, though its precise magnitude fluctuates somewhat with changes in weather conditions, carburetor setting, method of operation, etc.; (2) the oil in most cases dilutes 90 percent of the way to the final equilibrium viscosity in the first 150 to 180 miles of operation. Beyond 250 miles the curve is flat if operating conditions are reasonably constant. The reason for changing the oil is not then due to dilution, but to the collected in the crankcase in a low viscosity oil; (3) the diluent found in crankcase oils is a rather close cut, practically all boiling between 275° and 450° F., with 50 percent off at 350° F. It does not seem to vary much between cars that dilute slightly and those that dilute badly.

Aston[5] has shown that in some cases the oil after use has a higher viscosity than the new oil. The normal dilution of used oil during cold weather produces the required satisfactory oil conditions. Flash and fire points and viscosity become stabilised after a few thousand miles. Carbon has some sealing effect and we can get a higher compression ratio and better efficiency from the engine. Regarding changing the oil in the crankcase, Aston stated that , "if the dirt did not show an increase again at 10,000 to 15,000 miles, he would advise using the oil until there was a decided increase". Oxidation aids lubrication rather than the reverse, as it tends to increase compression. A certain amount of carbon or semi-oxidized product in oil actually aids its lubricating quality.

Koether[6] has given some data on " The Role of Graphite in Lubrication". Determinations of friction with and without graphite indicate that graphite is effective in prolonging the period of unbroken film lubrication, and in the ruptured film stage it reduces friction and minimizes metallic contact. This is probably because it deposits to a certain extent in the places of the metal, thus making a smoother surface, and also because when metal-to-metal contact does take place it abrades more readily and with less friction and damages than would plain metal surfaces.

McKee[7] has conducted tests that show kerosine decreases the so-called "oiliness" effect of lubricating oils. Then if the diluent is partly kerosine the lubricating oil film formed by diluted oils is not as effective as a film formed by non-diluting oils.

Gavin and Wade[8] have concluded from their test that the differences indicated by the alkali-absorption numbers are without significance with regard to engine service.

Dietrich[9] has shown that changes in characteristics of crankcase oils during service are dependent far more on the type of engine, its condition, and its manner of operation than upon the characteristics of the new oils as determined at present in the laboratory. The volatility of the oil, as measured by the spread in the distillation range and the viscosity in so far as it is affected by dilution at the time of service are the only characteristics which appear to have some quantitative relationship to the changes which the oils undergo.

Some typical views of the Lubricating Laboratory located in the Mechanical Engineering Laboratory on the campus are shown in the following pages. The majority of the tests were conducted in this room.

Figure 1.

This is a view of the laboratory showing very clearly the drying oven and dessicator used on the rate of wear tests.

Figure 2.

This is a photograph showing the dilution and conradson carbon residue apparatus. A Pensky-Martins closed cup apparatus for determining the flash and fire points is shown also.

Figure 3.

This view shows the American Society for Testing Materials pour point apparatus and other general equipment in the laboratory.

Figure 4.

The single unit wear test machine and Saybolt viscosimeter are shown in this picture. Oil sample bottles are shown on the table along with other equipment used in making the different tests on the used crankcase oils.

OBJECT OF THE INVESTIGATION

The object of this investigation was to determine the "Effect of Service on Automobile Crankcase Oils" from a purely practical standpoint rather than from the theoretical side; and to present the facts that have arisen from a practical test taken under actual and average driving conditions.

Method of Procedure

The oil samples upon which the various tests have been made were collected from two cars, one a 1931 Chevrolet sedan, and the other a 1931 Pontiac sedan. The Chevrolet had previously been driven approximately 30,000 miles, and the Pontiac 80,000 miles. Both cars, however, were in very good condition and no mechanical trouble was experienced with either car during the test periods.

In the case of the Chevrolet, the oil test samples were collected during a trip of approximately 3000 miles June, 1932. Before starting this trip the crankcase was drained thoroughly and filled with a widely distributed SAE 40 automobile oil, the properties of which are given in Table I . As shown by this table oil samples were siphoned from the crankcase approximately every 250 miles, except the last sample which was obtained after 601 miles and was collected by draining the crankcase. All samples were siphoned from the crankcase immediately after stopping the motor before the oil had an opportunity to cool or the sediment to settle out. During the trip 13 quarts of fresh make-up oil were added and approximately 9 quarts were siphoned out as test samples. The test samples so collected were placed in clean 12-oz. bottles, corked tightly and marked with identification numbers at the time of siphoning them from the crankcase.

The second set of test samples were collected from the 1931 Pontiac sedan during the summer of 1934. This car was owned by Prof. J. I. Glower. It had a 6 cylinder engine, 200 cu. in. displacement, 60 H.P. at 3000 r.p.m. The pistons were of cast iron. The lubrication system was as follows: pressure lubrication to main and camshaft bearings and connecting rods, splash and oil throw to cylinder walls. No oil filter was used. However, the car was equipped with a crankcase ventilator. A small pet cock was fitted to the drain and a small piece of pipe 3 inches long was attached in such a manner as to extend approximately 2½ inches into the crankcase. The purpose of this pipe was to insure that the test samples would be representative of the oil being circulated through the motor.

The crankcase was carefully flushed and filled with the test oil, which was Gargoyle D.T.E. Extra Heavy. Samples were taken at regular intervals of 50, 100, 150, 250, 350, 500, 700, 1000 and every 500 miles thereafter until the tests were completed. After each sample, of approximately 350 ml., was withdrawn, the crankcase was filled to the "full" mark on the oil gage rod with the original oil which was carried in the car at all times. The amount added , withdrawn, mileage, and general weather and driving conditions were all recorded.

In neither of the cases were the cars driven for the express purpose of obtaining oil test data; so no special precautions were taken to maintain constant operating speeds or to control the many other factors that have a bearing on crankcase oil deterioration. The Chevrolet was driven by four persons who were on the trip, the usual stops were made for gas, meals,etc. Of the 3110 miles, 2900 were over hard surfaced roads and the remainder were over dirt and gravel roads. The Pontiac was driven by one person the full 3763 miles. Of this mileage, approximately 2000 were made on two comparatively long trips, one of 600 miles, and the other of 1400 miles, the remaining mileage was made of comparatively short trips and driving around, Blacksburg, Virginia .

The following tests were run on the samples of oil taken from the Pontiac car as taken under the foregoing conditions.

(1). Viscosity at three temperatures
(2). Neutralization Number
(3). Dilution
(4). Specific Gravity
(5). Precipitation Number
(6). Pour Point
(7). Surface Tension
(8). Rate of Wear Tests
(9). Film-Rupture
(10). Conradson Carbon Residue

(11). Ash Content

(12). Iron Content

(13). Haemacytometer Count

All tests were run in accordance with the American Society For Testing Materials standards except those of iron content, ash , rate of wear, film-rupture, surface tension and haemacytometer count, for which the A.S.T.M. does not provide a standard test.

A short description of each test follows.

Viscosity

Each sample was carefully shaken so as to get a representative sample from the bottle. The apparatus was carefully cleaned and assembled according to specifications. After heating the bath and the oil to the desired temperature the oil was poured in through the strainer until the tube was filled. The bath and oil were stirred constantly until the desired equilibrium temperature had been reached. After conditions were constant for at least one minute, the oil tube thermometer was removed and the surplus oil removed from the overflow cup with a pipette. The 60 ml. flask was then placed in position, cork removed and stop-watch started. The bath was stirred constantly and maintained at the desired temperature throughout the test. When 60 ml. of oil had run into the flask the watch was stopped, and the time in seconds for the delivery of 60 ml. of oil was recorded as the viscosity of the oil at the temperature at which the test was made. The usual temperatures for running viscosity are 100, 130 and 210° F. Slight variations in the usual temperatures can be corrected to same by plotting the actual viscosity at the observed temperature on viscosity-temperature charts. From this curve(straight line) we can read directly the viscosity at the usual temperatures. Numerous tests were made until a close check was obtained. The results are the average of the tests.

Neutralization Number

Exactly 20 grams of the oil was weighed into a previously weighed Erlenmeyer flask. One hundred ml. of a mixture of 1:1 neutralized alcohol and distilled water was then added to the flask and the mixture agitated and heated to boiling over a Bunsen burner. To the hot solution was added 1 ml. of phenolphthalein as an indicator and the solution titrated while hot, with a standard KOH solution (1 cc.=5 mg. KOH) to a sharp pink endpoint. The color was noted in the alcohol-water layer. The neutralization number was calculated by the following formula:

$$\frac{\text{(Milliliters of KOH) x 5}}{\text{Weight of oil taken}} = \text{Mg. KOH per gr. of oil}$$

Dilution

The sample was mixed thoroughly and then 25 ml. of the oil to be tested was poured into a 25 ml. graduate. This was then transferred to a flask and the mixture made up to 500 ml. by adding water. The dilution trap was then filled with water and the apparatus assembled according to directions provided by the A.S.T.M. Heat was applied by an electric heater in such a manner that the refluxing began in the prescribed time limits. Readings were taken at stated times of the amount of dilution and the end point for the test was arrived at by following the criterion prescribed in the test.

Specific Gravity

The specific gravity was determined by means of a hydrometer immersed in the oil sample. The oil sample was thoroughly mixed before pouring it into the hydrometer cylinder, care being taken not to form bubbles. The temperature of the oil was recorded by means of a thermometer suspended in the cylinder. The correct scaled hydrometer was then carefully immersed in the oil and the gravity read according to specifications. The gravity was then corrected to $60^{\circ}/60^{\circ}$ F. by means of tables found in " Handbook of the Petroleum Industry". These tables are based on circulars prepared by the National Bureau of Standards and published by the Taylor Instrument Company. The A.P.I. gravity was also calculated and reported on $60^{\circ}/60^{\circ}$ F. basis.

Precipitation Number

The oils to be tested were carefully mixed, and exactly 10 ml. was measured into each of two clean and dry centrifuge tubes. Ninety ml. of petroleum naphtha was added to each tube and then carefully closed with a softened cork. The tubes were then inverted at least twenty times, allowing the liquid to drain completely from each end after each inversion. The tubes were then placed in a water bath at 90 to 95 $^{\circ}$ F. for five minutes. At the end of this period the corks were momentarily released to relieve pressure and then inverted twenty times as before. The tubes were then placed in opposite cups of the centrifuge and whirled at a rate of 1400 to 1500 r.p.m. for ten minutes. The volume of sediment was recorded at the end of each time period and the whirling continued until the volume of sediment was constant for three consecutive readings. The volume of sediment in the bottom ofeach tube read to the closest 0.1 ml. was reported as the A.S.T.M. Precipitation Number. Average results are shown in Table II.

Pour Point

The oilto be tested was carefully stirred and then poured into the test jar to a specified height. The thermometer and cork were placed in position and heated to 115°F. in a water bath , taken out and cooled in air to 90°F. The jar was then placed in the pour point apparatus and allowed to cool. The cooling medium used was solid carbon dioxide. The jar was carefully removed and tilted momentarily at a temperature of 20°F. above the expected pour point, and every 5°F. drop thereafter until the oil ceases to move in the jar. A temperature 5°F. above the solid point was reported as the Pour Point.

Surface Tension

The apparatus used was a du Nouy Surface Tensiometer which consists essentially of a stand provided at the top with a fine steel wire streched between supports at the end. One end is tightly clamped, the other being attached to a worm wheel controlled by a thumb screw. To the worm wheel is attached a pointer which moves over a metal scale graduated in degrees. To the middle of the wire is clamped a hollow, light steel lever with a small hook in the outer end. A stirrup is attached to this hook carrying a carefully made loop of platinum-iridium wire with a periphery exactly 4 cm. in length.

Procedure

The platinum-iridium wire was carefully cleaned by flaming it. The watch glass was also carefully cleaned according to instructions. The wire loop and watch glass were then placed in position, care being taken not to bring them in contact with any grease. The apparatus was then zeroed by bringing the needle to zero on the scale and adjusting the screw until lever was just above resting platform. The table was then carefully raised until the liquid just touched the platinum-iridium wire loop, thus making perfect contact. Then by simply turning the knob for the dial the torsion on the wire was increased until suddenly the film was broken. The dial reading was recorded and several checks were determined. The apparatus was then standardized against water as follows:

A small piece of clean paper was cut so as to fit over the loop. Then weights were added to the paper until the arm was forced down into the original horizontal position, but not in contact withh the resting platform. The weight of the paper plus the weights added was the load in grams on the wire. By formula:

$$A = \frac{M g}{2 L} \quad \text{where, } g = 981 \text{ dynes per sec.}^2,\ L = 4 \text{ cm.},\ M = \text{wt. of paper + weights added.}$$

Then after calculating A we have a direct ratio between this and any readings that we observe on the dial. For example; if A is 77 dynes, and if the water gave a reading of 72° we have a ratio of $\frac{77}{72}$, and any oil reading on the dial multiplied by this ratio would give the surface tension of the oil at that temperature.

<u>Rate of Wear Tests</u>

Two general methods have been devised for determining the rate and amount of wear of the moving parts of an internal combustion engine. They are to weigh the moving parts before and after a period of service , and to measure the parts before and after a test by means of micrometers. In most cases these tests have given erratic results, and practically no correlation at all seems to exist between the various data collected by different investigators. For the tests reported herein an especially designed machine was used. This machine was designed by Professor Clower for the Engineering Experiment Station and was built in the V.P.I. machine shops. The machine is practical and even though it is an experimental idea it has given what may be considered a fair test. Some difficulty, however, has been experienced with the machine, but as a whole it has given fairly satisfactory data. A photograph of the machine is given below.

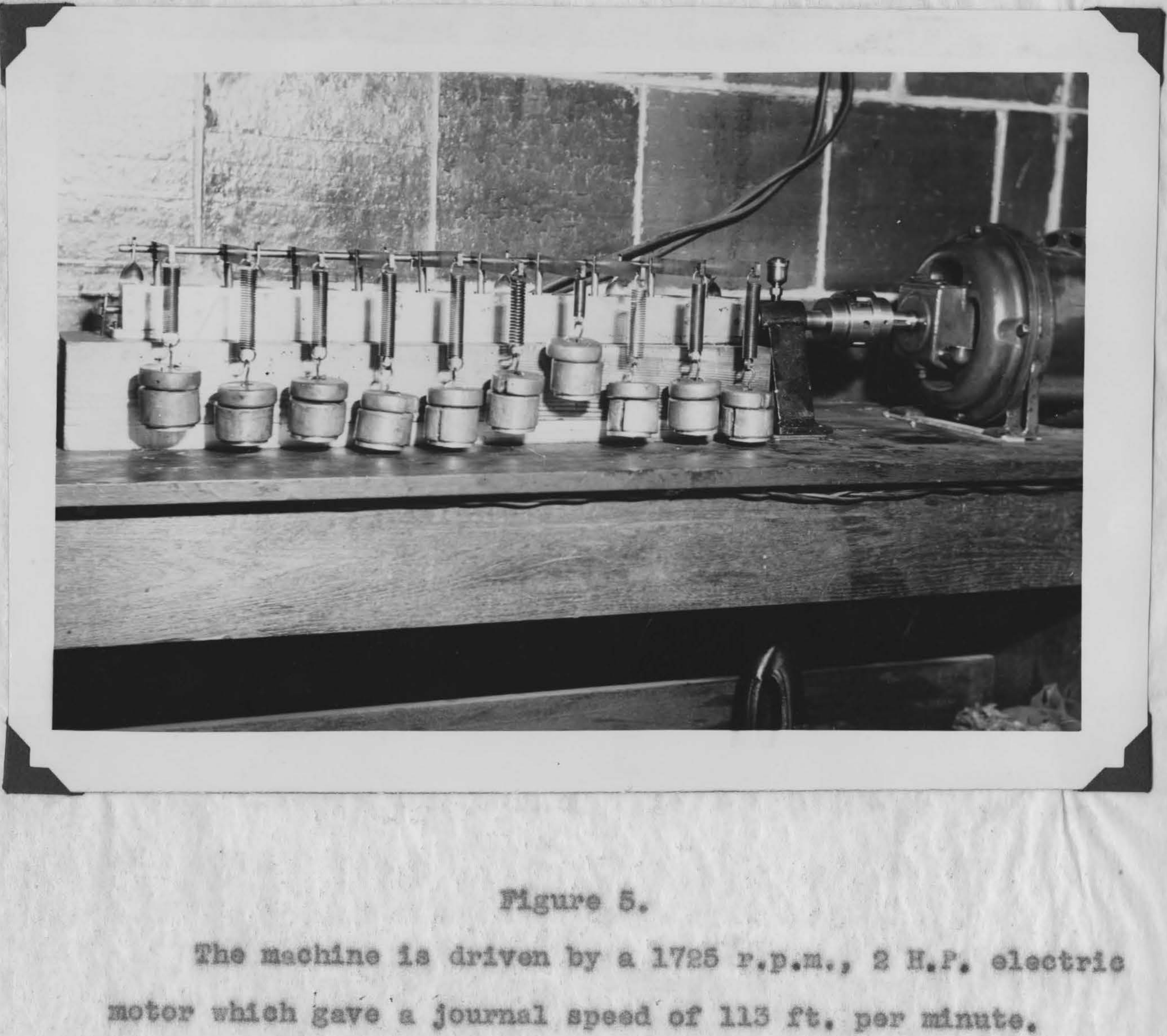


Figure 5.

The machine is driven by a 1725 r.p.m., 2 H.P. electric motor which gave a journal speed of 113 ft. per minute. Eachm bearing was loaded as shown by a weight; which produced a pressure of 150 lb. per sq. in. of projected area of bearing surface. Almen pins of equal hardness were used in all tests. These pins are designed especially for use in the Almen Extreme Pressure Machine. Each compartment is separated from the others by an oil seal through which a coupling passes with slotted ends. The machine was carefully tested for leakage and corrected by the use of iron glue and shellac on the joints. The test was run in the following manner.

All pins and bushings were carefully cleaned in gasoline, dried in oven at 220° F. for 24 hours, and then weighed on analytical balances. The pins and bushings were then carefully placed in position in the various compartments. The oil samples were carefully shaken to insure a representative test, and each compartment filled with the used oil of different mileage. The machine was started and the test continued for 150 hours. A careful log was kept. At the end of the test, the machine was stopped, pins and bushings removed in order of oil number, carefully washed and cleaned in gasoline and placed in drying oven at 220° F. for 24 hours. Care being taken to keep pins in the correct order. The pins and bushings were then removed from the oven, placed in a dessicator to cool to room temperature and weighed on analytical balance.

The loss in weight and per cent loss due to wear was calculated on the basis of the original weight of pins and bushings . For the second test the pins and bushings were reversed, but the oil in the compartments remained in the same order. This was done to check on the hardness of the pins and bushings used. The test was conducted under the same conditions and wear results calculated in the same manner. After a series of tests were conducted the machine showed signs of wear in couplings and main shaft bearings. Attempts to correct these difficulties were futile and in order to continue the wear tests a single unit machine was used. This was essentially the same set-up as the machine described above, except only one oil could be tested during a run. As the smaller unit appeared to give about the same results in shorter times, the period of a test run was reduced from 150 to 48 hours. This may not be in exact relation, but the time element had to be considered as only one oil could be used per test.

Film Rupture[10]

This test was run on an Almen Extreme Pressure Lubricant Testing Machine. Two photographs of the machine are given below.

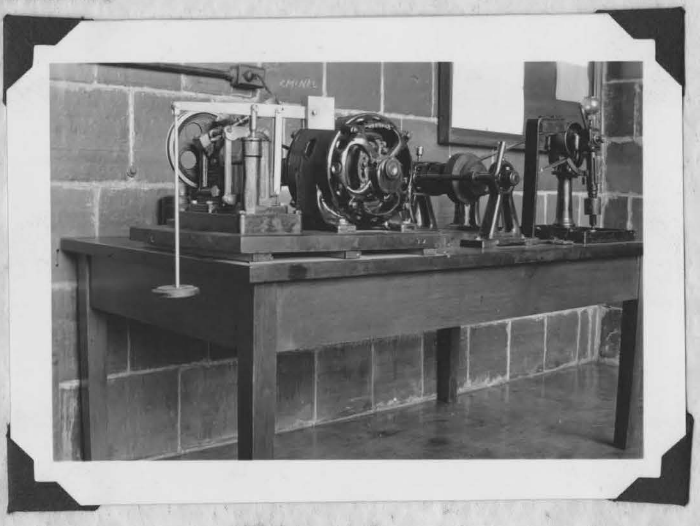


Figure 6

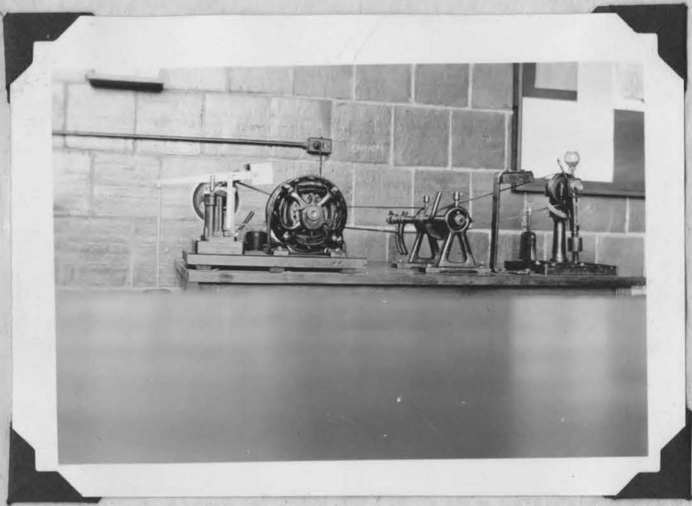


Figure 7.

This is a small portable machine employing a $\frac{1}{2}$-in. drill-rod journal and a $\frac{1}{2}$-in. split bushing made of S.A.E. 2315 cold-drawn steel. The journal is polished and the bushing after splitting is ground on the bearing surface with a form grinding wheel. A clearance of 0.007 inch is provided between the journal and the normal diameter of the bushing. Pressure is applied to the bushing by means of a hydraulic and mechanical loading system. The friction torque developed is indicated through a second hydraulic system to a Bourdon Gage. In conducting a test the oil container is first filled with oil to be tested, submerging the test journal. The machine is then started and run for 30 seconds at no load to insure thorough lubrication of the journal and bushing. The load is then applied at the rate of 2 lb. every ten seconds until seizure occurs, or until 30 lb. have been applied. The speed of rotation is 600 r.p.m. For timing the application of weights, a bell is provided and so arranged to ring at ten second intervals. Each 2lb. weight produced a pressure of approximately 1000 lb. per sq. in. of projected area of the test bearing. The results of the tests are shown in Curve Sheets 2 and 4.

Conradson Carbon Residue

Each crucible was heated to 800° C. to constant weight for 30 minutes and allowed to cool in a dessicator, then weighed on analytical balance. Into each crucible was weighed exactly ten grams of the oil. The crucible was then carefully placed in the center of the Skidmore crucible and the apparatus assembled according to directions. Heat was then applied from a Meker-type gas burner, so that the pre-ignition period was ten minutes plus or minus 1½ minutes. When smoke appeared above the chimney it was ignited by tilting the flame. The flame was then adjusted so that it burned uniformly with the flame above the chimney but not above the flame guide. The vapors were burned for a period of thirteen minutes plus or minus one minute. When the vapors ceased to burn the flame was readjusted to give red heat for exactly seven minutes. At the end of this time the flame was removed and the apparatus allowed to cool. The crucible was then removed and placed in a dessicator to cool, after which it was weighed on an analytical balance. The percent carbon residue was then calculated on the basis of the original ten gram sample. Check determinations were run and average results are shown in Tables Iand II.

Ash Content

The crucibles containgng the carbon residues were placed in an electric furnace at 800° C. for one hour. Then removed and allowed to coâl in a dessicator to room temperature and weighed on an analytical balance. The ash content was calculated in percent ash on the basis of the original weight of the oil taken for analysis.

Iron Content

The crucibles containing the ash were carefully digested with and dissolved in iron-free concentrated HCl. This was done by placing the crucibles in a beaker of concentrated acid and allowing them to stand on a hot plate for several hours until the ash and contents were completely dissolved. This was then concentrated to a volume that could be easily contained in a 100 ml. volumetric flask. The flask was then coâled to room temperature and diluted to the 100 ml. mark with distilled water. This gave the unknown iron solution by which the total iron was determined colormetrically. A 50 ml. sample was measured into a Nessler tube and then poured into a 100 ml. beaker. Five ml. of 6 N. iron-free HNO_3 was then added and the solution boiled gently for five minutes, removed from the burner stand and 3 drops of standard potassium permanganate added and cooled to room temperature. The solution was then washed into the Nessler tube and made up to the mark with distilled water, 5 ml. of standard KSCN was then added and the solution compared quickly with a standard iron solution of known concentration.

The standard ferric solution was made as follows; to a Nessler tube was added varying amounts of the iron solution, then 5 ml. of 6 N iron-free HNO_3 , made up to mark with distilled water and then 5 ml. of KSCN was added. This was compared with the unknown iron solution. Standard iron solution was added to the known until it matched the color of the unknown. The percent of the total iron was calculated as follows:

$$\frac{W \times A \times Y \times Z}{B} = \text{Percent Total Iron}$$

Where,

W = ml. of standard iron used to match color of unknown

A = Constant = 0.0001 gr. of Fe in 1 ml. of standard iron solution

Y = 2 , because 50 ml. was taken for analysis

Z = 100, to bring to percent.

B = Weight in grams of oil originally taken

Haemacytometer Count

This test gives the average number of carbon particles per cubic m.m. of oil. The test was run by an experienced person along this type of work using a standard apparatus and instruments. The oil samples were diluted with xylene before the test in order to make counting more accurate. Three separate counts were made on each oil sample and the average of these counts are shown in Tables I and III.

EXPERIMENTAL DATA

The data collected from this work is shown in the following Curve Sheets and Tables. In order to best explain some results a brief discussion on each oil sample is given below.

Sample No. 1

This sample was new oil and was taken June 30, 1934. The oil used in this test was Gargoyle D.T.E. Extra Heavy, and is manufactured by the Socony Vacuum Oil Company, Incorporated, New York, New York. All oil used in these tests was taken from one ten gallon can purchased through the Standard Oil Company of New Jersey's local distributor at Christiansburg, Virginia.

Sample No. 2

This sample was taken in Parisburg, Virginia, July 1, 1934. The motor was started 15 times during the 50-mile run. No oil was added. The weather was cloudy and rainy and pretty cool. Driving was done over 25 miles of dirt and 25 miles of hard surfaced roads.

Sample No. 3

This was taken July 1, 1934 in El Cento, West Virginia. The weather was cool, cloudy and rainy. The driving was over 13 miles of dirt and 37 miles of hard surfaced roads. No oil was added and the motor was started six times during the 50-mile run.

Sample No. 4

Taken in New Port, Virginia , July 1, 1934. Fifteen hundred cc. of oil was added. The motor was started twice during the trip. All driving was done on hard surfaced roads with moderate speed. The weather conditions were cloudy, cool and rainy.

Sample No. 5

This sample was taken July 2, 1934 , at Iron Gate, Virginia. The engine was started 15 times and 1000 cc. of new oil was added during the trip. The weatherx was clear and moderately warm. The driving was done over 41 miles of dirt and 59 miles of hard surfaced roads. Twenty-five miles of driving was done at a spped of 50 to 60 m.p.h.

Sample No. 6

This sample was taken at Glenvar , Virginia , July 4, 1934. No oil was added , but the motor was started nine times during the run. Driving was done over 38 miles of dirt and 62 miles of hard surfaced roads. The weather was fair and moderately warm. Moderate driving, very little over 50 m.p.h.

<u>Sample No. 7</u>
Collected July 15, 1934, at Mountain Lake, Virginia. There were 40 starts of the motor during the trip and 500 cc. of fresh oil was added . The driving was done over 40 miles of dirt and 110 miles of hard surfaced roads. Weather conditions were moderately warm. Driving was generally at a moderate speed, chiefly around town or on short trips. Frequent starts and stops were made.

<u>Sample No. 8</u>
Taken July 25, 1934 at Glenvar , Virginia. Five hundred cc. of new oil was added. All driving done over hard surfaced roads under moderate speeds . Weather very warm and dry.

<u>Sample No. 9</u>
This sample was taken at Milton, West Virginia, August 3, 1934. Twenty-five hundred cc. of oil was added during the trip . All driving was done over hard surfaced roads. Last 200 miles of the trip was in rainy weather.

<u>Sample No. 10</u>
Collected August 11, 1934, at Cincinnati , Ohio. Five hundred cc. of fresh oil was added. All driving was done over hard surfaced roads. Approximately one half of the mileage was comparatively fast, while the latter half was about Cincinnati at a much slower speed. Frequent starts and stops were made. The weather was pretty warm during trip.

Sample No. 11

Taken August 22, 1934 at Hurricane, West Virginia. Fifteen hundred cc. of the original oil was added. All driving was done over hard surfaced roads under moderately warm conditions.

Sample No.12

August 31, 1934 this sample was taken at Glen Lyn , Virginia. Fifteen hundred cc. of oil was added at the end of the trip. All driving was done om hard surfaced roads under moderately cool weather.

Sample No. 13

This sample was collected August 31, 1934, at Washington Court House, Ohio. Twenty-five hundred cc. of oil was added during the trip. Fifty miles of the trip was over dusty dirt roads, the remainder on hard surfaced roads. The weather was rather warm.

Sample No. 14

Taken September 1, 1934, in Hamond, Indiana. Nineteen hundred cc. of fresh oil was added. All driving was done on hard surfaced roads. Weather moderately warm.

Sample No. 15

Collected September 8, 1934 at Warsaw, Indiana. Twenty-five hundred cc. of new oil was added at the end of trip to fill the crankcase to the mark . All driving was done over hard surfaced streets. The weather was cool and rainy.

Sample No. 16

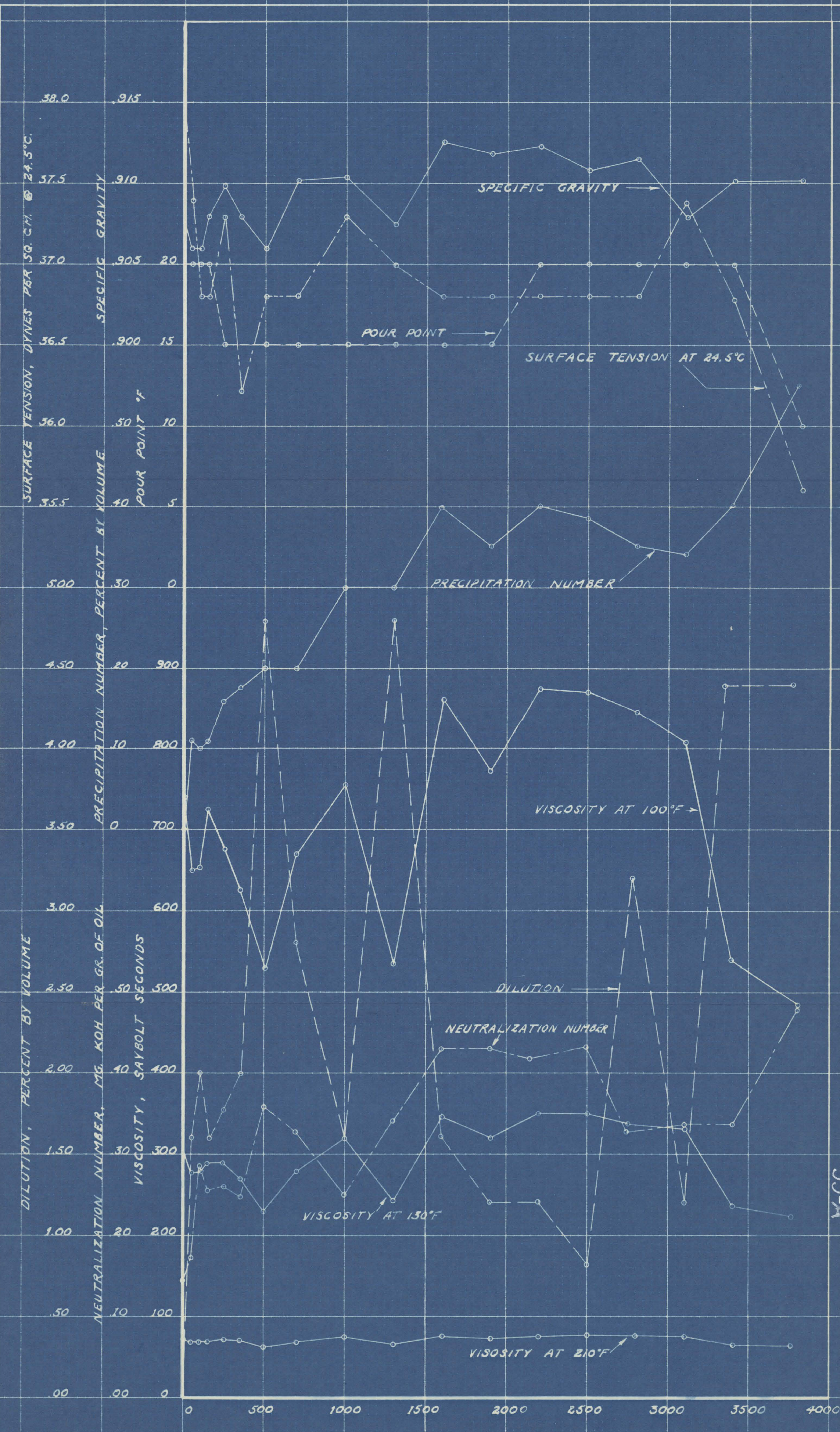
This sample was taken September 9, 1934, in Jackson, Ohio. Fifteen hundred cc. of fresh oil was added during the trip. All driving was over hard surfaced roads with moderately warm weather.

Sample No. 17

This sample was collected in Blacksburg , Virginia, September 21, 1934. Five hundred cc. of oil was added at the end of the trip to bring the oil level to the mark on the oilgage rod. The weather was moderately warm and clear. Two hundred-fifty miles of the trip was on hard surfaced roads the remainder was over dirt roads. The last 25 miles of the trip was around Blacksburg, Virginia, with frequent starts and stops being made.

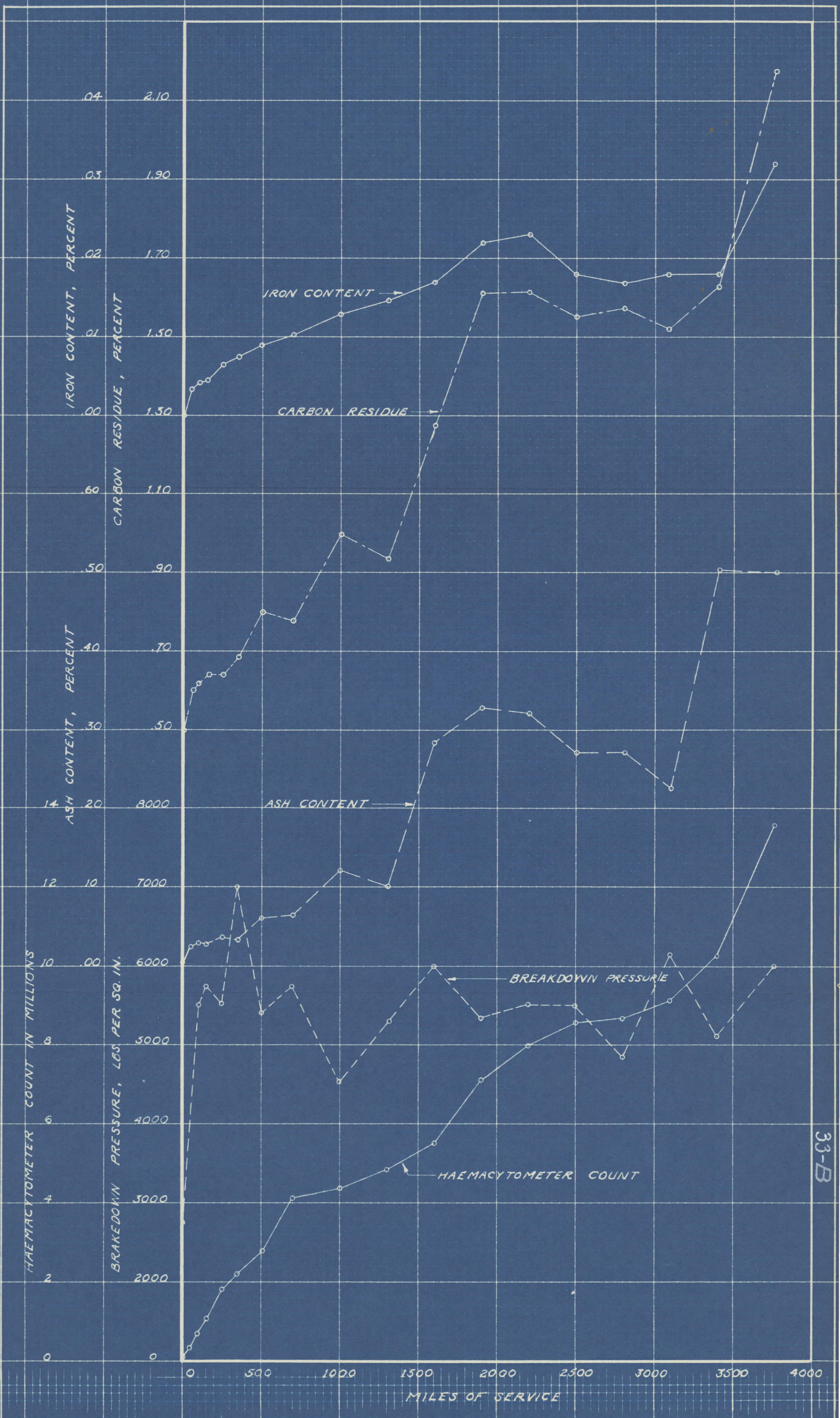
Sample No. 18

The final sample of the test was taken in Blacksburg, Virginia,November 1, 1934. This was taken when the crankcase was drained at the end of the test. All driving was done around town with frequent starts and stops being made. The weather was moderately warm throughout the test.



SHEET 1

W.D.C. 3-30-35

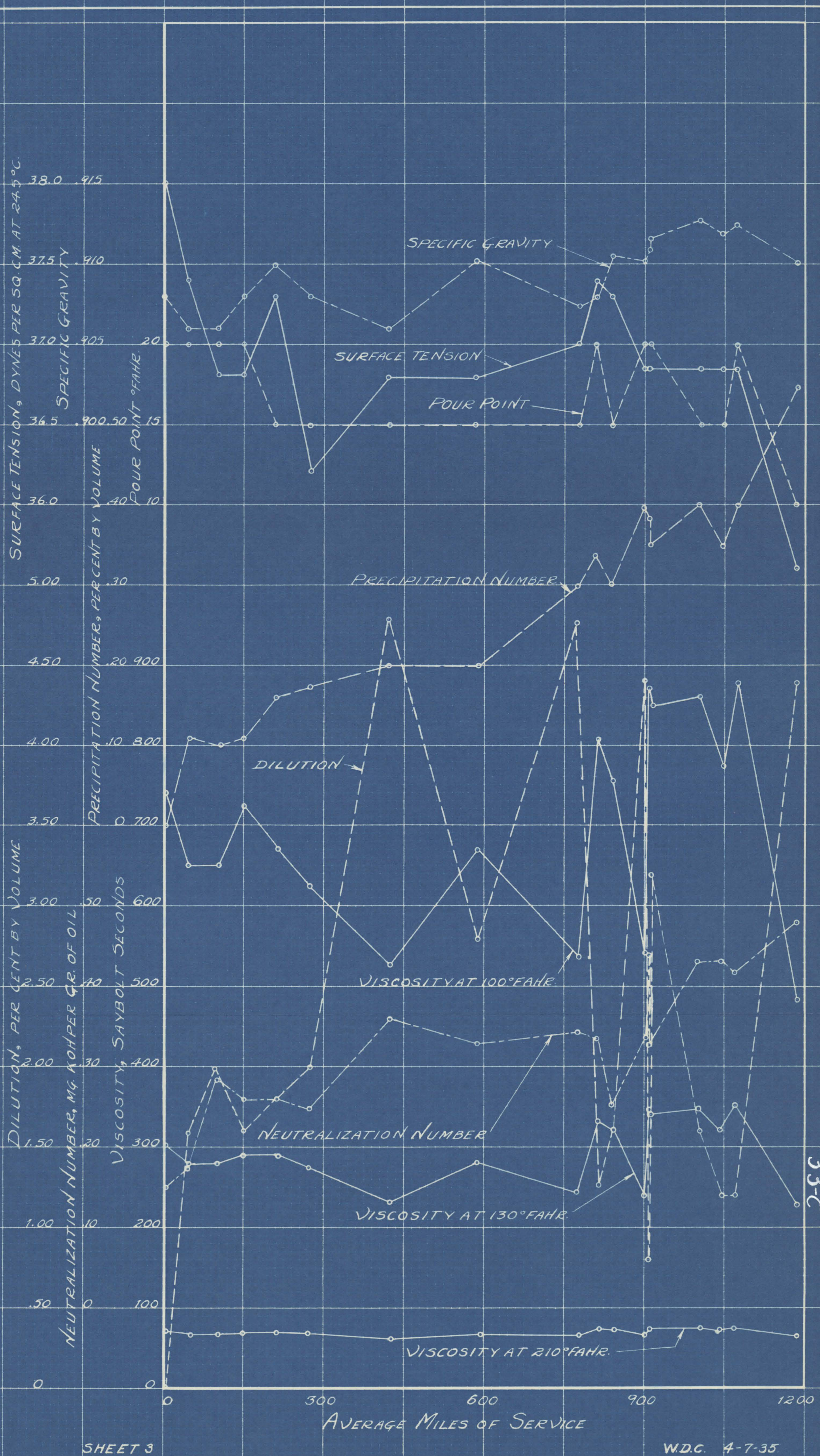


SHEET 2

W. D.C. 3-31-35

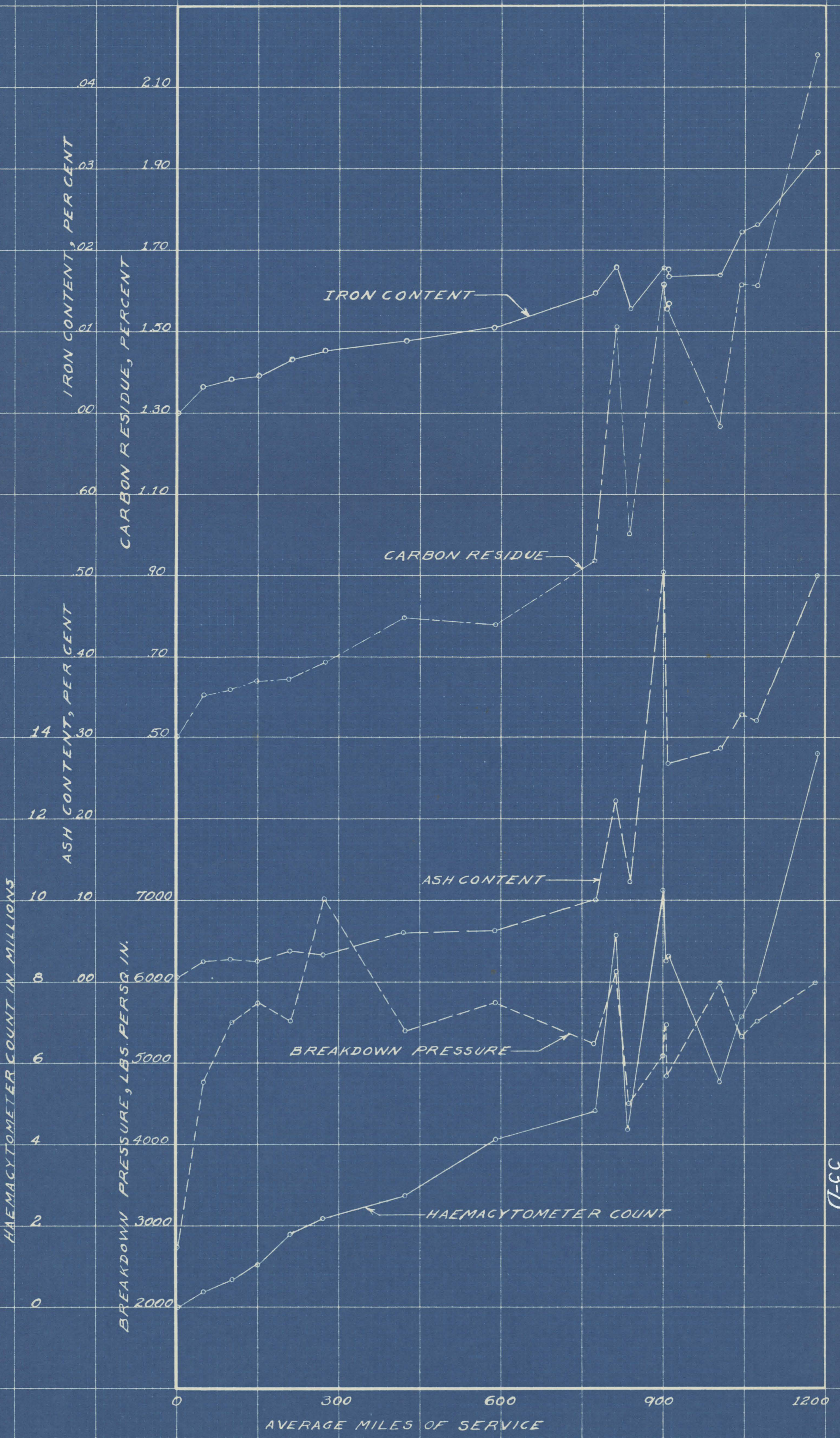
STANDARD CROSS SECTION 10 X 10 KEUFFEL & ESSER CO. — NEW YORK

33-C



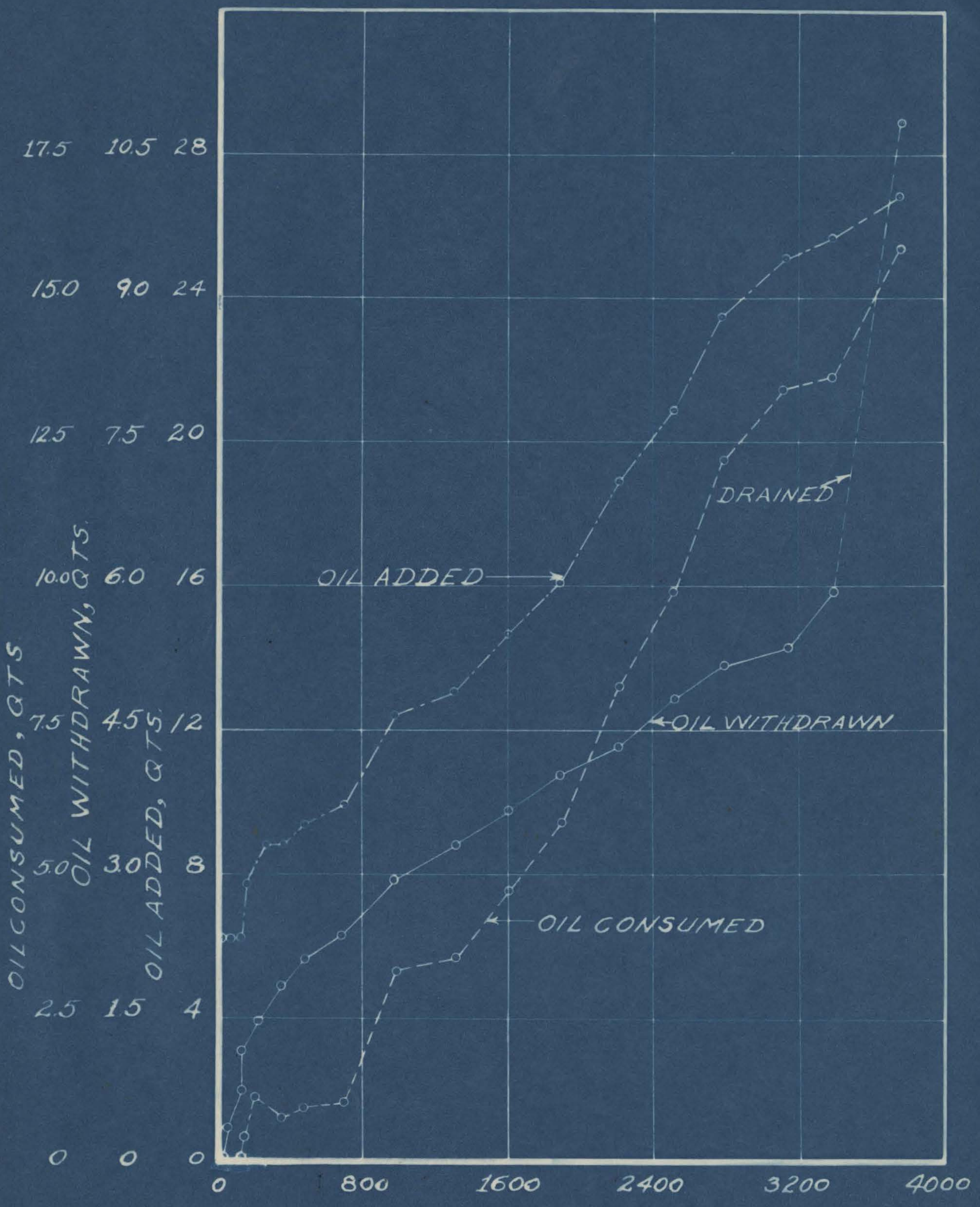
SHEET 3

W.D.C. 4-7-35



SHEET 4

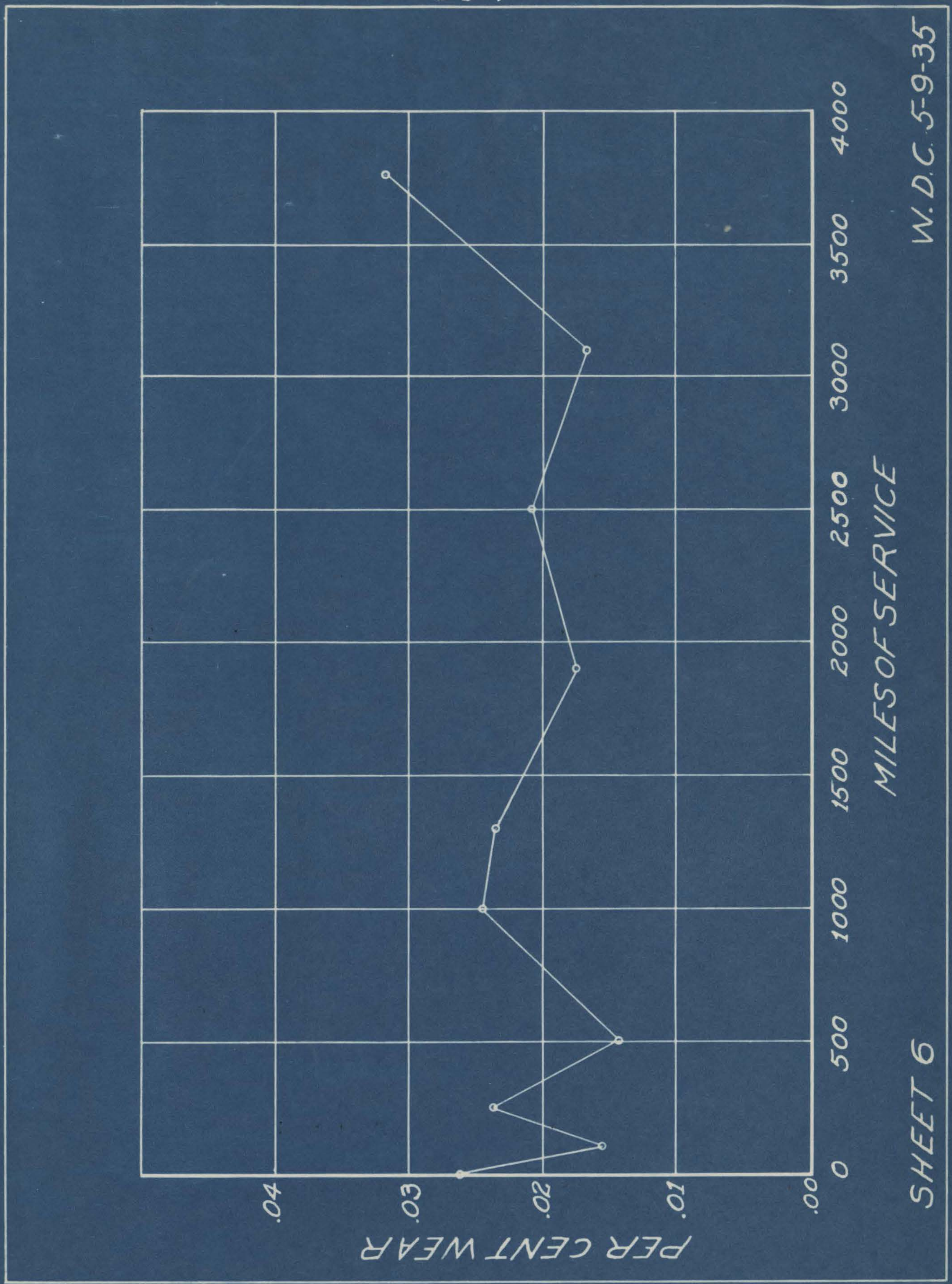
W.D.C. 4-1-35



SHEET 5

W.D.C 4-2-35

33-F


PER CENT WEAR
.00
.01
.02
.03
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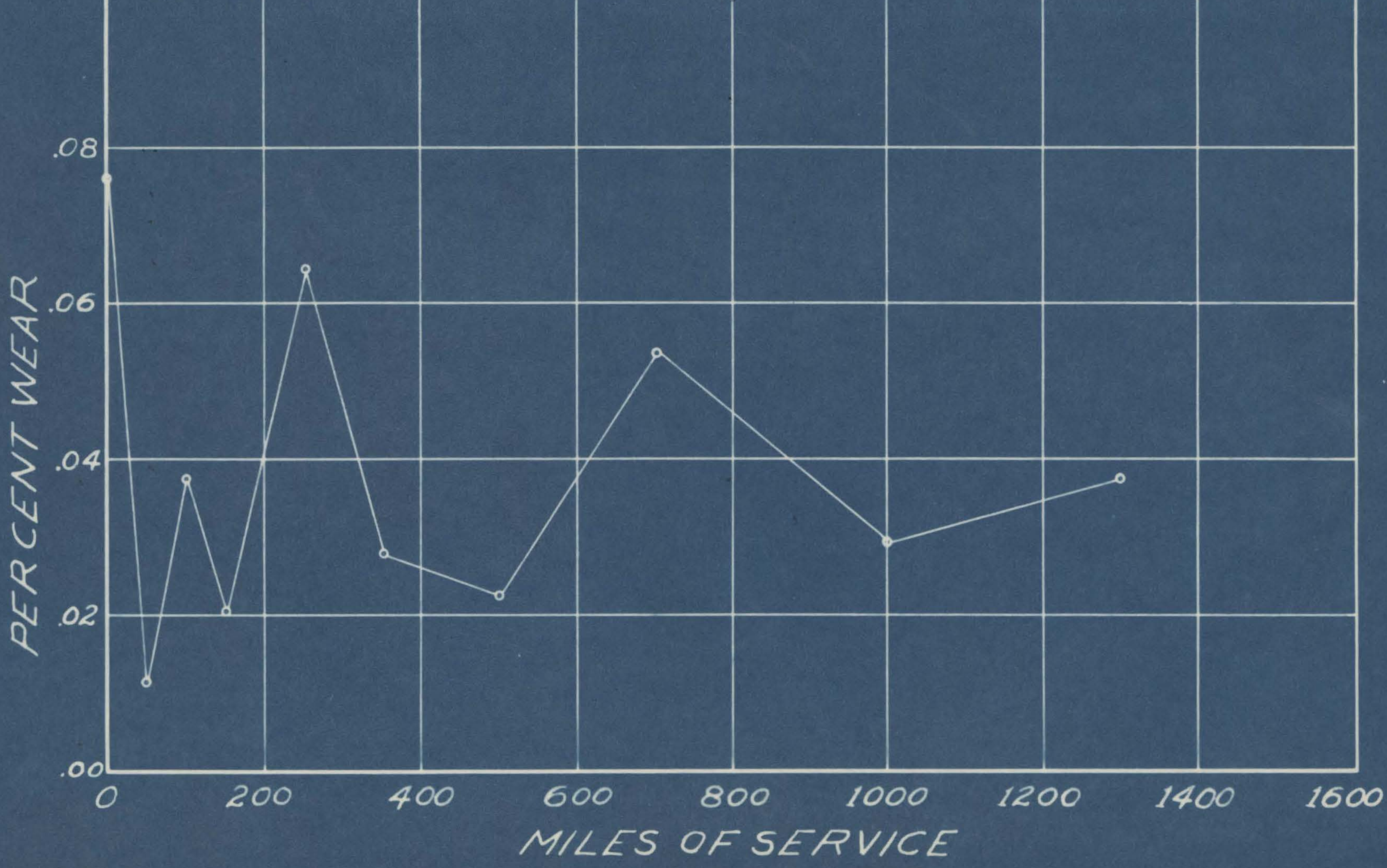
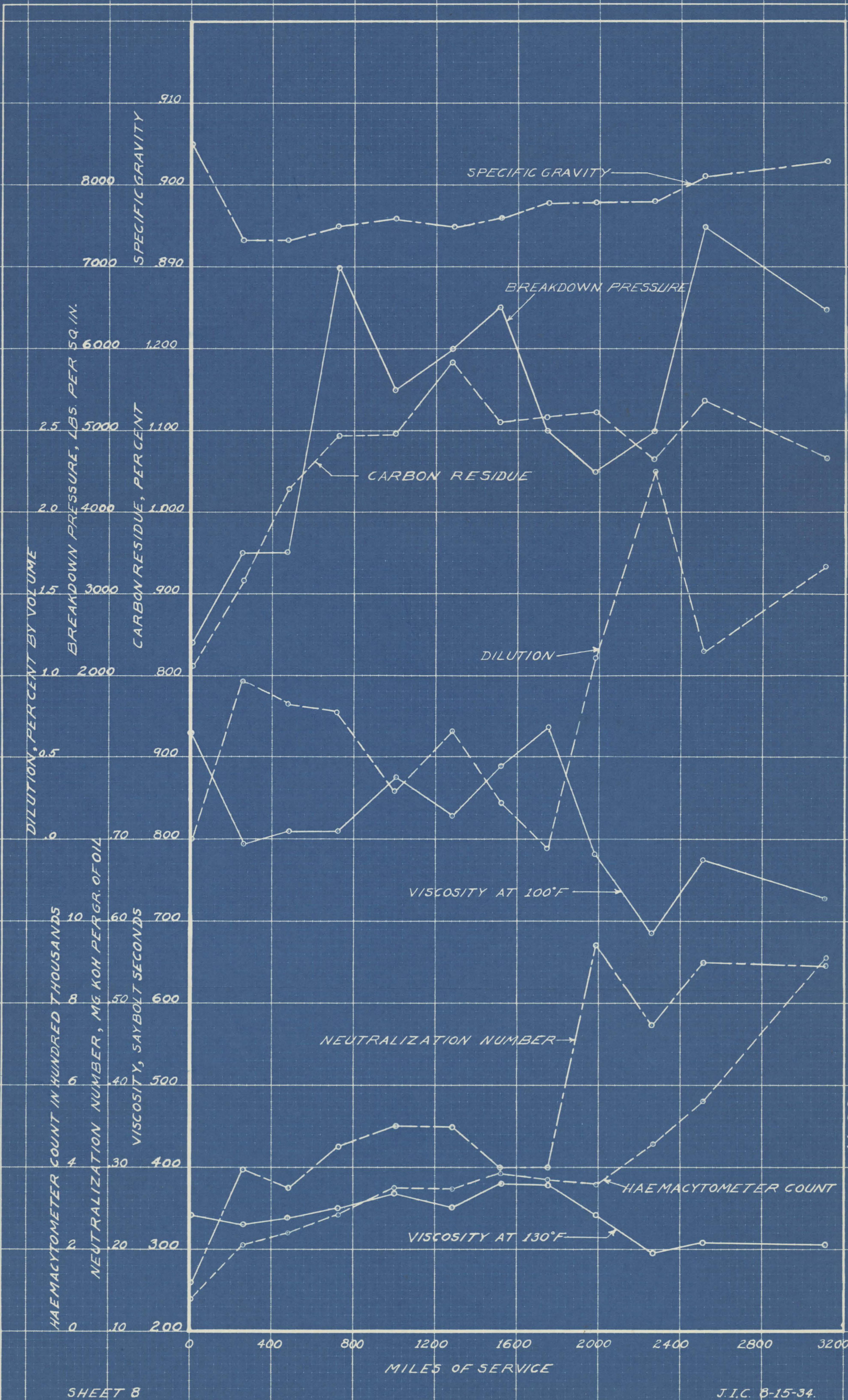
MILES OF SERVICE
0
500
1000
1500
2000
2500
3000
3500
4000
SHEET 6
W.D.C. 5-9-35



SHEET 7

W.D.C. 5-9-35



SHEET 8

J.I.C. 8-15-34.

TABLE I -- SUMMARY OF RESULTS OF OIL TESTS ON CHEVROLET CAR

Oil No.	Mileage	Viscosity, Saybolt Sec.			Dilution	Carbon Residue	Neutralization	Specific	Almen Film Rupture	Haemacytometer Count
		100°F.	130°F.	210°F.	Per cent	Per cent	Number	Gravity	Lb/sq. in.	Number per mm.
1	New oil	931	341	76	0.00	0.806	0.150	0.905	2250	70,000
2	254	793	329	76	0.97	0.918	0.299	0.893	3500	208,300
3	479	809	337	79	0.82	1.026	0.275	0.893	3500	238,300
4	723	811	348	80	0.78	1.095	0.324	0.895	7000	285,000
5	1004	876	370	86	0.30	1.098	0.349	0.896	5500	350,000
6	1286	829	350	81	0.66	1.186	0.349	0.895	6000	347,000
7	1521	889	379	84	0.22	1.110	0.300	0.896	6500	383,000
8	1749	937	378	87	-0.05	1.102	0.301	0.898	5000	370,800
9	1996	781	340	78	1.11	1.122	0.473	0.898	4500	360,800
10	2265	685	294	73	2.25	1.066	0.473	0.898	5000	457,500
11	2509	775	307	75	1.15	1.138	0.650	0.901	7500	563,300
12	3110	728	304	74	1.68	1.068	0.648	0.903	6500	912,500

TABLE II--SUMMARY OF TESTS ON USED CRANKCASE OILS TAKEN FROM PONTIAC CAR

Oil No.	Date Taken 1934	Apparent Mileage	Average Mileage	Oil Added Quarts	Oil Withdrawn Quarts	Oil Consumed Quarts	Specific Gravity	A.P.I. Gravity	Carbon Residue %	Precipitation Number	Neutralization Number	Pour Point °F.	Ash Content %	Iron Content %	Dilution %	Surface Tension Dynes/ sq. cm. at 24.5°C.
1	6/30	0	0	6.200	---	---	0.9079	24.35	0.500	0.400	0.149	20	0.006	---	---	38.0
2	7/1	50	50	6.200	0.37	---	0.9060	24.70	0.606	0.110	0.174	20	0.026	0.0034	1.60	37.4
3	7/1	100	100	6.200	0.74	---	0.9060	24.70	0.619	0.100	0.286	20	0.028	0.0042	2.00	36.8
4	7/1	150	150	7.788	1.11	0.478	0.9080	24.33	0.640	0.110	0.258	20	0.027	0.0046	1.60	36.8
5	7/2	250	211	8.845	1.48	1.165	0.9100	24.00	0.644	0.160	0.262	15	0.036	0.0066	1.80	37.3
6	7/4	350	275	8.845	1.85	0.795	0.9080	24.33	0.687	0.175	0.248	15	0.032	0.0076	2.00	36.2
7	7/15	500	425	9.375	2.22	0.955	0.9060	24.7	0.800	0.200	0.362	15	0.060	0.0090	4.8	36.8
8	7/25	700	589	9.910	2.59	1.120	0.9103	23.95	0.778	0.200	0.329	15	0.063	0.0104	2.80	36.8
9	8/3	1000	838	12.550	2.96	3.390	0.9105	23.90	1.040	0.300	0.251	15	0.120	0.0130	1.60	37.3
10	8/11	1300	774	13.080	3.33	3.550	0.9075	24.40	0.937	0.300	0.343	15	0.098	0.0148	4.80	37.0
11	8/22	1600	1007	14.660	3.70	4.760	0.9127	23.53	1.271	0.400	0.431	15	0.287	0.0170	1.60	36.8
12	8/31	1900	1045	16.24	4.07	5.870	0.9119	23.63	1.614	0.350	0.432	15	0.329	0.0220	1.20	36.8
13	8/31	2200	1073	18.90	4.44	8.260	0.9124	23.58	1.615	0.400	0.418	20	0.321	0.0230	1.20	36.8
14	9/1	2500	908	20.92	4.81	9.910	0.9109	23.84	1.554	0.385	0.434	20	0.271	0.0180	0.80	36.8
15	9/8	2800	909	23.56	5.18	12.180	0.9116	23.73	1.573	0.350	0.327	20	0.269	0.0170	3.20	36.8
16	9/9	3100	814	25.15	5.55	13.400	0.9079	24.35	1.520	0.340	0.336	20	0.224	0.0180	1.20	37.4
17	9/21	3400	902	25.68	5.92	13.560	0.9102	23.97	1.631	0.400	0.335	20	0.504	0.0180	4.40	36.8
18	11/1	3763	1186	26.81	10.96	15.85	0.9102	23.97	2.181	0.550	0.480	10	0.500	0.0320	4.4	35.6

TABLE III--SUMMARY OF TESTS ON USED CRANKCASE OILS TAKEN FROM PONTIAC CAR

Oil No.	Apparent Mileage	Film Rupture Lb./sq.in. (Almen)	Haemacytometer Count Number per mm.	Viscosity Index	VISCOSITIES: Saybolt Universal, Sec.			Kinematic, Centistokes			Absolute, Centipoise		
					100°F.	130°F.	210°F.	100°F.	130°F.	210°F.	100°F.	130°F.	210°F.
1	0	2750	18,333	80.0	740	304	71.0	162.56	66.31	13.29	145.3	59.3	11.42
2	50	4750	378,333	84.3	650	278	68.0	142.72	60.55	12.50	127.2	54.0	10.73
3	100	5500	695,000	86.0	652	280	68.5	143.22	60.96	12.63	127.9	54.5	10.88
4	150	5750	1,046,666	72.5	725	290	68.5	159.25	63.18	12.63	142.7	56.5	10.90
5	250	5500	1,843,333	90.5	675	290	71.0	148.23	63.18	13.29	133.0	56.7	11.45
6	350	7000	2,208,333	95.2	625	272	69.9	137.21	59.14	13.03	122.9	52.9	11.21
7	500	5400	2,763,333	92.0	527	230	64.0	115.66	49.82	11.42	103.2	44.4	9.83
8	700	5750	4,161,666	84.5	670	280	69.0	147.03	60.96	12.77	132.0	54.7	11.01
9	1000	4500	4,371,666	91.2	755	320	74.8	165.86	69.94	14.30	148.7	62.8	12.33
10	1300	5250	4,813,333	103.0	535	242	67.0	117.46	52.51	12.22	104.9	47.0	10.53
11	1600	6000	5,518,333	82.0	865	347	77.0	190.29	75.88	14.87	171.0	68.2	12.86
12	1900	5330	7,150,000	85.5	775	320	74.0	170.47	69.94	14.06	153.0	62.7	12.16
13	2200	5500	7,796,666	82.3	880	351	77.5	193.29	76.69	14.98	173.7	68.9	12.98
14	2500	5500	8,568,333	86.0	875	352	78.5	192.59	76.99	15.26	172.8	69.0	13.18
15	2800	4830	8,640,000	84.0	850	338	77.0	186.79	73.87	14.87	167.5	66.3	12.84
16	3100	6170	9,151,666	84.5	810	332	75.2	177.88	72.46	14.41	159.0	64.8	12.40
17	3400	5100	10,310,000	96.0	540	236	65.4	118.47	51.14	11.80	106.2	45.9	10.18
18	3763	6000	13,605,000	106.0	484	224	65.0	106.03	48.50	11.68	95.1	43.5	10.05

33-2

RUN No. 1

TABLE IV--SUMMARY OF WEAR TESTS RESULTS ON PONTIAC CAR

Hours of operation - 150.5 Journal speed - 113 ft. per min.

Load - 150 lb. per sq. in.

Oil	Bearing Metal Combination	Weight of Bearing		Loss in weight Grams	Per cent Loss in weight
		Original	Final		
1	Steel on Steel	31.5380	31.5206	0.0174	0.0552
2	" " "	31.4666	31.4611	0.0055	0.0175
3	" " "	31.5228	31.5089	0.0139	0.0441
4	" " "	31.4630	31.4569	0.0061	0.0194
5	" " "	31.5110	31.4782	0.0328	0.1040
6	" " "	31.4792	31.4679	0.0113	0.0359
7	" " "	31.2318	31.2244	0.0074	0.0236
8	" " "	31.3974	31.3719	0.0255	0.0815
9	" " "	31.4872	31.4760	0.0112	0.0356
10	" " "	31.2662	31.2525	0.0137	0.0438

RUN No. 2

1	" " "	31.2525	31.2219	0.0306	0.0971
2	" " "	31.4760	31.4741	0.0019	0.0060
3	" " "	31.3719	31.3624	0.0095	0.0302
4	" " "	31.2244	31.2178	0.0066	0.0210
5	" " "	31.4679	31.4600	0.0079	0.0250
6	" " "	31.4782	31.4720	0.0062	0.0197
7	" " "	31.4569	31.4504	0.0065	0.0209
8	" " "	31.5089	31.5008	0.0081	0.0257
9	" " "	31.4611	31.4539	0.0072	0.0229
10	" " "	31.5206	31.5108	0.0098	0.0311

TABLE -V- AVERAGES OF RUNS No. 1 and 2

OIL No.	RUN No. 1 PERCENT LOSS	RUN No. 2 PERCENT BOSS	AVERAGE PERCENT LOSS
1	0.0552	0.0971	0.0762
2	0.0175	0.0060	0.0118
3	0.0441	0.0302	0.0372
4	0.0194	0.0210	0.0202
5	0.1040	0.0250	0.0645
6	0.0360	0.0197	0.0278
7	0.0236	0.0209	0.0223
8	0.0815	0.0257	0.0536
9	0.0356	0.0229	0.0293
10	0.0438	0.0311	0.0375

TABLE VI- SUMMARY OF WEAR TEST RESULTS ON PONTIAC CAR OIL

Hours of operation, 48- Journal speed, 113 ft. per min.

Load, 125 lb. per sq. in.

OIL No.	Bearing metal Combination	Weight of Bearing Grams		Loss in Weight Grams	Per cent Loss in Weight
		Original	Final		
1	Steel and No.7	33.5626	33.5540	0.0088	0.0262
3	" " "	33.5806	33.5754	0.0052	0.0155
5	" " "	33.5734	33.5654	0.0080	0.0238
7	" " "	33.6472	33.6424	0.0048	0.0143
9	" " "	33.7300	33.7217	0.0083	0.0246
10	" " "	33.5974	33.5894	0.0080	0.0235
12	" " "	33.6702	33.6643	0.0059	0.0175
14	" " "	33.6422	33.6357	0.0070	0.0208
16	" " "	33.5948	33.5894	0.0054	0.0167
18	" " "	33.5306	33.5200	0.0106	0.0316

DISCUSSION OF RESULTS

The investigation was intended to collect data on the changes which crankcase oils undergo when used in automobile motors under normal operating conditions. It is believed by the author that the tabulated results and graphs show with a fair degree of accuracy the conditions that will probably result in an oil when a car is driven by the average owner in a reasonably careful manner. Considerable variations were expected, and expectations were fully realized.

The results obtained in the case of standard A.S.T.M. tests are in the main in agreement with results obtained by various other investigators, making due allowances for the different procedures in collecting the oil samples, operating conditions, etc.

Special attention is called to the difference between the apparent miles of service and the average as shown in columns 3 and 4, Table II for the Pontiac car. The actual number of miles the car was driven was 3763, yet at the end of this mileage the average miles of service on the oil was only 1186. This disparity, of course, is due to the " sweetening" of the oil to compensate for oil consumed and withdrawn as samples. It will be noted that the consumption for the 3763 miles was 15.85 quarts, or 238 miles per quart. This is not excessive, considering that the car had been 80,000 miles before the tests were started. This " sweetening " effect is greater of course where test samples are withdrawn, than it is in actual car operation, because of the necessity of adding oil to compensate for the quanity withdrawn. This serves, however, to illustrate, that the speedometer mileage is not an accurate record of the average miles of service that the oil has rendered. This varying with the oil consumption, and the difference between the two mileages, increases with increased oil consumption.

From the break-down pressure curves it is noted that film strength, as measured by the Almen machine is greater in every instance, in the case of the used oil, than that of the new oil. In the case of the Chevrolet car, the maximum film breakdown of 7500 lb. per sq. in. was obtained at the end of 2509 apparent miles of service. This is an increase of 233 % over the new oil. For the Pontiac, the maximum of 7000 lb. per sq. in. was reached at an apparent mileage of 350. This is an increase of 155 % over the new oil. This increase in film break-down is doubtless due in the main to the fact that solid particles (mainly carbon) aid in supporting the load imposed on the bearing. To a certain degree it may also be due to the effects of oxidation, as it has been found that oxidized oils are capable of withstanding higher operating temperatures before seizing than non-oxidized oils.[11]

The following photograph shows the duplicate pins and bushings used in the Almen machine for determing the break-down pressure on the 18 samples of oil.

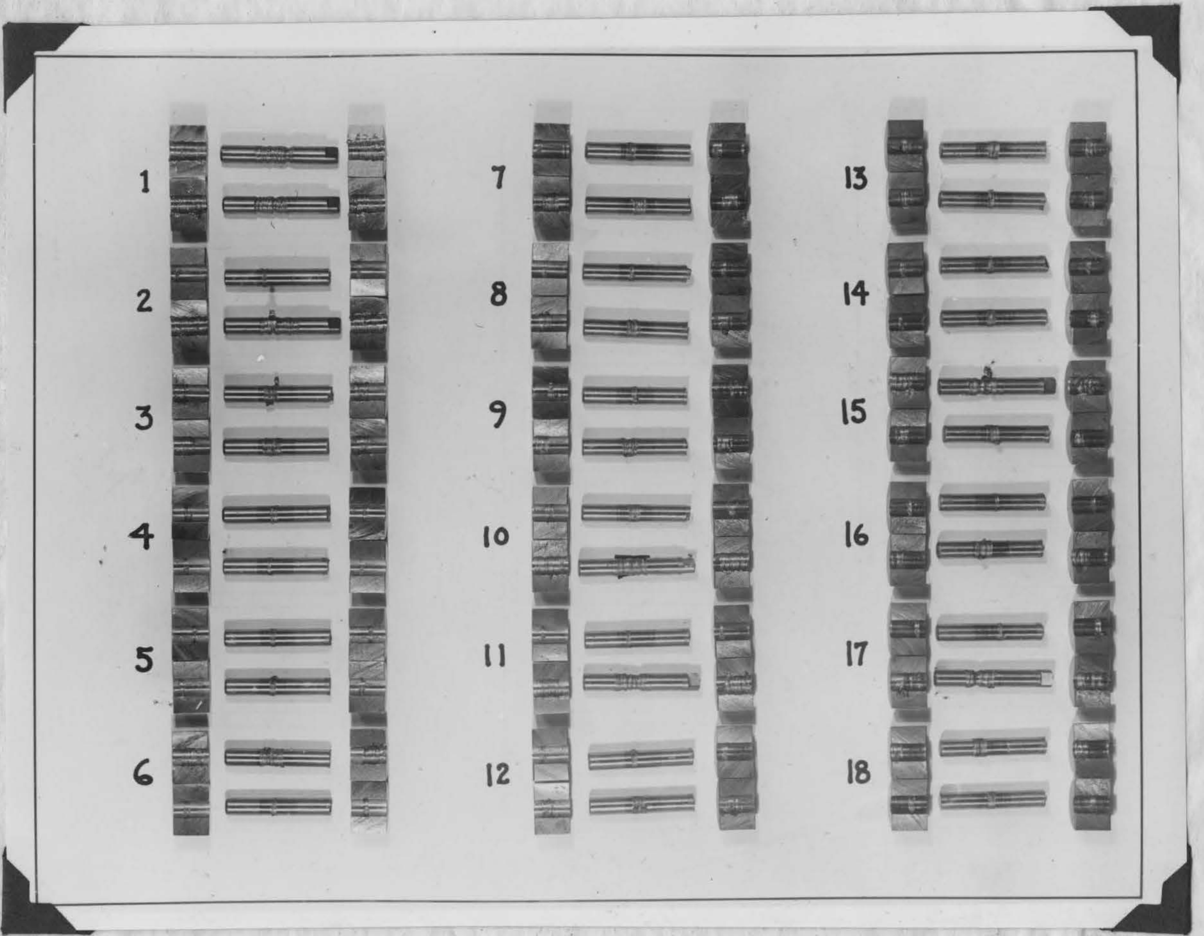


Figure 8

The purpose of the haemacytometer count(blood count) was to determine whether or not there exists a correlation between the number of solid particles and the film rupture. A comparison of the four curves, however, fails to show any direct relation. As to be expected, the haemacytometer count curves show a rather uniform increase in the number of particles present in the oil. The trend, however, of the film rupture curves is rather a rapid increase for the first few hundred miles and then a gradual flattening out.

The greatest variations in the curves are those of viscosity and dilution. If followed closely however, the peak points for dilution occur when the viscosity is at a minimum. This was expected and is clearly shown by the curves on Sheets 1, 2, 3, 4, and 8. From the discussion on each oil sample it will be noted that in practically all cases peak points on dilution curves were obtained on samples 7, 10, 15, 17, and 18; and that the motor was started frequently in most of these cases. Also the driving was comparatively slow and frequent starts and stops were made on these short trips. These factors certainly affect dilution and consequently the viscosity of the oil.

Dilution also affects the break-down pressure of an oil by thinning out the film. The curves show this very clearly. In general when the percent of dilution is low, the break-down pressure is high. This is obvious from the above statement.

Ash, iron and carbon residue curves show a gradual trend to steadily increase. This was expected as it is characteristic of all oils in general during service.

There is some relationship between specific gravity and dilution. A high dilution in most cases means a low specific gravity. This is evident by the relation between the curves for dilution and specific gravity. The general trend for the specific gravity curve is gradually upward, as service miles increase.

The significance of neutralization number is a debateable subject, but it does offer some idea of the sum of the quanities of mineral and the so-called organic acids present in the oil or the difference in organic acidity and the alkali present in the oil. From this we may suggest it gives some idea as to the extent of oxidation to which the oil has undergone. The general trend is upwards as shown by the curves on sheets 1 and 3.

A great part of the time allowed for this investigation was spent on the rate of wear of the new oil as compared to that for the old and used oil of different mileages. Many tests were conducted using different composition pins and bushings . These tests gave very erratic results in so far as the rate of wear was concerned. But in order to get a better correlation between oils it was decided to use only one type of pin. For this test the single unit machine was used exclusively. This proved to give a much better result than by using varying pins and varying oil. The test is not complete at this time , but some idea of the type of work and results are shown in the curves on Sheets 6 and 7. The calculated values for the points on the curves are given in Tables IV , V and VI. The work will be continued until the end of the year and complete results of the tests will be published as a bulletin of the college at some future date. While far from the curves shown herein it is evident that the rate of wear is not as great with used oil as it is for the new oil. This maybe partly explained by the carbon particles present that help to lubricate and prevent wear. In only one instance did the rate of wear exceed that for the new oil. This was sample No. 18,from the Pontiac car. It is the hope of the author that some very definite and conclusive results will be arrived at before the end of the year.

In the following few pages are shown some microphotographs, that give a picture of the oil samples. Due to the time allowance on this paper the pictures are not complete, but are only of a few of the samples. They do show the increased dirt and carbon particles as the oil number increases . This was to be expected,as it is most common for the oil to be come dirty as miles of service increases. This increased dirt and carbon particles is in general a detriment to the oil rather than a benefit. The increased carbon should act as a lubricant under some conditions, but the large amount of carbon and dirt together really act as factor to promote wear and scoring of the bearings and moving parts of the engine that are lubricated by this oil. This effect of carbon increase,as shown by the pictures, should show up in the carbon residue and haemacytometer count. It is the belief of the author that this is shown very clearly by the curves for carbon residue on Sheets 2 and 4, and haemacytometer count on curves on Sheets 2 and 4. The pictures beginning with oil sample No. 9 are shown in the following pages.

Fig. 9, Sample No. 9

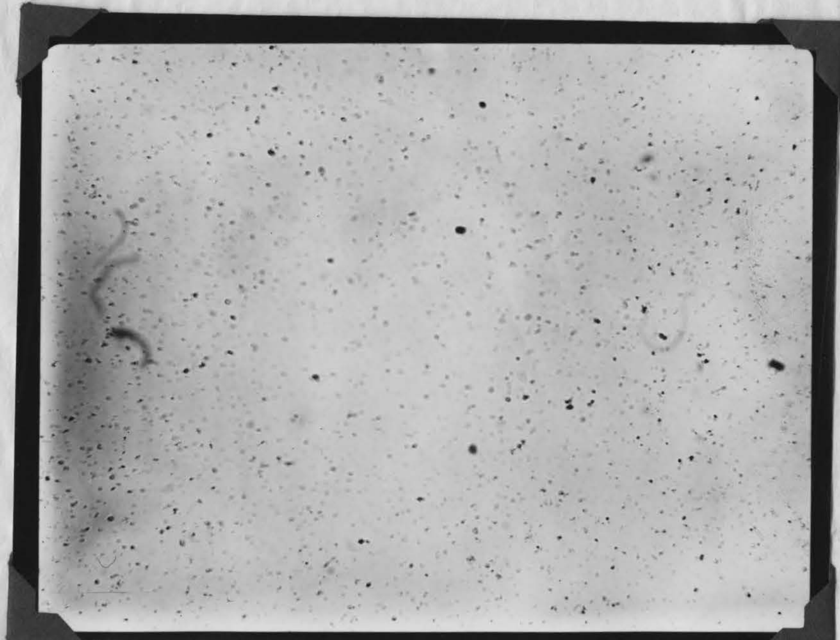


Fig. 10, Sample No. 10

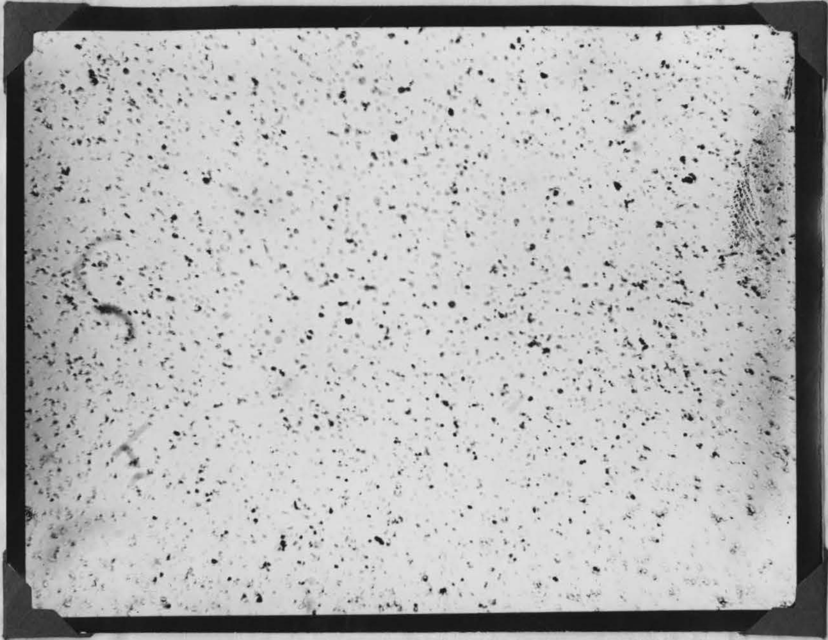


Fig. 11, Sample No. 11

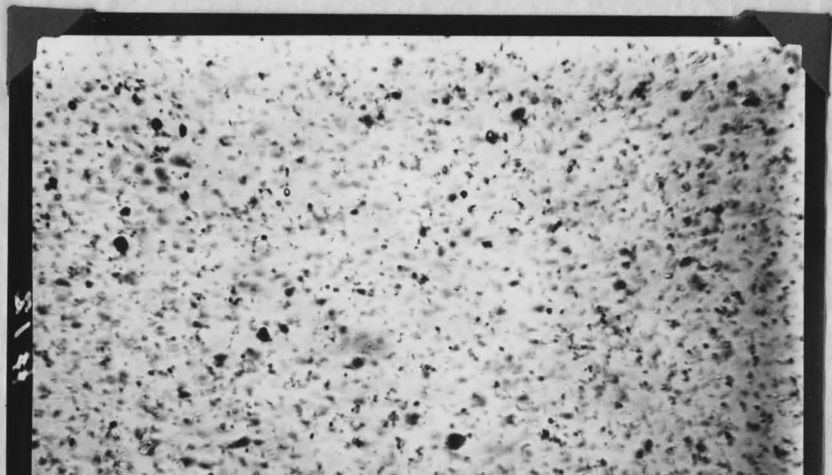


Fig. 12, Sample No. 12

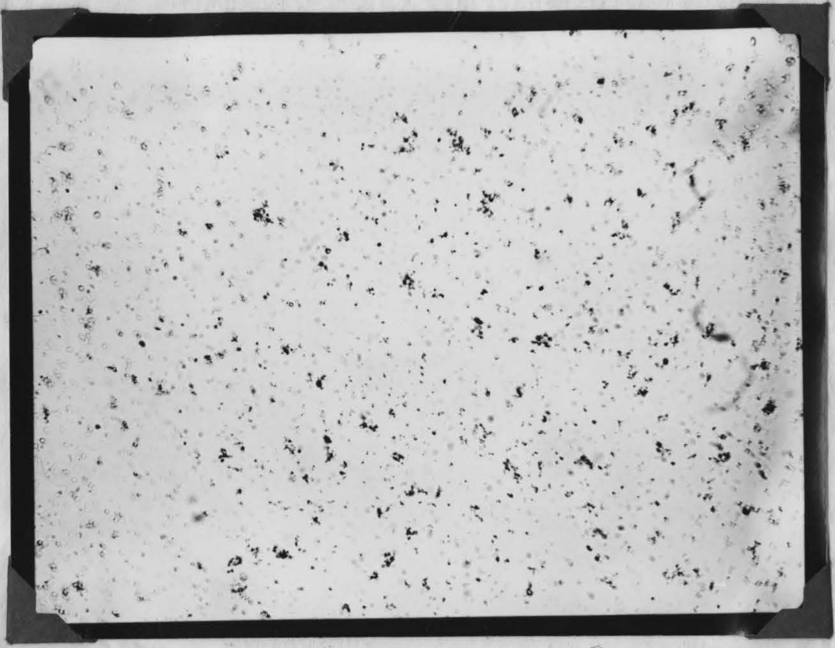


Fig. 13, Sample No. 13

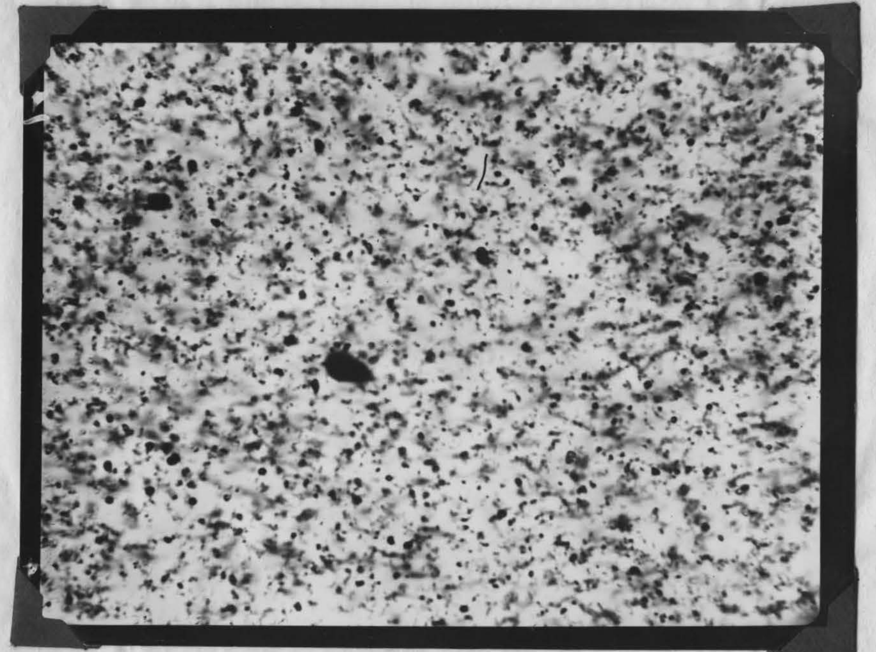


Fig. 14, Sample No. 14

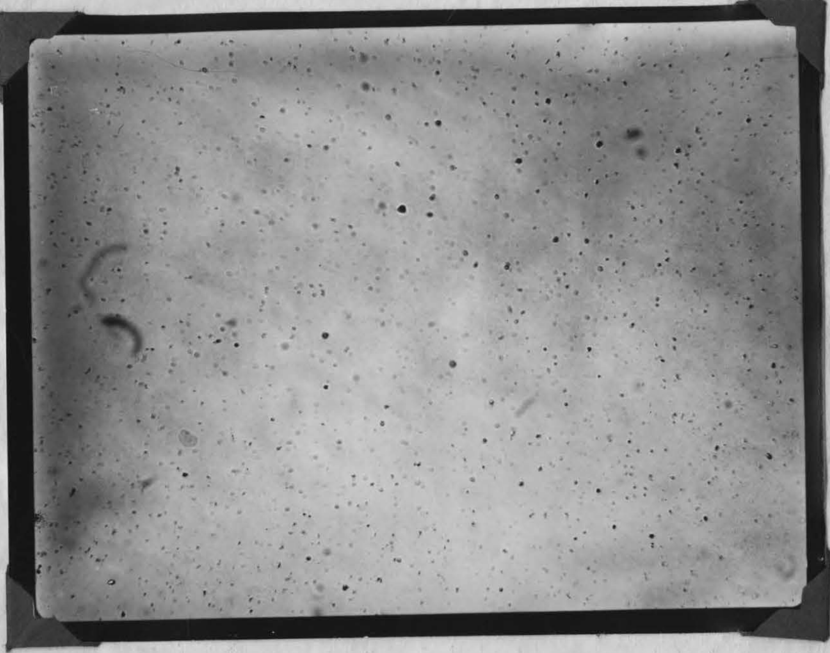


Fig. 15, Sample No. 15

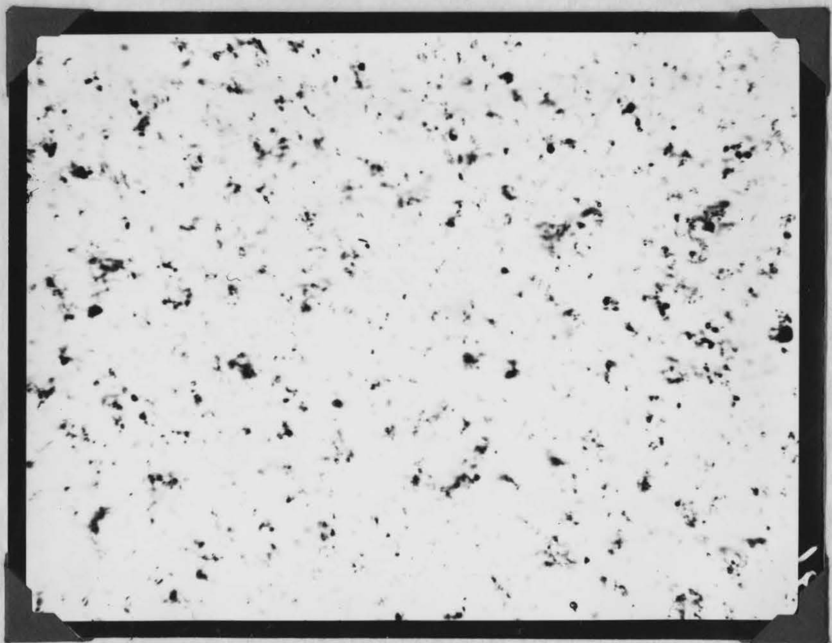


Fig. 16, Sample No. 16

Fig. 17, Sample No. 17

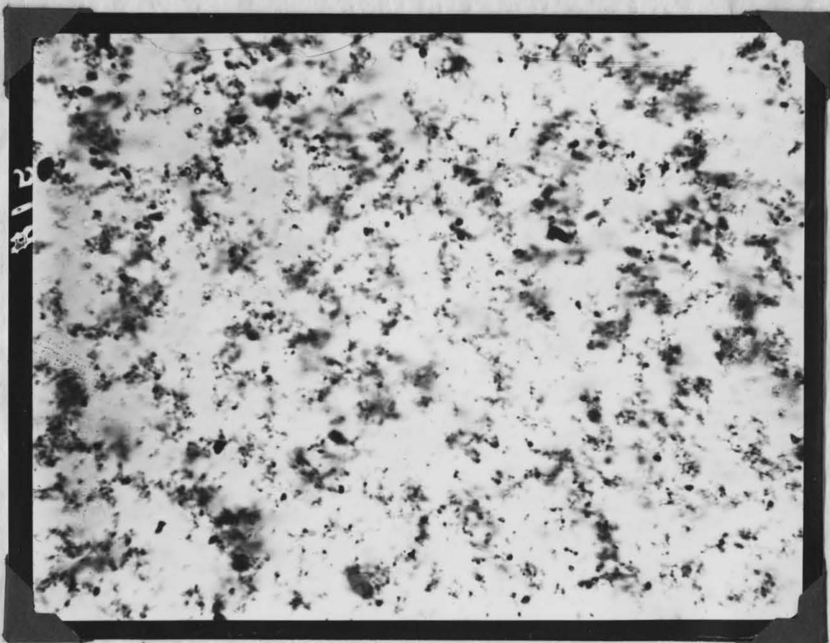


Fig. 18, Sample No. 18

CONCLUSIONS

From this investigation certain facts have been shown. First, that the film strength of an oil does increase with service. Second, that carbon residue, iron , ash , neutralization number and carbon particle count (haemacytometer count) do increase with use of the oil. Third, that dilution and viscosity are related and depend largely on the operating and driving conditions to which the oil in the car has been subjected. Fourth, that the speedometer mileage is not a correct indication of the actual mileage on the oil , because of the addition of make-up oil. Fifth, that the precipitation number shows a very steady increase with service, and that this may suggest some index as to when the oil should be drained. Sixth, the Viscosity Index of the oil does increase with service in most cases. Seventh, that the apparent rate of wear,as determined by the method on pages 21, 22, 23, and 24 of this thesis, for used oils is less than that for the new oil. The tests are not complete , but results to date indicate this to be true.

SUGGESTIONS FOR FURTHER INVESTIGATION

The subject of " Effect of Service on Automobile Crankcase Oils " is a major problem in the oil as well as automobile industry of today. With this in mind the author feels that this investigation has opened up new methods of attack on the problem, and has been an endeavor to try and present some of the facts that have arisen from an actual test. Much work remains to be done on this subject before the actual problem of crankcase oil deterioration is settled. The question before the general public is " When should I change the oil in my car ?" To the author's mind no single test or groups of tests can be significant enough to completely answer this very important question. Many investigators have given there own ideas on this subject, but the actual proof of an answer to the question has never been given.

In further investigations the author suggests some work in connection with film-breakdown pressure and its relation to the percentage of dilution that the oil may carry in order to bring the film-breakdown pressure back to that of the original oil. In connection with this, the subject of rate of wear vs. dilution might be investigated. The subject is very debateable at present and many conflicting reports have been advanced on this question. In connection with rate of wear the author suggests that more time be spent on this subject in order to carry the investigation over many and varied ranges, thereby being able to predict and realize more significant data than was obtained from this rather short investigation, on this very important field of lubrication.

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