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DEPARTMENT OF NORTHERN AFFAIRS AND NATIONAL RESOURCES

RESOURCES DIVISION

RESERVOIR STUDY

NORMAN WELLS FIELD

NORTHWEST TERRITORIES

-by-

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RESERVOIR STUDY

NORMAN WELLS FIELD, N.W.T.

SUMMARY:

The results of this study, conducted during the past several months, have indicated that a strong water drive exists. The limited history does not justify extrapolating this history to ultimate production as only approximately 1.8% of the oil in place has been produced. However, if the presently indicated water drive persists throughout the life, and the life is not too short (i.e. the producing rate is not too high), it can be said that ultimate production should be in the range of 40 to 60 per cent of the oil in place or 160 to 240 million barrels. If the water drive fails, recovery should still be a minimum 20%, or 80 million barrels. Explanation of this wide range of recoverable oil can be found in the text under "ULTIMATE RECOVERY".

The oil in place is calculated volumetrically at 419×10^6 barrels of stock tank oil.

The lack of reservoir data has necessitated some not too well qualified guesses as to reservoir factors for this field which has no comparable field in its remote area.

Difficulty is naturally experienced with determination of the average pressure due to so much of the field being under the Mackenzie River. This is not a critical

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factor, however, at the present pressure level, since a 100 per cent error in the calculated average pressure drop would result in only a 1.0 to 2.0 per cent error in the amount of water encroachment.

CONCLUSIONS:

1. There is no immediate need for production control, as both this study and Imperial's modified Carter Analyzer study referred to in the Text, indicate that producibility in the order of some 2,000 barrels per day should be sustained by water drive, especially with regard given to Item 2 below.

2. All tight wells should be reworked to lower GOR's and increase productivity.

3. The study of the effect of producing characteristics on the Reservoir should be maintained or brought up to date from time to time.

4. There does not appear to have been any harm done by the injection of gasoline base stock and it is felt that gas should not be reinjected as there is not sufficient cap space for it.

5. Assisted recovery is not needed presently due to the strong water drive.

6. Some system for determining the level of the encroaching water table should be instituted in field operation, - EXAMPLE: a log run every five years.

- TEXT -

INTRODUCTION:

This study was the result of a request by Mr. A.D. Hunt, Head of the Oil & Gas Section, Department of Northern Affairs and National Resources, Ottawa, to answer the following questions:

(1) Is the Field being overproduced, resulting in higher gas-oil ratios and lowering pressures?

(2) Should the particular wells: 14X, 21X, 23X, 24X, 25X, 26X, 28X and 35X, and those on Bear Island, have curtailed production or be shut in?

(3) What is the type of drive and what are recoverable reserves?

(4) Should injection of gasoline base stock be continued and should gas be reinjected?

(5) Should assisted recovery be initiated now?

A particular cause for concern was the reduction below saturation pressure (565psig) of certain wells: 14X, 23X, 25X and 26X, and of some other wells being down near to saturation pressure. Also, these and other wells and those on Bear Island generally were exhibiting high and rising gas-oil ratios.

To answer most of these questions a reservoir study was needed.

METHOD:

Graphs of the history of producing data were brought up to date from those shown in the report by Mr. E.R. Outlan of Imperial Oil Limited of December, 1951. These plots are shown in FIGURE 1.

Pressure maps were then made for the pressure surveys of 1958 and 1959 and an average reservoir pressure determined by areal planimetering. For the intervening years 1952-1957, the average pressure figures determined by Imperial Oil Limited were used as they appeared reasonable with comparison to 1958 and 1959 figures, and were obtained in the same manner. These are shown as FIGURE 2 and FIGURE 3. This simplified method of pressure determination was made on the subsea datum of 1,130 feet. Although the reservoir has a dip of approximately 4 degrees, which amounts to some 800 to 900 feet, calculation of average pressure by other means is largely ruled out because reservoir fluid analyses at varying depths through the reservoir have not been made, and the solution gas and formation volume factors as well as compressibility of the reservoir fluid have only been determined at the 1,130 feet subsea datum. The direction of the effect is discussed under "RESERVES".

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A solution gas analysis furnished by Imperial Oil Limited was used to determine the compressibility of the gas and the conversion factor to barrels at reservoir temperature and pressure, and this data is shown in FIGURE 4.

A plot of cumulative gas versus cumulative oil production was made and is depicted in FIGURE 5 to determine the trend of solution gas production. This was inconclusive. Next, an attempt was made to fix the oil in place by material balance, assuming no water drive. It soon became apparent that a water drive must exist because of oil in place figures of some 50 billion (50×10^9) barrels.

Oil in place was then calculated volumetrically from an isopach drawn by Mr. S.A. Kanik. A revision was made to this isopach in the tighter Bear Island sector and in the down dip water edge, as shown in Figure 6 to reduce area and volume by about ten per cent to get, it was thought, more into reality with the physical aspect.

Using the figure for oil in place by volumetric means the material balance was used to calculate water influx. Production was reduced by refinery excess product injection. Gas production was reduced by reinjected gas rather than accounting for the negligibly small gas cap expansion separately.

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FIGURE 7 shows the cumulative water influx and pressure plotted against fraction of oil in place produced.

Finally, a review was made of the pressure and GOR histories of critical wells, and Pressure-GOR versus Cumulative Oil Production graphs are shown for some of these wells: 14X, 23X, 24X, 25X and 28X.

DISCUSSION OF RESULTS:

Reserves and Reservoir Factors:

Reserves are based on the figures shown in TABLE 1. Porosity and net effective footage (per cent) were determined from the one complete core analysis, which was for well 37X, taking as effective footage that with 1.0 millidarcies and greater. The formation volume factor was taken from Imperial Oil Limited's Reservoir Fluid Analysis, Laboratory Report No. 40150, of December 6, 1950. Water Saturation was assumed to be 30 per cent only after considerable deliberation and should probably be a liberal estimate. Spot core and Connate Water Saturation Analyses done in 1944 show Connate Water Saturations from 1.8 to 5.1 per cent and are not thought to be reliable. Limestone water saturations are very variable from a relative low of 15 per cent in Swan Hills to 40-50 per cent, or higher, in some Mississippian lime reservoirs producing oil.

- TABLE I -

Average Porosity (K ≥ 1.0 md.)	13.4%
Flash Formation Volume Factor	1.23 Res.bbl / S.T.bbl
Interstial Water (assumed)	30.0 %
Reservoir Area (revised)	5,202 acres
Reservoir Volume (revised)	1,005,700 acre-feet
Effective thickness	70.3 %
Effective Reservoir Volume	706,500 acre-feet
Effective Oil in place	594 bbl/acre-feet
Average effective thickness of Reservoir	136 feet

The oil in place from TABLE I came to 419,000,000 S.T. barrels. For convenience, and because there was negligible error, which, in any case, is in the right direction, 400 x 10^6 barrels was used in material balance calculations. As mentioned under METHOD, if account could be taken of probable higher solution gas ratios and higher formation volume factors at the higher pressures down dip, the result would be a reduction of the oil in place.

TABLE II shows the reservoir and oil factors used in the material balance calculations and FIGURE 8 shows the formation volume factors and solution GOR's for flash and differential liberation. It was assumed that the flash liberation at 50 psig paralleled the differential liberation to zero pressure in so far as the solution GOR was concerned, since the end result is approximately the same: 352, as against 353, cubic feet per barrel, respectively, and because gas

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measurements are made at the separator. For shrinkage, it was considered that the flash formation volume factor should be used for the condition of flashing from saturation pressure to zero pressure, because actual oil shrinkage includes loss of stock tank vapours. Hence, in FIGURE 4 the GOR curve is for differential liberation or the equivalent 50 psig Flash condition; the Flash Volume Factor curve is for 0 psig flash conditions.

- T A B L E II -

Oil in Place	400×10^6	barrels (S.T.)
Original Pressure	690	psig at 1130' subsea
Saturated Solution GOR	353	c.f.p.b. by differential liberation
Compressibility of Reservoir Fluid	7.1×10^{-6}	barrels/barrel per psi
Formation Volume Factor	1.23	@ 565 psig by Flash Lib.
Formation Volume Factor	1.2291	@ 690 psig, Flash Lib.

Another argument to support the above is the fact that considerable excess solution gas over the solution GOR by differential liberation, or flash liberation to zero for that matter, has been produced and is continuing to be produced, which suggests that either: (i) there was originally more gas in solution than the Laboratory data shows and the saturation pressure may be higher than determined, OR (ii) producing pressure drawdowns were higher than thought to be, being drawn down below saturation pressure, resulting in sufficient free gas saturation in the reservoir to cause free gas flow. Of these two possibilities the first is thought to be the most likely or predominant, and if so, would mean that true solution GOR's and Formation Volume Factors would be higher than those determined experimentally.

FIGURE 7 shows plots of Reservoir pressure and cumulative water influx versus fraction of the oil in place produced. As can be seen to the date of the last pressure survey in October, 1959, only one and two-thirds per cent of the oil has been produced and some 11 1/3 million barrels of water have encroached into the Reservoir, while the pressure has declined 33 psi to 657 psig. Analysis of the drive mechanisms shows that water constitutes almost 99 per cent of the drive. Solution gas and gas expansion drives are each less than one per cent, and together are only slightly more than one per cent. There was, however, approximately 60 per cent excess gas production over that of the indicated solution gas. This excess gas has the two possible explanations mentioned previously. This excess solution gas drive effect is indeterminate but can hardly exceed one per cent and so it is not considered important, at least at the present, because of the dominant water drive.

The effect of using the compressibility given,

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rather than the true average compressibility, if it could be found, is to cause an error of less than half of one per cent in amount of water influx and is therefore negligible at the present pressure levels.

Similarly, the effect of an error of 100 per cent in the calculated average pressure drop would result in a maximum error of slightly less than one per cent in the water drive index.

The combined errors therefore do not reduce the water drive index below 0.96 or 96 per cent, although other unaccountable errors may reduce the index to the order of 0.95.

ULTIMATE RECOVERY:

Recovery is rather uncertain due to three unknown or limited factors:

(1) Water Saturation

(2) Residual oil Saturation

(3) Short production history in terms of fraction of oil produced

Factor (1) has been previously discussed.

The residual oil Saturation had to be largely assumed and was chosen at 30 per cent of pore volume. This

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figure actually had as a basis the average of 13 spot core samples on which determinations were made in 1943-44. The average was 28.6 per cent on the 13 samples, ranging from 8.5 per cent to 68 per cent residual oil by volume. The variability indicates a possibly large error in an average of only a few samples, however 30 per cent residual oil was assumed as reasonable under the circumstances with some attempt at conservatism.

The recovery then should appear to be 40 per cent (1.0 -Sw - Sro) if the water drive continues effectively. Depending on water saturation and residual oil saturation recovery may be as high as 60 per cent. If the water drive should fail at some time in the near future the recoverable oil may reach only 20 per cent, but should not be less than this. Hence reserves may range from 80 x 10^6 to 240 x 10^6 barrels, with 80 x 10^6 barrels considered proved, 80 x 10^6 barrels probable additional and 80 x 10^6 barrels possible additional. FIGURE 7 shows extrapolation to minimum recovery and the extrapolation curve typical of a full water drive recovery.

It has been assumed that the reef is water wet and that imbibition takes place, for otherwise a large percentage of the oil could be by-passed. Engineers of Imperial Oil Limited stated that they have no tests to indicate whether the formation is oil or water wet.

High rates of production may also decrease the amount of water imbibition resulting in lost oil. There is no way of determining what such an optimum producing rate should be. The calculated water table rise to 26 OCT 59 is about 15 feet.

In view of the small production to date it is also impossible to determine the production rate which would be best sustained by water drive. Reviewing the past history it does appear that the rate, which sometimes reached 4,000 barrels per day during the Camel project, was excessive and that the subsequent rate of about 1,000 barrels per day, reached in the early 1950's, was near optimum in maintaining reservoir pressure. The rate is partly related to the total well productivity which will be dealt with under "CRITICAL WELLS".

The optimum rate is more directly related by oil-water relative permeability and fluid flow formulae which are based on the relative permeability data and residual fluid saturations. None of these data have been determined. The criterion for determination of the best rate appears to be only the GOR, or more specifically, the rate of change of the curve of cumulative gas production with cumulative oil production, as plotted in FIGURE 5.

If this curve should rise steeply and rapidly there would be an excessive producing rate with implications of falling pressure and possible failure of the water drive. It is a signal of depletion of the solution gas drive energy. A parallel governing criterion with this is the average reservoir pressure.

CRITICAL WELLS:

Following are plots of pressure and GOR versus cumulative oil production for these wells: 14X, 23X, 24X, 25X, 26X and 28X. They are considered critical wells in that either the GOR is high and rising and/or the static pressure at 1130 feet subsea is below or down near to the saturation pressure of 565 psig. Most of these wells also exhibited high GOR's in 1945-46 when their producing rates were relatively high but there were no pressures available for that period in the files.

One well, 28X, is one of four exceptionally good wells, (the others are: 5X, 12X and 27X) which have together produced 37 per cent of the total Norman Wells production. the well, 28X, is now at nearly 565 psig, static and has a high GOR which is still rising. At an average production of 96-plus barrels per day it has declined from an original rate of 250 barrels per day, but would appear to be over-produced presently.

Other wells have been studied as to decline but so far a decline relationship has not been obtained on any well. There appears to have been something of a decline levelling off for some wells.

Although pressures do not appear critical on Bear Island producers, they generally all exhibit high and rising GOR's which may well become alarming.

It should be noted that Imperial Oil Limited's producing practice has been, and is still, to control production on poor wells. However, this review of wells is intended to show that their productivity should be improved. This is considered of prime importance at this time in view of increasing field production, decreasing pressure and the trend of rising GOR.

RECOMMENDATIONS:

The recommendations considered in order of importance are:

(1) Improve the productivity of the poorer wells and maintain a study of performance of these and other "not so good" wells.

(2) Maintain the study of field performance in order to spot unusual deviations from normal and to determine any variations in the water drive index.

(3) Do not impose field or individual well allowables at this time.

(4) If any new wells are drilled they should be cored for analyses. Determinations of water saturation, residual oil, and relative permeabilities should also be made if possible.

At one time it had been thought that another fluid analysis should be made. It is now new thought to be very helpful. A fluid analysis down dip on Bear Island or Goose Island would be an aid in predicting total solution gas because it is believed there may be more gas in solution at the greater depths and if so natural GOR's there would be higher than on the Mainland.

ADDENDA:

Since this study was completed, more or less, a meeting was held with officials of Imperial Oil Limited and the well and pool history were discussed. Imperial Oil Limited showed the results of a modified Carter Analyser study they had made on the reservoir. It indicated that approximately 2,000 barrels of oil per day could be produced continuously at a constant reservoir pressure of about 540 psig on the Mainland sector.

In obtaining their match to reservoir producing history the average permeability to oil came to 100 millidarcies. This is almost ten times the average 10.95 md. figure obtained from the core analysis for well 37X (Permeability to air $\geq$ 1.0 millidarcies). This is mentioned because evidently the permeability of the good wells (5X, 12X, 27X and 28X) must exceed the 100 millidarcies obtained by the analyzer match. At one time these four wells could produce 1,300 barrels a day, but at present their combined production is only a little over 400 barrels a day. This indicates a large productivity decline even though pressure has been fairly well sustained by water drive. This argues for improving the productivity of poor wells and perhaps even the "good" wells will eventually have to be improved.

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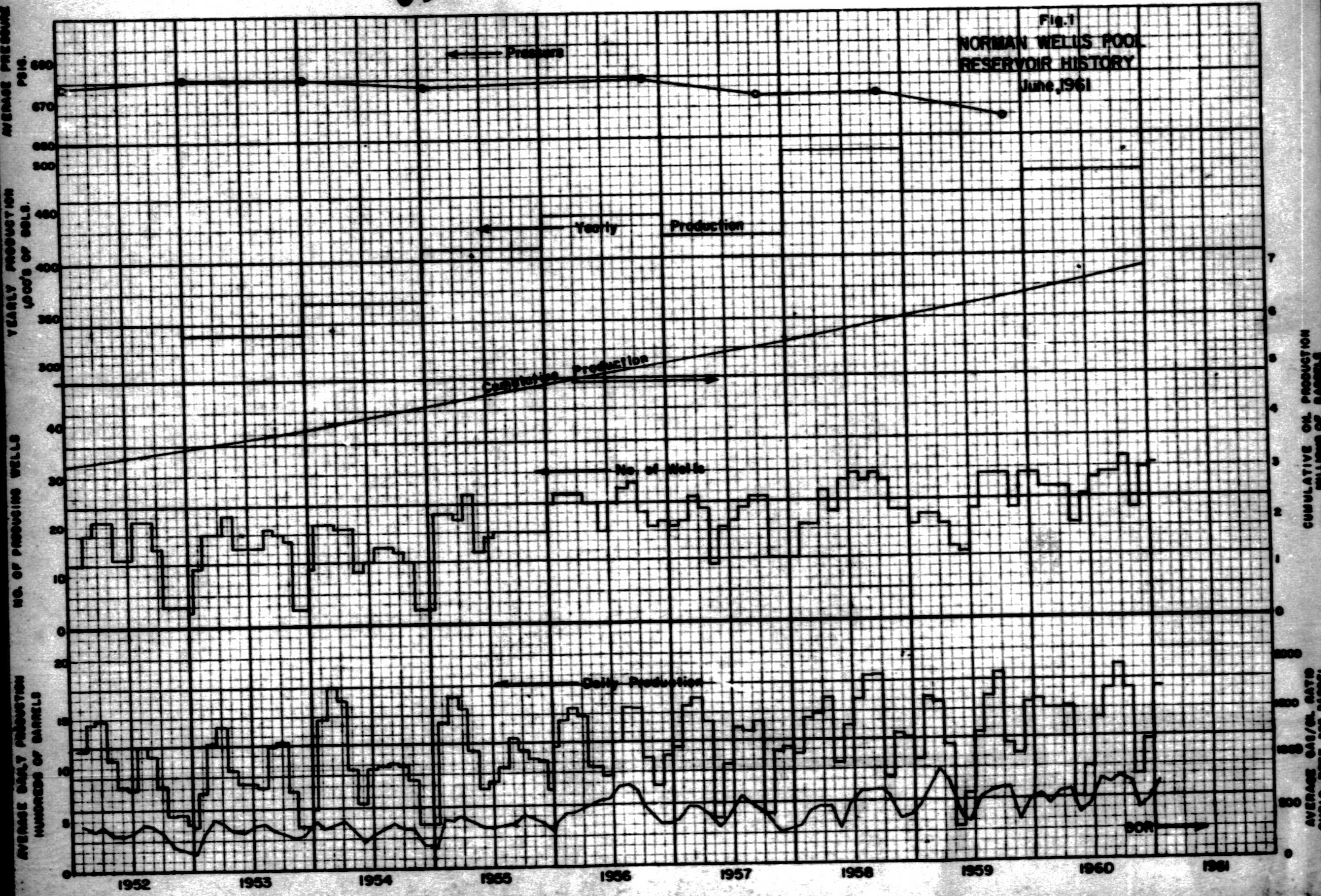
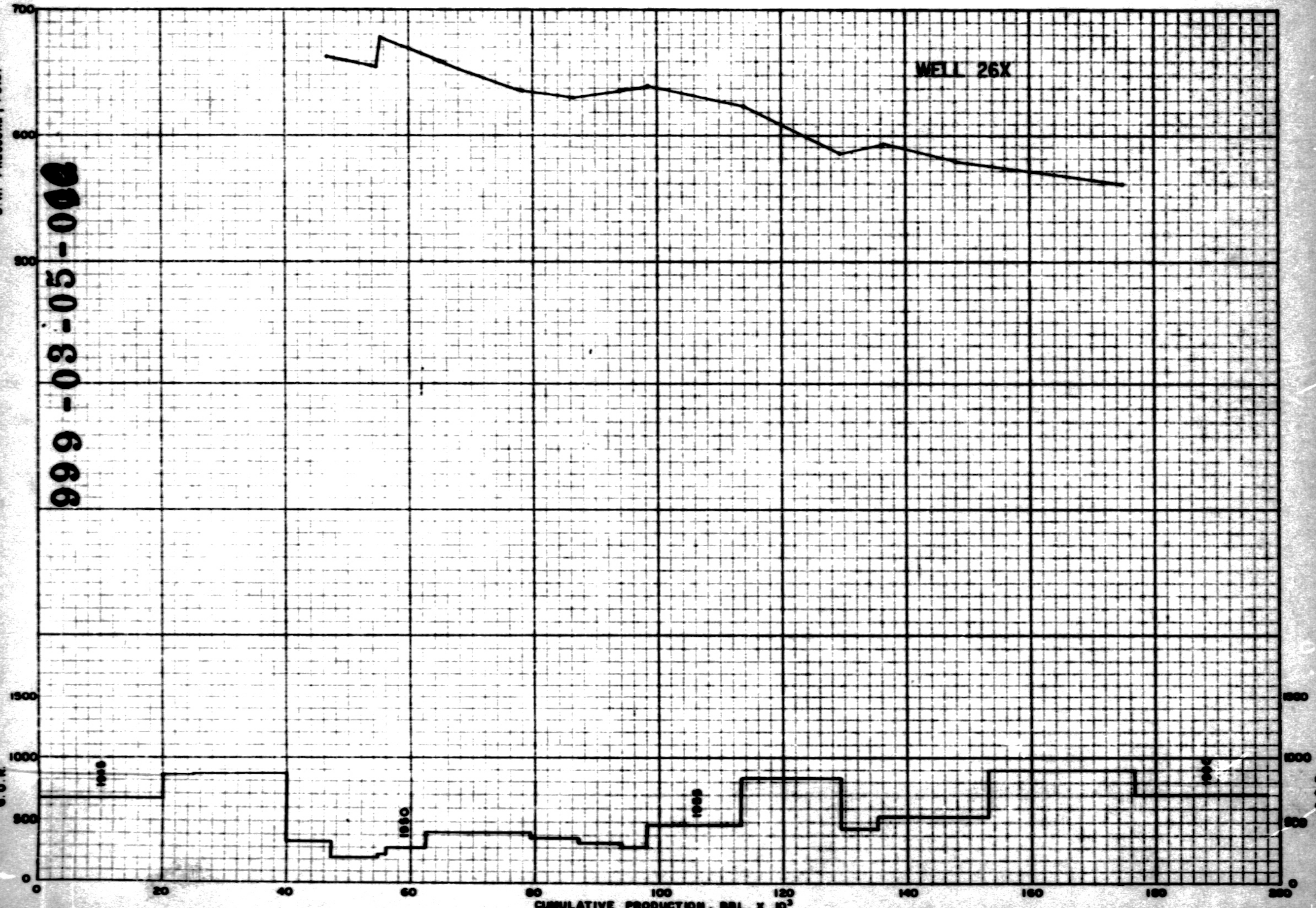
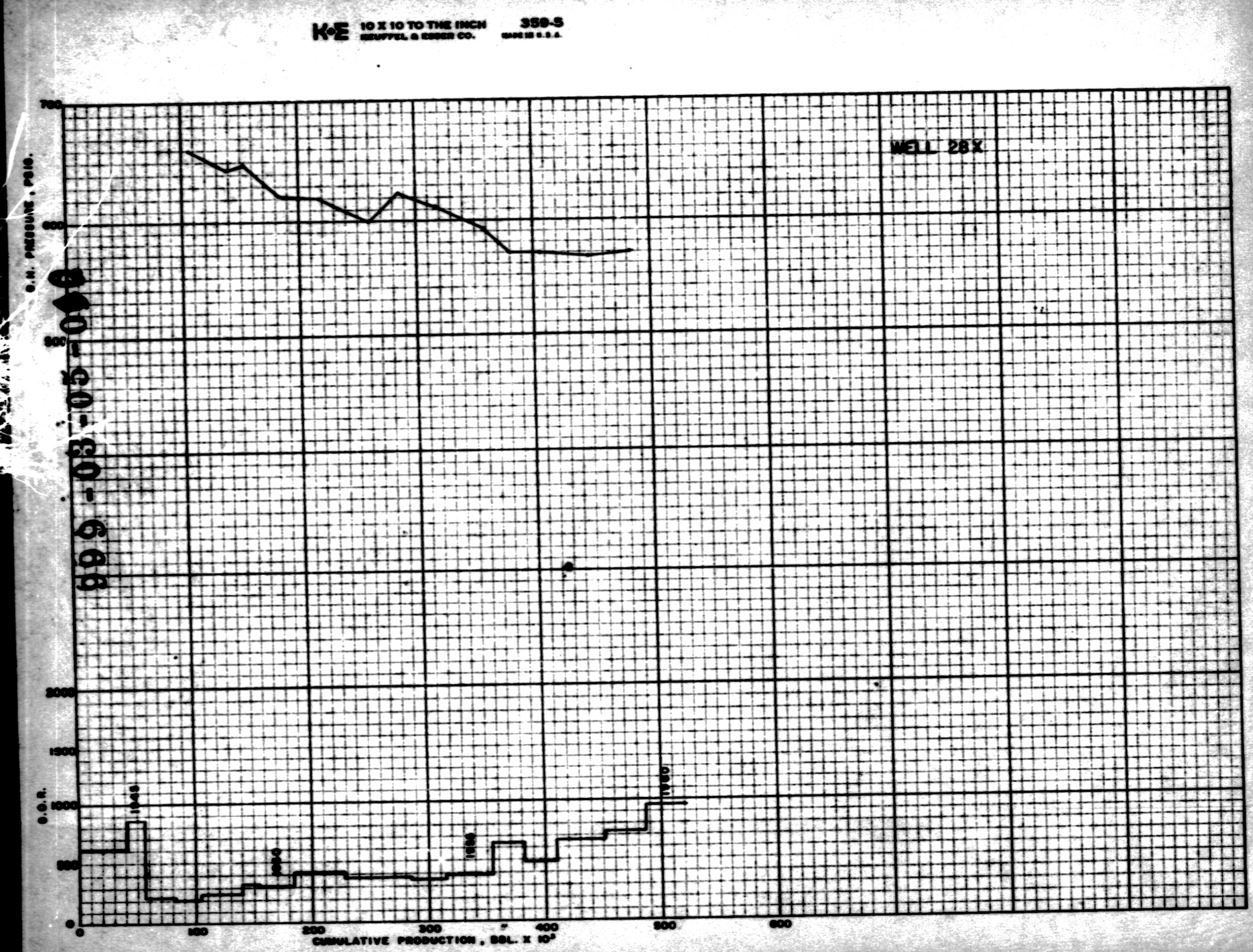
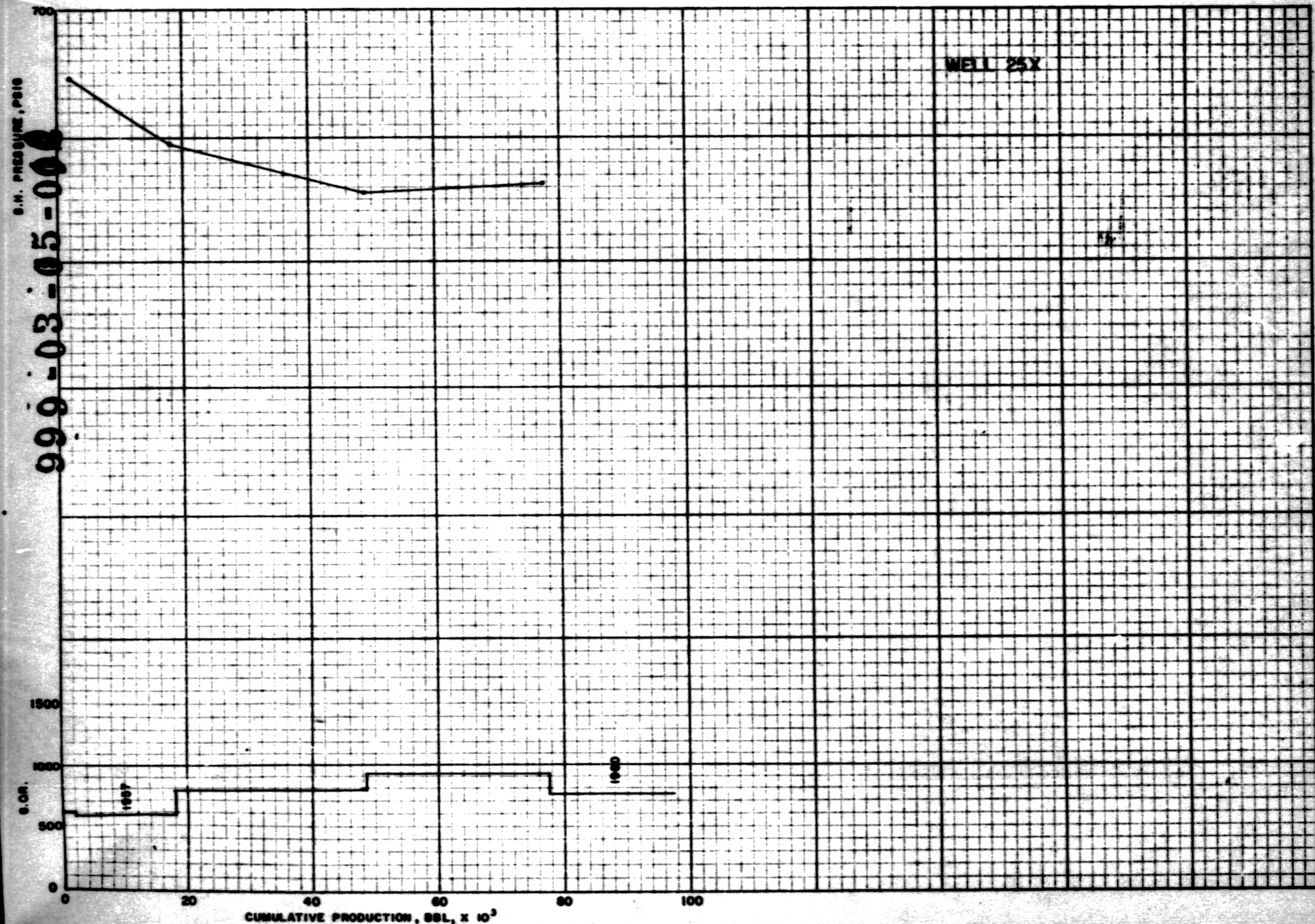


Fig.1
NORMAN WELLS POOL
RESERVOIR HISTORY
June, 1961
AVERAGE PRESSURE PSIG.
YEARLY PRODUCTION 1,000'S OF BBLS.
NO. OF PRODUCING WELLS
AVERAGE DAILY PRODUCTION HUNDREDS OF BARRELS
CUMULATIVE OIL PRODUCTION MILLIONS OF BARRELS
AVERAGE GAS/OIL RATIO CUBIC FEET PER BARREL
Pressure
Yearly Production
Cumulative Production
No. of Wells
Daily Production
GOR
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961

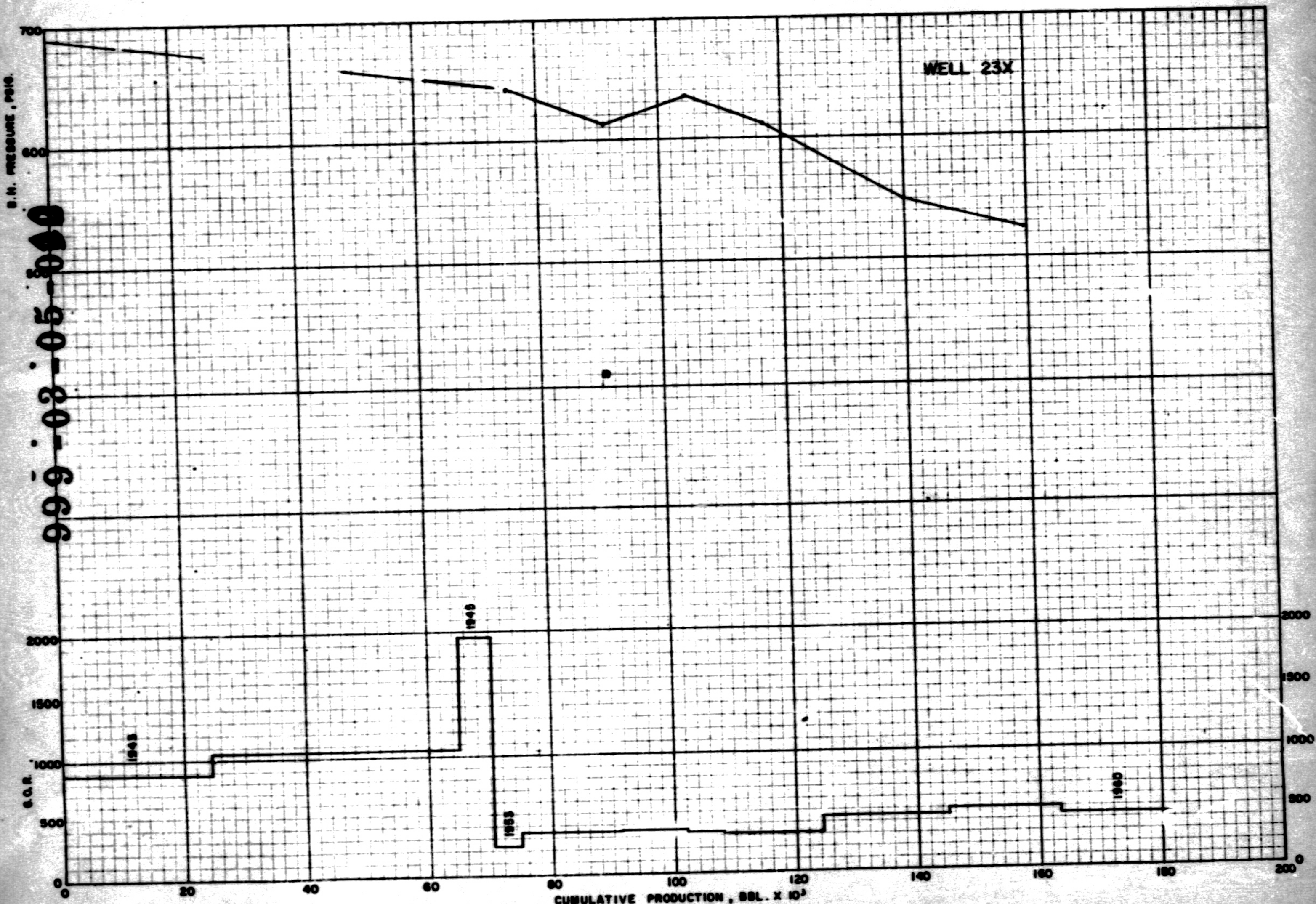
K&E 10 X 10 TO THE INCH 359-5
KEUFFEL & ESSER CO. MADE IN U.S.A.

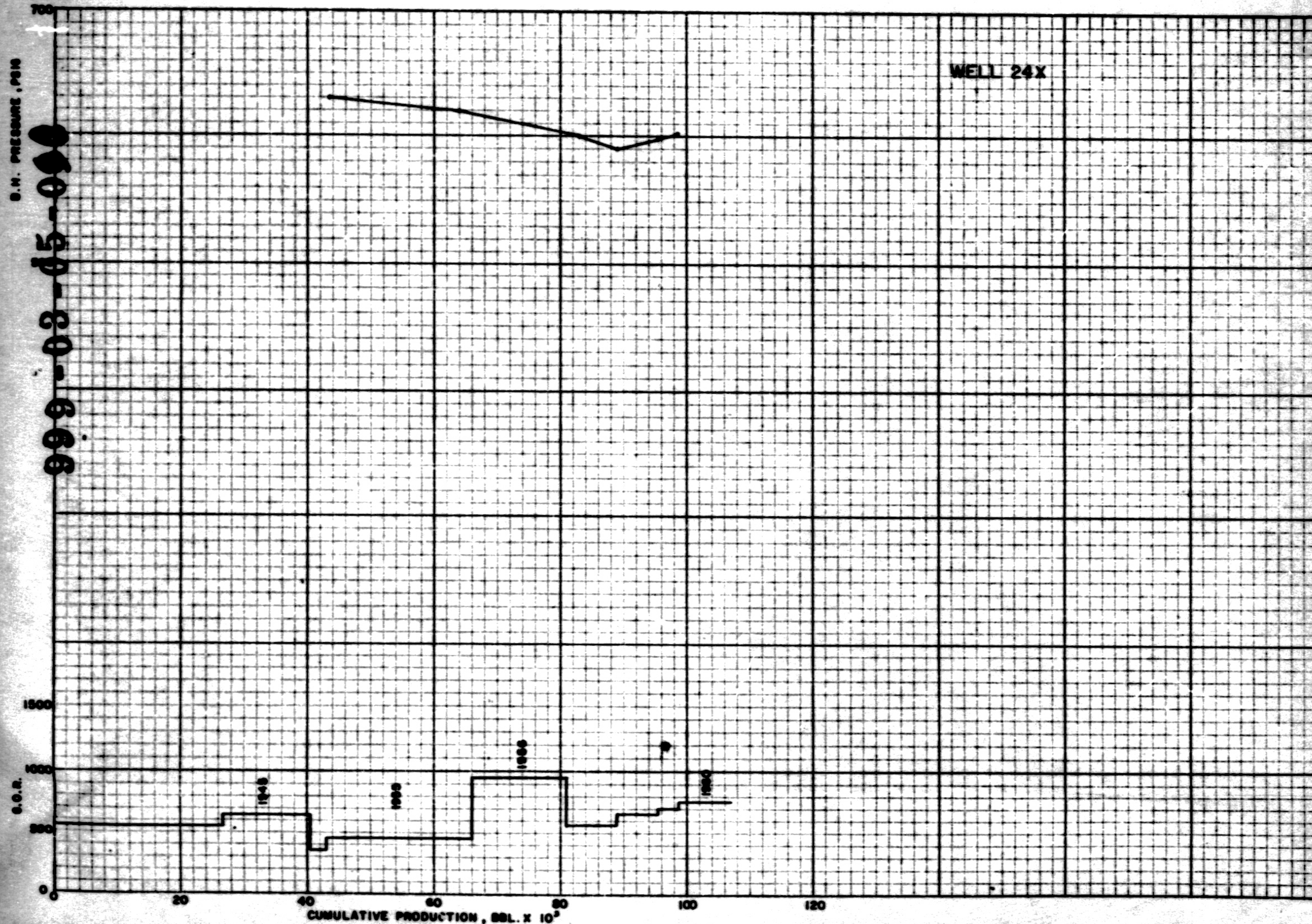



K+E 10 X 10 TO THE INCH 359-5
KEUFFEL & ESSER CO. MADE IN U.S.A.
WELL 28X
B.H. PRESSURE, PSIG.
G.O.R.
CUMULATIVE PRODUCTION, BBL. X 10³
0
100
200
300
400
500
600
500
600
700
1000
1500
2000
1948
1950
1954
1960
999-03-05-048

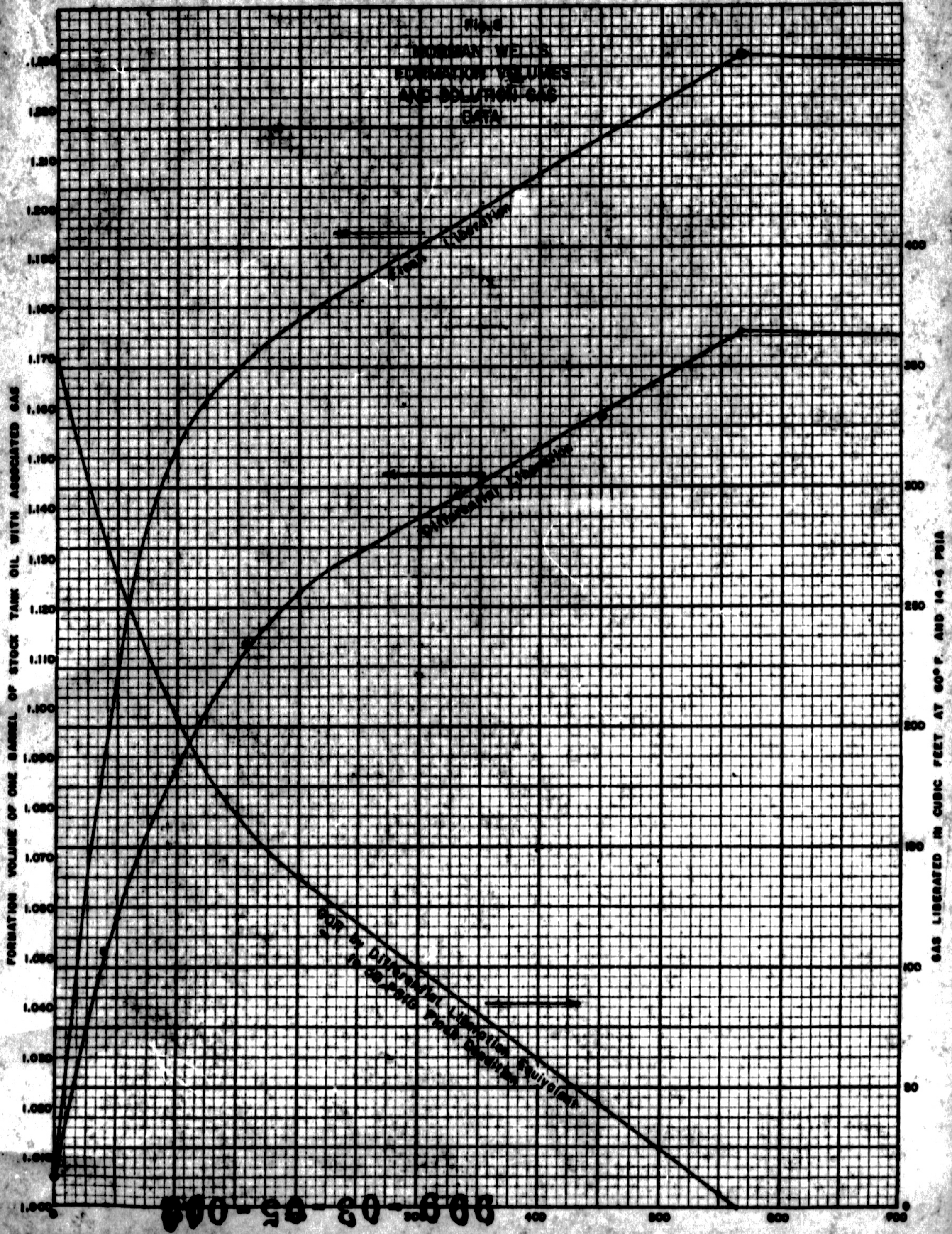

WELL 25X
B.H. PRESSURE, PSIG
700
G.O.R.
1500
1000
500
0
1957
1960
0
20
40
60
80
100
CUMULATIVE PRODUCTION, BBL, X 10³
999-03-05-00?

K•E 10 X 10 TO THE INCH 359-5
KEUFFEL & ESSER CO. MADE IN U.S.A.



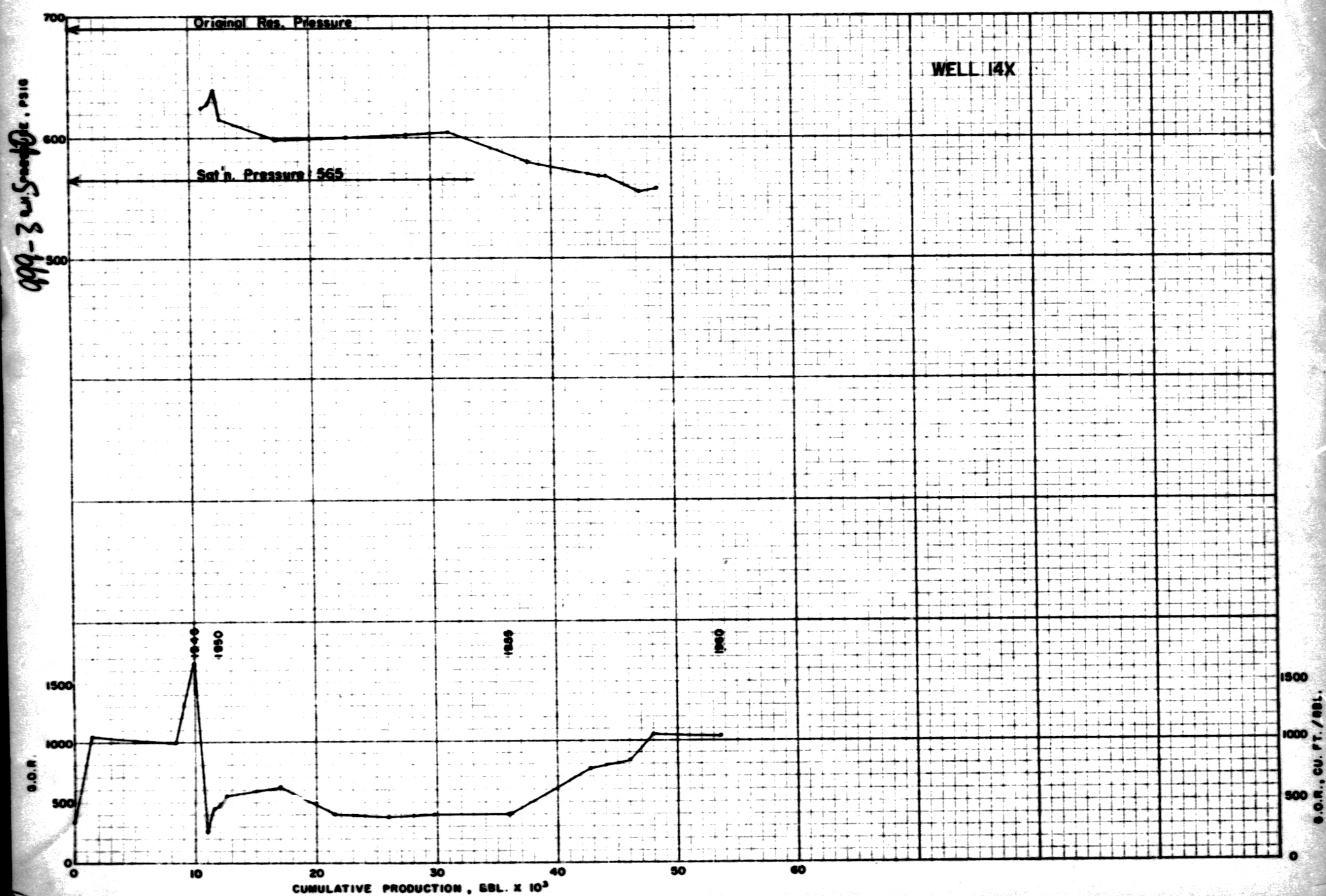


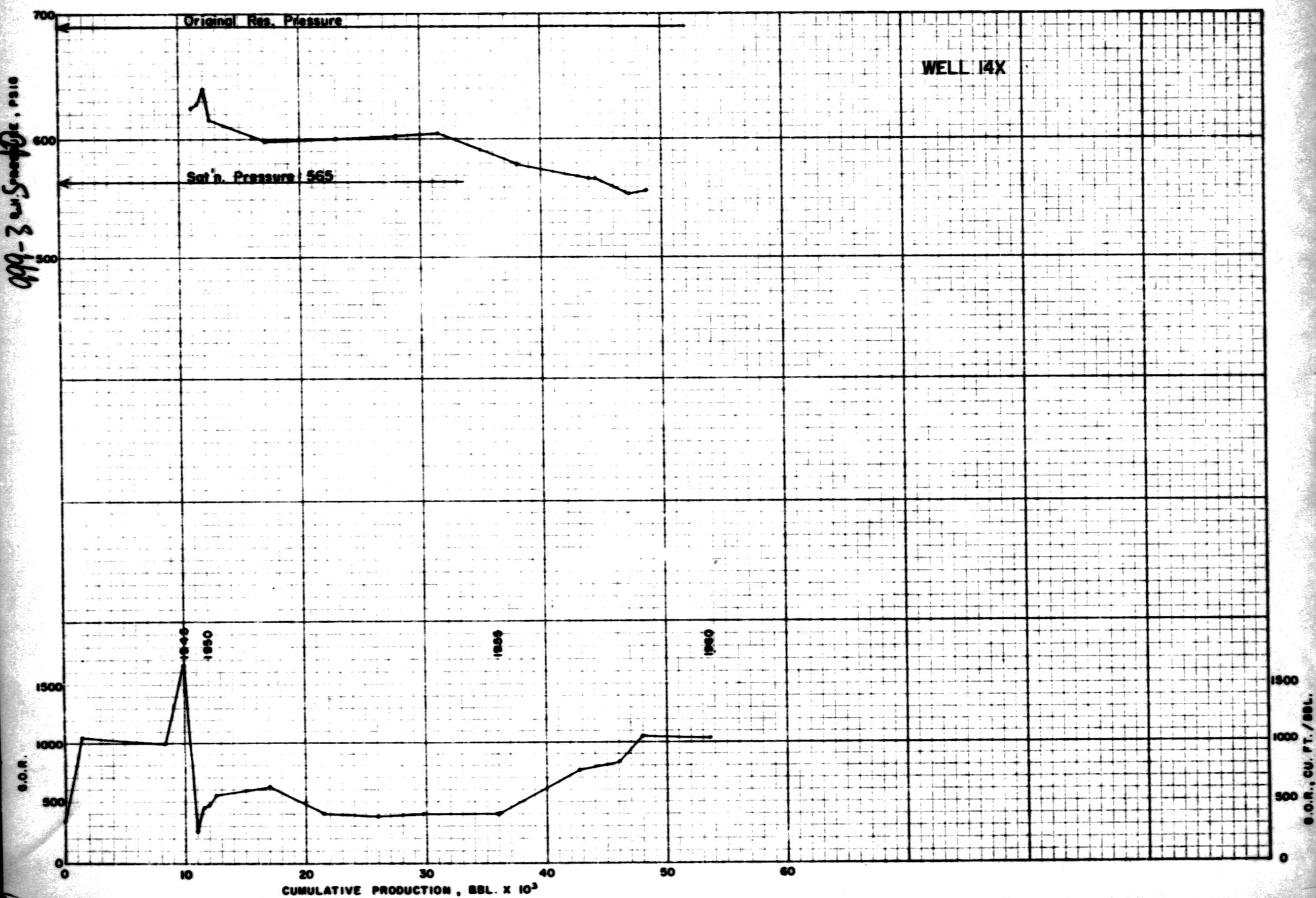
WELL 24X
700
1500
1000
500
0
0
20
40
60
80
100
120
CUMULATIVE PRODUCTION, BBL. X 10^3
B.H. PRESSURE, PSIG
G.O.R.
1948
1953
1956
1960
999-03-05-090



WELLS
FORMATION VOLUMES
AND SOLUTION GAS
DATA
Flash Liberation
Differential Liberation
FORMATION VOLUME OF ONE BARREL OF STOCK TANK OIL WITH ASSOCIATED GAS
GAS LIBERATED IN CUBIC FEET AT 60° F. AND 14.4 PSIA
K+E 12 X 18 TO THE INCH
KEUFFEL & ESSER CO.

K+E 10 X 10 TO THE INCH 359-5
KEUFFEL & ESSER CO MADE IN U.S.A.




WELL 14X
Original Res. Pressure
Sat'n. Pressure 565
700
600
500
1500
1000
500
0
999-3
, PSIG
G.O.R.
G.O.R., CU. FT./BBL.
1949
1950
1955
1960
0
10
20
30
40
50
60
CUMULATIVE PRODUCTION, BBL. X 10³

K+E 10 X 10 TO THE INCH 359-5
KEUFFEL & ESSER CO. MADE IN U.S.A.

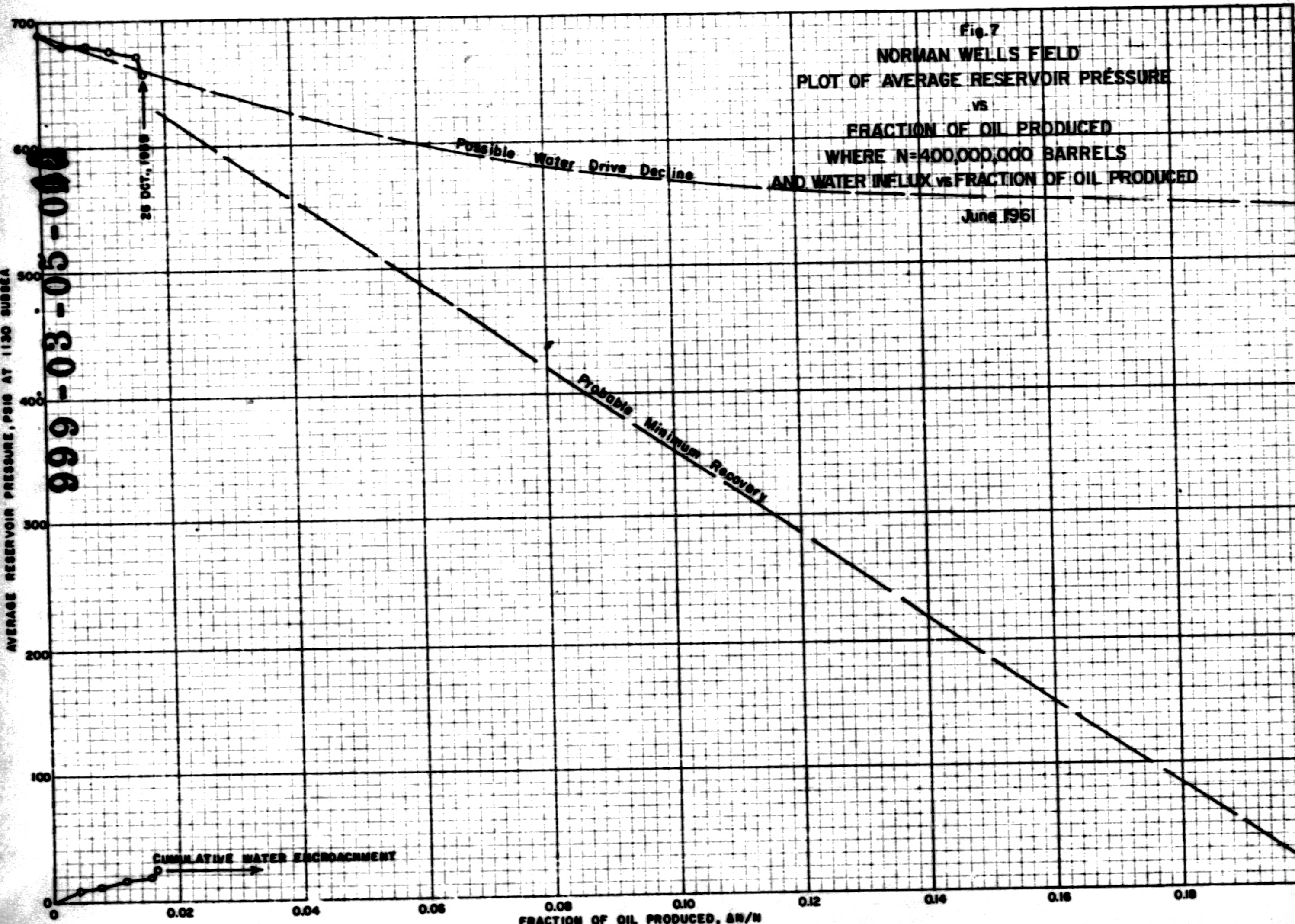


Fig. 5

Fig. 5

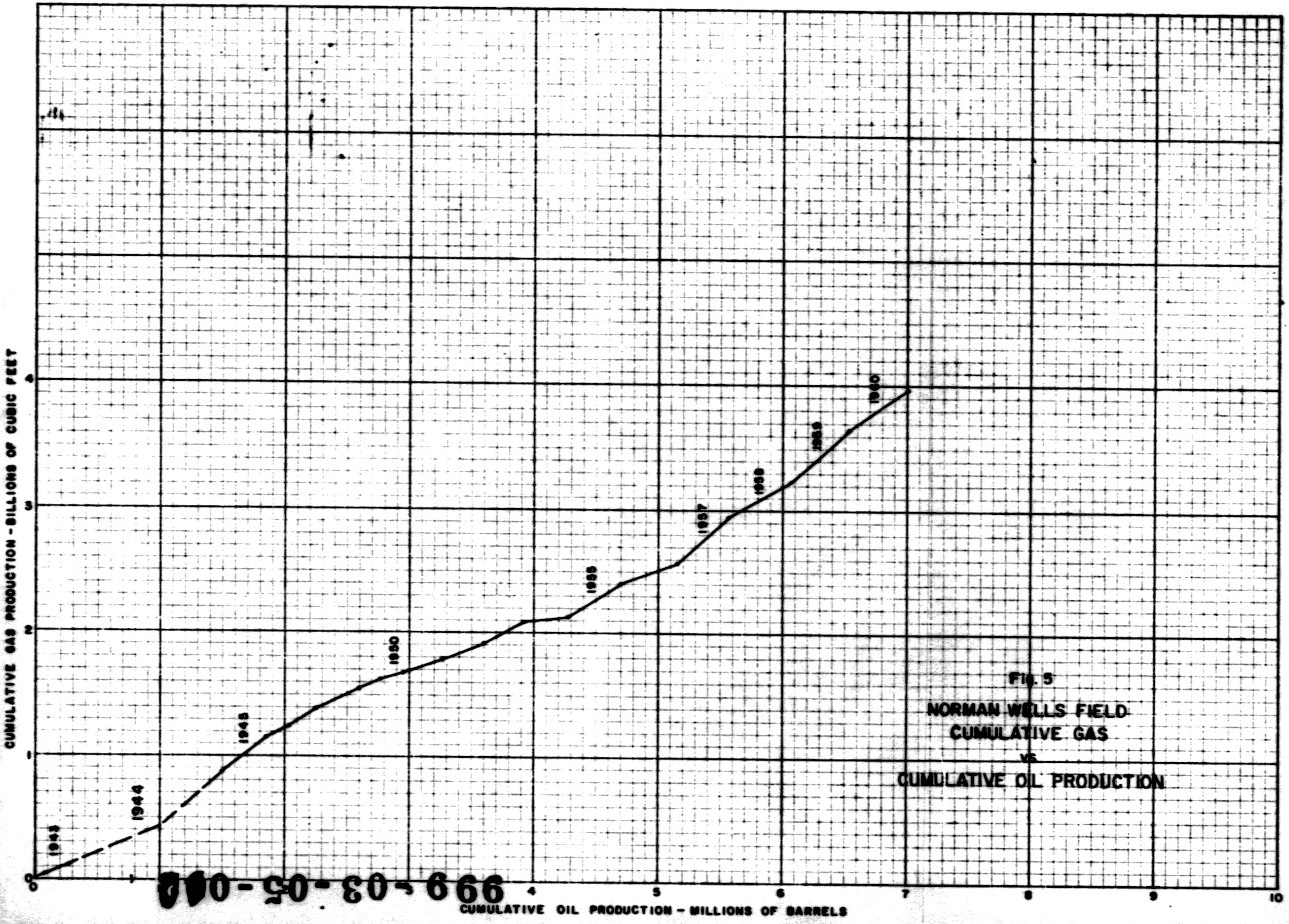
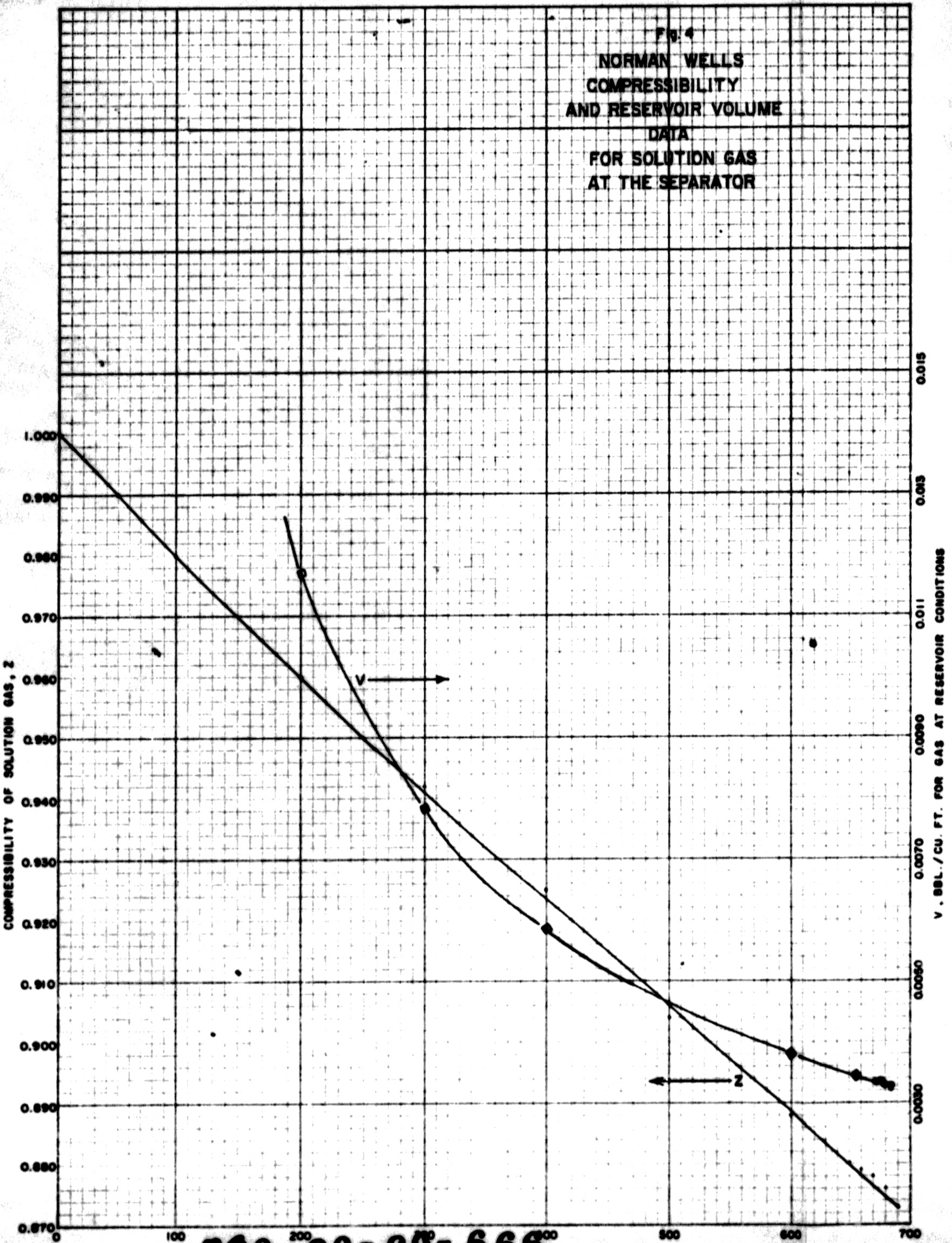


Fig. 5
NORMAN WELLS FIELD
CUMULATIVE GAS
vs
CUMULATIVE OIL PRODUCTION
CUMULATIVE GAS PRODUCTION - BILLIONS OF CUBIC FEET
CUMULATIVE OIL PRODUCTION - MILLIONS OF BARRELS
0
1
2
3
4
5
6
7
8
9
10
1943
1944
1945
1950
1955
1957
1958
1959
1960

Fig. 4



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