Requested by

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Subtitle

Saturation exponents and capillary pressure (gas-brine)
at room-conditions. 8 core-samples from 34/10-2,
3103 - 3390 meters, Rannoch and Statfjord

Co-workers

Title

MEASUREMENT OF SATURATION EXPONENT

AND CAPILLARY PRESSURE

34/10-2

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CONTENTS

INTRODUCTION

The main purpose of this work was to measure the resistivity
saturation exponent, n, from the equation:

$$I = S_W^{-n}$$

Where I is the resistivity index, the ratio of the resistivity
of the partly watersaturated core to the resistivity of the core
fully saturated with water. S_W is the water saturation.

The equipment used in this work did not allow measurements with
net confining pressure to be made.
On the other hand, pressure influence on the "n-exponent" is
through to be small. I is the ratio between two resistivities
which will both increase under net confining pressure, if change
at all. This will diminish the effect of the applied pressure
on the n-exponent.

Sample description

Eight plugs were selected from a log K-∅ plot to give a wide
distribution in K and ∅.
Samples 8 to 31 from Rannoch. Samples G to 146 are from
Statfjord. The samples had been drilled out by Geco using
freshwater as drilling fluid.

The following list gives the depth and the permeability,
porosity and grain density measured by Statoil.

Plug no	Depth m	Permeability KA, md	Permeability KL, md	Porosity $\emptyset$, %	Graindensity g/cc	
8	3103.30	99	88	23.5	2.67	⎫
11	04.35	146	132	24.0	2.66	⎬ *Rannoch.*
31	11.30	1.1	.75	13.8	2.66	⎭
G	3354.10	.78	.52	12.9	2.66	
99	61.20	62	53	19.5	2 .63	
132	80.70	17.4	14.5	14.7	2.63	
143	88.90	3.38	2.4	17.6	2.65	
146	89.95	331	300	22.7	2.63	

METHODS AND EQUIPMENT

Prior to this analysis the sample were extracted using toluene and methanol and then dried in an oven at $80^{\circ}C$ for 24 hours, without humidity control.

The core samples were evacuated for two hours and then filled with CO_2 gas. This was repeated. The evacuated samples were allowed to saturate with NaCl-solution of 50.000 ppm strength, and then placed under 100 bar pressure for 24 hours.

The NaCl solution had previously been filtered throught a micro-pore (0.45-micron) filter and degassed.

Equilibrium between a core and its contained fluids is critical for obtaining accurate measurements of electrical properties. Therefore the samples were left in the brine for one week after saturation. This would allow equilibrium between ionic exhange clay swelling, and with deposited salts to establish.

For sample saturated weight and resistivity to be measured accurately, excess saturation due to surface water has to be avoided. Touchdrying with an absorbent material, such as paper or cloth, can result in a variable saturation determination. Therefore the samples were mounted on a brine saturated porous plate, and left to drain in a vapor saturated atmospherie for 24 hours at atmospherie pressure. Then they were weighted and this value was taken as the saturated weight.

The resistivities were measured in a 4 electrode cell with wet leather pads to minimize contact resistance.

To obtain lower water saturation, S_w, the cores were replaced on the porous plate, which was mounted in a cell. Pressure was applied using air saturated with water vapor. To ensure good capillary contact, a layer of kiesel guhr was put between the samples and the plate. At least two days were allowed for water drainage to reach equlibrium.

The saturation of each core was found by weighing. The water
saturations have to be corrected for grain loss. Grain loss
correction for water saturation were small with these samples.
The resistivity was then measured using the 4 electrode cell.
After the resistivity mesurement the samples were mounted back
on the porous plate and a higher air pressure was applied.

RESULTS

The values for resistivity index, I, and saturation, S_w, are
listed in Table I and plotted in Fig. I, II and III.
From these data the n-exponents were calculated by least squares
method and are listed in Table II. The curves were forced
through point 1,1.
Capillary presssures and the corresponding saturations are
listed in Table I and plotted in Fig. IV and V.

TABLE I   34/10-2   Room conditions, 50.000 ppm NaCl.
           Resistivity index I, brine saturation Sw,
           related to capillary pressure Pc

SAMPLE	Pc (bar)	.069	.40	1.20	5.0	12.2
8	Sw	98.2	43.4	29.0	24.4	23.4
	I	1.18	3.88	11.8	15.1	14.5
11	Sw	98.4	38.7	25.4	21.2	20.5
	I	1.30	6.46	16.3	22.2	22.2
31	Sw	97.4	97.2	90.5	78.8	78.2
	I	1.27	1.19	1.51	1.61	1.70
G	Sw	93.9	93.2	91.9	78.0	77.4
	I	1.0	1.0	1.01	1.28	1.40
99	Sw	95.8	55.2	39.6	32.9	31.1
	I	1.37	4.15	8,76	11.8	12.5
132	Sw	95.3	64.2	43.7	34.8	32.6
	I	1.24	2.60	5.36	7.32	8.24
143	Sw	96.8	95.3	61.1	51.4	50.5
	I	1.02	1.19	2.48	3.39	3.47
146	Sw	96.9	36.3	25.8	21.1	20.6
	I	1.13	9.74	18.2	30.2	30.2

TABLE II   34/10-2   Room conditions, 50.000 ppm NaCl.
           Saturation exponents, n.

Sample	n-exponent	
8	1.88	⎫ *Rammoth*
11	1.99	
31	2.30	⎭
G	–	
99	2.25	⎫ *Statfjord*
132	1.93	
143	1.83	
146	2.18	⎭

DISCUSSION

n-exponents

All I-Sw plots show good linearity exept for samples 31 and G. These two samples had a very high irreducible water saturation, about 78%. This causes a poor spread of the points on the I-Sw plots and hence a higher uncertainty in the n-exponents for samples 31 and G.

To check reproducebility of the n-exponents we included three of the samples which were analysed in this study; 8, 11 and 132, in a later capillary pressure and n-exponent study of 34/10-2 core material.

However, in the later study several changes were made in the experimental procedure. Instead of using the wet leather pad electrodes described earlier, the plug-samples were silver painted at both ends. This was to avoid contact resistance and other unwanted effects of the leather pad technique which were discussed in the report LAB 81.17. Also changed was the frequency in the measurement of the resistivities, 50 Hz in this study and 1250 Hz in the later study. Also instead of a pure NaCl solution simulated 34/10-2 brine was used.

TABLE III

n-exponents and correlation coefficients for 34/10-2 samples measured with to different techniques.

Sample	This study		Later study	
	n	Corr.coef	n	Corr.coef.
8	1.88	(.9816)	1.94	(.9986)
11	1.99	(.9896)	2.03	(.9990)
132	1.93	(.9855)	2.02	(.9915)

The n-exponents and the corresponding correlation coefficients are listed in Table III. It is seen that the n-exponents are all higher and the corr.coef. are all better in the later study. The increases in n are .06, .04 and .09.

What effects on n should be expected from the changes in experimental procedures? Wether the use of silver paint has reduced the contact resistance electrode - core is not known. The effect of brine-transfer from the wet leather pad to the desaturated core, decrease in resistivity of the plug and a lower n-exponent, is avoided. The increase in measurement frequency could possible lower any polarisation effects, show a decrease in resistivity and give a lower n in the later study. The differences in brine composition is not believed to have any effects.

In conclusion, the only sure effect of the change in experimental procedure is an increase in n due to avoiding liquid transfer from the leather pads to the plug. This can explain the differences in n in the two studies.

Capillary pressure

The capillary pressure curves are as can be expected for this material. The irreducible water saturation increases with decreasing permeability. As explained above samples 8, 11 and 132 were run again in a later study and the results are shown as extra points in Fig. IV and V. The results of the two studies agree fairly well.

CONCLUSION

The relationship $I = Sw^{-n}$ is found to be valid for these
samples. In the case of two of the samples the watersaturation
established were not low enough for a good n-exponent to be
calculated.

The capillary pressure curves are as can be expected for this
type of material.

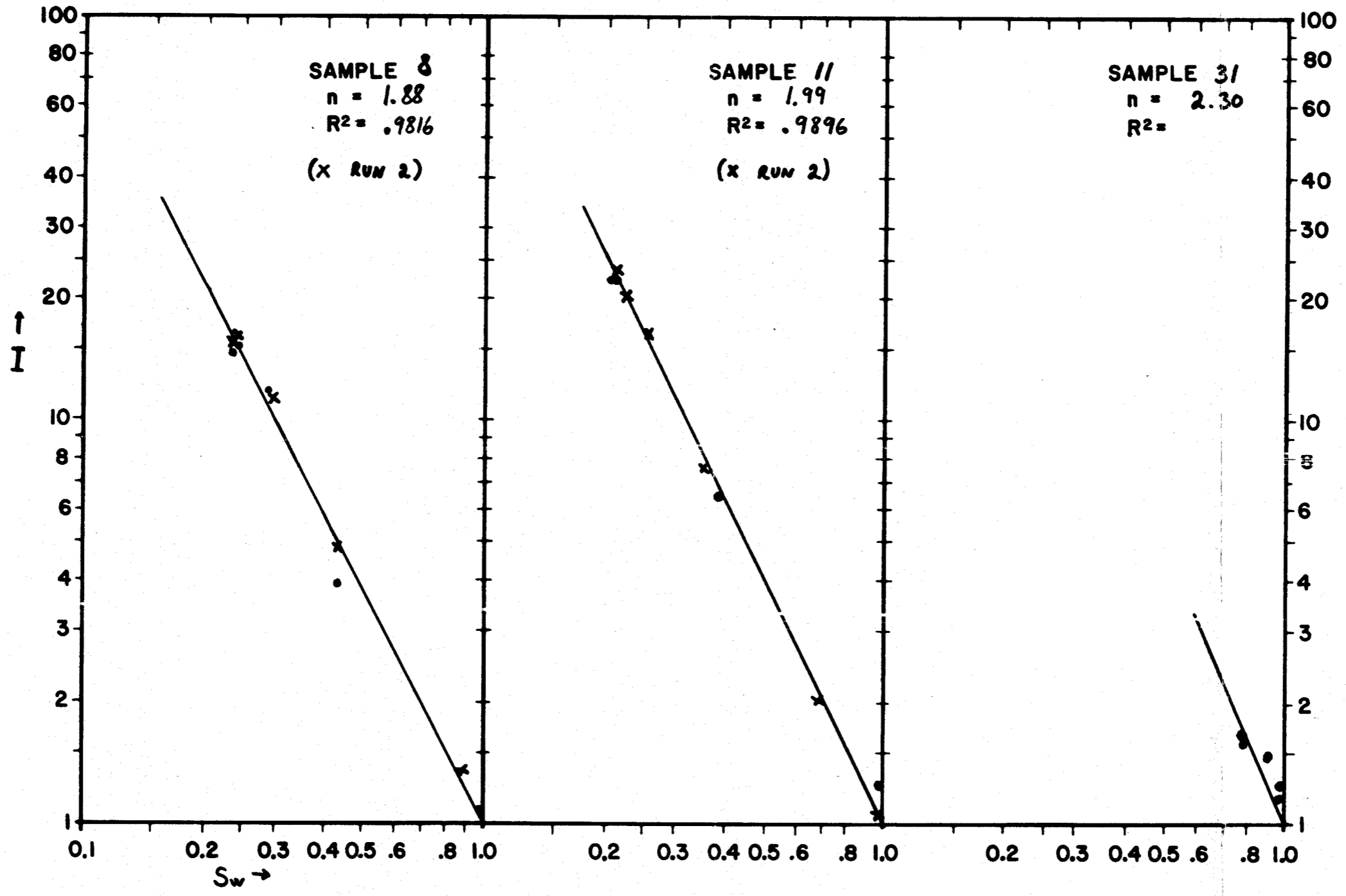FIG I.   RES. INDEX I V.S. BRINE SATURATION Sw.
          WELL 34/10·2

SAMPLE 8
n = 1.88
R² = .9816

(x RUN 2)

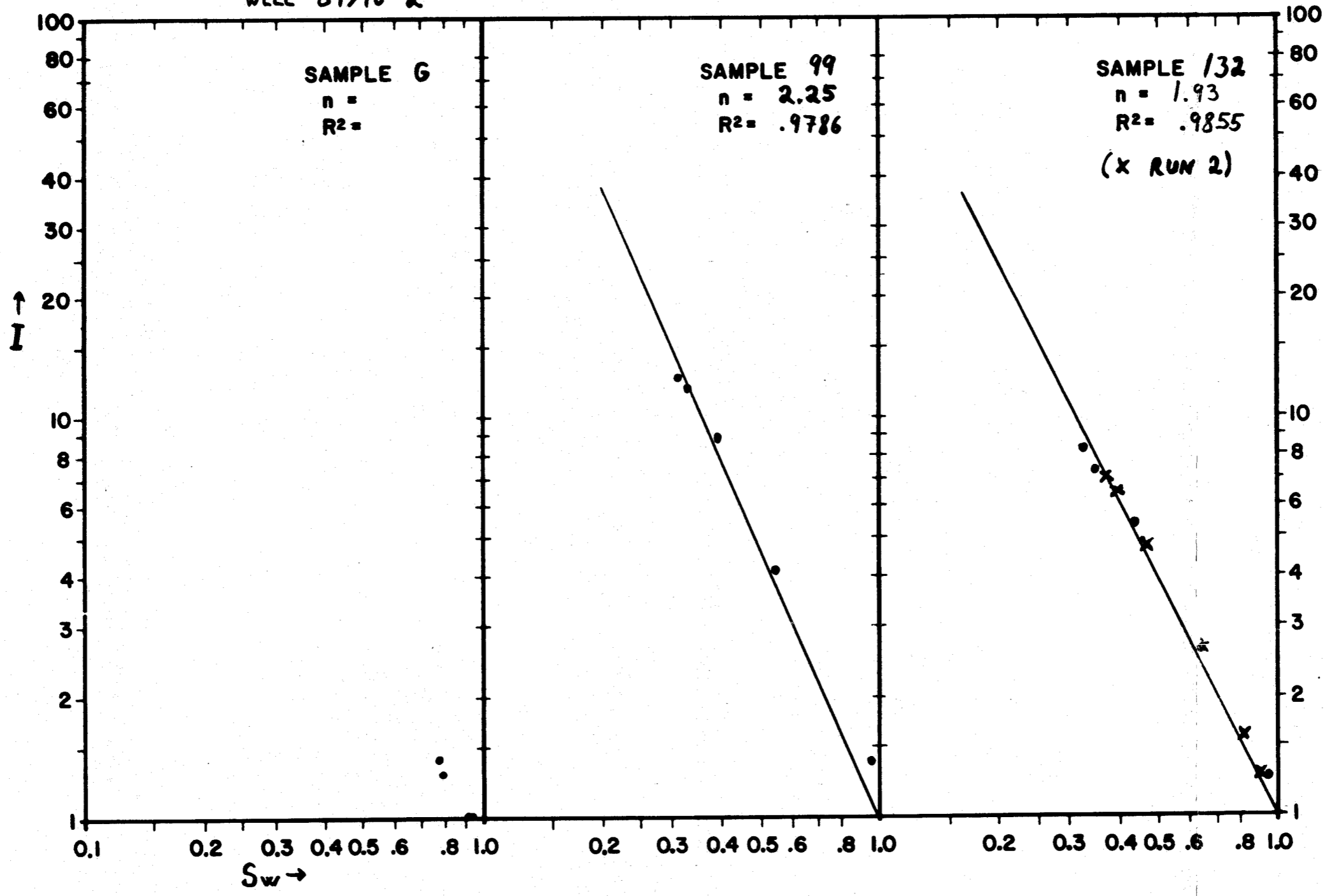SAMPLE 11
n = 1.99
R² = .9896

(x RUN 2)

SAMPLE 31
n = 2.30
R² =

FIG. II   RES. INDEX, I   v.s.   BRINE SATURATION, Sw
WELL 34/10-2

SAMPLE G
n =
R² =

SAMPLE 99
n = 2.25
R² = .9786

SAMPLE 132
n = 1.93
R² = .9855

(x RUN 2)

I

Sw →

FIG. III   RES. INDEX, I   V.S.   BRINE SATURATION, S_w
WELL 34/10-2

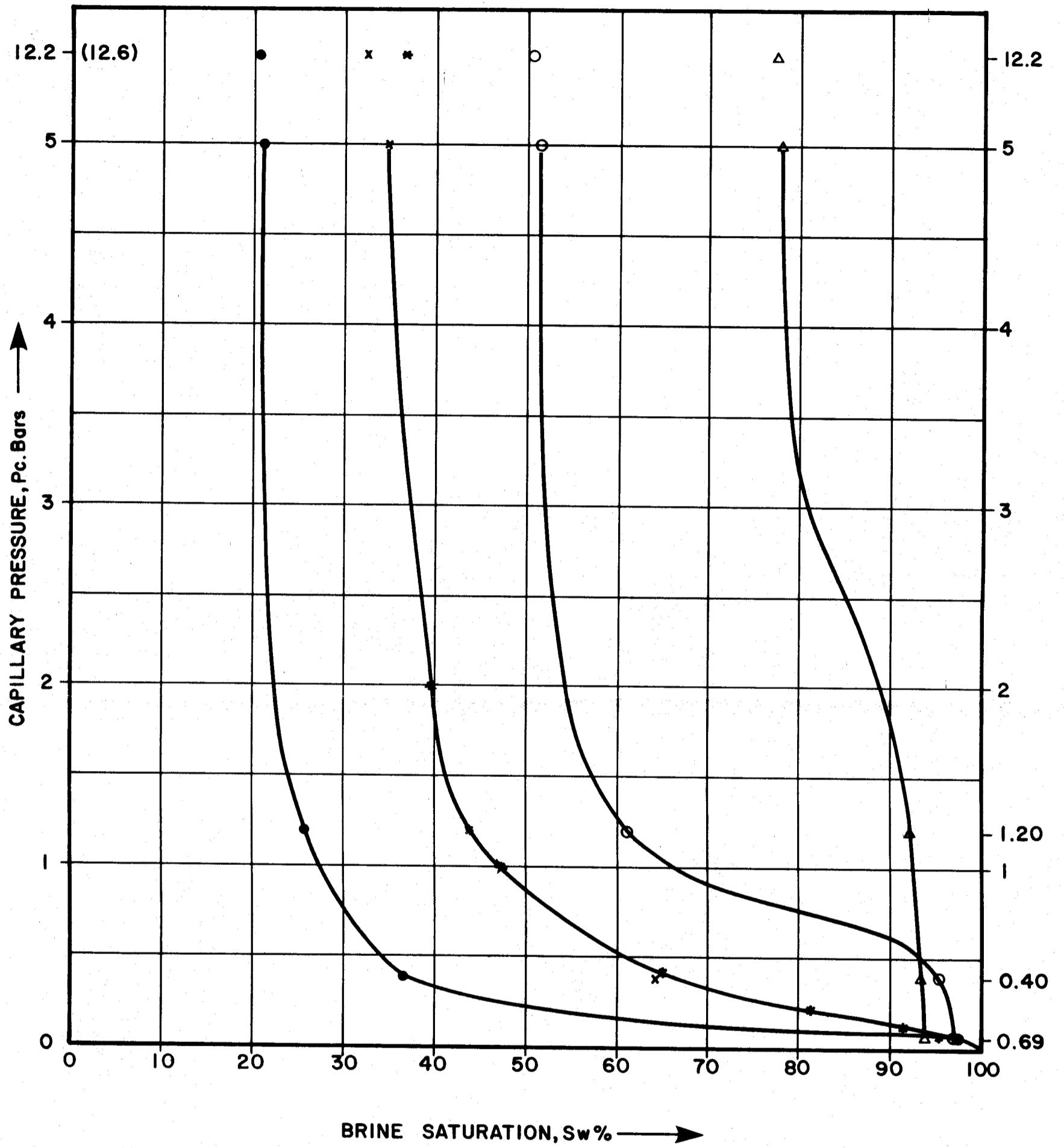SAMPLE 143
n = 1.83
R^2 = .9933

SAMPLE 146
n = 2.18
R^2 = .9987

SAMPLE
n =
R^2 =
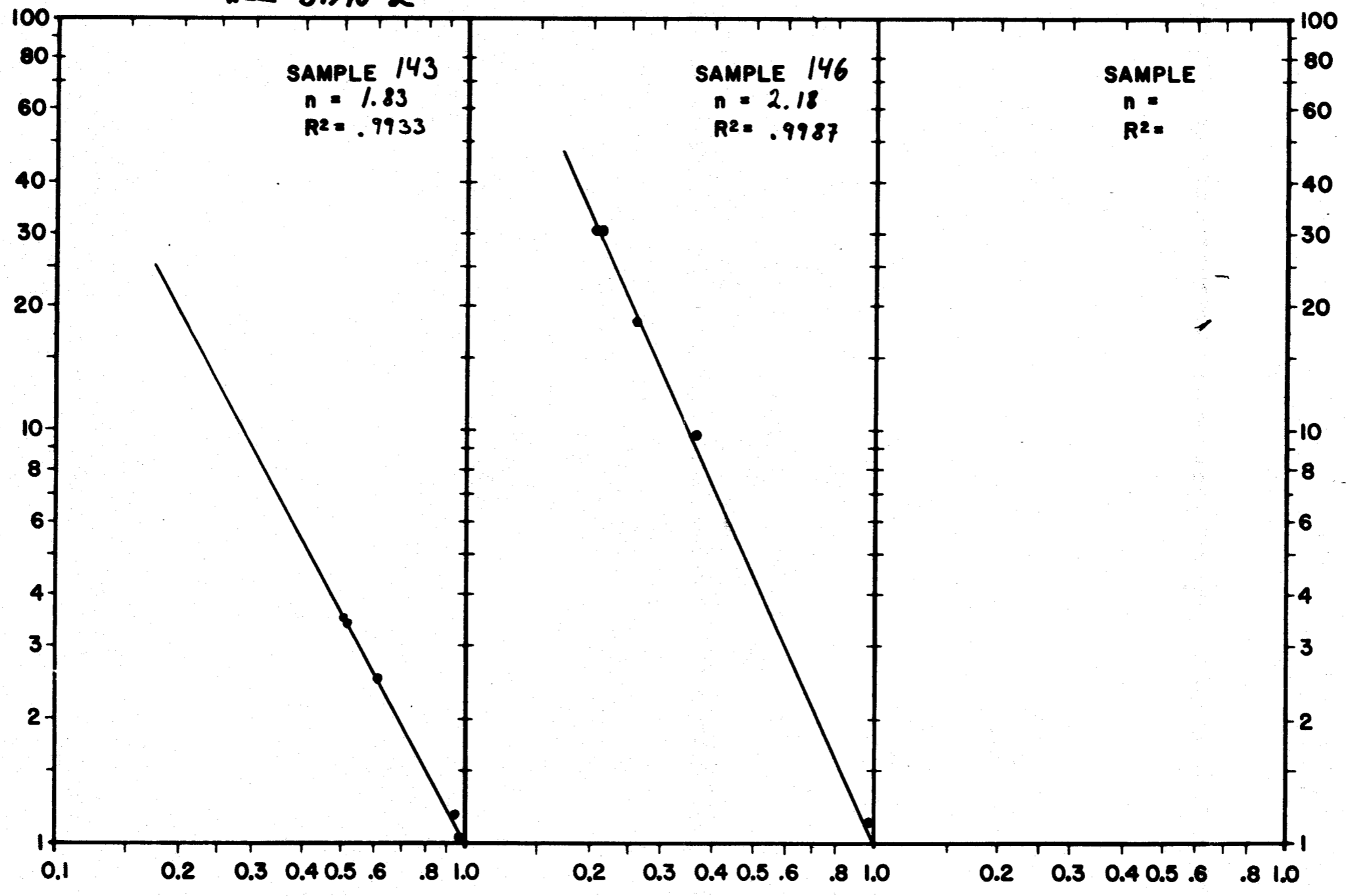
FIG IV   34/10-2   CAPILLARY PRESSURE AIR-BRINE
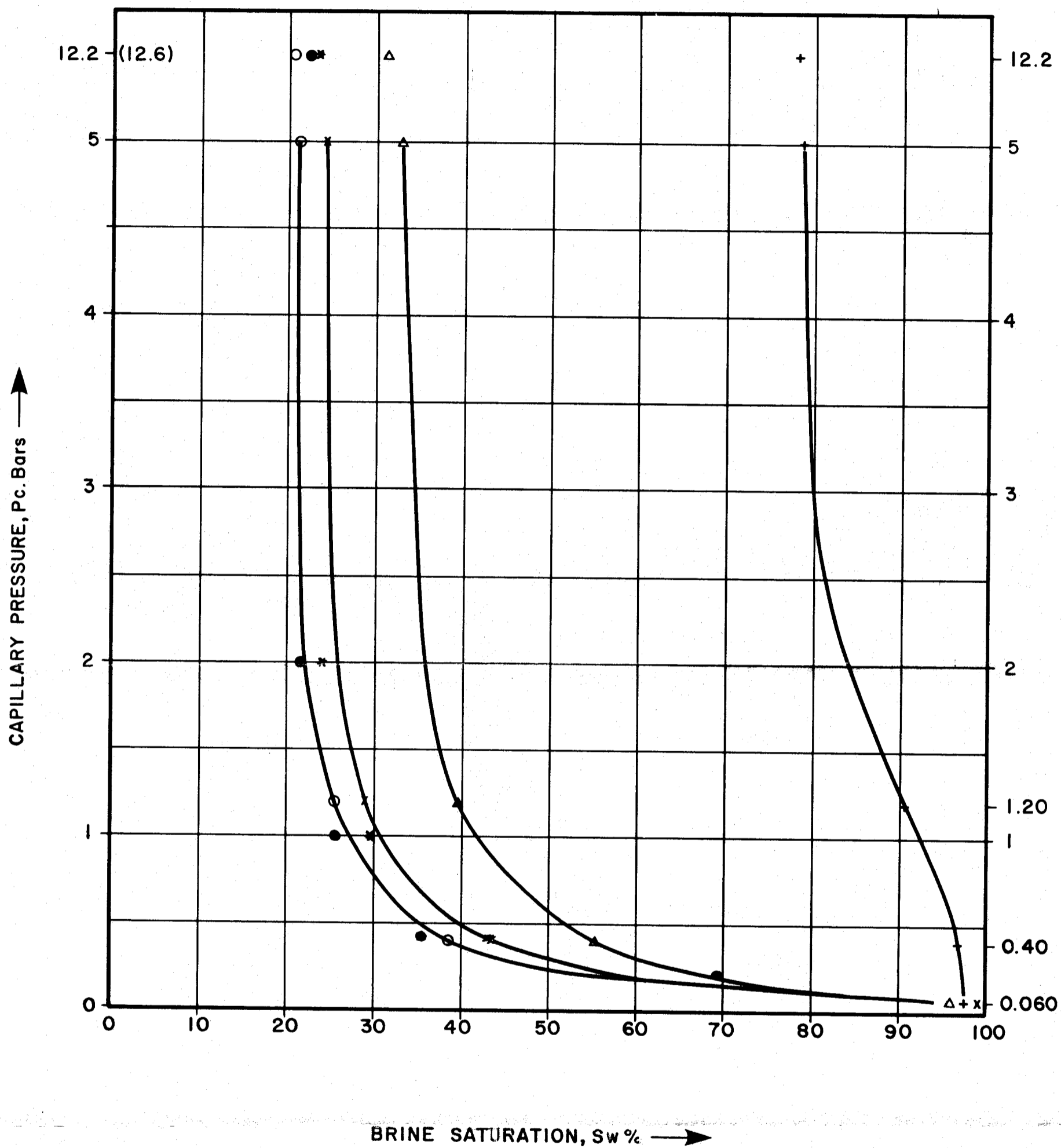
SYMBOL	PLUG
x	8
*	8(RUN 2)
○	11
●	11(RUN 2)
+	31
△	99

FIG V   34/10-2 CAPILLARY PRESSURE AIR-BRINE

BRINE SATURATION, Sw%

CAPILLARY PRESSURE, Pc. Bars

SYMBOL   PLUG
  ×   132
  ∗   132(RUN 2)
  ○   143
  ●   146
  △   6