STUDIES IN DIELECTRICS.

PART IV. THE EFFECT OF IMPURITIES ON THE BREAKDOWN VOLTAGE OF TRANSFORMER OIL.

By B. S. Ramaswamy, N. V. Narayanaswami and F. N. Mowdawalla.

Insulating oils used in transformers are liable to contamination by impurities like cotton and pressboard fibres and insulating varnishes absorbed from the transformer. Moreover, sludge is formed in the oil due to oxidation. All these impurities together with the moisture present in the oil considerably influence its dielectric strength and, when present in large quantities, may render it unfit for use.

Hirobe (*Tokyo Electrotechnical Lab. Report*, No. 25, Section iii) was the first to show that small fibres of cotton and other insulating materials in moist oils considerably lower their breakdown strength. Mclaughlin (*Electrician*, 1921, **86**, 325) reports having observed a sudden increase in the conductivity of oil containing fibres and dust particles. He concludes from the consideration of conductivity that moist fibres should greatly reduce the dielectric strength of oil. The actual formation of liquid and fibre bridges has been observed by many investigators. Armstrong (*Electrical World*, 1913, **62**, 1322) attempted the study of the effect of rubber on the B. D. V. of transformer oil. After keeping a small piece of rubber in contact with oil for several hours, he noted a large drop in the dielectric strength of oil. His result is only qualitative and has not been verified by any other investigator.

The effects of oxidation of transformer oil have been studied by Ornstein (*Archiv. f. Elektrot*, 1933, **27**, 489) and others from a purely chemical point of view. Elsa Pechmann (*Archiv. f. Elektrot*, 1932, **26**, 46) has investigated the effect of heating, in the presence of oxygen, nitrogen and lac-impregnating material on the colour, acid number, saponification number and tar number of insulating oil. The results show that the worst effects are produced by the lac-impregnating material. This work is purely chemical in character and does not concern itself with dielectric properties at the various stages of the reactions. F. M. Clark (*Journal Frank. Inst.*, 1933, **215**, 39 and 1933, **216**, 429) has investigated the action of dissolved gases on the dielectric strength of transformer oil. He comes to the conclusion that a test of the dielectric strength as carried out at present is really a test of the dissolved gas or gasifiable matter contained in the oil and hence the B. D. V. can be modified by modifying its gas solubility.

A systematic investigation of the behaviour of transformer oil containing impurities such as cotton and pressboard fibre, moisture and carbon has been made by the British Electrical and Allied Industries Research Association (*Journal I. E. E.*, 1929, **67**, 750). This investigation has shown that while any one of these impurities by itself has a small effect on the B. D. V. of dry transformer oil, fibres in combination with moisture can produce a very great lowering of the dielectric strength. In the presence of moisture carbon appears to have the least and cotton fibre the greatest effect. 500 mg. of carbon with 1·92 c.c. of water in 10 000 c.c. of oil reduces the B. D. V. from 100 to 60 kV while 2 mg. of cotton fibre with 1·21 c.c. of water in 10 000 c.c. of oil lowers it to 20 kV.

The above report, however, does not cover all the impurities in transformer oil. In addition to fibres, carbon and moisture, other impurities likely to be present are sludge, insulating varnishes and waxes used for transformer coils. These varnishes and waxes, though good insulators themselves, might still reduce the dielectric strength of oil. A study of their effect on the breakdown voltage of insulating oil appears, therefore, to be of great interest and importance. The present investigation deals with the effect of traces of alcohol, shellac, paraffin wax and sludge on the B. D. V. of transformer oil. The effect of carbon has already been studied and the results are given in Part III. In addition to the study of the effect of these impurities on the dielectric strength of oil, the effect of a large number of successive discharges through oil containing these impurities has also been investigated.

EXPERIMENTAL.

High Voltage Supply.—The high voltage required for the purposes of the tests was obtained as described in Part III and the diagram of connections is shown in fig. 1 in Part III.

Test cell.—The test cell and the electrodes used for this investigation were similar to those described in Part III. The cell was similar to the smaller cell used for the experiments with successive discharges and had a capacity of 450 c.c. of oil.

Method of testing.—The preparation of pure, dry oil and the method of cleaning the cell and the electrodes to make them fibre-free have been described in the previous part.

Preparation of test samples.—The test samples were prepared by adding requisite quantities of the impurities, prepared as follows, to 450 c.c. of pure transformer oil.

Paraffin wax.—1 gram of pure paraffin wax was added to 25 c.c. of pure dry transformer oil, and the mixture was warmed and well shaken. The paraffin dissolved and the solution was used after cooling as required.

Alcohol.—1 c.c. of alcohol was added to 25 c.c. of pure dry transformer oil and shaken well to form an intimate mixture. Small quantities of this mixture were added, as required, to the test sample of oil which was then well stirred with a clean glass rod.

Shellac.—An unbleached variety of shellac was first powdered so as to pass through a 200-mesh sieve and made into a suspension in oil; this suspension was added to the test sample as required. For another series of tests the shellac was first dissolved in alcohol. On spreading the solution on a glass plate and allowing the alcohol to evaporate, thin films of shellac were obtained. They were scraped out and powdered so as to pass through a 200-mesh sieve. A suspension of this powder in a small quantity of dry oil was prepared as before and added to the test sample as required.

Sludge.—With the object of determining the effect of sludge formed in oil in the presence of copper, the method described in the British Standard Specification No. 148 of 1927 for sludging tests of insulating oils was used with a slight modification for the preparation of sludge. The only difference was that a bigger flask containing a larger quantity of oil was used and the quantity of sludge formed after 45 hours was found to be 0·75 g. in 100 c.c. of oil. This sludged oil had a B. D. V. of 38 kV while the pure oil before sludging had a B. D. V. of 70 kV.

Mixture of impurities.—In order to study the combined effect of some of the impurities, when present together, on the B. D. V. of oil a mixture was prepared as follows: 1·5 g. of paraffin wax was dissolved in 50 c.c. of sludged oil and 0·5 g. of shellac powder was added to this mixture. This mixture was added to the test sample of transformer oil as required.

Estimation of the breakdown voltage.—The estimation of the breakdown voltage is rendered difficult owing to the great divergences in the values obtained under identical test conditions. Hence, in such an investigation, the method of determining the breakdown voltage is very important. Very few of the previous investigators seem to be clear on this point. In order to obtain consistent results the average of ten successive breakdown readings each time was taken to represent the B. D. V. of the oil. The effect of each impurity was studied by adding it successively in small doses to the same sample of oil, the B. D. V. at each stage being measured by ten successive breakdown tests as referred to above.

In this method of conducting the tests, a small amount of carbon is introduced into the oil at each discharge, which may affect the B. D. V.

As it is not possible to eliminate this, it was necessary to minimise the number of discharges without at the same time making it too small for consistent results. In order to ascertain the extent to which the B. D. V. was affected by this carbon, experiments were conducted with varying doses of the impurity thereby altering the total number of discharges passed in each set of readings. It will be seen from the graphs that the influence of carbon as compared to that of the impurity is negligible.

RESULTS.

Effect of alcohol.—The results obtained with alcohol are shown in fig. 1. Curves 1, 2, 3 and 4 represent the result of adding 1 c.c. of

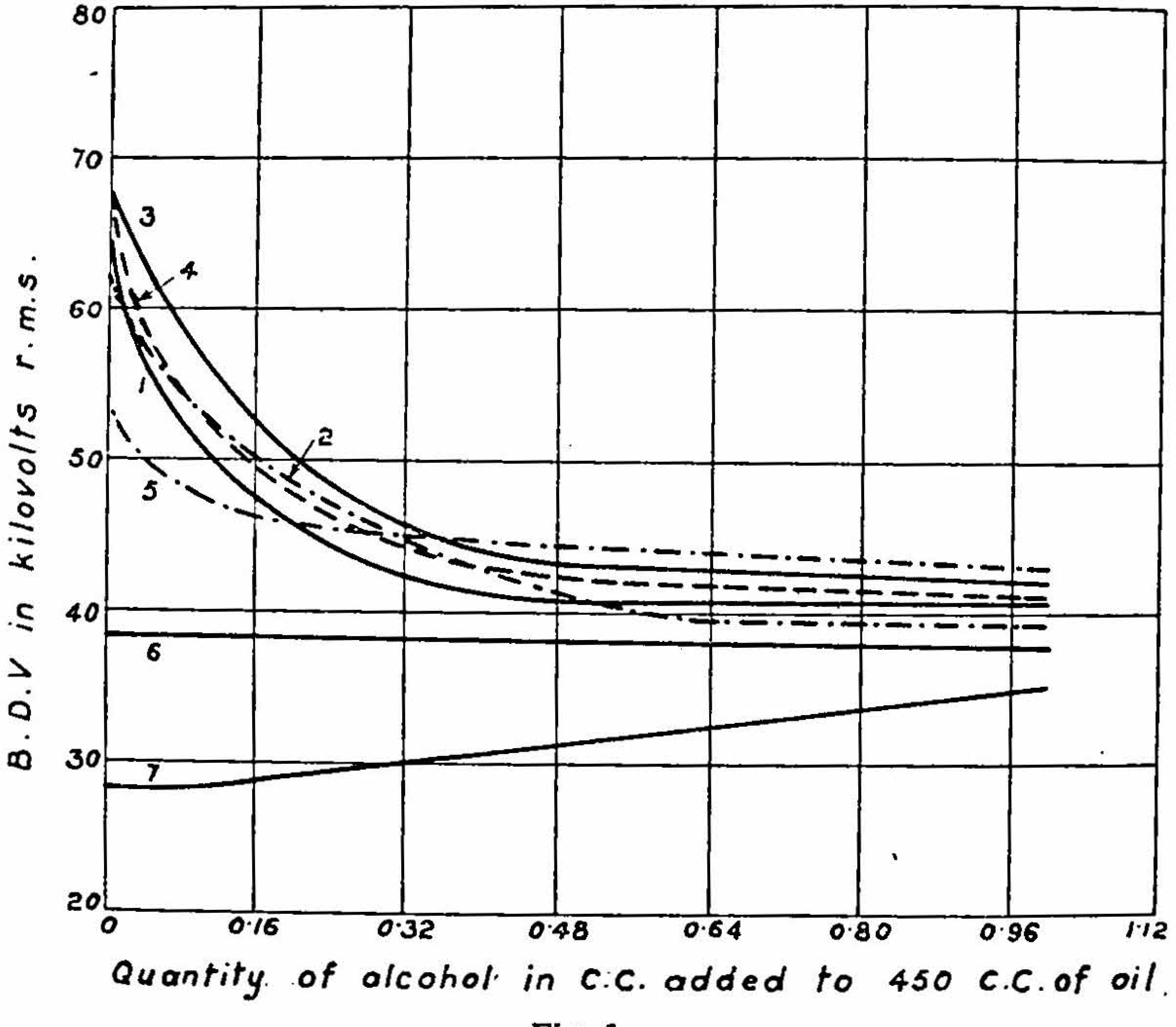

Fig. 1.

Effect of Alcohol on the B.D.V. of Transformer Oil.

alcohol to 450 c.c. of pure dry oil in doses of 0·04, 0·08, 0·16 and 0·24 c.c., respectively. The curves drop rapidly at first, but less and less rapidly with further additions until a practically steady value is reached when 0·4 c.c. has been added and the addition of further quantities has little effect. In all cases the final steady value is about 40 kV. Allowing for the divergences in the graphs due probably to slight differences in the initial moisture content of the four test samples, all the curves are substantially the same, indicating that the effect of the products of decomposition produced by the discharges is negligible in comparison with that of alcohol.

Curves 5, 6 and 7 represent the effect of the addition of alcohol in doses of 0·08 c.c. to oils with different moisture content. In a slightly moist sample (curve 5) the drop is smaller than in the dry samples. This indicates that the effect of alcohol is partly neutralised by the effect of removal of moisture due to the discharges. In a moister sample having an initial B. D. V. of 38 kV, the curve remains level, indicating that the two effects are exactly balanced. In the wettest sample having an initial B. D. V. of 28 kV the curve rises instead of falling. This is because in this case the effect of the removal of moisture predominates.

In all these cases the final steady value does not appear to have been reached when 1 c.c. of alcohol has been added. In curves 5 and 7 this is apparent. In order to bring this out more clearly in the case of the dry sample, the effect of the addition of a larger quantity of alcohol is represented in fig. 2 which shows that the final steady value of 37·5 kV is not reached before nearly 2 c.c. have been added.

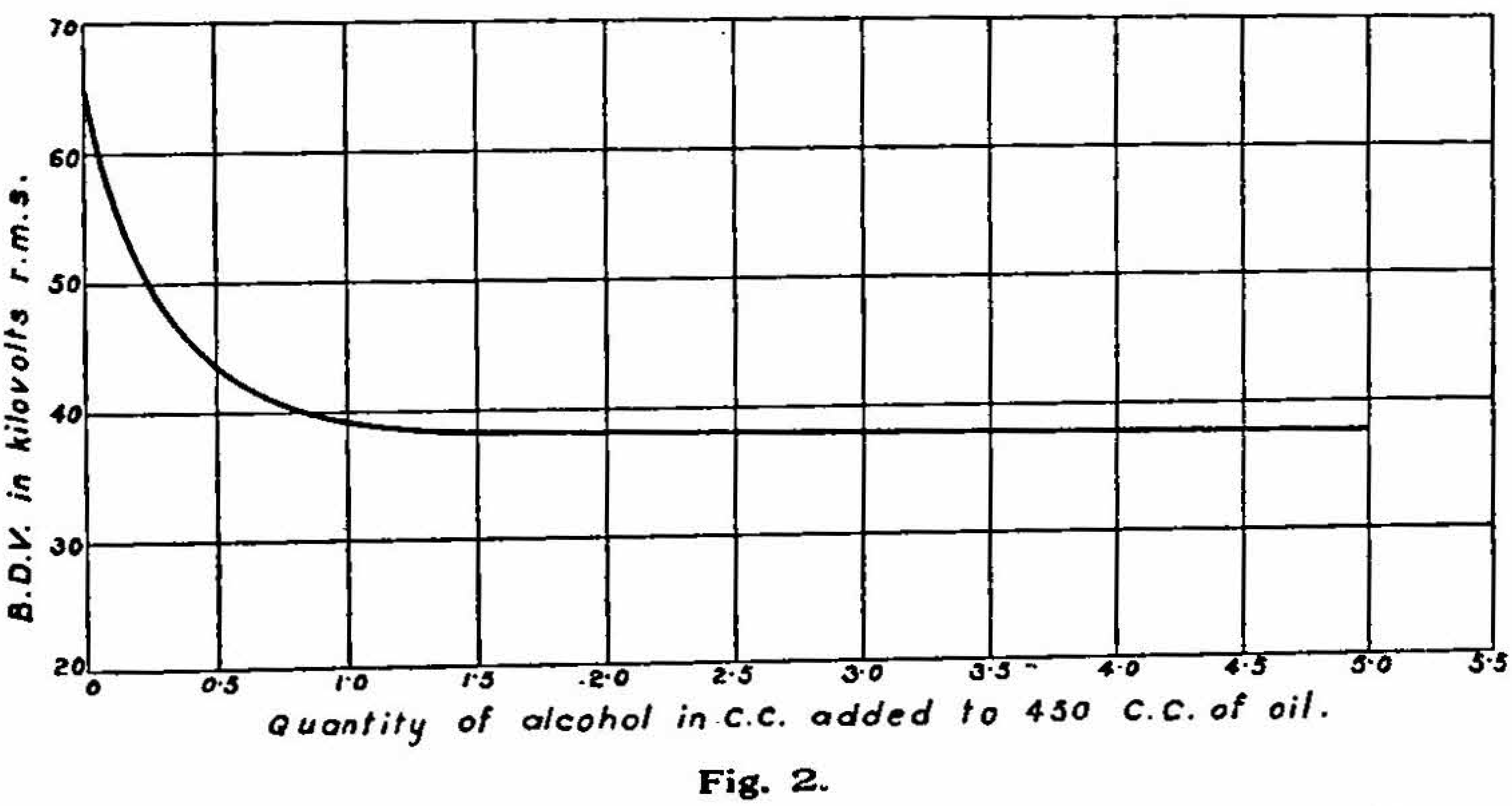

Fig. 2.

Effect of Alcohol (Large Quantity) on the B.D.V. of Transformer Oil.

Fig. 3 shows the effect of successive discharges on dry oil containing 1 c.c. of alcohol. The low initial B. D. V. (40 kV) is due to the presence of alcohol. This steadily rises with successive discharges, due probably to the removal of alcohol, until a final steady value of 44·5 kV is reached after about 1 000 discharges.

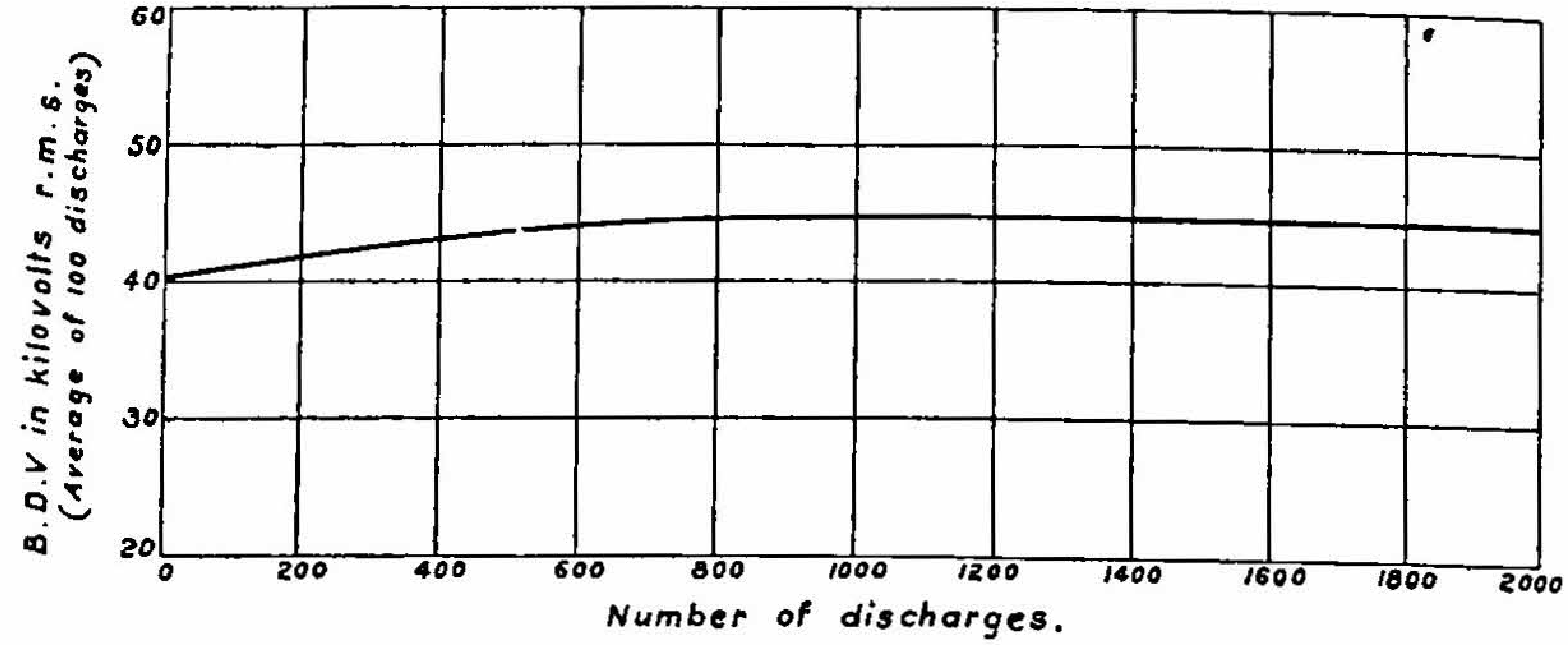

Fig. 3.

Successive Discharges in 450 c.c. of Transformer Oil containing 1 c.c. of Alcohol.

Effect of shellac—(*i*) *Unbleached shellac.*—Fig. 4 represents the effect of unbleached shellac when added to oil. Curves 1, 2, 3 and 4 show the effect of adding it to dry oil in doses of 0·025, 0·05, 0·075

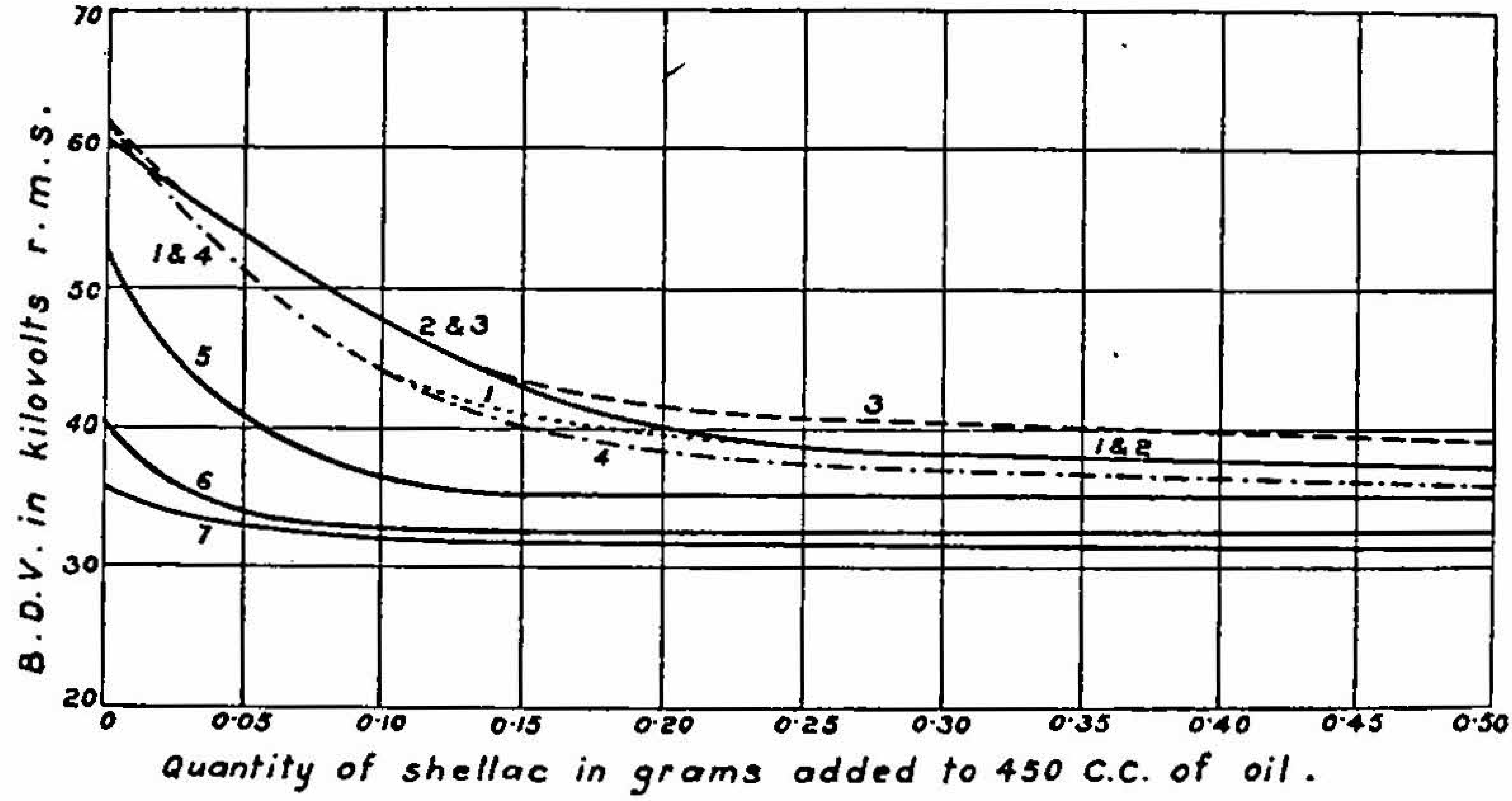

Fig. 4.

Effect of Unbleached Shellac on the B.D.V. of Transformer Oil.

and 0·1 g., respectively. The nature of the curves is similar to that obtained with alcohol, but the final steady value does not seem to have been reached when 0·50 g. has been added.

Curves 5, 6 and 7 show results obtained by adding shellac in doses of 0·05 g. to oils of varying moisture content. In all cases there is an initial drop which indicates that the lowering of B. D. V.

produced by the addition of shellac is greater than the effect of the drying of oil due to the discharges. However, the initial drop is smaller the moister the oil, and it may be presumed that with oil having an initial B. D. V. below 31 kV there would be a rise instead of a drop.

The results obtained by subjecting samples of oil with varying moisture content to successive discharges after adding 0·5 g. of shellac are shown in fig. 5 which shows that in all cases the B. D. V. rises and

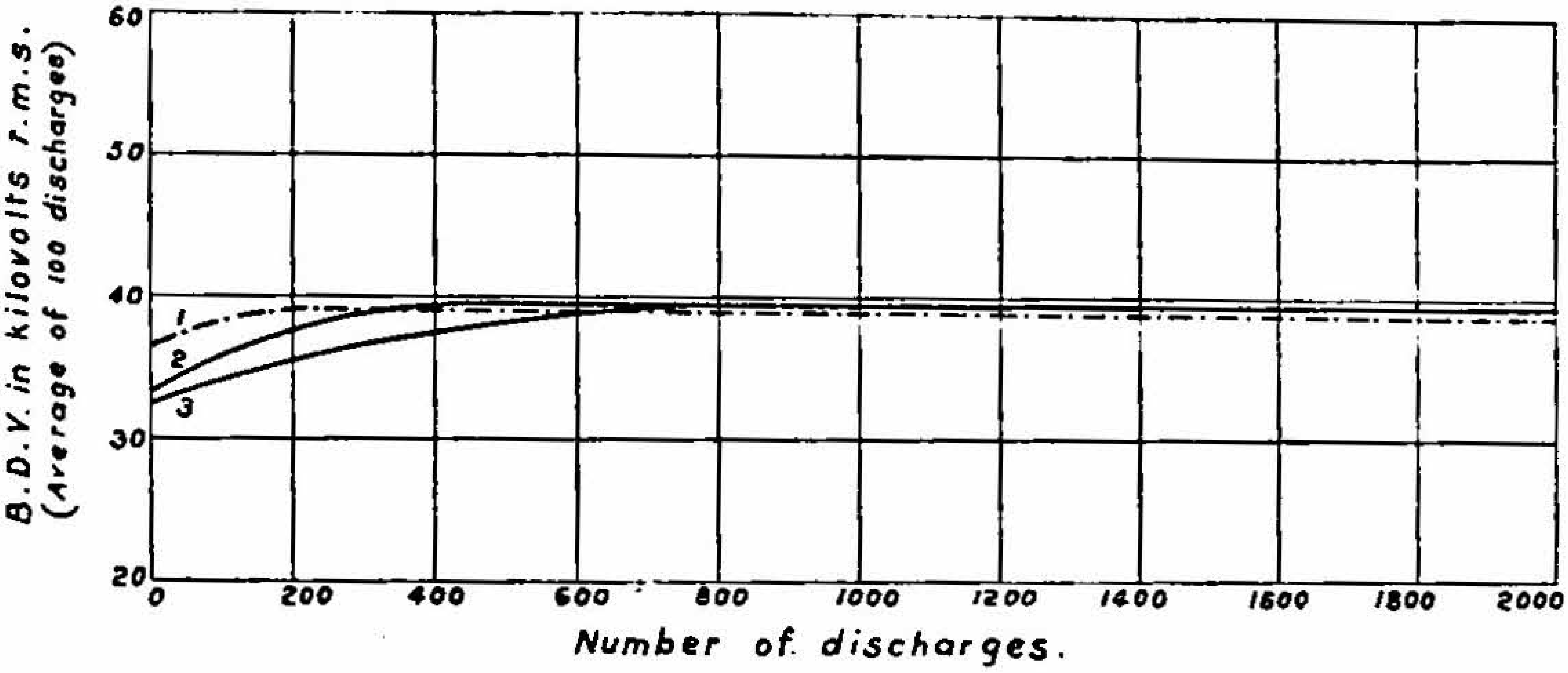

Fig. 5.

Successive Discharges in 450 c.c. of Transformer Oil containing 0·5 grams of Shellac.

finally reaches a steady value of about 39 kV. This is probably due to the drying effect of the discharges.

(*ii*) *Shellac purified by solution in alcohol and subsequent drying.*—The results obtained by adding shellac, prepared from solution in alcohol and subsequent drying, in doses of 0·025, 0·05, 0·075 and 0.1 g. are shown in fig. 6 and are substantially the same as for unbleached shellac shown in fig. 4. This indicates that the impurities in unbleached shellac have little, if any, effect on the B. D. V. of oil.

Effect of paraffin wax.—Fig. 7 shows the effect of paraffin wax when added to dry oil in doses of 0·05, 0·1, 0·15, 0·2, 0·25 and 0·3 g., respectively. There is nothing noteworthy about these curves which are similar to those in figs. 1 and 4. The effect of the wax on moist oil, shown in fig. 8, is more interesting. Curves 1 and 2 were obtained with 0·1 g. doses and curve 3 with 0·05 g. doses of wax. All these curves pass through a minimum before reaching the final steady value. This can be explained by assuming that initially the effect of addition of wax is greater than the drying effect produced by the discharges; at the point corresponding to the minimum value the two effects are equal and thereafter the effect of drying predominates.

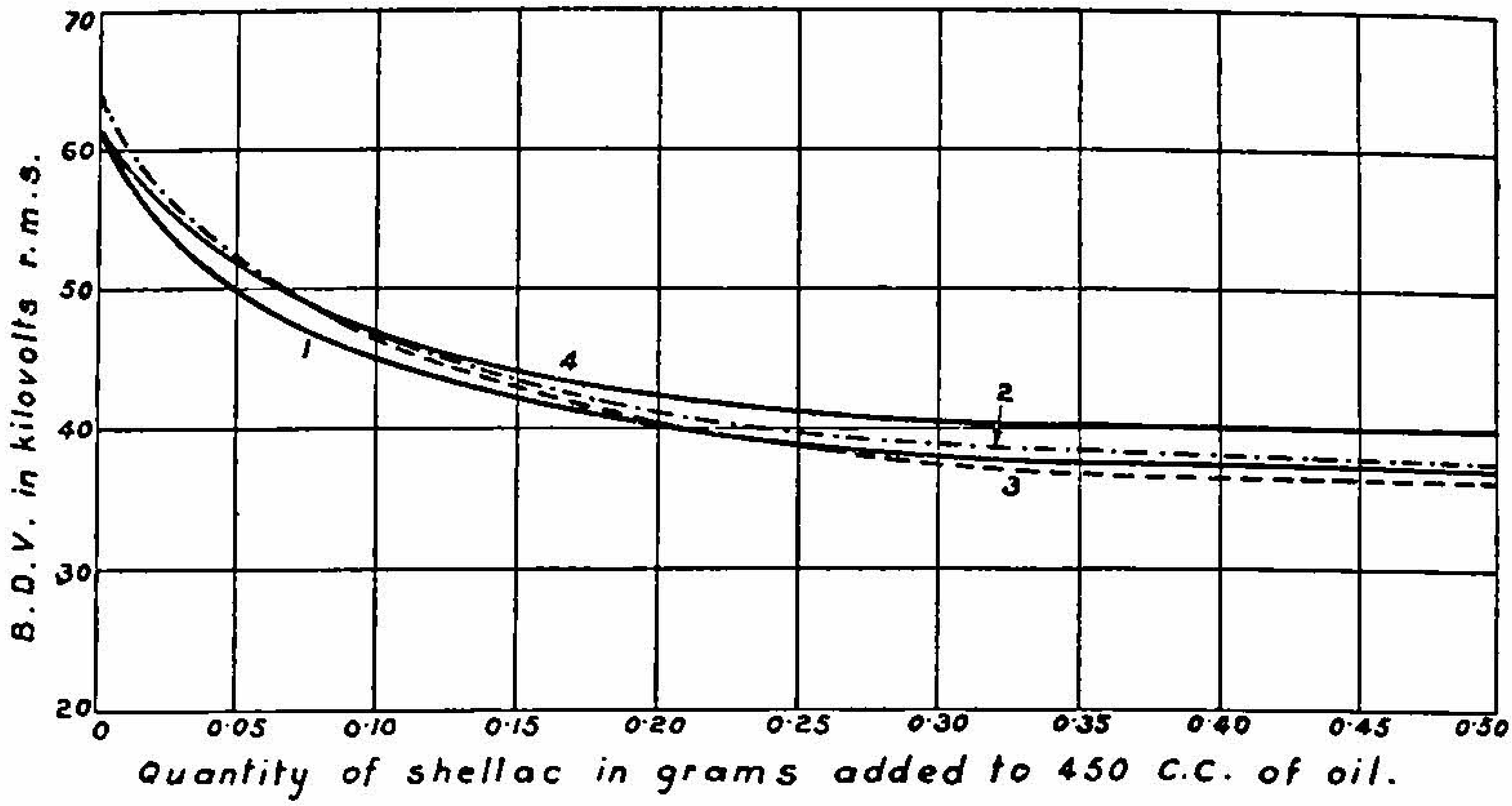

Fig. 6.

Effect of Shellac (dissolved in Alcohol and dried) on the B.D.V. of Transformer Oil.

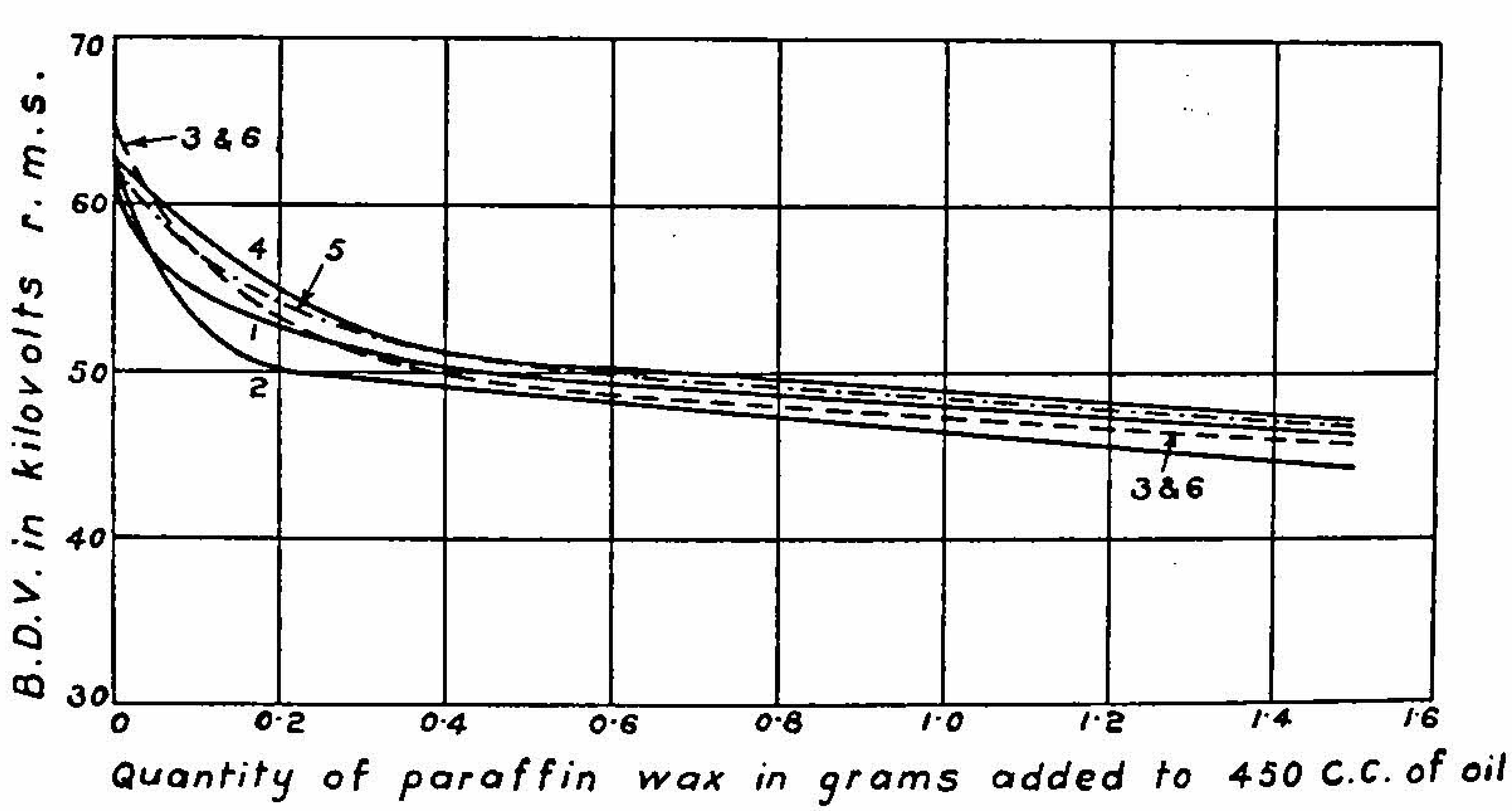

Fig: 7.

Effect of Paraffin Wax on the B.D.V. of Transformer Oil.

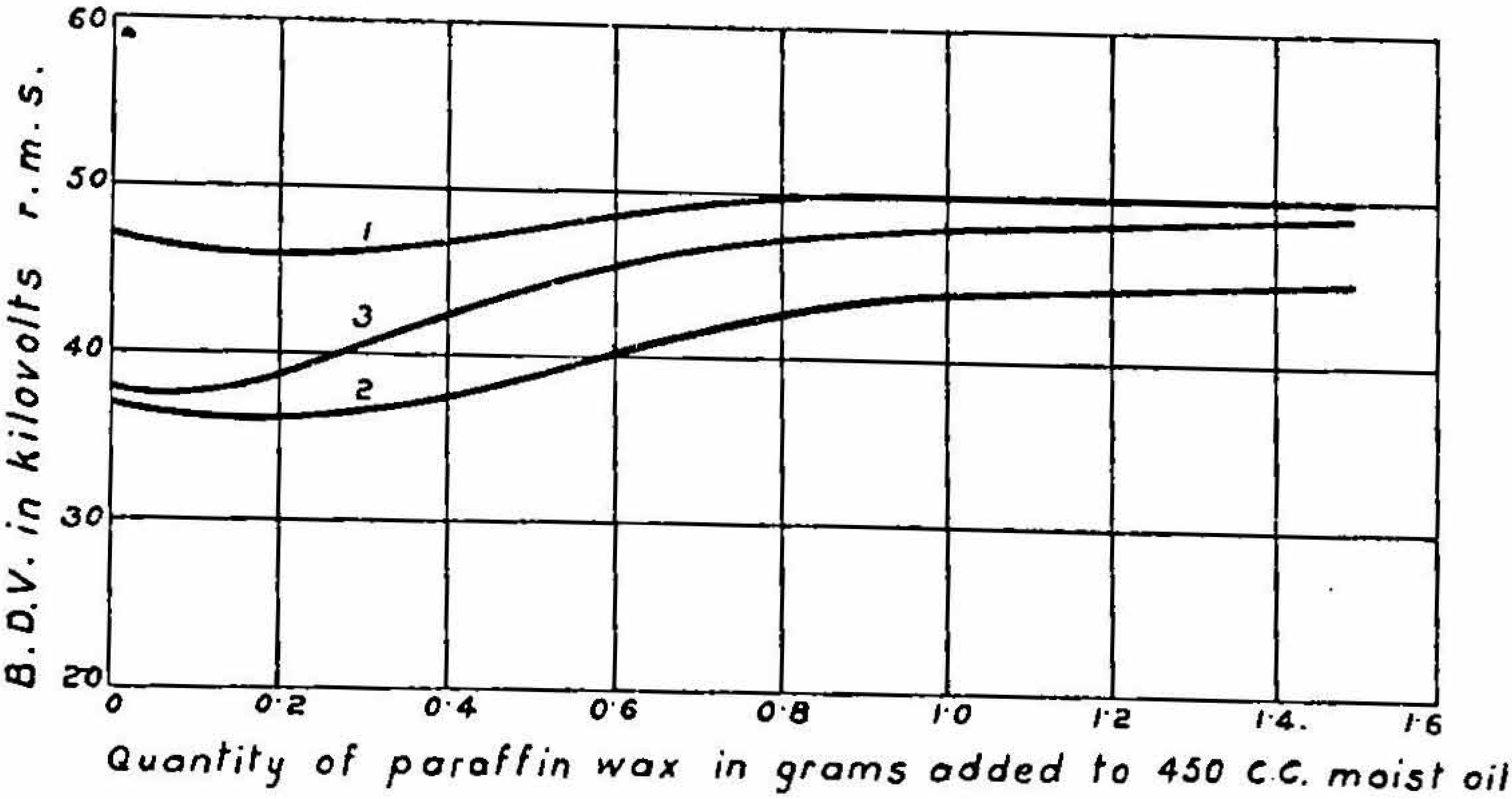

Fig. 8.

Effect of Paraffin Wax on the B.D.V. of Moist Transformer Oil.

This is borne out by curve 3 in which the number of discharges is doubled due to the smaller dosage. Consequently the minimum point is reached earlier and the curve rises steeper.

The effect of successive discharges on dry and moist oil is shown in fig. 9. But for the initial lowering of B. D. V. the addition of paraffin wax does not seem to alter the B. D. V. of oil.

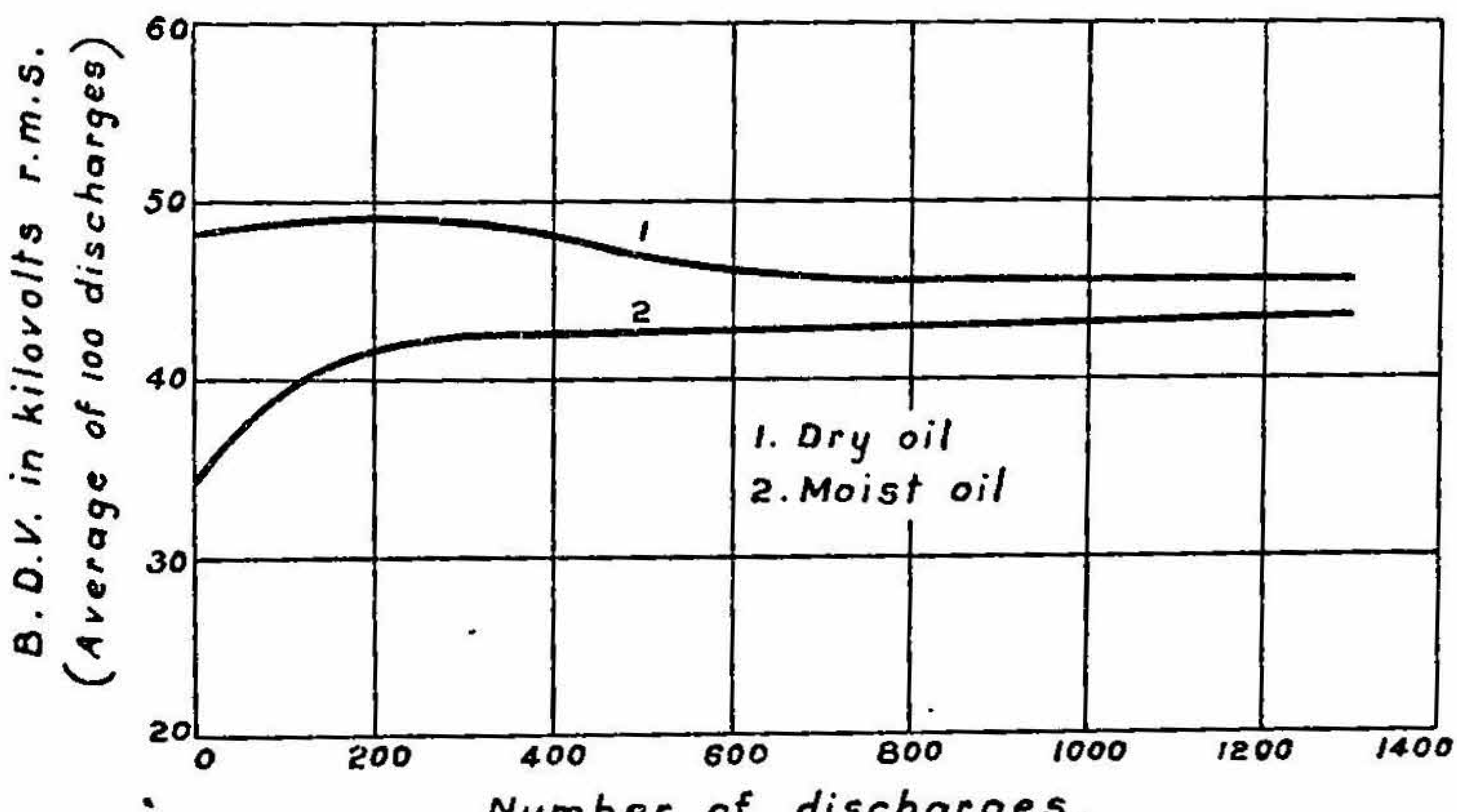

Fig. 9.

Successive Discharges in 450 c.c. of Transformer Oil containing 1·5 grams of Paraffin Wax.

Effect of sludge.—The curves in fig. 10 representing the effect of sludge are similar to the curves for other impurities. Curves

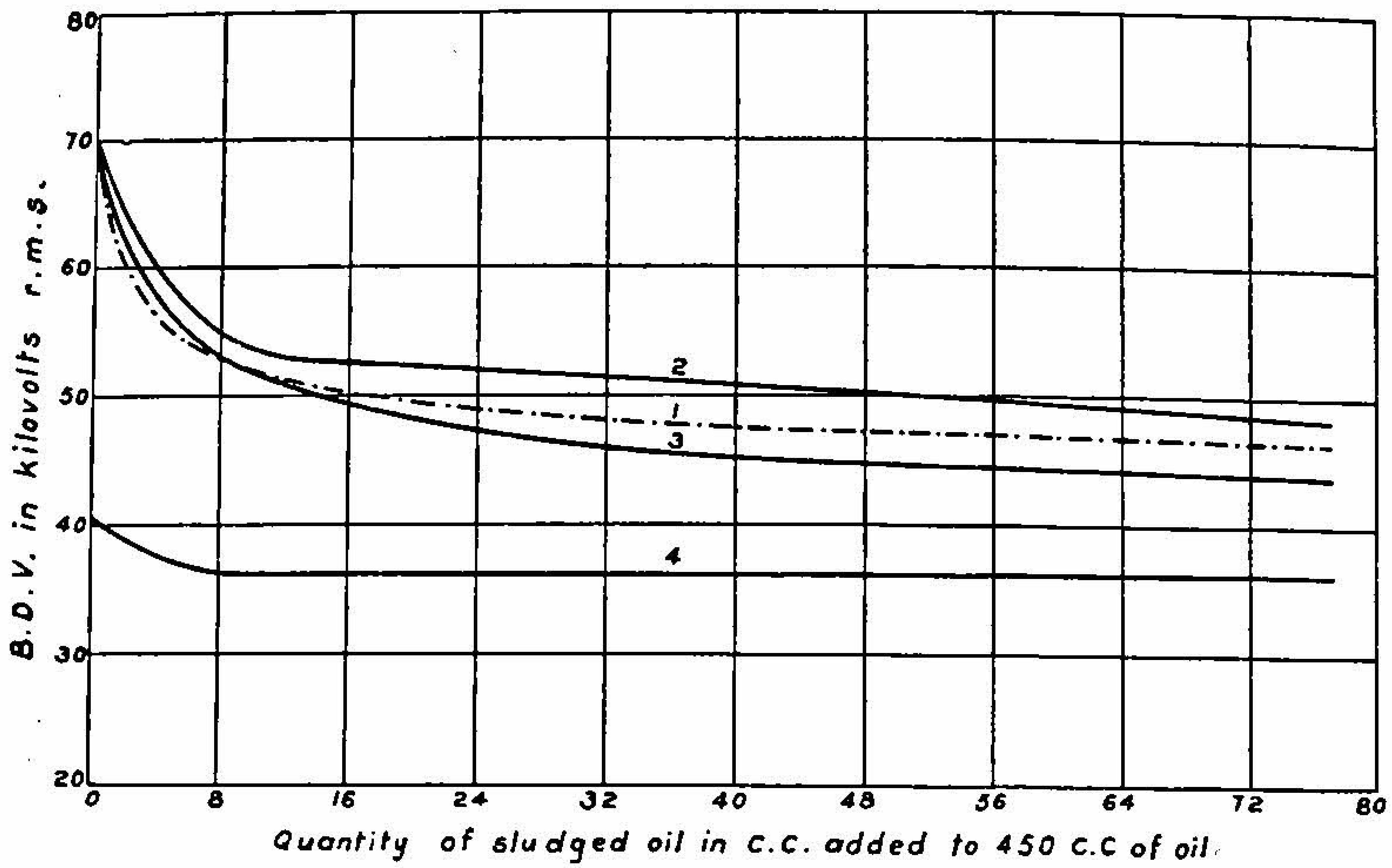

Fig. 10.

Effect of Sludge on the B.D.V. of Transformer Oil.

1, 2 and 3 correspond to the addition of 1, 2 and 5 c.c. doses respectively, to dry oil, while curve 4 is for moist oil. In dry oil considerable further addition of sludge would be necessary to bring it to its final steady value of B. D. V. This value cannot fall below 38 kV which is the B. D. V. of the sludged oil obtained as explained before. In moist oil a constant value is obtained, as in the case of shellac, with a very small quantity of sludge.

Effect of mixture of impurities.—Fig. 11 represents the effect of the mixture of sludge, paraffin wax and shellac on the B. D. V. of dry and moist oil. A comparison of these curves with those obtained with shellac shows that the effects are similar and that the lowering of the B. D. V. of oil is approximately the same as that produced by shellac alone. This is to be expected because, of all the impurities tested, shellac produces the maximum change.

Comparison of results for moist oil.—While the curves for dry oil are generally of the same nature, the differences exhibited by the curves for moist oil are interesting. Fig. 12 shows the effect of the various impurities on moist oil having an initial B. D. V. of about 40 kV. 0·15 g. of shellac reduces it to 31·5 kV but beyond this point it remains constant at this value because the effect of further addition of shellac is balanced by the drying of oil due to the discharges. With sludge the

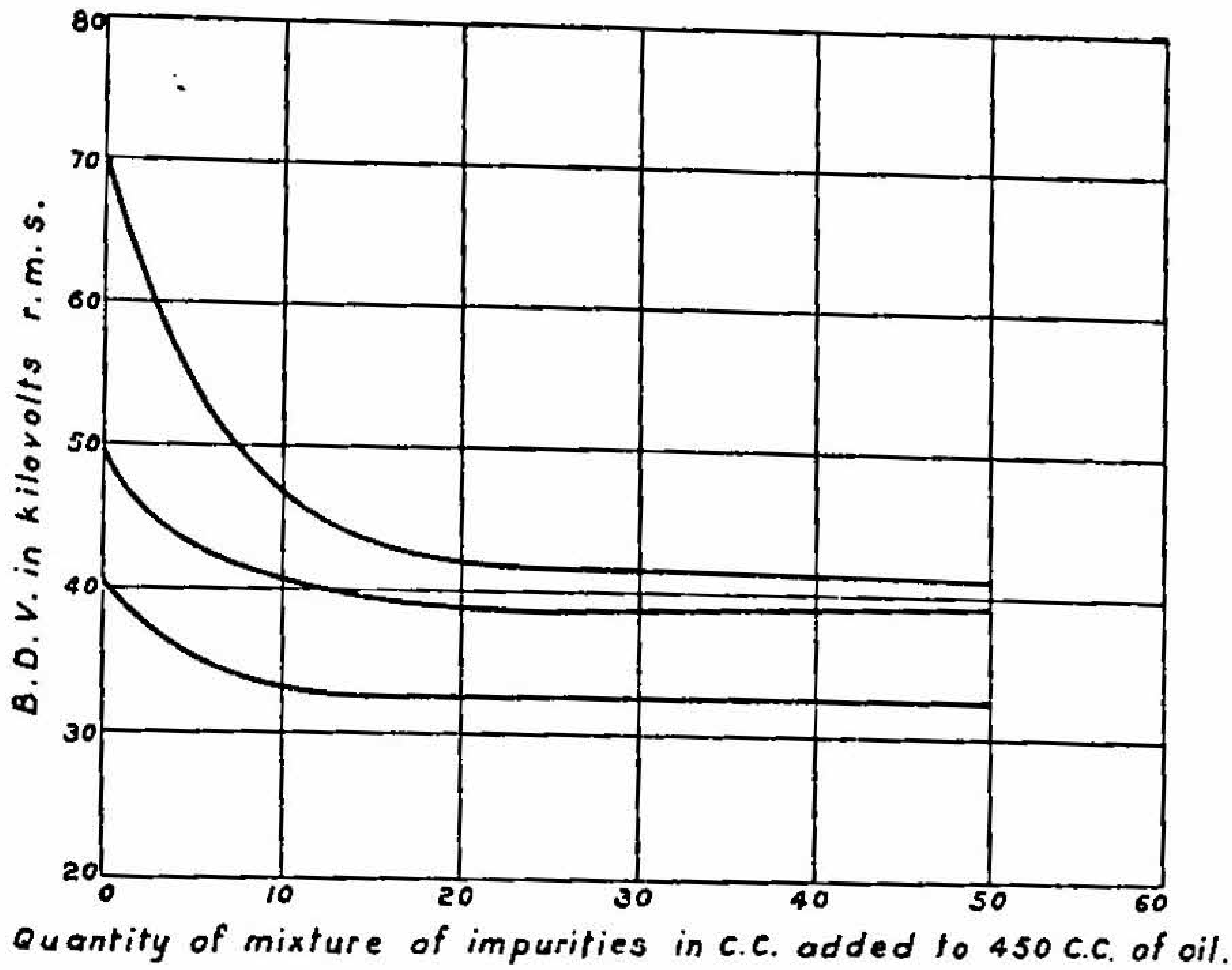

Fig. 11.

Effect of a Mixture of Impurities on the B.D.V. of Transformer Oil.

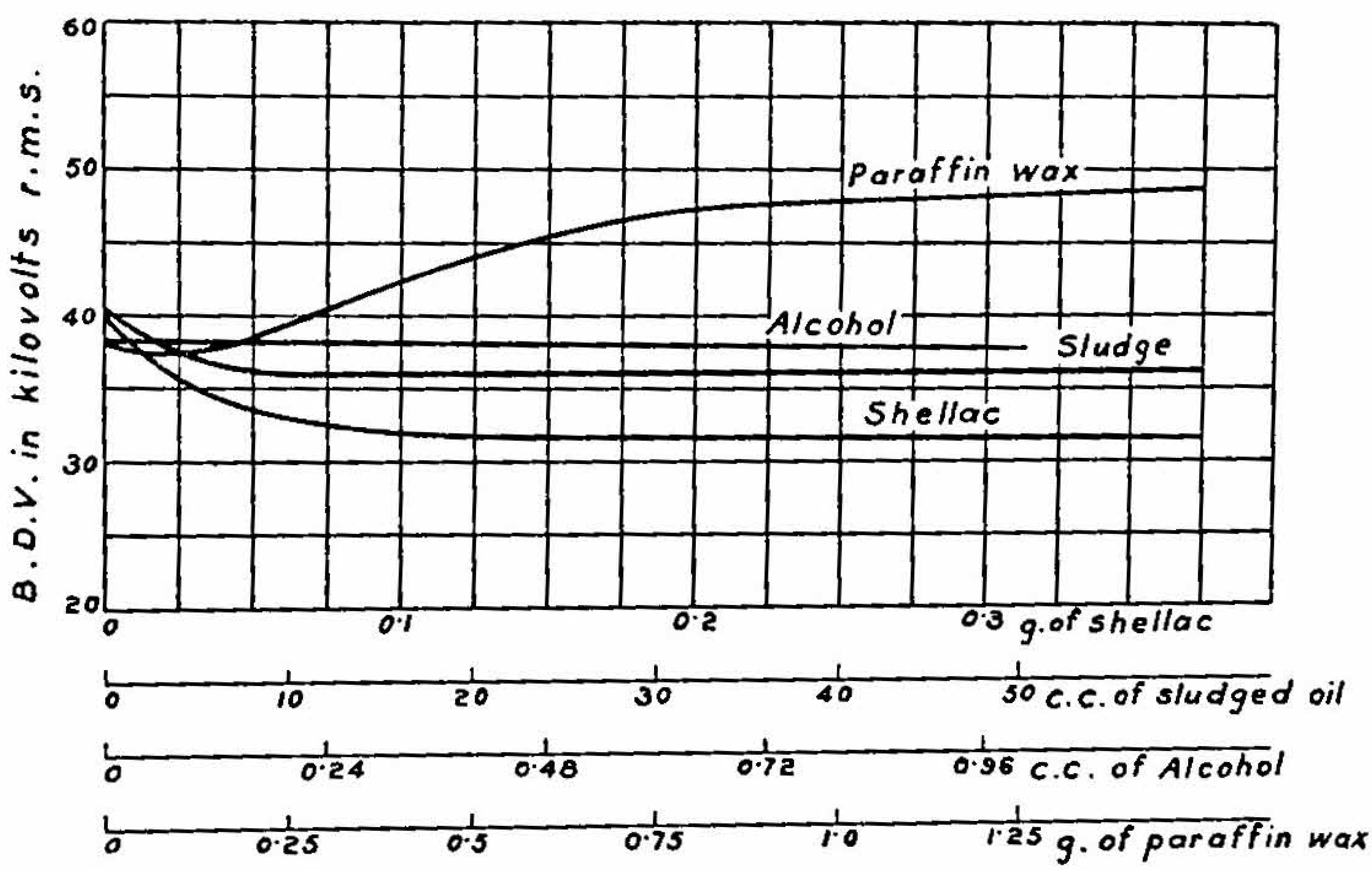

Fig. 12.

Effect of Impurities on the B.D.V. of Moist Transformer Oil.

B. D. V. drops to 36 kV and remains constant at this value. With alcohol there is practically no lowering but a steady value is maintained throughout. With paraffin wax, there is an initial lowering followed by a steep rise due to the preponderating effect of the removal of moisture, and the high value of 49 kV is reached in a comparatively small number of discharges.

CONCLUSIONS.

In dry oils, alcohol, shellac, paraffin wax and sludge do not lower the B. D. V. substantially below 40 kV and therefore do not render it unfit as an insulating medium from the point of view of electric breakdown strength. Of these impurities, shellac and sludge produce the greatest effect even in small quantities. The effect of paraffin wax and alcohol is not so great.

In moist oils the effect of impurities varies considerably with different substances, the greatest effect being produced by shellac and sludge. In the case of paraffin wax the effect of drying is very prominent and the B. D. V. rapidly improves after a small initial drop.

In dry oils the effect of successive discharges after the addition of the impurity is negligible. In moist oils the B. D. V. generally improves and settles down to about 40 kV. Starting from dry or moist oil the final value attained is the same.

The effect of superposition of the impurities is not additive, but the B. D. V. is determined by the impurity which produces the greatest effect.

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