DISCUSSION

MR. L. B. SCHOFIELD.[1]—Mr. Doble has presented a very comprehensive paper on insulating oils. Early in his paper, he speaks of a "new concept" that properly serviced insulating oils can be given practically unlimited extension of life free from the formation of sludge or excessive acidity due to oxidation, even in free-breathing transformers. At one point, he concludes that "the life characteristics of moderately re-refined oils (with inhibitor) can be controlled economically." This concept, whether new or old, leads into cost considerations, although it has been agreed that over-all economic evaluations will not be discussed at this time.

Mr. Doble has contributed greatly to our technical knowledge of what may be accomplished by re-refining and inhibiting a used transformer oil. However, he has not compared a new inhibited oil with an inhibited re-refined oil from the standpoints of oxidation resistance and oil "life." The performance characteristics of new inhibited oil and reclaimed old oils should necessarily be determined as a basis for economic evaluations which eventually must be considered.

The probable increase in cost for procuring a transformer oil with improved resistance to oxidation is relatively unimportant since the cost of the oil is only a small percentage of the total installed cost of such equipment. Also, in considering the cost of replacement and the frequency of replacement, previous studies[2] have indicated that a new inhibited oil containing 0.3 per cent DBPC will have about double the service life of a conventional noninhibited oil in old transformers of the open-breather type. Many transformers of this type are still in service.

In some more recent tests conducted in our laboratories, the main objective was the determination of the relative oxidation stabilities of a new inhibited oil and various re-refined oils with inhibitor added. Several barrels of a typical used oil of known source were drawn from a transformer in service. Appropriate volumes of this oil were re-refined to approximately 30, 40, and 45 dynes, respectively. DBPC was then added in various percentages to the different lots of re-refined oils. A total of 22 different sample oils were prepared for test. Oxidation resistance was evaluated by: (*a*) an accelerated laboratory oxidation test on all of the sample oils and (*b*) a heat-aging test on four of the oils in transformers.

The procedure used for the accelerated tests is commonly identified as the Transformer Oil Oxidation Test (TOOT) which is a modification of ASTM Method D 943 – 47 T for oxidation of steam turbine oils. Table I shows the results

[1] Materials Engineer, Commonwealth Edison Co., Chicago, Ill.

[2] H. Halperin and H. A. Adler, Technical Paper No. 51-208, Am. Inst. Electrical Engrs. Presented at AIEE meetings, Toronto, Ont.. Can., June 25–29, 1951.

TABLE I.—RESULTS OF ACCELERATED OXIDATION TESTS ON VARIOUS OILS.

Sample Oil Number	Transformer Number[a]	Oil Description	DBPC, per cent by weight	TOOT[b] Life, days
1.....	...	Original oil A from service transformer "H"—IFT of 18 dynes.	0	⅓
3.....	...	Oil A re-refined with fuller's earth to IFT of 30 dynes.	0	¾
4.....	...	Same as No. 3 with inhibitor added.	0.3	9
5.....	1	Same as No. 3 with inhibitor added.	0.6	15
9.....	...	Oil A re-refined with fuller's earth to IFT of 46 dynes.	0	3
10.....	2	Same as No. 9 with inhibitor added.	0.3	43
11.....	4	Same as No. 9 with inhibitor added.	0.6	69
22.....	3	New inhibited oil C—IFT of 50 dynes.	0.3	150
23.....	...	New noninhibited oil—IFT of 47 dynes.	0	6

[a] Numerals 1, 2, 3, and 4 indicate transformers containing these oils on simulated service, aging tests in transformers.
[b] Transformer Oil Oxidation Test is modified ASTM D 943 – 47 T turbine oil oxidation test.

For the heat-aging test, a type of simulated service aging test on the oils, the setup consisted of four old 10-kva distribution transformers reconditioned for the tests and thoroughly cleaned. One transformer was filled with a new inhibited oil and the other three with the inhibited re-refined oils of selected types, as indicated in Table II. The covers were left resting loosely on top of the cases without being bolted down to allow some access of air by breathing which could occur in an unprotected transformer in service.

For these heat-aging tests, the transformers were operated with a constant top oil temperature of 95 C except for one 16-hr cooling period each week. The heating was produced by passing current through the windings with the low-voltage windings short circuited. By adjusting transformer currents as required, the same top oil temperature of 95 C was maintained, within one degree, in all the transformers throughout the tests, regardless of the different amounts of sludging.

TABLE II.—CHANGE IN OIL CHARACTERISTICS[a] FROM HEAT-AGING TESTS FOR VARIOUS PERIODS IN TRANSFORMERS.

Transformer Number	Oil in Transformer	Color Number		Acidity, mg KOH		Sludge, per cent by weight	
		Original	1 Yr	Original	1 Yr	Original	1 Yr
1........	Re-refined to 30 dynes (0.6 per cent DBPC).	3½	8	0.10	1.02	0	0.160
2........	Re-refined to 46 dynes (0.3 per cent DBPC).	1½	6	0.005	1.08	0	0.130
3........	New inhibited oil (0.3 per cent DBPC).	¾	3¼	0.01	0.71	0	0.030
4........	Re-refined to 46 dynes (0.6 per cent DBPC).	1½	6¼	0.005	0.94	0	0.080

[a] Color number determined by ASTM Tentative Method D 155 – 45 T (Union Colorimeter). Acidity determined by ASTM Tentative Method D 974 – 52 T (color-indicator titration). Sludge measured by procedure defined in Sections 26, 27, and 28 of ASTM Tentative Method D 670 – 42 T.

of the accelerated oxidation tests on nine samples prior to the transformer aging tests. The TOOT life of 150 days attained by the new inhibited oil (containing 0.3 per cent DBPC) is more than three times that of the oil reclaimed to 46 dynes, with comparable inhibitor content; it is ten times the life of the oil re-refined to 30 dynes with 0.6 per cent DBPC added. Other comparative evaluations are evident in the test data. While the life of an oil from this test cannot be accurately converted into actual predicted life of an oil in a transformer, considerable reliance may be placed in this test to indicate relative propensities to oxidation or sludging.

Oil samples were taken from the transformers at 6-month intervals and tested for color, acid number, and sludge content to indicate the comparative degrees of deterioration. The heat-aging tests were discontinued after 1 yr. The data of the oil tests at various stages of the heat aging treatment are shown in Table II.

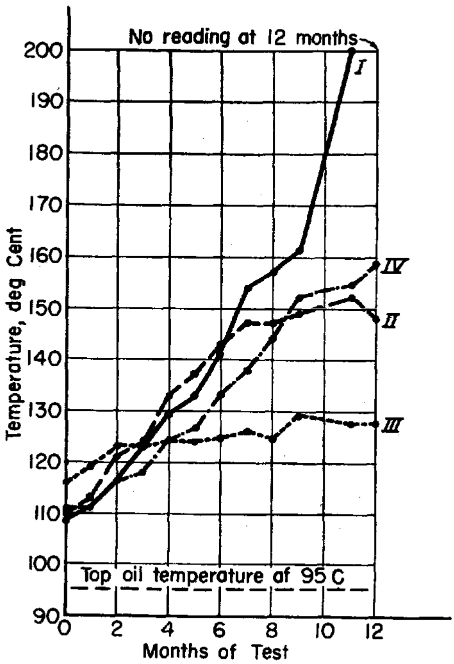

FIG. 1.—Transformer Copper Temperatures.
I. Re-refined Oil plus 0.6 per cent DBPC (30 dynes).
II. Re-refined Oil plus 0.3 per cent DBPC (46 dynes).
III. New inhibited oil—0.3 per cent DBPC.
IV. Re-refined oil plus 0.6 per cent DBPC (46 dynes).

It is generally conceded that the re-refining of an old oil to an IFT of 46 dynes per cm is well beyond the limits of economical practice. In those companies where reclaiming procedures are regularly used, re-refining to a maximum IFT of 30 to 35 dynes is generally favored. Therefore, of all the reclaimed oils on test, probably our greatest interest is in the 30-dyne oil. The comparative data of all the tests on the 30-dyne oil in transformer 1 and the new inhibited oil in transformer 3 are most interesting, especially with reference to the relative degrees of sludging.

In addition to the tests on the oil after the heat-aging treatment, another test, allowing an important observation, was made. The average copper temperature in each transformer was measured periodically throughout the heat-aging treatment. The temperatures were determined by measurements of copper resistance. These copper temperature readings might be considered one of the most significant observations that were made. The trends in the copper temperatures in the four transformers are shown

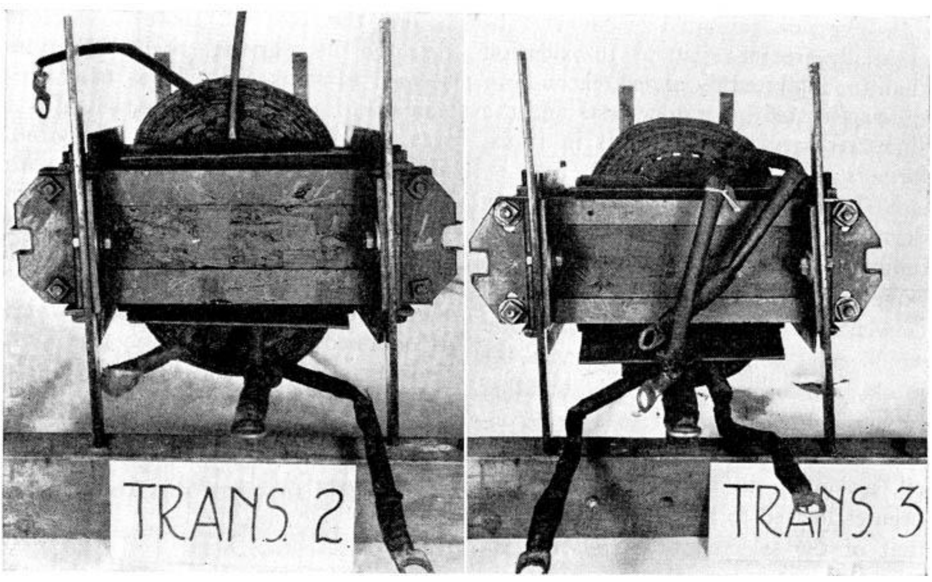

FIG. 2.—Transformers Used in Heat-Aging Test.

in Fig. 1. Most interesting is the relatively flat temperature curve for transformer 3, with the new inhibited oil, compared with the curves for all the other transformers containing the inhibited re-refined oils. Also note the extremely rapid increase in copper temperature of transformer 1, attributed to sludging and clogging of the oil ducts.

At the end of the tests, the four transformers were dismantled for inspection. Transformer 3 showed a much less degree of sludge contamination than any of the other transformers as indicated by the top view photographs shown in Fig. 2. There was no significant difference in the general appearance of transformers 1, 2, and 4 containing the reclaimed oils, and in no case were any of the oil ducts open in these transformers.

While there is no accurate or practical method of correlating the laboratory test results with actual service performance, the following deductions would appear to be reasonable:

1. The test results presented here carry some very different implications from those in Mr. Doble's paper.

2. The new inhibited oil shows substantially greater resistance to oxidation than the inhibited reclaimed oils on both the accelerated laboratory tests and the simulated-service, aging tests in transformers.

3. A used oil carried to a moderate degree of re-refinement (30 dynes) and inhibited with DBPC has about the same resistance to oxidation as a new conventional oil (noninhibited) and would have an anticipated service life in old transformers of the open-breather type roughly equivalent to a new conventional oil. The service life of such an oil, according to previous studies, has been estimated to be no more than half that of the selected brand of new inhibited oil containing 0.3 per cent DBPC.

MR. F. M. CLARK.[3]—The importance of maintaining transformer oil in the best possible condition, and the laboratory-demonstrated possibility of more easily assuring this desired condition by the addition of an inhibitor, will be readily acknowledged by all leading engineers in this field.

Mr. Doble's paper is a desirable re-emphasis of factors that have been quite generally recognized but which possibly have not been sufficiently emphasized as to their value in insuring trouble-free transformer operation.

In the introduction to his paper, Mr. Doble states, "The new concept is that insulating oils, when properly serviced, can be given practically unlimited extension of life free from the formation of sludge and excessive acidity. . . ." It is somewhat surprising that this is given as a new concept. It has been observed that transformer operators seem to take such a possibility for granted. Apparently, the only question that ever has been pressing in their minds was how frequently they could treat the oil before the cost of these treatments defeated its purpose. Some operators seemed to think that it was most economical to leave the oil alone as long as it was in good dielectric condition, and, after extreme oxidation, to replace it with new oil. Others have been concerned in evaluating the frequency of oil treatment in terms of improved oil properties in comparison with the practical economies and technical transformer safety which is obtained—this is probably the most progressive approach. From a purely technical view, probably the best transformer oil condition is that which is free from any type of oxidation effect. It is toward that goal that the engineer

[3] General Engineering and Consulting Lab., General Electric Co., Schenectady, N. Y.

has been striving by study of oxidation in his effort to produce a more stable oil (*a*) by the introduction of the conservator, (*b*) by the use of inert gases, such as nitrogen, and (*c*) by the use of an oxidation inhibitor. The use of oxidation inhibitors or retarders, as Mr. Doble indicated, is not new and has been under almost continuous study since the early 1920's both here and abroad.

The importance of the author's paper appears to be that it is another link in a chain of technical papers demonstrating the possibilities that may be realized by the use of a properly selected oxidation inhibitor.

In the prosecution of his concept, Mr. Doble recognizes the need for a good set of screening tests to evaluate the condition of an oil in the system. His analysis of each of the screening tests for acidity, color, dielectric strength, IFT, power factor, gravity, and pour point is generally quite acceptable. Each one of us may possess a different degree of confidence in any of the tests given, but we cannot seriously disagree with the Doble generalizations that have been made.

It is in the survey of the accelerated oxidation tests where differences may arise with the Doble suggestions and conclusions. The author states that the bomb and the sludge accumulation tests give results that are "... of little value in modern operating practice...." Does the author really mean such a sweeping statement? Mr. Doble presents a type of test which by inference at least, is free from the objections raised against the bomb and the sludge accumulation tests. One concludes, therefore, that the author's accelerated test is of value to the transformer operator. It would be helpful to see the data upon which his conclusions are based.

It has been this discussor's observation that an accelerated oxidation test is completely acceptable only as long as it is being studied and used solely by its advocator. Round-robin studies are invariably highly destructive and disillusioning in their results. The bomb test and sludge accumulation test have been generally accepted in their ability to distinguish between bad and good transformer oil when new. Difficulty enters in when too fine a distinction between oils of generally similar qualities are studied. In general, however, the past progress that has been realized with the oil-filled transformer has been based in part on the application of results obtained from tests of that type. In this respect, therefore, these tests have been of real value to the transformer operator. It is only when they have been used in an attempt to evaluate the oxidation condition of an oil in service use that these bomb and sludge accumulation tests have not been completely satisfactory. Mr. Doble's suggested test procedure rests on an end point which is the first appearance of sludge or some selected amount of acidity. Each of these criteria has been used in tests for years in one form or another without general acceptance. Also, these criteria have been used together in procedures that have not been generally accepted. Maybe the form of tests suggested by Mr. Doble will be satisfactory on oils from different crudes, refined to different degrees and used under widely varying conditions. But the burden of proof is with the advocator of the test. Perhaps the author, in a later publication, will do this.

Mr. Doble emphasizes the elimination of the so-called natural inhibitor by refining. This is easily possible. Has the author studied the effect produced by the proper blending of a re-refined oil with a good quality of new and properly refined transformer oil from which the natural inhibitors have not been removed? If so, the results obtained would be of interest. The increased laboratory-demonstrated oil life which is made possible by the addition of an inhibitor to a new or used oil properly re-refined is now generally accepted and should no longer merit space in our crowded technical literature. What is of interest now is the consideration of the merits of such inhibited oils in terms of actual commercial use under widely varied conditions. Until practical conclusions based on experience of this type are available, the acceptability of the new and re-refined inhibited oils and the tests associated with their use in commercial service must be held in abeyance. In this field Mr. Doble may be able to contribute in a most valuable way.

MR. E. L. RAAB.[4]—First, Mr. Doble should be complimented for an extremely interesting and comprehensive paper dealing with a subject which has been attracting considerable attention.

In one of the General Electric Co.'s publications, it has been stated that in the normal course of operation there are a number of transformers which constantly indicate to operators an oil problem. The number is not large compared to the total number in use, but it is sufficiently so to justify study of reclamation methods and to warn some operators and apparatus manufacturers that the problem is increasing. For many years the General Electric Co. has practiced the fuller's earth reclamation of small quantities of oil where it could be blended or diluted with new oil to such an extent that certain objectionable effects of such refinement were alleviated. This procedure was recognized as not entirely satisfactory and was recommended to operators in only a few special cases.

Certainly the apparatus, supervision, and economics of reclamation procedures present problems which require considerable engineering and which have not justified more effort on the part of apparatus manufacturers than the primary problem of producing new apparatus which will give very long life to the oil.

It appears that certain recommended procedures based upon reclamation processes dealing to a suitable degree with fuller's earth followed by the addition of a satisfactory inhibitor should be useful in extending the life of old oil in old transformers if suitably controlled.

Possibly some comment should be made concerning situations when such reclamation procedures might be advantageously applied. Necessarily, this raises the question as to what constitutes the life of oil in service. As might be expected there seems to be a wide diversity of opinion among operators on this question. Presumably such a divergence of opinion is influenced to a large degree by cost considerations which cover such questions as the amount of observation, maintenance, reclamation, or replacement which is considered justifiable under a particular set of conditions. One extreme view is that no sludge should be permitted. This will require meticulous knowledge and a very active maintenance and reclamation program and will, of course, be based on the determination of the first appearance of sludge.

A more reasonable view might be the one chosen in some of our earlier studies; that is, an amount of accumulated sludge and acid should be tolerated which has not yet affected the operating characteristics of the transformer but

[4] General Electric Co., Pittsfield Works, Pittsfield, Mass.

which indicates the desirability of corrective action within a reasonable time.

Between these two views, intermediate values of sludge and acid are chosen by individual operators and there will probably continue to be some divergence of opinion.

Mr. Doble states that low IFT values indicate that the sample is "damaged." Necessarily, if Mr. Doble's definition is accepted—that any soluble oil contamination, whether detrimental or innocuous, should be classified as "damaging"—then his contention must be granted. However, as Mr. Doble pointed out, it should be noted that it is possible to have oil-soluble materials present in oil that will result in lowered IFT values but that will not necessarily decrease the oil life or the effectiveness of the oil.

Concerning the water content tests, Mr. Doble stressed that under certain conditions as little as 10 to 20 ppm of water in oil will greatly reduce its dielectric strength. Our company's experience so far indicates that a water content as low as 20 ppm in oil does not materially affect the oil's dielectric strength. Would the author care to amplify his statement and indicate under what practical conditions an operator might expect to obtain greatly reduced dielectric strength because of water content? While on the subject of moisture and its importance to electrical equipment and oil, should not a moisture content test be recommended as a diagnostic or screening test for oils in service?

One last point concerns Mr. Doble's recommendation that to inhibit oils in transformers the concentrate can be added at any convenient point near the top of the oil level in the unit and that under load conditions natural convection will uniformly disperse the inhibitor. In October, 1950, we reported to the Transmission and Distribution Committee of the Edison Electric Inst. that the dielectric strength of oil containing heavy concentrations of the DBPC inhibitor was somewhat reduced and that conservative practice indicated the need for a thorough dispersion of any high concentration before energizing the equipment. One possible approach might be to take the apparatus off the line, add the concentrate as recommended while the oil is still hot, and allow sufficient time for complete dispersion before re-energizing.

MR. T. A. MCCONNELL.[5]—An excellent paper has been presented this evening by Mr. Doble. He refers to the tendency of re-refined oils to oxidize more quickly than new oils. Does he have data to show to what extent, in years of service, the effective life of the oils referred to have diminished as a result of re-refining? How or by what tests was this established? He states that several power companies have attempted and abandoned re-refining of oils because of diminished returns. This does not coincide with The Detroit Edison Co.'s reclamation experience. Limited information thus far obtained (dealing with approximately 20 transformers) indicates that partial re-refining (IFT of 30 to 35 dynes) with fuller's earth will produce an oil with a service life of at least 10 yr. He speaks about the diminished service life of re-refined oil with each successive treatment. What does this mean in terms of years in service? Again, this is not borne out, to any significant extent, by experience in The Detroit Edison Co. Our company expects a longer service life with new oil but not necessarily a 2 or 3 to 1 ratio. Mr. Doble says that the ASTM bomb and the sludge accumulation tests are of little value in modern operating practice. What exactly is wrong with a

[5] The Detroit Edison Co., Detroit, Mich.

test showing a rate of sludge formation? The Detroit Edison Co.'s experience is that sludge up to $\frac{1}{16}$ in. in thickness apparently will not impair transformer cooling but that $\frac{1}{8}$ in. and above would. The rate of sludge formation therefore would appear to be an important characteristic, once sludging had started. Tests by this company have shown no material advantage in the use of DBPC with oil re-refined to an IFT of 30 to 35 dynes. Can it be that the oxidation-resistant characteristics of DBPC are rendered inactive ("poisoned") by soluble oxidation products left in the oil after re-refining?

MR. O. E. FAWCETT.[6]—Mr. Doble stated that oils re-refined to 30 dynes had 270 hr of life, while oils re-refined to 45 dynes had a 1500-hr life. Mr. Schofield's curves showed nearly equivalent results—from 3 to 15 days—that is, the 45-dyne oil lasted about five times longer than the 30-dyne oil. Mr. Doble stated it costs about three times as much to recondition the 45-dyne oil as it does the 30-dyne oil. Because of the much shorter life of the 30-dyne oil then, which overshadows its lower re-refining cost, it probably would never be economically sound to re-refine the oil and inhibit at 30 dynes. It would always be desirable to inhibit at perhaps 45 dynes.

MR. E. R. THOMAS.[7]—Mr. Doble has certainly presented a very interesting paper on how to operate transformers in a different way. However, there should have been some dollar signs in it. After all, any number of technical improvements or technical modifications on ways to do things can be made, but in operating a system the engineer is faced with the question as to what is the most economical way to do it. A particular case will be cited involving a transformer having in it 12,000 gal of oil which had been reclaimed by refining but not inhibiting. The process, which only involved refining, changed the IFT to a value of 45 dynes and the neutralization number to 0.05. It cost approximately 13½ cents per gal for that oil reconditioning with no overhead charges in the cost. It should be realized, as indicated in Mr. Doble's paper, that in addition to the physical work there is a technical control job to do; therefore, it appears that the cost would be a minimum of 15 cents per gal for some degree of conditioning (with or without inhibiting). The added cost of inhibitor would be rather minor. New oil costs at the time of these tests were approximately 25 cents per gal. It seems to us good business to discard old oil and replace with new oil. The discarded oil, however, has an economical use in the system; it is burned under our boilers. As fuel, it is worth about 10 cents per gal. Therefore, it costs the same to recondition the oil and buy new fuel oil as it does to buy new transformer oil and burn the discarded oil for fuel.

What result would be obtained if reconditioned, inhibited oil is used? From the information presented, the reclaimed oil would produce about the same result as the original oil.

A rather striking effect, evident in one of the curves presented by Mr. Doble, and also in the data presented by Mr. Schofield, was that of the inhibitors which produced enormous improvements in life of the new oils. This was evident by the type of life measurements of Mr. Doble and by transformer tests presented by Mr. Schofield. Thus it seems a far greater improvement is obtained by using new inhibited oil rather than reclaimed old oil.

Based on operating experience with sealed transformers having nitrogen over

[6] West Penn Power Co., Springdale, Pa.

[7] Test Engineer, Consolidated Edison Co. of New York, Inc., New York, N. Y.

the oil, we normally expect an oil life of 25 to 30 yr. This also approximates the normal useful life of those transformers at their particular spot on the system. Economically, how much premium can we afford for an oil life longer than that of normal uninhibited oil?

Recently, a study was made on oil removed from approximately 250 distribution transformers from our system. Fifty transformers from each of five oil-classified types were returned from service and their sludge contents were measured. These varied from "none" to "very heavily sludged" (having approximately ⅛ in. of sludge deposited on the case or on the windings). Unfortunately, the data, in terms of the usual test parameters for such an oil study—IFT, color, dielectric strength, neutralization number—do not give a precise index of numbers for evaluation of the oil's condition inside the transformer case. This is becoming increasingly evident as the investigation proceeds. At present, none of the usual tests (admittedly developed for new oils) give a clean cut, easily obtainable index of the life remaining in a given oil as removed from a transformer that correlates with the condition of the oil inside the transformer case.

MR. G. R. LITTLE.[8]—What is a precise definition of an inhibitor?

MR. GEORGE H. VON FUCHS.[9]—The question, "What is an inhibitor," cannot well be answered in a few words.

About 20 yr ago, the elaborate testing methods of today were not available. There were only the Indiana test and a few beaker tests in which the oil was cooked and changes in the viscosity, sludge content, and neutralization number observed. One of the problems faced in 1936 was the preparation of a better refrigerator oil. The old SO_2 refrigerator with piston type compressor using the conventional low pour-point oil was not considered technically and economically sound any more, and better engineered, hermetically - sealed, oil - immersed machinery using rotary compressors and the new Freon type refrigerants was being built. When this machinery was lubricated with the old type oil, some of the units did not function properly. The rotary compressor kept rotating but the sliding vanes or valves stuck in open position and the unit did not refrigerate.

In cooperation with C. E. Waring, then of the Frigidaire Division of General Motors, we found that the deposit causing the valves to stick contained copper. In all the stuck units copper was also found in small quantities in solution in the oil. Thus, the first thing to be done was to eliminate those oil constituents which caused copper to go into solution and to form deposits on the valves. This was done in laboratory experiments by letting the oil dissolve all the copper it wanted and then separating the oil from the copper soaps by vacuum distillation. In such a way an oil was obtained which would not dissolve copper under the experimental conditions for 24 to 48 hr. But after this time the oil again became corrosive. Apparently, some changes occurred in the oil which resulted in the formation of acids replacing those which were removed by the copper treating and redistilling process. The next question was: "How could we prevent the formation of these newly formed acids?" We turned to inhibitors.

In those days inhibitors were relatively new and there was only one inhibited oil actually on the market. This oil, an oxidation-inhibited turbine oil, contained phenyl-α-naphthylamine. No copper could be detected in solution in the oil

[8] Chief Engineering Inspector, Power System, City of Los Angeles, Department of Water and Power, Los Angeles, Calif.

[9] Consultant, Niagara Falls, N. Y.

treated with this inhibitor, but nevertheless sludge, containing copper, was again found. This meant that all inhibitors are not "safe" and that some of them, while being able to prevent the oxidation of the oil, will form sludge as a result of their own oxidation.

But with dibutyl-*p*-cresol (DBPC) inhibitor we were able to prevent the oxidation of the oil for a considerable period (1000 hr or more) without any copper going into solution and without formation of sludge. (Such an oil containing DBPC is still being used by Frigidaire to their entire satisfaction.) This same principle was then applied to turbine oil and transformer oil. In transformer oils using this same DBPC we were able to obtain the same results: the stopping of oxidation reactions, the preventing of copper and other metals' solution, and the preventing of sludge formation.

This problem of sludge formation is very important, because the early investigations on oxidation inhibitors to which Mr. Doble referred (carried out at M.I.T., beginning in 1923) did not consider the oxidation products of the inhibitor itself. The main point then was to keep the neutralization number down and prevent the oxidation of the oil. These investigators did not consider what would happen if the inhibitor itself was actually oxidized. The treatment with copper, which was the first step in removing acidity and other impurities, was not the final method of doing these things and better methods were found. The essential function of the refiner today is to make an oil, removing the impurities which affect the susceptibility of the oil to inhibitors, and to prevent the formation of additional impurities with an inhibitor which does not form sludge of its own.

The most recent theory concerning the action of DBPC is that it forms an aldehyde on oxidation which is an effective antioxidant in its own right and which, instead of causing the oil to sludge or break suddenly, gives you added protection and an easy "let-down." This is somewhat like the effect of a double parachute—when the first inhibitor wears out, the second one is still available. Thus, while the oxidation product of an amine is sludge, the oxidation product of DBPC is another inhibitor.

This has been a practical discussion on how we came to use inhibitors. Considering the theory of oil oxidation through hydroperoxides and the theory on how inhibitors work, Dr. Zuidema has written a very interesting paper on the "Oxidation of Lubricating Oils," published in the April, 1946, *Chemical Review*. Also in his recent book, "Performance of Lubricating Oils," he elaborates his theory of hydroperoxides and also discusses the action of inhibitors along with other related theoretical and practical aspects.

MR. H. H. ZUIDEMA.[10]—The original question was "What is an inhibitor?" We might definite an inhibitor as something that slows down the rate of oxidation. The generally accepted theory is that oxidation proceeds by a chain mechanism whereby an active molecule is formed (which could be a peroxide) which in turn reacts further to release active oxygen to another molecule; one "hot-spot" can be passed on from one molecule to another and this results in the destruction of many molecules. However, the inhibitor is able to react in some way at the first step and thereby break the chain so that one molecule of inhibitor can act to protect several hundred or several thousand molecules of oil—hence, the large effect of a small concentration of inhibitor.

MR. W. G. WALKER.[11]—The relative

[10] Research Chemist, Shell Oil Co., Inc., Wood River, Ill.

[11] The Philadelphia Electric Co., Philadelphia, Pa.

merits of re-refining used transformer oil to 30 dynes and to 45 dynes IFT has been discussed previously. Mr. Doble has mentioned that the cost of re-refining to 45 dynes is three times the cost of re-refining to 30 dynes. He has stated that if there is oil sludge in the transformer at the time reconditioning is started, there is no economical means of washing all of that sludge out of the transformer. Therefore, if one re-refines the oil to 45 dynes and inhibits the 45-dyne oil, some of the sludge left in the transformer will be dissolved and this will accelerate the shortening of the life of the oil put back. As brought out in previous meetings, if one has allowed the transformer oil to go to the sludging point, it might be more economical to re-refine only to 30 dynes and inhibit. Put this 30-dyne oil back in the transformer and allow it to dissolve the sludge left in the transformer. Then, after a short period, as determined by tests, the oil is re-refined again, assuming that all the sludge left in the transformer has been dissolved. This oil can now be re-refined to the 45 dynes and give a long service life, comparable with new oil.

MR. VON FUCHS.—The point Mr. Walker mentioned is very important. In a series of transformer tests started by Mr. Schofield in August, 1946, in the very same manner as he described to us tonight, oil was put in "dirty" transformers. This discusser was quite concerned over this and mentioned it in his paper, "Inhibited Transformer Oil" (at the third ASTM symposium on insulating oils held in Washington some three years ago). This discusser's feeling at the time was (and still is) that much of the good obtainable by inhibiting an oil is lost when the inhibited oil is added to dirty oil and sludge left in the transformers, conditions under which many of the transformers operate. Mr. Walker emphasized the ability of a reclaimed and inhibited oil not only to gain additional life for the oil fill but also to regain additional life for the transformer. If economics are considered, we must realize that the value of the oil is just a fraction of the value of the transformer. If the transformer is sludged up, it is an economic liability. The method of reclaiming or re-refining and inhibiting discussed by Mr. Walker is a feasible and simple way to reclaim the transformer as well. The great advantage of inhibiting oils is not so much to save the oil fill—it is to save the transformer.

MR. W. C. MILZ.[12]—Mr. Doble mentions that "Water will cause at least partial and possible complete blocking of the clay, thus making it necessary to discard that batch of clay." Perhaps this discussor is mistaken in the impression received that Mr. Doble was referring to the tendency of fuller's earth and similar clays to form a mud-like consistency in contact with water, thus blocking the flow of oil. This characteristic is not true of activated alumina which does not change its size or form in any manner when in contact with water. This is one of the primary differences between activated alumina and other so-called clays. I have seen other papers where the characteristics of clays have been treated collectively in this manner, thus giving the false impression that activated alumina also breaks down in contact with water.

MR. F. C. DOBLE (*author*).—It is very gratifying to have had so many helpful discussions in general expressing approval of the author's outline on "The Reclamation of Insulating Oils."

Several of the discussions refer to economics. This seems to indicate a misunderstanding of the limitations in the scope of this paper, as defined by the sponsoring Subcommittee IV, which stated that "the chief theme . . . would

[12] Aluminum Company of America, New Kensington, Pa.

deal primarily with the practical functional aspects rather than economy features." The final oral instructions by the chairman were even more definite.

For this reason no consideration was given in the paper to economics *per se* or the inhibition of new oil, even though the economic factor is basic to the new concept as compared to the past practices mentioned by Mr. Clark. Indeed, economics would probably be the controlling factor in answering the question posed by Mr. Schofield's data and the query of Mr. Thomas as to how far we are justified in extending the life of an oil beyond that of the equipment in which it is used. In cases of national emergency when conservation of petroleum products is essential, this factor may be dominant, for the reclamation of 1 gal of insulating oil represents a saving equivalent to 5 gal of aviation gas.

Economics again would provide the answer to Mr. Fawcett's contention that oil should be reclaimed to 45 rather than 30 dynes before inhibition. Mr. Walker's comments on the use of 30-dyne oil for cleaning up a sludged transformer are certanly pertinent to this question.

Although Mr. Clark questions my evaluation of the bomb and sludge accumulation tests as applied to modern operating practice, he apparently agrees that they have not been "completely satisfactory" when used to evaluate the oxidation condition of an oil in service use. As this is the primary problem under consideration, I intended to limit my evaluation to this application. With respect to his other question as to our work with blends of new and re-refined used oils, we have done very little in this field. From Mr. Raab's comments it would appear that such a procedure is not entirely satisfactory. Some of our work in an allied field leads us to believe that new oils may contain certain constituents, damaging to insulation, which are not found in reclaimed oils, possibly because of what might be described as a refining process of aging. We hope to cover these studies in a later paper.

Mr. Raab states that the possible extremes for the end point of oil life might be (1) the first appearance of sludge and (2) an amount of accumulated sludge and acid which has not yet affected the operating characteristics. Mr. McConnell's experience apparently leads him to join this latter school of thought. In reply to his question concerning the "poisoning" effects on DBPC of soluble oxidation products left in the oil after re-refining to 30 to 35 dynes, is it possible that this effect is due, not to products left in the oil, but to products left in the transformer? We agree with him that the rate of sludge formation is an important characteristic *once sludging has started.* Under the new concept, however, this point should never be reached during normal operations.

Mr. Raab questions our definition of an oil as "damaged" when it has a low IFT value arising from conditions not affecting the oil life or effectiveness. Such conditions are certainly possible but it seems questionable to classify them as "innocuous" when they may mask other more serious conditions and so make it difficult to analyze operating test data.

I would like to amplify my statement that under certain conditions as little as 10 to 20 ppm of water in oil will greatly reduce its dielectric breakdown strength. I refer to amounts of water in excess of so-called saturation. It is well known that finite amounts of water can be associated with an insulating oil without a noticeable change in electrical characteristics such as breakdown or loss and power factor. Commonly such water is said to be in solution in the oil and the parts-per-million saturation point may vary from a few parts up to several hundred parts per million depending principally on the type of oil and temperature. Above the saturation point 10 or 15 ppm as stated may greatly affect the electrical conditions just referred to.

We do not have specific data showing the diminishing returns in life expectancy from successive re-refining runs on used oils under service conditions which Mr. McConnell questions. We can, however, refer him to several of our clients whose experiences of this nature before the advent of DBPC had led them to discontinue the reclamation of oil and place their reclaiming outfits on the shelf. The new concept has changed this situation completely.

The comments by Mr. von Fuchs and Mr. Zuidema on the development and action of inhibitors and Mr. Milz' statements on activated alumina are informative and require no comment on my part.

In closing may I express the hope that this paper will prove useful to ASTM in studying test requirements for standards in a modern economical program for reclamation and inhibition of used insulating oil.