GENERAL DISCUSSION

Mr. O. E. Fawcett.\textsuperscript{1}—I was very much interested in the discussion of limits for neutralization number and interfacial tension number. A neutralization number of 0.2 seems to be rather low as an upper limit. I have been thinking in terms of maybe 0.4, and before we would change oil in a transformer the neutralization number would be 0.5 or above. On the interfacial tension, several of us have considered a value in the neighborhood of 18 dynes before we would consider that we should change the oil. I am wondering whether the spread of results was wide—and I presume these results, in the case of the ASTM oils, are averages of a number of determinations by the members—especially in the interfacial tension tests. In the work of Section T, we had quite a variation among the various members who reported interfacial tension tests. If the results were fairly consistent, then we would have to consider that perhaps the results are correct, and maybe we are not putting as much importance on low readings of neutralization values, for example, as we should.

The other thing I think the tests brought out very definitely is that you are getting a balance between the soluble and the insoluble sludge. As soon as you drop out this insoluble sludge you get a change in your sludge accumulation for the better, and then when it begins to build up again the condition is reflected in the test results. When the test was finally stopped and the percentage of sludge in the oil was revealed, was it considered that much of the sludge was possibly and quite probably missing on the filter press, because it was soluble sludge which would not be removed by the paper?

In regard to the discussion on transformer J, and especially with regard to the steam emulsion tests, I think that the increase in the steam emulsion value was probably an indication that the resins shown by the determinations were present in the oil. That was an example of why we use this test for a determination of the contaminants in a used oil. Even though this is an unorthodox transformer and it is a case that may not occur again, you may find some other contaminant that will show up the same way.

Mr. E. R. Thomas.\textsuperscript{2}—I am glad it has been emphasized that these tests that we have undertaken to correlate with the actual transformer operation are really for three different types: first, for predicting how long a new oil might be expected to last, or its relative rating with respect to another oil; second, tests that could be made during the operational life of an oil to tell us where it stands relative to its expected life; and third, tests that would tell us how much longer you might expect satisfactory operation. It is logical that each type of test will give you a different answer relative to the other. Also, I am very glad that it has been brought out that you cannot

\textsuperscript{1} Consolidated Edison Co. of New York York, N. Y.

\textsuperscript{2} West Penn Power Co., Pittsburgh, Pa.
directly compare the actual results on oils obtained from transformers in the field one with another. Operating companies do not operate all transformers in the same way. It is just as if in the laboratory tests on oil, one would run a test where time was the only coordinate and no attention was paid to temperature. Yet if you look at most of our data which we have plotted, we use only one coordinate and that is time. I have no good suggestion as to how to include the temperature phenomenon to evaluate it. The various operating companies who have furnished the transformers and know the electrical operational use of them might provide information as to what the oil temperatures were and for what period of time, as another factor to be considered in comparing these oils under test. In general, most of the chemical phenomena are related to the first power of time. When it comes to temperature you have a rather complex chemical reaction: it is very seldom linear and it is very apt to be logarithmic. Therefore, when you plot a particular curve of test data against time, as a comparison between oils in transformer M and transformer J, for example, these do not represent, to my mind, the exact correlation between these oils because there is an operational factor missing which may greatly influence the results.

Mr. M. Zwelling.—I should like to call attention to the fact that although transformer C-9 had a higher peak load which would tend to cause a higher oil-operating temperature, there are no data to indicate that the oil temperature of transformer C-9 was, at any time during the test period, greater than that of either transformers C-7 or M. Because all three transformers were of the water-cooled type, it was a simple procedure for the operator to adjust the water flow to maintain oil temperatures below a figure of 45 C maximum, consistent with established practice in the Detroit Edison Co.

I should like to suggest the probability that the C-9 transformer did have much higher influences for oil deterioration. I propose that oil will travel through a coil, as well as through the structure of the tank itself, and that in doing so it is subjected to higher oil temperatures, say to that of average copper and of hot-spot temperatures. That is indicated by the fact that the operators had to increase water flow in order to maintain the low oil temperatures. Therefore I believe one should reconsider the data of the C-9 transformer.

Mr. E. S. Ross.—If another symposium of this sort is held, there should be a paper dealing with the source, derivation, and refining of petroleum oils specifically aimed at the production of such oils as are under discussion at this symposium. I say that because I am astounded at the similarity of data presented in these papers. The observed results follow closely the pattern that could have been predicted, based on a knowledge of the constitution of the mineral oil bases that were used, the method and degree to which they were treated, and the method by which they were evaluated in the laboratory. A very interesting paper could be prepared to give a very logical and a very plausible explanation of some of the things that have been observed here.

Mr. H. H. ZuideMa.—Some data have been presented on the quantity of sludge removed from the used transformer oil by filtration. Were the data on a dry basis or did the sludge contain entrained water and oil?

Mr. R. G. Call (author).—Regarding

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5 Shell Oil Co., Wood River, Ill.
Mr. Fawcett's comments, it was not meant to imply that the steam emulsion number obtained on oil from transformer J was due to resins only. Semicolloidal material such as carbon, hydrous iron oxides, metallic soaps, and atmospheric dusts would also affect this value.

Mr. E. A. Snyder. 6—After living with this problem for about 8 yr and studying data, I would be interested to know Mr. Clark's and Mr. McConnell's opinions, as to which, if any, of the tests are best for predetermining the behavior of an oil in a transformer in service. What have we gained in this study over the past 8 yr?

Mr. F. M. Clark (author).—Our tests are evaluating transformers. The evaluation, however, is not too significant, because we do not have sufficient statistical data to overcome the uncontrolled operational factors which make such practical evaluations very difficult. Mr. Thomas has referred to this in his discussion. If, however, we concern ourselves only with the basic problem for the solution of which these studies were established, then the uncontrollable operational factors are not of major importance as long as the transformers were operated under conditions which are encountered in commercial practice. We are concerned with the correlation of the oil characteristics and sludge formation. On this basis, each transformer is a testing laboratory in itself. Despite the fact that one transformer may be operated differently from another, our goal is to establish the method by which the oil oxidation changes and the hazards presented by the use of an oil can be evaluated for all conditions of normal transformer operation. Despite differences in the oil base, oil refining, and the method of oxidation involved in the varying conditions of practical use, we assume, in the broadest sense, that there is a constant relationship which exists between the sludging propensity of an oil and the other oil properties which undergo a change as a result of the normal operation of the transformer. To the extent that we find this broad correlation is untenable, just by so much do we restrict the application of the laboratory control and maintenance test which we ultimately hope to recommend. If all the transformers of the present study were operated under exactly the same conditions, we would have a better basis for evaluating the effect of transformer design but would be severely limited in the practical evaluation of any laboratory oil testing method which we might recommend for the selection and proper maintenance of the oil during commercial transformer use.

The selection of oils of different quality for inclusion in this study was made in order to give a broader base for the establishment of a hoped-for oil testing procedure. It is obvious that a suitable test for the selection and maintenance of transformer oil must give consideration to the vagaries of the test when applied to "poor" as well as "good" oil. Therefore, three different grades of oil quality were selected for study. The selection of the oil was based on the background of experience on which the present successful manufacture and use of oil-filled transformers have been established. Since all that was desired was the study of oils having different oxidation (sludging) stabilities, the exact nomenclature used in the labeling of the oils appears to be of little basic importance.

Mr. Ross' comments are extremely interesting. I suggest that others would

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6 Socony-Vacuum Oil Co., New York, N.Y.
find them equally interesting and valuable if Mr. Ross could be persuaded to present his data in the form of a technical paper at a future symposium of this type.

Mr. Snyder asks what tests are best for the selection of an oil for transformer use. It is presumptuous for me to answer this question in view of the background of knowledge and experience which Mr. Snyder possesses. However, it is my belief that our study to date does indicate that the two ASTM sludging tests will classify new and unused oils quite satisfactorily from the standpoint of the sludging characteristic. It is my further belief that our studies have shown that to evaluate properly an oil in commercial use, one must have knowledge concerning the oil characteristics at the time of sampling, the trend of change in these properties during the previous use of the oil, and the expected sludging characteristic as obtained by the use of an oxidation (sludge) test. It is my belief that if the operator does not have all of these data, then the rate change in such properties as oil color or oil acidity gives information of no less value than that based on tests such as the interfacial tension which has been so strongly advocated during recent years. I have tried to bring out in my paper that a sludge test on an oil is not a test to tell whether or not there is sludge “presently” in the transformer. Such a test is for the sole purpose of forecasting the future stability of the oil during service use. For proper and safe forecasting, a cumulative history of the characteristics of the oil during previous transformer use is necessary because of the wide differences in transformer operation and design which are met in commercial practice. This, I believe, is what is supported by a careful study of the data now available. Future studies will be very important, for it is only now approaching a period of operation where the oxidation of the oil will become a maintenance problem.

Mr. T. A. McConnell (author).—In answer to Mr. Fawcett’s first question regarding limiting values for neutralization number and interfacial tension, there was no intent to imply that when values of 0.20 mg KOH and 22 dynes, respectively, were reached that sludging might be severe. Rather it was meant to show the possibility that sludging of oil could take place at those limiting values but probably only in small quantities. It has been the author’s experience that a prediction of oil sludging would not be established with 100 per cent certainty until a value of 0.6 mg KOH for neutralization number was attained. Certainly on the basis of neutralization number alone, I would agree that a transformer oil would not normally be considered unfit for service until a value in the vicinity of 0.6 mg KOH was reached. Experience has shown that such an oil would exhibit an interfacial tension value of 18 dynes or below.

The values for both neutralization number and interfacial tension given were averages from as many as five different laboratories, and the spread between individual values was not great, probably a maximum of 0.1 mg KOH for neutralization number and 2 dynes for interfacial tension. In isolated cases where a wide difference existed, certain test values were disregarded.

In regard to the question of missing the soluble sludge from the oil removed from the transformers, the fact was recognized that only the oil-insoluble sludge was removed by the blotter press when the transformers were removed from service. It should be remembered that of the three transformers removed from service, only the oil in C-9 was considered of questionable quality for continued service.
Some doubts have been expressed concerning the logic of drawing conclusions relative to the merits of oils C-7 and C-9. The author agrees that, because of the disparity of loading, all conclusions necessarily must be and were qualified. In attempting to analyze all phases of the tests, there certainly were these and other variations that prevented making definite conclusions of any nature. Perhaps a re-evaluation of these data at the conclusions of the entire testing program will allow a better interpretation of the test results.

Reference is made to Mr. Zwelling's suggestion concerning the possibility of the oil in C-9 having been subjected to much higher localized temperatures than was the case with C-7 or M. That, of course, was a good possibility as evidenced by the necessity of increasing water flow in order to maintain a temperature in the body of the oil of 45° C maximum. Again, as in the case of disparity of loading, conclusions drawn concerning the relative service quality of the several oils must be qualified.

In regard to Mr. Zuidema's question relative to the basis on which sludge content was given, all values were for sludge as is and not on a dry or oil-free basis. An analysis of a representative sample of the sludge made by Mr. R. G. Call, not included in the paper, showed the sludge to have the following composition:

**Oil-Free Basis**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition loss (per cent by weight)</td>
<td>74.3</td>
</tr>
<tr>
<td>Ash (per cent by weight)</td>
<td>25.7</td>
</tr>
</tbody>
</table>

**Chloroform Extraction**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroform soluble (per cent by weight)</td>
<td>62.3</td>
</tr>
<tr>
<td>Chloroform insoluble (per cent by weight)</td>
<td>37.7</td>
</tr>
</tbody>
</table>

The amount of water contained in the sludge was not determined, but it probably was small. The water content of the oil taken from transformer C-7 was, by Mr. Call's analysis, 0.01 per cent by weight.

I agree with Mr. Clark on the reproducibility of the several tests, especially regarding the neutralization number and the interfacial tension. I stated previously that there were a few data that varied quite widely, but there were very few of these cases and they were not considered in the averages. In general, the values for interfacial tension did not vary by more than two dynes, and as far as the neutralization number was concerned, the maximum variations were not greater than 0.1 mg KOH. Another thing that I believe has been proved is that the sludge accumulation test tells pretty well initially, on a new oil, what its quality is as compared with an oil of an inferior grade, but as far as this test on a used oil is concerned, I do not think it has any value at all unless one has a previous history of the oil on test. I believe further that as a purchase acceptance test, sludge accumulation would have merit. Regarding the pressure oxidation test, I believe it to possess value as a routine service test, but I do not think it would be as significant as the interfacial tension test and the acid number or a combination of those two tests. I agree with Mr. Clark that there is no one test that can be relied upon as an indicator of oil service quality.

It was not intended, in the paper, to ignore color, but insufficient data were available to give it as much consideration as was given the two sludge tests, interfacial tension, and neutralization number.

Mr. L. B. Schofield,†—Mr. Snyder requested that the authors express themselves as to what we were getting out of these tests after 8 yr and the question as to where do we go from here. Now, if he was in the least implying that we should question the significance and value of

† Commonwealth Edison Co., Chicago, Ill.
further work on the Section B cooperative tests at this time, I am one who is in favor of continuing these tests for an indefinite period in the future. I have a particular interest in the oil performance in transformers D, E, and F which are large power transformers of the nitrogen-blanketed type, and I would favor study of the performance of these even if the present oil continued in service to the point of obsolescence of the transformers.

Mr. Snyder.—I had no intention of indicating that I did not think these tests were worth while or that we should not continue them. I thought it was a good time in this discussion to take stock as to how far we have progressed and to point out that this problem of writing quality specifications or quality tests has many variables to consider. It becomes so complicated that it is not quite so easy a proposition as many may have thought—say five years ago. We are learning more and more about it, so I think we should definitely continue the tests.

Mr. Clark.—There is one more thing that I should like to say, and that is that I am rather alarmed at the tendency in the transformer oil investigations to trend away from exactly controlled laboratory tests, because of all the recognized difficulties, to the substitution of a transformer test. That seems to be going on everywhere. It is going on in this country and also in Europe, and everybody is tending more and more to place final reliance on the behavior of an oil in what I considered an uncontrolled transformer test. I think that such tests as those we are considering here contribute greatly to our understanding of oil, but I do think that we can overemphasize the exact technical knowledge that we get from that type of test. It must be kept in its place.