IEEE Symposium on Electrical Insulation, Montreal, Quebec, Canada, June 1976

A FLAMMABILITY TEST FOR DIELECTRIC FLUIDS

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Summary

A modification of the Cleveland Open Cup Test, ASTM D92, was developed for dielectric fluids in non-fire hazard power capacitors and transformers. This was on the basis of considering fire situations in these apparatus. Two criteria for non-flammability were deduced and applied in this test: that burning may only be initiated at the boiling point, and that burning cease on cooling when separated from the heat source. A number of fluids were tested. Effects of soot are noted.

Introduction

In undertaking to develop alternate dielectric fluids for tri- and penta- chlorobiphenyls, for non-flammable or non-fire hazard power capacitors and distribution transformers, it was realized that there is a need to determine the essential fluid (non-) flammability properties for these applications. Possible problems of ecological pollution by chlorinated biphenyls, that may halt their continued use, have necessitated searches for alternates. It is the fluid component in impregnated power equipment that causes particular consideration for fire-hazard. Attention was directed to understand why power equipment has been satisfactorily non-flammable with these chlorinated biphenyls - as shown by experience of 40 years - so that the same could be achieved with new fluids.

This was deemed necessary because it was realized that the Cleveland Open Cup Test, ASTM D92, which is extensively used to determine flammability of dielectric fluids, and according to which tri- and penta- chlorinated biphenyls are classified as non-flammable, may not always be sufficiently reliable. "Non-flammable" has really only relative significance, rather implying difficultly flammable, as probably almost anything will burn if sufficient heat and oxygen are made available to it. L. J. Frisco and K. N. Mathes[1] caused polytetrafluoroethylene (Teflon) to burn, in a simple test where the oxygen concentration and temperature were high. Tests for (non-) flammability of a liquid generally give an intensity factor that will cause the liquid to ignite or burn continuously, such as temperature in the Cleveland Open Cup Test and oxygen concentration in the Critical Oxygen Index Test.[2] But the flammability or fire hazard problem due to a fluid in a power capacitor or transformer is caused by an arc, which can cause chlorinated biphenyls to burn in its vicinity. The fact that non-flammability is achieved with them, in these applications, is therefore not unequivically associated with their high flame points in the Cleveland Open Cup Test.

Background - Flammability Considerations for Dielectric Fluids

This is a simple analysis of a bad condition of a fire in a fluid filled power capacitor or transformer, as a basis of the required fluid flammability properties to avoid spreading of the fire. The events leading to a fire in the unit are insulation breakdown (due to deterioration or overvoltage), then high current arcing, which is followed by rupture of the container. Only when the latter occurs can there be extensive burning of the fluid, with oxygen available from the ambient, since there is no gas space in a power capacitor and the amount of gas above the fluid in a transformer is very limited. Then, the fire could spread. Since the fluid is ignited by an arc, which due to its very high temperature could ignite almost any fluid, the magnitude of its ignition temperature has little effect at this point. The situation is helpless within the unit while arcing persists. Capacitors impregnated with trichlorobiphenyl have been consumed almost completely when the fault current sustaining the arc was not interrupted for a long time, which could occur only rarely when the circuit breaker or fuse failed to operate. However, burning within a unit should be extinguished very soon after the current is interrupted. But moreover, it is reasonable to insist that the burning fluid be extinguished immediately when such fluid escapes from the unit, and hence from the source of heat. This would prevent spreading of the fire.

It should be noted that, under these circumstances, the temperature in the mass of a burning fluid cannot exceed its atmospheric pressure boiling point. This is because the fluid is unconfined, due to the rupture of its container.

These considerations lead to two essential flammability characteristics of a suitable fluid for non-flammable or non-fire hazard power equipment. It should not burn freely in air below its boiling point. And, if it does burn at that temperature, the flame is extinguished as soon as it starts to cool when removed from the source of heat. The two are interrelated, since, if the ignition temperature of a fluid is below the boiling point, it is possible that it could continuously burn at least in that temperature interval, either during cooling from the boiling temperature, or with the flame increasing its temperature if ignited below the boiling temperature.

An additional problem is presented when fluid is heated to the atmospheric pressure boiling point and higher temperatures. Some of it will be vaporized into the ambient, which could constitute an explosive mixture with the oxygen. This hazard can be amplified or even dominated by the presence of flammable volatile gases, such as hydrogen, generated by arcing in the fluid. Such a situation is analogous to releasing compressed flammable gas, from a tank, into an area where there are flames or sparks. This matter of a potential explosion arising from a fluid exposed to a failure arc should be dealt with separately, and not from the point of view of flammability, although there is some relationship.

Experimental and Results

A flammability test was accordingly devised to determine the ignition temperature for continuous burning of a fluid, whether it was boiling then, and whether it would cease to burn after it was separated from the source of the heat.

The equipment consisted of a Cleveland Open Cup Test cell, or cup, a high temperature hot plate (Corning PC-35), an aluminum block 6 in square by 2 in,

n thermocouple and bridge, and a Bunsen burner. The thermocouple lead wires were fastened to the cup handle, and its sensing bead was located inside the cup, about 1/32 in from the bottom. A small piece of Teflon was attached to the bead to weigh it down and to keep it from touching the heated metal. The hot plate and the aluminum block were next to each other with their surfaces at about the same level, so that the cup could be easily moved from the hot plate onto the aluminum block. They were located in a draft-free enclosure. For any test, the hot plate was always at its highest temperature, and the aluminum block was initially at room temperature.

In a typical test, a sample of fluid in the cup was ignited with the burner to continuous burning while heated on the hot plate, and then moved onto the surface of the aluminum block and cooled until the flame extinguished, temperature being recorded throughout, and also time during the cooling. At the time of ignition the fluid was checked visually if it was boiling. The cup was cleaned carefully before each test, removing any soot, and was filled with fluid to the designated level. A specimen was assumed to be burning continuously when the flame persisted for 10 seconds. When a fluid was tested for the first time, the burner flame was applied for about one second every 5-10 C rise. In a subsequent test the flame might be kept on the surface for several seconds at a lower bulk fluid temperature to affect forced ignition. Or, the sample was ignited at a higher temperature than in the first test. This was the most meaningful test, particularly when the specimen was ignited at or near boiling.

The following fluids were tested: pentachlorobiphenyl (Aroclor 1254), trichlorobiphenyl (MCS 1016), mineral oil, various solutions of trichlorobiphenyl and mineral oil, tricresyl and tributyl phosphate, diisononyl phthalate, and polydimethyl and polymethylphenyl silicone (Dow Corning 200, 20 cs, and DC 550). The trichlorobiphenyl fluid and mineral oil served as respective "markers" of non-fire hazardous and fire hazardous fluids in this test. Solutions of these two were checked to observe the effects of a controlled change in flammability. This is also of practical interest because both fluids are often used at the same manufacturing site, and may be mixed inadvertently. Tricresyl phosphate, the silicones, and the phthalate ester were of particular interest because they are occasionally considered as non-flammable.

Results of these tests are shown in Figs. 1, 2 and 3 where the temperature of the fluid is plotted as a function of time, from the ignition to a continuous, 10 second, flame to extinction of the flame while cooling. The criteria for a fluid to be non-fire hazardous in power equipment are satisfied by only pentachlorobiphenyl, and by trichlorobiphenyl and its solutions of up to 10 w % mineral oil, Fig. 1. In fact, pentachlorobiphenyl did not even burn for 10 seconds when ignited at its boiling point. A solution of 20 w % mineral oil in trichlorobiphenyl could be ignited well below its boiling point, and then continued to burn until its temperature decreased by about 40 C. Mineral oil itself continued to burn for some time during cooling until the flame extinguished, its temperature, in fact, increasing during the ignition period and during the initial cooling period, Fig. 2. This effect was observed in some of the other tests here. Tributyl phosphate, Fig. 2, showed this effect of continuing to burn during cooling even when the sample was "forced" to ignite. On the other hand, tricresyl phosphate burned continuously, for about 10 seconds, and then the flame extinguished immediately, when it was ignited at 335 C and 366 C, Fig. 3. When it was ignited at 420 C, still below boiling, its flame extinguished only after it cooled about 35 C. Both silicone oils required relatively high temperatures to be ignited to continuous burning, Figs. 2 and 3. But once this occurred, they continued to burn during cooling. In fact, polydimethyl silicone continued to burn from about 290 C to less than 80 C without its flame extinguishing. It should be noted that the ignition temperatures of the silicone oils and tricresyl phosphate are about as high or higher than that of trichlorobiphenyl, but they are more flammable by the criteria presented here.

It was observed that the chlorinated biphenyl fluids produced considerable soot and flashes of flame at considerable distances from the specimen in this test, as well as in the Cleveland Open Cup Test, when exposed to a flame at or near boiling. The soot and flashes of flame seem to be associated. Some fluid may be sorbed on the soot, and, perhaps by catalysis, may burn even at a relatively low temperature. The possibility of a fire spreading this way should be considered. But it is not as dangerous as when a fluid like mineral oil is ignited, where the bulk fluid burns continuously, while here only very small amounts are involved.

Discussion

The results of this test are quite reasonable. It is significant that positive flammability results, indicating fire hazard, were obtained with polymethyl phenyl silicone (DC 500), polydimethyl silicone and tricresyl phosphate whose Cleveland Open Cup Test fire points are either about the same as, or higher than trichlorobiphenyl. These fluids burn freely, after being ignited at atmospheric conditions, because of their relatively high hydrogen contents.

However, the magnitude of the Cleveland Open Cup test fire point, or the ignition temperature in its modification here, is significant when considered in conjunction with the non-flammability criteria that separate fluids into two distinct categories. Fire point magnitude may then be considered with respect to each category to further subdivide different fluids. This is especially important for working with fluids, especially ones that are a fire hazard in power equipment, like mineral oil, where a fire through a shop mishap or auto-combustion has a finite, hopefully very small, probability.

Acknowledgement

The authors wish to thank Dr. T. W. Dakin, Westinghouse Research Laboratories, for his suggestions to work with the Cleveland Open Cup Test procedure and to follow the temperature of the burning fluid, in this investigation.

References

1. L. J. Frisco and K. N. Mathes, NASA Report, Evaluation of Thin Wall Spacecraft Wiring, NAS 9-4549, September 28, 1965.

2. ERA Symposium - Flammability and Smoke Testing Techniques, The Institution of Electrical Engineers, February 6, 1974, ERA 74-22. Papers by E. L. Charsley and R. A. Schulz, and by A. G. Day where an adaption of the Critical Oxygen Index Test to liquids is presented.

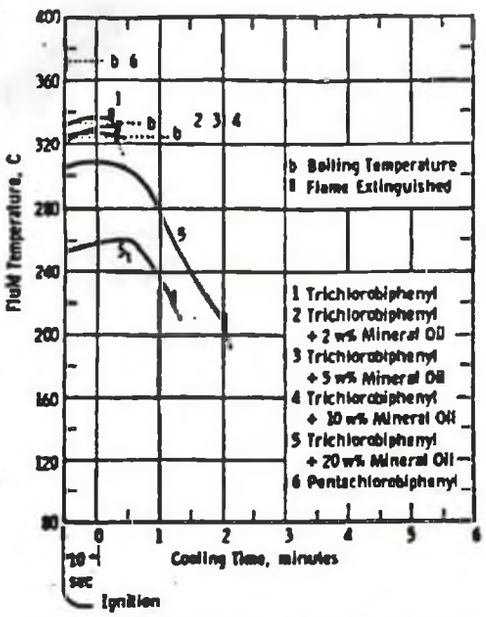

Fig. 1—Flammability temperature relationships for dielectric fluids in a modified Cleveland Open Cup test. Subscripts refer to different tests on the same fluid

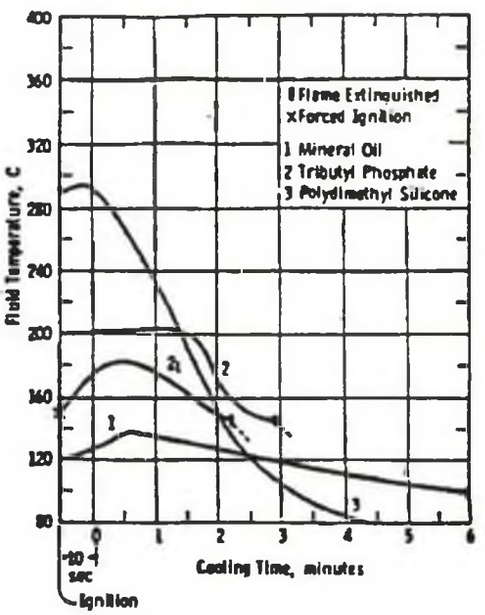

Fig. 2—Flammability temperature relationships for dielectric fluids in a modified Cleveland Open Cup test. Subscripts refer to different tests on the same fluid.

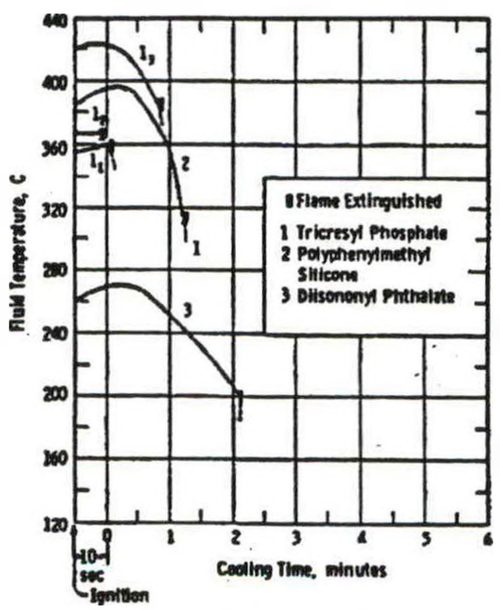

Fig. 3—Flammability temperature relationships for dielectric fluids in a modified Cleveland Open Cup test. Subscripts refer to different tests on the same fluid

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Director 12/31/75 Date

APPROVED:
J. Swiss, Division Manager
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Scientific Paper 75-1B8-CAPDI-P1

December 31, 1975

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