SPECIALIZED POLYMER CONCRETE MATERIAL FOR IN-SITU CLEANSING/IMPROVEMENT OF TRANSFORMER OIL

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SUMMARY

That transformer oil degrades with age and service in transformers is a well known fact. Such degradation is the result of complex oxidation processes and can lead to significant and costly maintenance and/repair problems in the transformer. Presently there is a worldwide need and tendency to develop methods to extend the useful life of service equipment, with an eye to prolonging efficiency while simultaneously reducing the cost. While all classes of transformers involving insulating oil can benefit from such an approach, power transformers, especially in view of their size and cost, stand to benefit the most, especially if the methods are amenable to in-situ procedures which do not render the transformers inoperable during oil change-out or related procedures. The feasibility of achieving this now seems eminently feasible with a class of specially engineered composite materials known generically as polymer concrete. These materials have been extensively researched, developed and commercialized, especially in the USA, for high voltage electrical insulation applications in lieu of standard electrical porcelain, cycloaliphatic epoxy, etc. Excellent field experience with polymer concrete materials now spans over two decades and newer applications are continually coming to market.

Polymer concrete is a highly-filled composite material that is processed essentially at room temperature. It is a thermoset material which tends to be of relatively low cost because of the high filler loading, which in turn, is made feasible by the utilization of low-viscosity organic binder systems. While many different binders have been utilized, the preferred resins are specialty polyesters by virtue of their handling and processing ease and excellent technical properties as manifested in composites. Siliceous fillers of various gradations, including microfine fractions, together with alumina trihydrate, have been widely used as the inorganic phase of polymer concrete composites. The design of these fillers is a critical factor in the formulation of a good polymer concrete for transformer oil purification/enhancement.

Preliminary studies both in the USA and abroad have indicated that polymer concrete has the potential to clarify transformer oil without itself degrading mechanically or electrically. Transformer oil aged for a long time in the presence of polymer concrete in temperature regimes similar to those experienced by transformers in real life has been found to exhibit dielectric and physical properties superior to those possessed by similar oil that has been merely aged. In some instances, practically no degradation occurred in the oil containing the polymer concrete and the polymer concrete itself improved its electrical and mechanical properties. The polymer concrete appears to act as a very efficient molecular sieve in its purification mechanism.

Clearly, with further studies and corroboration, polymer concrete holds the promise of revolutionizing transformer rehabilitation and possibly oil conservation through design changes involving the incorporation of polymer concrete sub-systems in the tank of the transformer itself.

This paper presents a brief over-view of polymer concrete in the context of the electric power industry, presents preliminary data pertaining to the purification aspects of polymer concrete in a transformer oil environment, and discusses various scenarios whereby polymer concrete composites can play a significant technical as well as economic role in enhancing the performance of insulating oil. The relative advantages of polymer concrete over conventional processing for the regeneration of insulating oil will be pointed out. The paper will also touch upon needed areas of further research to ensure quality assurance and the sustainability of a fully developed polymer concrete system for the transformer environment.
POLYMER CONCRETE

Polymer concrete is a highly filled composite material. It is not a hydraulic cement concrete but a thermoset material. It is processed essentially at room temperature. The processing can involve either simple batch processing methods or utilize microprocessor-controlled sophisticated continuous output machines. Where necessary, polymer concrete can be internally reinforced with chopped fibres of glass, aramide ("Kevlar"), carbon, etc, and can also incorporate continuous reinforcement based on these materials. Polymer concrete is increasingly being engineered for a wide range of applications in many different fields of engineering. The electric power industry in the USA is one area where polymer concrete has come into much prominence in both underground as well as overhead applications.

In the past twenty five years, polymer concrete has progressed considerably as a low-cost dielectric material that is a viable alternative to porcelain in a wide variety of high voltage insulation applications. It now finds use in post insulators, transformer/ capacitor and other apparatus bushings, CTs, PTs, dry-type transformers, surge arresters, etc. Successful experience with polymer concrete in outdoor field applications in the USA now extends to about 20 years. It has also been proven for third-rail insulator applications in the UK and has been put to use in electric rail transit applications in Brazil. The mechanical damping characteristics of polymer concrete have resulted in its utilization in machine tool bases (in lieu of cast iron/steel) in Europe and Japan and have provoked interest in being considered for specialized insulators/structures in earthquake-prone regions such as California. The failure of large porcelain insulating systems in recent earthquakes in California has been catastrophic.

Nearly 30 years ago, at the height of the oil crisis, the feasibility of utilizing specialized low-cost composites to displace some of the oil in transformer tanks, without any operational obstacles, was considered, and some limited studies were carried out. With the advent of polymer concrete and the examination of its applicability to transformer bushings, further interest has emerged in the mutual compatibility between transformer oil and this composite material. Studies have been conducted in various countries at temperatures typically found in distribution transformers. It has been found that excellent compatibility exists between the two materials and that, in fact, the polymer concrete has a beneficial purifying effect on the oil, without itself undergoing any deleterious changes.

Polymer concrete for dielectric applications not involving sulphur hexafluoride usually consists of a carefully graded mixture of coarse and fine aggregates and fillers based on silicon dioxide, bound together by means of a low-viscosity organic resin system. The organic resin system binder is only about 10%-15%, by weight. It exists more as a film on the inorganic particles rather than in bulk form, a feature that is believed to contribute to the unique properties of polymer concrete. The technical properties of dielectric-grade polymer concrete have been presented and discussed in numerous publications. Some examples are those authored by Gunasekaran (1-3), Gunasekaran and Duguid (4). Suffice it to say here that polymer concrete has been thoroughly tested in both the laboratory and in the field and has been proven to be a viable insulating material with versatility and utility in a broad range of electricity distribution applications.

By the very nature of its composition, involving the presence of micron-size particles bridging the various aggregate fractions in the matrix, a very large specific surface becomes available for adsorptive mechanisms to come into play. The diffusion of fluids through the polymeric films on the filler materials in polymer concrete, coupled with the adsorptive nature of the matrix, together offer a beneficial opportunity of interest to the transformer industry. Specifically, this opportunity pertains to the in-situ cleansing/ improving of transformer oil during the operational life of the transformer. The premise of this paper is that the purification ability of polymer concrete in an oil-filled transformer environment can render many economic benefits in both a specific and overall sense by reducing or eliminating oil-related maintenance chores.

TYPICAL RELEVANT PROPERTIES OF AGED TRANSFORMER OIL CONTAINING POLYMER CONCRETE

Even though polymer concrete can be made with a range of organic binder systems, by far the most commonly used system is based on low-viscosity polyester resin. Numerous studies have been conducted in the USA, Brazil, India, etc, on the mutual compatibility and purification aspects of polymer concrete. It is interesting to point out that though the polymer concrete specimens
used in the various studies were made with raw materials from different sources, the results obtained were essentially similar.

Typically, the dissipation factor of transformer oil increases by a factor of 4 or 5 at the operating temperature as opposed to that at room temperature. This value can be further increased by a factor of 3 to 25 on ageing at the elevated temperature. Much of these increases are due to the chemical imbalances in the cellululosic insulation which is continuously accelerating as ageing progresses further.

Interestingly, it was found that transformer oil which was in contact with polymer concrete exhibited significantly lower increases in the value for the dissipation factor. In some instances, it was found that there was practically no change in the dissipation factor even after ageing. These studies lend credence to the view that the polymer concrete is somehow attracting and retaining the impurities and degradation products in the oil.

What is further interesting is that mechanical studies on polymer concrete samples that had been aged in the transformer oil did not show any deterioration in the compressive strength of the samples. In fact, it was found that in some instances, there was a slight improvement in the compressive strength. This could have been due to the delayed enhanced polymerization within the polymer concrete due to the sustained elevated temperature. The compressive strength is a good indicator of the overall integrity of the polymer concrete. If its value is stable, the rest of the properties will also be found to be stable.

The values for the Neutralization Number for oil aged with polymer concrete samples was found to be lower than that obtained for the oil alone on ageing. The colour of the oil was also better in the presence of the polymer concrete.

Based on observations such as the above, those conducting these tests concluded that polymer concrete and various grades/types of transformer oil were fully mutually compatible.

ADVANTAGES OF POLYMER CONCRETE TECHNOLOGY OVER EXISTING OIL REGENERATION TECHNOLOGY

Conventional methods for recovering spent transformer oil rely largely on methods involving filtering, heating, centrifuging, degassifying, etc. They are inherently inefficient and tend to be expensive as a result of the types of equipment that necessarily must be brought into play. Additionally, the techniques involved themselves may degrade the oil. Further, considerable energy expenditures are required for the processing and the sludges emanating from the processes have to be disposed of in an environmentally acceptable manner.

Polymer concrete does not suffer from any of the disadvantages mentioned above. It can be readily made anywhere (e.g. off-site factory or on-site at electric power substations). It is a passive regenerator of the oil. It can be cast and used in any shape or form and can be conveniently attached to the interior of transformer tanks as a discrete singular unit or in a modular format. It has a large adsorptive capacity. It is also relatively inexpensive.

NEEDED RESEARCH

The polymer concrete materials tested so far for compatibility with transformer oil in different parts of the world were formulated for use as insulation in primary and secondary bushings. They were not specifically designed to be adsorptive cleansers. However, the technology of these materials is very amenable to tailoring for specific needs.

It is foreseeable that formulations can be developed to have a much higher adsorptive capacity and also to have a faster rate of adsorption. This can be accomplished in many ways, among which are the use of specialized natural or synthetic aggregates with molecular sieve properties and 'gap grading' techniques. One synthetic aggregate is derived from a material known as 'PIC' (which stands for 'polymer impregnated concrete') which has a matrix structure of polymer nodules essentially filling the capillary porosity of a dried hydrated cement body. The so-called cement 'gel' is known to have an enormous specific surface capable of adsorbing a large amount of impurities brought to it by diffusional mechanisms. This gel, again, is amenable to considerable tailoring to furnish desired properties. To optimize the potential of polymer concrete for transformer oil cleansing functions, it would be useful to know what would be the ideal surface area to weight or volume of the oil involved. Profiles similar to those of weathershedded insulators are obviously feasible and in use; similar shapes, if necessary, can be employed for the polymer concrete in this application.

A futuristic, synergistic approach would be to explore the feasibility of using polymer concrete for the transformer tank itself, which would then facilitate the dual function of structure and adsorbent. The electric utility industry in the USA presently uses precast polymer concrete panels with fibreglass webbing which are assembled in the field to make large underground vaults which can be direct-buried without any fear of corrosion. A similar approach appears quite feasible for large power transformer tanks. After mechanical assembly, the connections can be smoothly grouted with polymer concrete, presenting an appearance quite similar to metal tank systems. If necessary, as a fail-safe or security measure, with respect to tank integrity, a
metallic barrier liner can be integrally cast into the polymer concrete.

It would also be worthwhile to research the best set-up for mobile field units for oil regeneration based on the polymer concrete adsorbent concept. Essentially, parametric engineering studies would need to be carried out to establish an optimum combination of size of unit, rate of regeneration, level of pressurization and vacuum loading of the adsorbent units with the oil, etc.

CONCLUSION

Enough technical data exists in the electric power distribution industry confirming the viability of polymer concrete for high voltage insulation applications, including transformer bushings. Industrial test data is available regarding the mutual compatibility of transformer oil and polymer concrete, and the latter’s propensity to serve as an efficient cleansing adsorbent for the former. This propels one to believe that an energy-efficient, low-cost system can be readily built at the present state-of-the-art to address effectively the important problem of purifying transformer oil on-line and also in an adjunct external process.

REFERENCES


