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A NEW SYNTHETIC IMPREGNANT FOR HIGH TENSION HOLLOW CORE CABLES*

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The "paper/thin mineral oil" composite dielectric used as insulation in high voltage cables dates back to 1924 when the first hollow core cable (a 130 kv pioneer) was experimentally laid at Brugherio (Milan, Italy). Since then, thanks to continuous investigations and growing experience, each single characteristic of this impregnant has been brought more and more into focus, eventually reaching the at present strictly defined features[1].

The general properties which characterize the presently used thin mineral oils can be regarded as the best obtainable with petroleum derivatives; as a matter of fact mineral oils are made up of complex mixtures of many different hydrocarbons some of which behave satisfactorily whilst others, unfortunately very difficult to remove, show undesirable properties. An additional disadvantage which is connected with mineral oils and is related to their natural origin, is the difficulty in obtaining them with absolutely consistent characteristics.

To overcome this situation and reach the desirable target of better impregnants, the ideal solution could lie in synthetic products made up of those "tailored molecules" which have already been suggested for solid-insulating materials. Such a solution, however, would require someone in the chemical industry willing to investigate and perfect new products without a reasonable certainty of very large future consumptions; a very serious limitation to start with.

For this and other reasons our attention was thus oriented towards the great bulk of synthetics, trying to see if there were existing "tailored" materials able to fit the new situation.

In the course of a search which started some six years ago[2], an interesting material was selected: dodecylbenzene. Such a material, produced by the big chemic[illegible] companies as an intermediate to detergents of world-wide use, gave promise that th[illegible] desired impregnant was near to being identified.

This assumption was based on the following theoretical considerations: technical dodecylbenzene, even if not consisting only of one single chemical bu[illegible] rather a large mixture of monoalkylbenzenes, is nevertheless made up of homolo[illegible] molecules which should show almost the same behavior; thus the drawback of th[illegible] [illegible]sirable components present in natural products would be avoided. With regar[illegible] [illegible] desirable constant composition this end also should be attained, as dodecylb[illegible] is

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* Paper presented at the 1963 Conference on Electrical Insulation [illegible])

obtained through well-defined and easily controlled processes starting from pure materials (benzene and propylene). With regard to the behavior connected with its molecular structure, the expected results were thought to be the following: the benzene ring should ensure: 1) exceptional stability to both thermal and electrical stress; and 2) an extremely good gas absorption property[1]. In its turn, the saturated aliphatic chain was likely to provide, due to the sufficient number (twelve) of carbon atoms, physical properties (such as viscosity, etc.) very close to those of the best thin mineral oils.

Dodecylbenzenes of technical grade were then tested and after exhaustive experiments the chemists had the satisfaction of realizing that all was behaving to their expectations. The general properties of a dodecylbenzene of electrical grade are given in Table I compared with those of widely used mineral oils (normal and low viscosity grades) which can be considered among the best available at present.

Table I

Comparison of Some Properties of Dodecylbenzene (D.B.D.) and Thin Mineral Oils, Normal Viscosity (N.V.) and Low Viscosity (L.V.) Grade

TEST	PROCEDURE	UNIT	D.D.B.	N.V.	L.V.
Specific gravity at 15°C	ASTM D 1298-55	gr/ml	0.8769	0.8920	0.8856
Kinematic viscosity at 20°C	ASTM D 445-61	cSt	12.5	26.6	14
Pour point	ASTM D 97-57	°C	-63	-47	-63
Flash Point (Cleveland O.C.)	ASTM D 92-57	°C	135	155	135
Autogenous ignition temperature	ASTM D 286-58T	°C	440	260	250
Power Factor at 100°C	Pirelli R.T.127				
original		%	<0.3	≤ 0.3	≤ 0.3
after ageing*		%	<0.3	≤ 0.6	≤ 0.6
Resistivity at 100°C	Pirelli R.T.127				
original		MΩ cm	$\geq 25 \cdot 10^7$	$\geq 5 \cdot 10^7$	$\geq 5 \cdot 10^7$
after ageing*		" "	$\geq 15.10^7$	$\geq 1.5.10^7$	$\geq 1.5.10^7$
Gas absorption after 300 mins. at 80°C under a 16 kv stress	Pirelli L.R.356i	ml	2.3	1.4	0.5

*Ageing: 24 hours at 100°C in the presence of both air and metallic copper.

From the examination of these data, conclusions are that dodecylbenzene not only has characteristics at least equal to those of mineral oils but that it is definitely very superior in two important instances, showing: 1) the expected higher gas absorption under electric stress and 2) a higher autogenous ignition temperature which leads to higher resistance to both thermal and electrical cracking. Moreover its low viscosity, even lower than that of the so-called low viscosity oils, is an additional point in its favor.

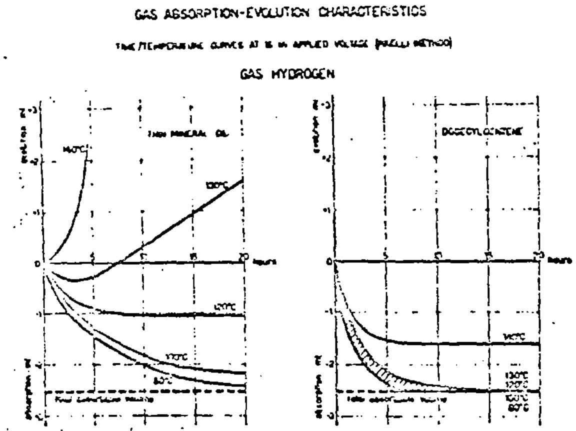

Fig. 1.

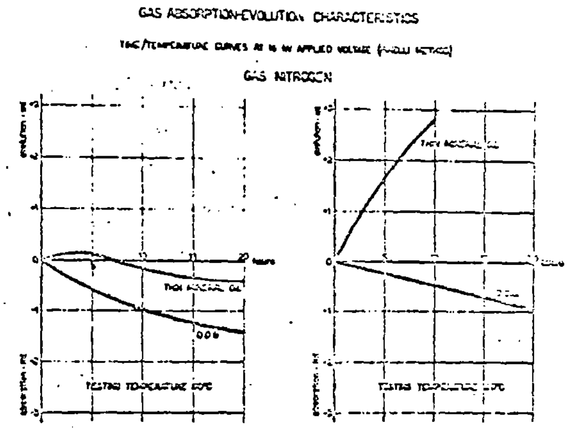

Fig. 2.

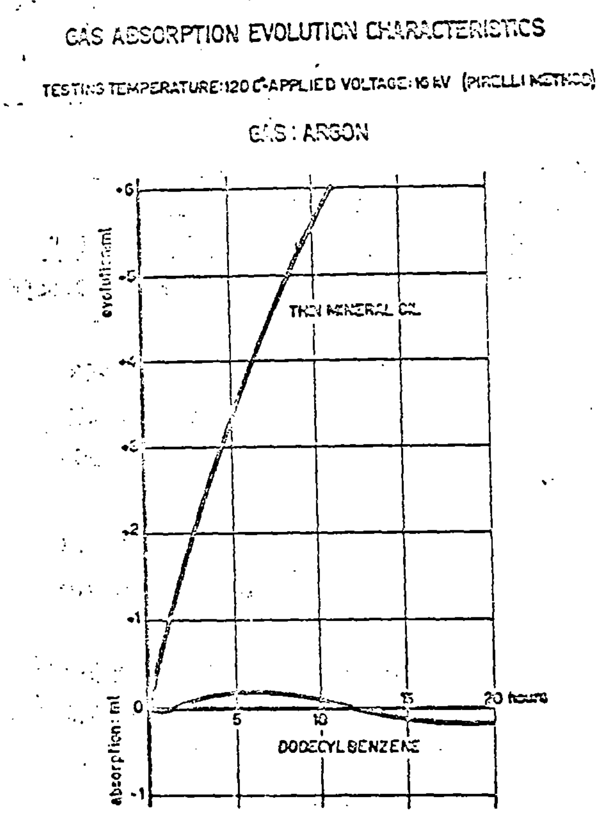

Fig. 3

As regards the higher gas absorption, some results are given in Figures 1 to 3 which are self-explanatory. In such tests comparison is made between the dodecylbenzene and the thin mineral oil (normal viscosity grade) the characteristics of which are reported in Table I. These tests were carried out following the Pirelli method[1] with the only exception that the testing period was extended to 20 hours.

A perculiar and unexpected property of dodecylbenzene is that not only does it absorb gas at temperatures and/or for testing periods at which mineral oils evolve, but that its capability to absorb takes place, after an evolving transient, even with water vapor (see Figure 4), a phenomenon never observed with mineral oils of current use.

It has to be mentioned that even if the reported values could be quantitatively incorrect, because of some difficulties encountered in performing this last test, they are nevertheless qualitatively exact, as confirmed by other tests described farther on.

In addition to the laboratory investigations, technological experiments which took some five years to complete, fully confirmed the previous findings and our expectations. As a direct consequence dodecylbenzene has, since the beginning of this

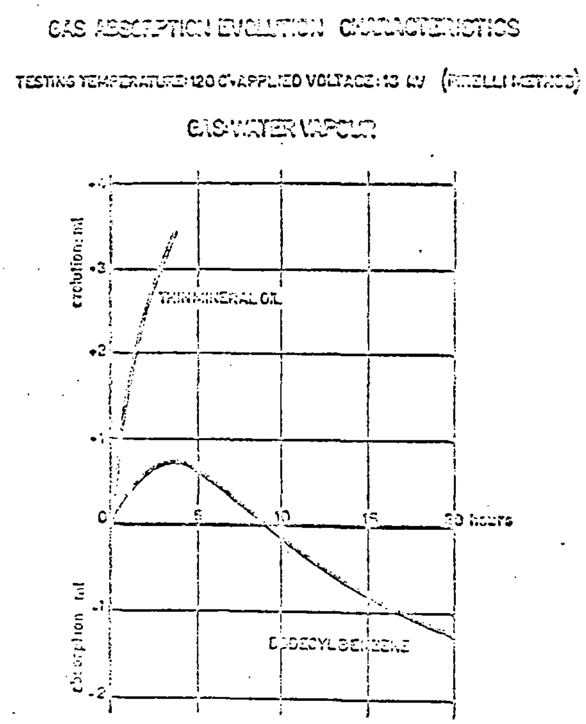

Fig. 4.

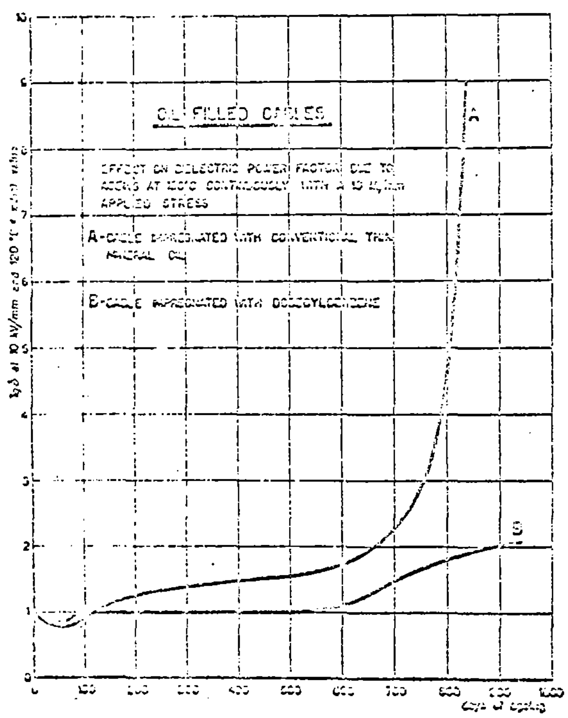

Fig. 5

year, completely replaced thin mineral oil in the O.F. cable manufacture at the plant of the firm with which the author is associated.

One of the more interesting experiments carried out on actual cables will be briefly described hereunder. Two lengths of a hollow core cable designed for a nominal voltage of 50 kv, one impregnated with conventional thin mineral oil and the other with dodecylbenzene, were subjected to a 40 kv voltage (applied between the conductor and the outer screen and corresponding to a maximum gradient of 10 kv/mm) whilst kept at 120°C by means of external heating.

The cable impregnated with mineral oil showed after about 500 days an increase of power factor which continuously rose (see Figure 5) until too high to be measured. On the 840th day the cable failed. In the meantime a great gas evolution was observed. Such gases collected and analyzed by means of gas chromatography technique were found to be: CH_4 (84.6%) H_2 (7.8%); CO (5.5%); C_2H_6 (1.4%); C_2H_4 (0.7%). When the cable was dismantled for inspection, the insulation was found strongly altered, resembling a unique compact material in which the paper tapes were unwindable and extremely brittle. The impregnant, extracted by solvent, was a very dark liquid with an extremely high viscosity (35,000 cSt at 40°C); the gaps were completely filled with "X" Waxes, an unmeltable and insoluble material originating from mineral oil when its alteration takes place under intense electrical stress. In addition a great amount of water, given off by the cellulose on account of its thermal degradation, was found in the oil feeder.

After a same period the cable impregnated with dodecylbenzene was perfectly efficient; the power factor was still quite good (see Figure 5), and no sympton of gas evolution was observed. It is worth stressing the meaning of this finding, i.e., dodecylbenzene not only did not evolve gas but did absorb those gases ($CO - CO_2 - H_2O$) which originate from the thermal deterioration of the paper.

The test was thus protracted up to 941 days before dismantling the cable for inspection. The insulation was practically unaltered and the paper tapes (which of course underwent a certain embrittlement) could be easily unwound; no traces of "X Waxes" were found in the gaps. As regards the impregnant, dodecylbenzene showed unaltered physical properties; a slight increase in the power factor was noticed and a small chemical alteration (ascertained by I. R. spectrography) was found. This latter alteration is certainly to be related to some modifications which took place on account of the absorption of the products evolved by the cellulose during its degradation. In addition, no water was noticed in the oil reservoir, a confirmation of its capability to absorb water-vapor as already ascertained by the gassing test previously mentioned.

With regard to the dodecylbenzene used in the tests and now introduced in actual production, it is composed, to an extent of 99.5% of a mixture of monoalkylbenzenes whose aliphatic chain (which is saturated and shows a prevailing branched structure) is in the range between C_{10} and C_{14} inclusive. The main portion, over 65%, consists of C_{12} whilst C_{11} and C_{13} are 12% and 18% respectively. The mean molecular weight corresponds to that of dodecylbenzene; for this reason this term is the one broadly used in defining such a product. As regards the whole structure, the aromatic ring can, of course, be linked to the main aliphatic chain at different positions: thus either the head or other linking positions are likely to occur.

Dodecylbenzene, obviously is not the only alkylbenzene which can be advantageously used as cable impregnant. Products whose bulk is characterized by aliphatic chains higher than C_{12}, are generally not interesting as they show too high an increase in viscosity without adding any other advantage.

On the contrary, for special applications (as for example, lengths of O.F. cables which for particular reasons could require very widely spaced oil feeders) those products whose bulk presents chains in the range from C_{11} to C_{10} can be very interesting as they possess an extremely low viscosity (about 5 cSt at 20°C for C_{10}). Products with a chain smaller than C_{10} are however, not advisable as their flash point decreases very rapidly (118°C open cup for C_{10}) and danger of fire can arise in jointing operations.

References

1. "Insulating oils for electric cables" by C. Palandri and U. Pelagatti - Presented at the 1954 Convention of the Associazione Elettrotecnica - Bellagio, Oct. 3-10,1954.
2. U. Pelagatti - "Prodotto per L'impregnazione dei cavi ad alta tensione e cavi così ottenuti" - Italian Patent No. 59475, Aug. 2, 1958.