MATERIALS WITH LOW ENVIRONMENTAL IMPACT TO BE USED IN ELECTRIC POWER ENGINEERING

Bogdan NICOARĂ[1*], Marian COSTEA[2]

***Abstract**: Electric power installations have no significant environmental impact concerning chemical pollution, in normal operation conditions. But the manufacturing procedures used to obtain electrotechnical materials require, normally, large energy consumption, expensive raw materials and emit noxious by-products, all of them with harmful consequences for the environment. The paper analyses the features of the most used electrotechnical materials in order to assess their environmental impact. Another threat for environment and living beings is the accidentally leakage of certain liquid or gaseous insulations during transport or in operation of equipment. To avoid the environmental impact of these insulations, some alternatives are proposed such as biodegradable oil, hexafluoride-nitrogen mixtures or vacuum. The main features of these new materials are presented, in order to justify the preference for them in a near future, when the acceptation criterion to use a certain material will be, certainly, the level of environmental impact. Referring to Romanian power transmission lines the quantities of the most used materials were estimated and also the benefits for recycling them.*

Keywords: electric power engineering, recycled materials**,** insulating biodegradable oil, sulphur hexafluoride-nitrogen mixtures.

1. Introduction

In any country where electrical energy generation is based on fossil fuels, power industry represents a very important pollutant factor for the environment, mainly because of the emissions from fuels burning. A Romanian investigation carried out in 2005 confirms that this industry constitutes the most important atmosphere pollutant. Therefore, at national level, burning of fossil fuels for electrical and thermal energy generation is responsible for about 88% of the total emissions of NO_x, for 90% of those of SO_2 and for about 72% of suspended powders ejected in the atmosphere. Consequently, the reduction of pollutant emissions in this industry constitutes the most important action to be done in order to reduce atmospheric pollution in Romania.

The electric power component is less visible regarding atmosphere, water and soil pollution. But this component also plays a role in environmental quality diminishing by means of energy consumption during technological processes used

[1] Prof., Faculty of Power Engineering, University "Politehnica" of Bucharest, Romania
[2] Assoc. prof., Faculty of Power Engineering, University "Politehnica" of Bucharest, Romania

to produce materials and equipment, by-products evacuate during these processes and, on a smaller scale, by noxes emitted during operation (for example, ozone and nitrites engendered by corona discharge). A particular environmental pollutant due to electric power equipment is the electromagnetic one (low and high frequency electric and magnetic fields).

The paper presents the problems raised by materials used in electric power domain, analyzes their recycling possibilities and also the tendencies to replace them by environmental friendly materials.

First of all, we must remark that in electric power field a great volume of materials is necessary (i.e. ferrous and non-ferrous materials, solid insulation made by ceramic, glass or silicon rubber etc.). Manufacturing of all of these materials requests a large energy consumption, expensive or in course of depletion raw materials. Many of the materials used in electric power industry have a significant impact to the environment, being non-recyclable (i.e. some solid dielectrics) or non-biodegradable (mineral or synthetic oil). Another threat for the environment represents certain gaseous dielectric like sulphur-hexafluoride (SF_6), used as insulating and quenching medium in gas insulated substation or circuit breakers.

2. Traditionally used materials in electric power engineering and their recycling possibilities

In electric power engineering field, a large amount of installations and consequently used materials (both conducting and insulating) are included in the transmission grid. This includes transmission lines and substations with their high voltage equipment: transformers, switching equipment, arresters, instrument transformers etc. The transmission lines under authority of Romanian Transmission and System Operator (Transelectrica) are mainly overhead lines with nominal voltages between 110 kV and 750 kV. These lines are made of lattice metallic towers with concrete foundations and equipped with phase and ground wires made of aluminium-steel. The phase-to-ground insulation is provided by classic (from toughened glass or porcelain) or composite insulators. Table 1 presents the features of some materials integrated in power transmission grid, referring to their environmental impact.

Gladdening, the materials used for structures and overhead line equipment are, in a large majority, recyclable. Based on data published in [2], it was possible to estimate at about 231,704 t the amount of steel and about 7,287 t the zinc included in the Transelectrica overhead line towers. As an example, referring to the indirect environmental impact of Romanian overhead transmission lines (without taking into account the consumption until finite products) to obtain this amount of steel was necessary about 95 GWh, and yet 29 GWh for zinc (using the electrolytic method). If only coal was used to produce this incorporated energy fraction in metallic towers of transmission grid, about 62,000 t would have been necessary and the corresponding emission in atmosphere of carbon dioxide would have been about 120,000 t.

For environmental protection is recommended the use of recyclable materials, as much as possible. Regarding the steel production, for a recycled tone is saved 1,030...1,130 kg of iron ore, 580...635 kg of coal and about 50 kg of limestone. For the same purpose the electric energy consumption is only about 20...25 % of that necessary to produce the same amount of steel using ore and other raw materials. Regarding protection of steel against corrosion, it could be mentioned that the main method is yet hot deep galvanizing. Unfortunately, it requires a large amount of energy and represents a pollutant technology, if no special precautions are adopted.

Table 1

Features of some materials used in electric power transmission grid

Material	Features referring environment impact
steel	recyclable, with metal loss < 4 %
concrete	recyclable, with relative large costs
aluminium	recyclable, with metal loss < 2 %
porcelain	non-recyclable; re-usable as filling material for road constructions
glass	recyclable
mineral oil	recyclable; non-biodegradable
sulphur hexafluoride	recyclable; non-biodegradable; potent greenhouse gas

Overhead line wires have aluminium-steel structure. Aluminium is also a recyclable material. Recycling one tone of aluminium saves about 6 t of bauxite, about 4 t of another chemical raw materials and 14 MWh of electric energy. In aluminium recycling process, energy consumption is only 5 % and the same is the percentage of carbon dioxide emitted in the atmosphere during procedure compared to similar data for obtaining the metal starting at ore (bauxite). Aluminium represents the material which is less expensive to recycle comparing with others. Aluminium, steel and zinc are infinite recyclable materials without diminishing their qualities if technological processes are correctly performed.

Concrete of tower fundations is also recyclable using mechanical or even electrical methods. For glass insulators recycling, a difficult problem still remains the economical separation of their components: glass, cast iron, cement and steel. The porcelain isn’t a recyclable material. In some countries porcelain is reused as filling material for road construction after a preliminary crushing. It must mentioned that in Romania the components of glass and porcelain insulators are not recuperated in order to be recycled, although in 2005 [2] the total amount of those was more than 800 t only from Transelectrica.

The interest for recycling materials used to build an overhead line is justified not only by the simple recuperation of a part of costs at its end of life, but also to protect the environment and to comply with durable development concept.

Another aspect that can be highlighted is that, traditionally, in Europe are used lattice towers for power transmission lines. In the USA, towers of wood (impregnated with fireproof substances) are used up to 345 kV nominal voltages. At the same voltage wood towers are cheaper and have also the advantage to be biodegradable. The use of wood towers for overhead lines could be one of agreed solution regarding environment.

3. Biodegradable liquid insulation

Among liquid dielectrics used in electric power engineering, mineral oil (obtained by crude oil distillation) holds the preponderance. It is used as insulating, quenching and cooling medium in transformers and circuit breakers and carried out, in combination with solid dielectrics (as paper or electrotechnical board) the insulations for cables and capacitors. The total amount of mineral oil included in Transelectrica equipment (power and instrument transformers, coils and circuit breakers) reported in [2] is 14,060 t.

Beside of mineral oil, were (and still are) used synthetic oils, category that includes chlorinated, fluorinated and siliconic oils. Mineral and synthetic oils are non-biodegradable, being a permanent threat for the environment. Then, frequently contaminations of soil and waters were produced during accidents in operation, transport or maintenance. Among synthetic liquid dielectrics, the use of chlorinated oils is forbidden in many countries because of their high carcinogenic potential. A notable example is the clophene (PCB – polychlorinated biphenyl). Moreover, the crude oil deposits are finite and its price increases permanently.

All these problems lead toward researches to identify other alternatives to mineral oil. The attention was directed to vegetable oils, as soya, castor, coconut, palm tree, rapeseed or sunflower oil. The idea is not a new one, some experiments using vegetal oils as liquid dielectrics being performed even at the end of XIX-th century. At that time the unfavorable properties such as too large water absorption capacity, great rate of oxidation and high viscosity were insurmountable, and the idea was abandoned.

The researches started in the ’80s were directed to adding particular stabilizers in order to remove the disadvantages presented by vegetable oils in a pure state. Nowadays there are few trade marked biodegradable oils used to fill power transformers (generally of small power and medium voltages). These oils are based especially on soya oil. Other vegetable oils are in research state or experimental use.

The first putting into operation of a transformer filled with vegetable oil was carried out in USA, in 1997. In the last decade, these oils were used to fill more than 35,000 transformers in the USA, but also in Canada or Europe (in the United Kingdom). If usually these oils were used up to 69 kV and up to 20 MVA power transformers, in 2006 in the UK with such oil a transformer having highest voltage 132 kV was filled, the first use at this voltage level.

Nowadays, as a rule, biodegradable insulating oils commercially available contain about 98.5% vegetable oil and about 1.5% additives (antioxidants). Their costs is still higher with about 25...30% compared with mineral oil, but the advantages in operation make it competitively.

The main advantages of vegetable oil consist in a higher dielectric rigidity and higher flash point compared with mineral oils. But regarding the environment the most important property is their biodegradability. Table 2 presents some important features of vegetable oil compared with similar mineral oil.

Dielectric rigidity of vegetable oil remains satisfactorily high, even in conditions of a relative large content of water. Nevertheless, if a threshold of a 500 ppm water content is exceeded, dielectric qualities are diminished. It is well known that in multilayer insulation, values of electric field strength are distributed inverse proportional with dielectric constants of materials. The internal insulation of transformers is usually carried out by a paper-oil combination. Because vegetable oil has a large dielectric permitivity compared to paper, the dielectric stress for this oil will be reduced compared to mineral oil. Then a higher stress will be transferred to solid insulation. Consequently, it is possible to reduce the oil layer thickness and the overall dimensions of the transformer. Flash and burn points with practically double values compared to mineral oils are another arguments to use vegetable oils, because it is possible to fill indoor transformers having overall dimensions and costs smaller than dry transformers.

Because normal operation temperatures of vegetable oil could be higher compared to the classical ones filled with mineral oil, it is possible to charge at superior values and consequently to use it in a more economical mode. For the outdoor transformers, the elimination of fire quenching systems also diminishes their operating costs.

Table 2

Comparative physical and chemical characteristics of vegetable and mineral oil

Characteristic	Vegetable oil (average values)	Mineral oil (average values)
Dielectric rigidity [kV/mm]	> 20...22,5	> 15
Flash point [°C]	> 300	145
Relative dielectric permittivity	3,2	2,2
Pour point [°C]	–20...–15°C	–50...–40°C
Viscosity at 100°C [cSt]	10	3

Other features which favours the use of vegetable oils are:

- larger thermal conductivity, compared to mineral oil, which improves heat transfer;

- there are non-corrosive and non-aggressive versus gaskets of rubber;
- gases resulted by electric arc decomposition (predominantly carbon monoxide and hydrogen) represent only 25% of the volume of gases produced in the same stress conditions by mineral oils;
- the vegetable oils are decomposed by microorganisms present in atmosphere, (almost totally) in about 20 days; the decomposition substances are mainly carbon dioxide and water;
- replacing of mineral oil with a vegetable one increases the life duration of insulation based on cellulose. Generally speaking, the increase of life of a transformer compensates the initially higher cost of vegetable oil;
- there are miscible in any proportion with mineral oils, the mixtures having higher flash point than mineral oils.

Between disadvantages, not eliminated up to now, there can be mentioned comparing to mineral oils:

- higher viscosity;
- higher pour point, but this could be a disadvantage only for zones with very low temperatures;
- high oxidation rate in contact with atmosphere. Consequently, these fluids must be carefully manipulated in recipients with dry nitrogen blanket; if the exposure of this oil to atmospheric air is even for a few hours, it is necessary to be degassed before use.

Several countries support researches in biodegradable oils based onto their particular vegetable production. If the USA carried out dielectric oils based on soya bean, Sri Lanka tried to use coconut oil, Malaysia palm oil etc. As an example, for Romania an opportunity could be the rapeseed oil, because rape growing is at present extended, because of the use for biodiesel production.

4. Gaseous insulations with reduced environmental impact

Although compared to other insulations (in identical stress conditions) the gases have the lowest disruptive discharge voltages, they are used as insulating, cooling and quenching medium in diverse equipment: circuit breakers, gas insulated substations, capacitors etc. Their most attractive feature is the self-restoring capacity. Another favorable characteristics are the value of their relative dielectric constants, practically one ($\varepsilon_r \cong 1$) and negligible dielectric losses. Excepting atmospheric air, in order to increase disruptive voltages at different stresses, the gases are used at high pressure. In theses conditions mainly air, nitrogen and carbon dioxide were used for different electric power equipment. From the ’60s, the use of pure sulphur hexafluoride (SF_6) was started and then rapidly extended. The exceptionally good insulating features were conducted to it extensive usage, not only for circuit breakers, but also for gas insulated substations. And this because SF_6 has a dielectric rigidity three times larger compared to air at same pressure and is, moreover, a non-flammable, non-corrosive and non-toxic gas. The large volume of molecule and their electronegativity (the affinity for electrons) explain the good dielectric and arc quenching properties. In accordance with [2], Transelectrica installations (gas insulated substation and circuit breakers) contains 16,58 t of SF_6.

After the enthusiasm of the beginning, the signs of worry appeared: the SF_6 molecule is very stable in atmosphere, its lifetime exceeds 3000 years and the gas presents a potent greenhouse effect, about 24.000 times greater than carbon dioxide. Hence, the emission (leakage in atmosphere) of one single kg of SF_6 is equivalent with emission of 24 tons of CO_2. Consequently, the Kyoto Protocol (from 1997) regarding greenhouse gas emissions included the SF_6 on the list of gases with controlled use. (It could be mentioned that up to June 2007, 172 stats were signed ant ratified this protocol).

Of course, these problems can occur if a leakage of the gas in atmosphere will occur, and consequently the first applied measure refers to careful manipulation during transport, filling of equipment and maintenance works. If in a pure state sulfure hexafluoride is non-toxic, it's decomposition under electric arc effect or corona discharge and combination with substances integrated in the equipment structure can produce hazardous chemical components for the environment and personnel. The gaseous components such as SF_4, SiF_4, SO_2F_2, SO_2 and HF are very irritant substances for eyes and respiratory tracts and the solid ones (in powder state) such as AlF_3 and CuF_2 are dangerous for human body mostly if they are inhalated or swallowed. Consequently, interventions during operation period of equipment and at their end of life must be performed by qualified personnel and according to particular work protection measures.

Environmental problems raised by SF_6 require solutions for replacing this insulating gas or, at least, to diminishing the used quantities and this last tendency has been confirmed by recent worldwide statistics.

Researches were (and still are) conducted to use SF_6 mixture with other gases such as N_2, CO_2, He, Ar or CF_3I. Up to now the N_2- SF_6 mixtures have been proved a suitable technical and economical solution. The main features of these mixtures are:

- the inception discharge voltages are greater for the mixture compared to pure SF_6 for electrodes with protrusions;
- they have acceptable disruptive discharge voltages even for reduced concentrations of SF_6 in volume of gas. As example [3], a mixture which contains only 20% SF_6 has U_{50} for standardized lightning impulse voltage representing 69% of those corresponding of pure hexafluoride, at same pressure and for strong non-uniform electric field conditions;
- for circuit breakers: if in SF_6/N_2 mixture the content of nitrogen is up to 25%,

the electric arc interruption capability remains unchanged comparing to those of pure hexafluoride [4];

Concerning the replacement of SF_6 in circuit breakers, certain tests have been performed using a gas with a negligible greenhouse effect: CF_3I (iodotrifluoromethane) [5].

Another substitute for SF_6 in the case of circuit breakers (nowadays at least for medium voltages) is the vacuum. Vacuum circuit breakers have no impact to the environment, both during operation period and at end of its life cycle. During maintenance operations no special measures for chemical protection of personnel are necessary, because no exposure at toxic components occurs. Vacuum circuit breakers (usually pressures are, generally, between $10^{-5}...10^{-7}$ bar) are characterized by a very good arc extinguishing capability, require reduced trail between contacts (only a few mm) and, consequently, have reduced weight-operating mechanisms. Comparing to SF_6 , the mass of vacuum breaker mechanisms is only about 1/3, at similarly electrical parameters. Electrical and mechanical reliability of vacuum circuit breakers are superior to those of SF_6.

5. Conclusions

The concept of intelligent electrical network must include the component concerning environmental impact because “climatic changes” and “global warming” aren’t abstract notions. In electric power domain is mandatory to increase the efforts directed to recycle, in a larger measure and with lowest losses, the materials that admit such a processes. Another direction of action is to produce new equipment using materials with lowest environmental impact, such as above presented materials.

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