For a better environment

Recycling opportunities for insulating components

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Power transmission and distribution utilities generate significant quantities of epoxy, silicone and porcelain waste products, especially during the process of renewing aging infrastructure. In the near future, the introduction of smart grid technology, while helping to create an energy-efficient power network, will inevitably add to this waste disposal problem, as old equipment is replaced with new. Currently there are no well-defined technologies that can be used to recycle insulating components that have reached the end of their useful life. This kind of waste frequently ends up in landfills.

With a view to reducing the impact of ABB's products on the environment and satisfying customers' requirements to fulfill ever tougher environmental regulations, ABB has carried out a number of product-recycling feasibility studies. These studies have identified potential recycling or reutilization options for insulating components that could be developed to create greater sustainability for power transmission and distribution products.

Silicone[1] rubbers and other thermosetting materials are very broadly used in electrical apparatus because of their excellent dielectric properties and robust characteristics. Huge quantities of scrap insulating components are generated both by manufacturers and utilities every year. An appropriate waste management policy should be used so that these components do not end up in landfills, but are instead recycled or reused.

Life-cycle studies show that recycling and incineration with energy recovery are the most effective ways in which to treat polymeric waste.

Recent estimates show an annual plastic product consumption for Western Europe of 40 million tons [1], from which 20 percent is thermoset. Such massive consumption of plastics inevitably results in vast quantities of waste, estimated at around 22 million tons annually, less than 40 percent of which is reutilized [1]. Polymeric wastes can be recycled, incinerated or disposed of in landfills. The results from several life-cycle studies show that recycling and incineration with energy recovery are the most effective ways in which to treat this waste. Deposition in landfills should be avoided since it implies no material or energy recovery from the waste. If the waste material is “clean“ and well defined, it can be collected easily, dismantled and reprocessed for use in new products. If, however, these conditions are not fulfilled, incineration with energy recovery is probably the most suitable treatment. The advantage of using polymer wastes as fuel for power or heat generation is that most polymers have high energy content. However, it is important that the incineration is carried out under controlled conditions in plants with efficient air-pollution control devices, since polymers often contain chlorine, fluorine, bromine, sulfur or other additives, which upon combustion may result in harmful emissions. The preferred treatment of polymer wastes containing harmful organic additives is to carefully control their incineration so that these compounds are destroyed and removed. Deciding whether a product or product part should be recycled or incinerated is complex and should be considered case by case.

European waste-management directives have encouraged higher rates of recovery and recycling through the restrictive use of landfills.

In the power industry, many products contain metals embedded within the cured thermosets. These may be housed within epoxy or silicone 1. The feasibility of recovering valuable components embedded within such polymeric insulators is currently under investigation in the laboratory.

Waste management directives throughout Europe have encouraged higher rates of recovery and recycling through the restrictive use of landfills. Recent restrictions include:

Austria Additional restrictions on landfills (2004)

Denmark Ban on the deposit of combustible wastes suitable for incineration to landfills (1997)

France Ban on the disposal of non-residual wastes to landfills (2002)

Germany Ban on the disposal of non-treated wastes to landfills (1993) and combustible wastes to landfills (2001)

Netherlands Ban on all wastes that can be reused or recovered going to landfills (1995)

Sweden Ban on non-treated municipal solid wastes to landfills (1996), combustible wastes to landfills (2002), and organic wastes to landfills (2005)

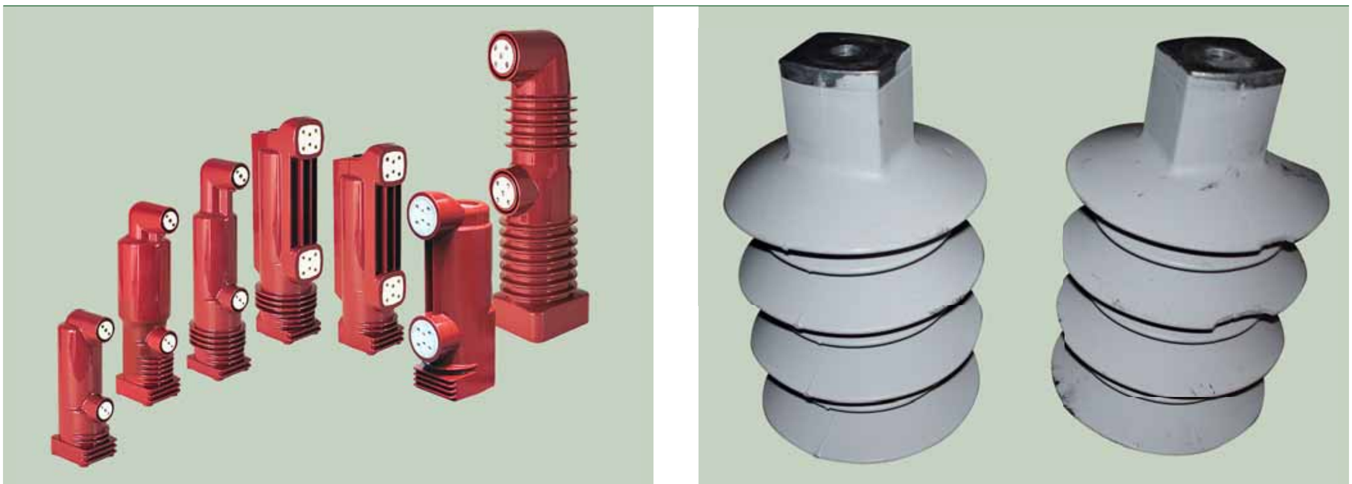
Similar new directives, eg, the directive 2002/96/EC of the European Par-

Footnotes

1) Silicones are polymers that include silicon together with carbon, hydrogen, oxygen, fillers and sometimes other chemical elements. Liquid silicone rubbers (LSR) are one type of silicones.

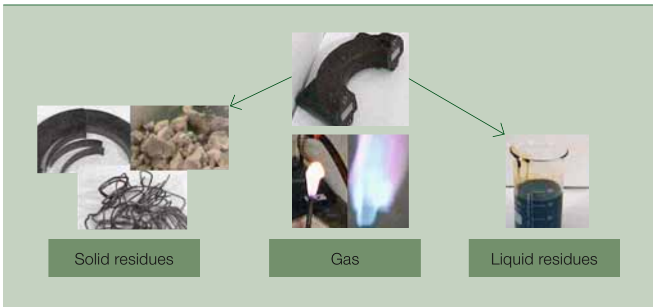
2) The “EEE” refers to equipment, which is dependent on electric currents or electromagnetic fields in order to work properly, and equipment for the generation, transfer and measurement of such currents, and fields falling under the categories set out in Annex IA and designed for use with a voltage rating not exceeding 1,000 V for alternating current and 1,500 V for direct current.

1 Thermosetting products



liament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE) states that all "electrical and electronic equipment" (EEE)[2)] should be recycled and bans the disposal of such electrical waste in landfills [2]. Greater restrictions on electrical waste, now and in the future, means that producers and final users of high-voltage apparatus should identify alternative waste-management methods.

2 Products from pyrolysis of used epoxy product



Scrap thermosets disposal methods

Cured thermosets are not classified as hazardous and can be disposed of in landfills. In fact more than 90 percent of such waste is disposed of in this way [1]. However, increasing quantities of scrap materials and a limited amount of space for their disposal has created a need for more sophisticated, sustainable technologies for the reuse of these materials.

Several different options have been proposed for the reutilization of thermosetting wastes that would avoid the use of landfills:
- Reuse in construction material
- Mechanical recycling
- Energy recovery
- Degradation

A simple way to reutilize cured epoxy-based waste is to add it to concrete or asphalt construction materials. However, since only small amounts of waste material are generated relative to the construction material required and because it is dispersed geographically over a wide area, the economic incentive to reutilize such materials in construction materials is low. Moreover, epoxy-based material is widely used to insulate electrical equipment, which means that various internal parts (cores, windings) made of metals must be removed before it can be reused. Some companies apply cryogenic techniques to recycle the embedded parts, but the quality of such parts is poor.

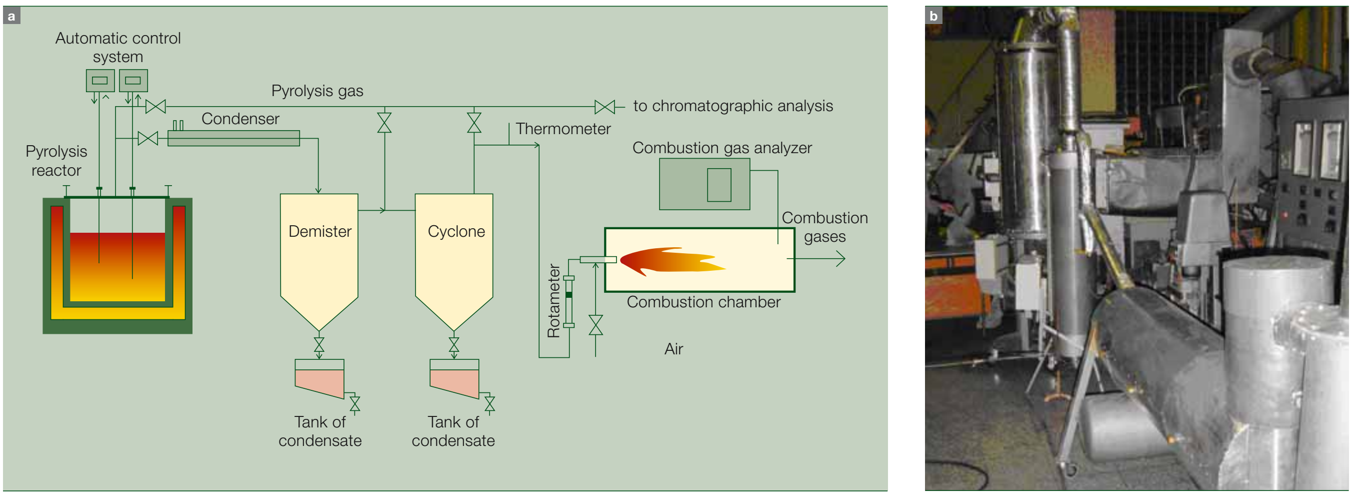
Recycling rubber materials, including liquid silicone rubbers (LSR), have so far been limited to mechanical separation methods, such as grinding. Rubbers are highly elastic, cross-linked (vulcanized) polymer materials, which, owing to their crosslinking, cannot be melted and reprocessed. This characteristic has restricted its reuse to the production of asphalt and athletic field materials; however, novel methods for devulcanizing rubbers are currently under development, which if successful, will greatly enhance the range of uses for recycled rubber materials.

Energy recovery from thermosets is an attractive alternative to recycling. Generally the energy content of thermosets is high – with lower heat values (LHVs) from 10 to 20 MJ/kg, depending on filler content – making this type of material an attractive fuel for heating and power generation. The drawback is that thermoset combustion would result in the production of large amounts of inorganic matter, in the form of filler, which would have to be disposed of economically and with minimum impact on the environment. On a positive note, air pollution from the combustion of thermosets is relatively safe; with carefully managed combustion no hazardous emissions are generated [3].

A simple way to reutilize cured epoxy-based waste is to add it to concrete or asphalt construction materials.

The degradation of plastics to lower molecular weight materials by photo-degradation, chemical-degradation or bio-degradation are also attractive options for the recycling of thermosetting polymers. Pyrolysis is a specific form of chemical degradation, which is of particular interest since it is

3 Experimental pyrolysis set-up a and pilot installation for pyrolytic thermal utilization b



attractive both environmentally and financially, and does not require the prior separation of components to recover materials and energy.

Solutions under investigation by ABB

ABB is investigating several alternative strategies by which to reutilize insulating components.

4 Experimental conditions for pyrolysis at different temperatures

Process	Low temp. pyrolysis	High temp. pyrolysis	High temp. pyrolysis
Thermoset waste	1820 g	4390 g	1270 g
Pyrolysis time	3 hours	3 hours	5.5 hours
Pyrolysis temp.	450 °C	750 °C	850 °C
Products			
Gas	97 dm^3/kg resin waste	103 dm^3/kg resin waste	98 dm^3/kg resin waste
Liquid	43.96 g/kg resin waste	62.19 g/kg resin waste	226.77 g/kg resin waste
Solid	854.40 g/kg resin waste	895.22 g/kg resin waste	689.76 g/kg resin waste

Pyrolysis

Pyrolysis is an attractive proposition for the reutilization of thermosets. It is a thermal degradation process carried out in an oxygen-free environment that results in three product categories **2**:

- Pyrolytic gas
- Liquid products
- Solids (char, mineral fillers, metals)

In test experiments in the laboratory a pyrolytic reactor mainly comprised of electric heaters and a thermocouple was developed **3**. The apparatus was designed so that a wide range of temperatures could be regulated within the reactor.

The gas produced by the pyrolytic thermal degradation of thermosets must be purified prior to combustion in the combustion chamber. Purification was achieved using a demister[3] and a cyclone[4], which condense the impurities from the gas to produce liquid products.

In the laboratory it took between three and five hours to pyrolytically degrade epoxy waste materials depending on the quantity of waste processed and the temperature at which pyrolysis was conducted. Low temperature pyrolysis was conducted at 450 °C, while high temperature processes were performed at either 750 °C or 850 °C.

Pyrolysis can be used to thermally degrade resin wastes, thereby producing gas and oil for use as fuel, while reclaiming metallic components for recycling.

In total, three different sets of experiments were performed. Optimally the organic material should be properly decomposed (ie, the goal is to reduce the carbon content of solid residues to a minimum), while retaining good quality metallic parts for recycling **4**.

The results of these experiments showed that pyrolysis can be used to thermally degrade resin wastes and reclaim metallic components for recycling. The gas and oil produced by pyrolysis can be reused as fuel, recovering the energy trapped within the old discarded products.

Novel approach – cement process

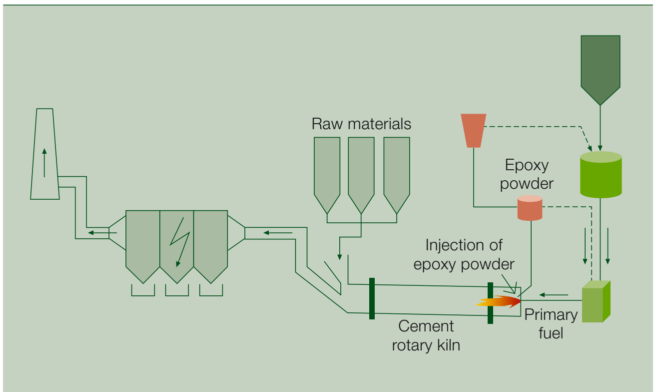
An alternative use of epoxy-based wastes is to burn them to heat the kilns of the cement industry. Due to its relatively high energy content, the epoxy can be used as an additional source of heat in a clinker burning process. Moreover, the inorganic filler (SiO_2 or Al_2O_3 in most formulations) could be incorporated into the clinker itself. Ground-cured epoxy powder would be injected into the flame (preferably in a mixture with pulverized coal) inside the cement rotary kiln **5**. In the normal operation of a cement kiln, hazardous nitrogen oxides are generated. These are derived from the oxidation of chemically bound nitrogen in the fuel (fuel nitrogen oxides) and by the thermal fixation of nitrogen in the air (thermal nitrogen oxides). It is possible that such nitrogen oxides could be reduced as a result of introducing cured epoxy powder to the combusting fuel. The fuel type used affects the

Footnotes

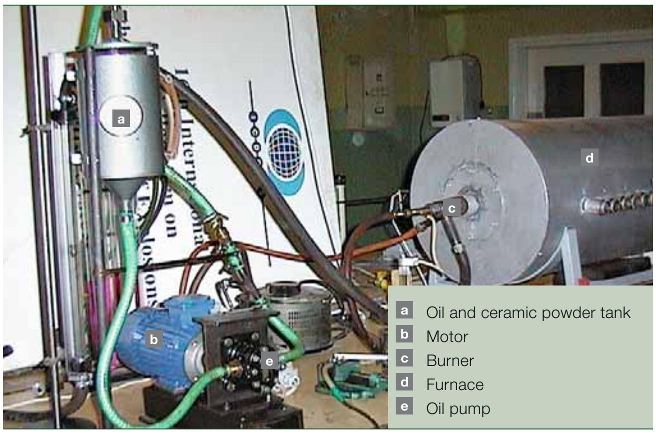
[3] Demister – a device for removal of liquid droplets from a gas stream.

[4] Cyclone – a device for removal of particulates from air, gas or water stream through vortex separation.

5 The concept of epoxy waste utilization in a cement rotary kiln (here the hot end of the kiln is shown)



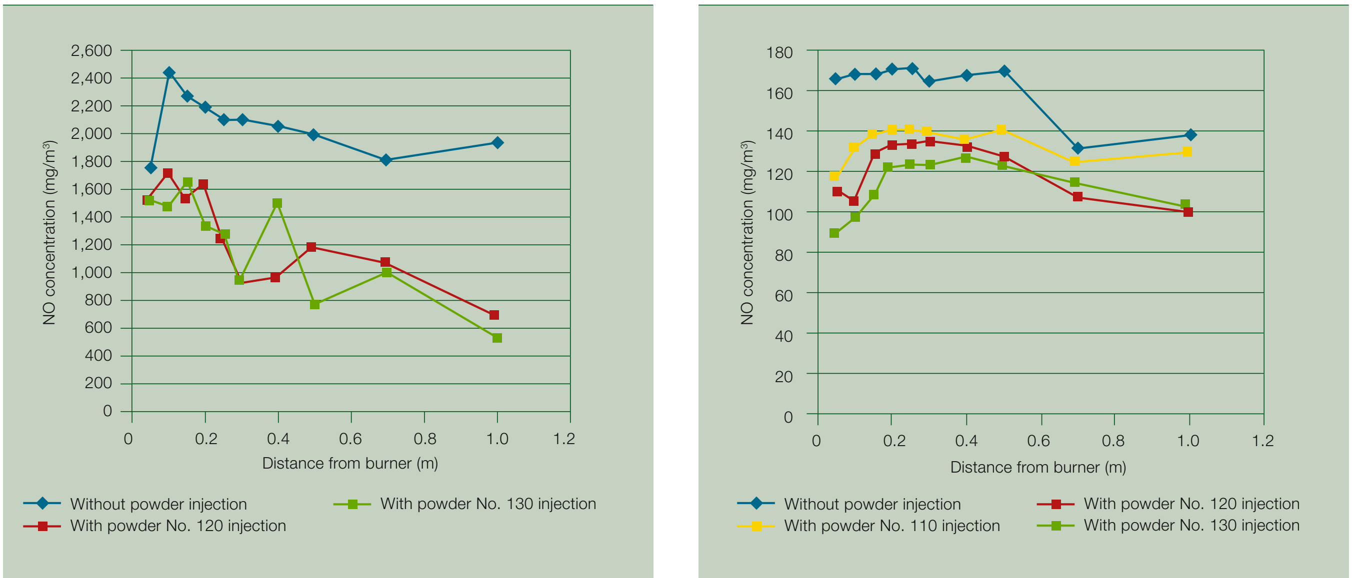
6 Experimental setup for utilization of porcelain insulators



7 NO concentration during injection of ceramic powder:

a Diesel oil supplemented with pyridine

b Natural gas



quantity and the type of NO_x generated, as does the temperature at which it burns (significant increases in nitrogen oxides are generated at temperatures above 1,400 °C). In the cement manufacturing process, the burning zone of the kiln and the burning zone of the precalciner vessel reached temperatures above 1,500 °C. These temperatures promote the formation of NO_x. The catalytic properties of introducing cured epoxy powder to the flame may promote the reduction of NO_x to nitrogen. Nitrogen oxides are the most hazardous components generated in a cement kiln creating a major environmental problem to cement manufacturers. In the wet technology[5)], emissions of NO_x can exceed 4 kg/ton of clinker [4].

This proposal for the utilization of scrap epoxy to reduce nitrogen oxide emissions is not proven, but a number of laboratory investigations on the disposal of used porcelain insulators have shown a similar utility to reduce nitrogen oxide emissions [5]. Laboratory tests have shown that diesel oil mixed with a ceramic powder, obtained by grinding used porcelain insulators, can reduce nitrogen oxide emissions when supplied to the burner.

To increase the amount of nitrogen oxides generated in the process experimentally, up to 10 percent weight per volume pyridine C_5H_5N was added to the diesel oil. This allowed nitrogen oxide concentrations in the flue gases to exceed 2,000 mg/m³. Such concentrations made it easier to record the effects of adding ceramic powder to the diesel oil on the concentration of nitrogen oxides produced. To check the effect of the process on thermal nitrogen oxides, additional tests were carried out using the same laboratory equipment, but replacing the diesel oil with natural gas as fuel. In this case, the oil burner was removed and a natural gas burner (6 kW thermal capacity) with the powder injection system was installed 6. All NO concentrations were recalculated for a 3 percent oxygen level in order to compare the results of the combustion tests with and without the powder injection.

The introduction of the ceramic powder results in a significant reduction of nitrogen oxides formed during combustion of diesel oil and natural gas.

The results show that the introduction of the ceramic powder resulted in a significant reduction of nitrogen oxides formed during combustion of both types of fuel. The magnitude of the reduction of the respective NO_x concentrations is presented in 7. The concentrations of NO_x in 7a are one order of magnitude greater than those in 7b, because the former, in addition to the thermal nitrogen oxides, also includes the fuel nitrogen oxides resulting from the addition of pyridine. It is interesting to note that the magnitude of the reduction in NO_x concentration in 8a increases with the distance from the burner, while the opposite trend is observed in 8b. This is an effect of various temperature distribution profiles for both fuels and the resulting different mechanism of nitrogen oxide formation in the flame region along the combustion chamber. Regardless of these trends, 7 and 8 suggest that the addition of ceramic powder to both diesel oil and natural gas fuels can help reduce NO_x emissions during combustion.

The observed reductions in NO_x emissions can be explained on the basis of

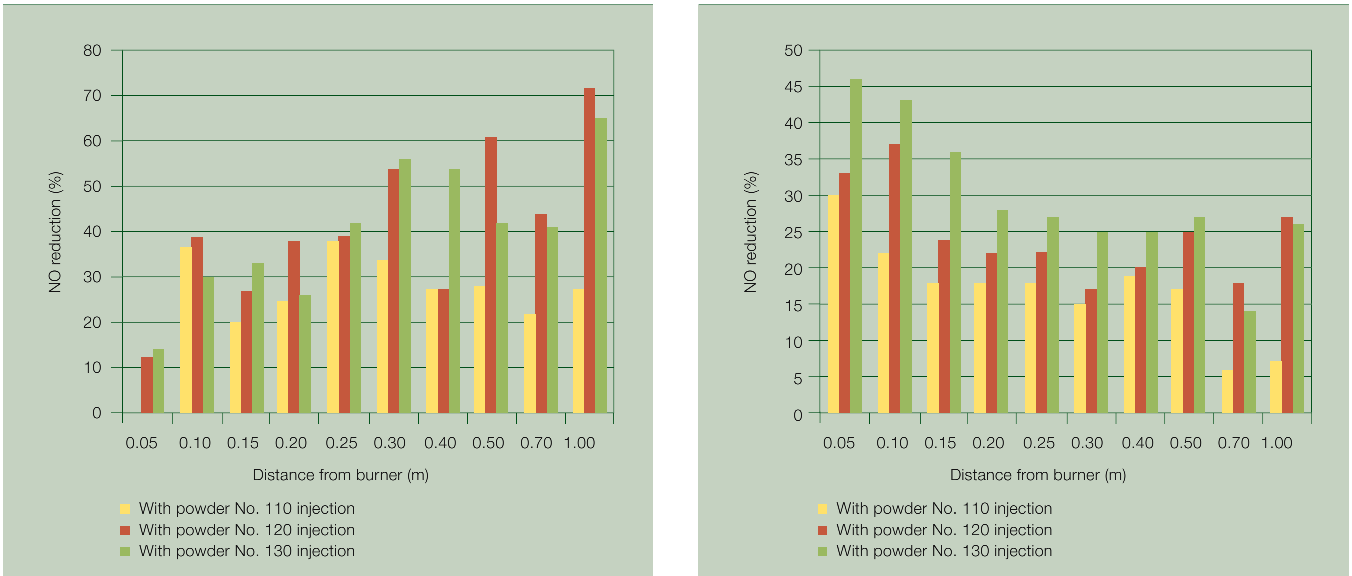
Footnote

5) Cement production is either "wet" or "dry," depending on the water content of the raw materials used. The wet technology processes slurries instead of dry powders. Although the chemistry is easier to control, it requires much more energy to drive off the water by evaporation from the slurry. The dry technology is far less energy intensive.

8 Reduction of NO concentration during injection of ceramic powder:

a Diesel oil supplemented with pyridine

b Natural gas



some catalytic effect of the ceramic powder components 8. This is probably the same effect as was observed by DeSoete [6], who pointed out that NO can be destroyed in the presence of a reducing agent (eg, CO) on both cenospheres[6)] and even on the wall of an empty quartz reactor. DeSoete proposed reaction kinetics models for the destruction of NO and HCN on fly ash, gas phase formed soot, and cenospheric soot. In all cases, the nitrogenous species was efficiently destroyed. The components found in ceramic insulators are similar to the components found in fly ash, suggesting a similar mechanism for the promotion of NO reduction using ceramic powder. However, at present, the influence of metal oxide concentrations on the reaction kinetics of NO and CO reduction at the ceramic powder surface is not well understood. A similar positive effect on the reduction of NO_x emissions is expected for an epoxy powder containing mineral fillers. It is important to note that Fe_2O_3, which is commonly used as a dye in epoxy mixtures, is known for its strong catalytic effect.

ABB has identified potential recycling and reutilization options for insulating components.

Scrap surge arresters

Recently, silicone-housed surge arresters have found a broad application in a wide range of medium- and high-voltage systems. A polymer surge arrester consists of polymer housing with metallic flanges and terminals made of aluminum, steel or copper (metal oxide varistor[7)] blocks are the most important components in surge arresters).

ABB aims to create greater sustainability for power transmission and distribution products.

The metal-oxide varistors are sintered[8)] bodies composed of mainly ZnO (90 percent) and other oxides, mostly of heavy metals. Since this type of silicone rubber material is rel-

9 Recycled components from scrap surge arresters

a b

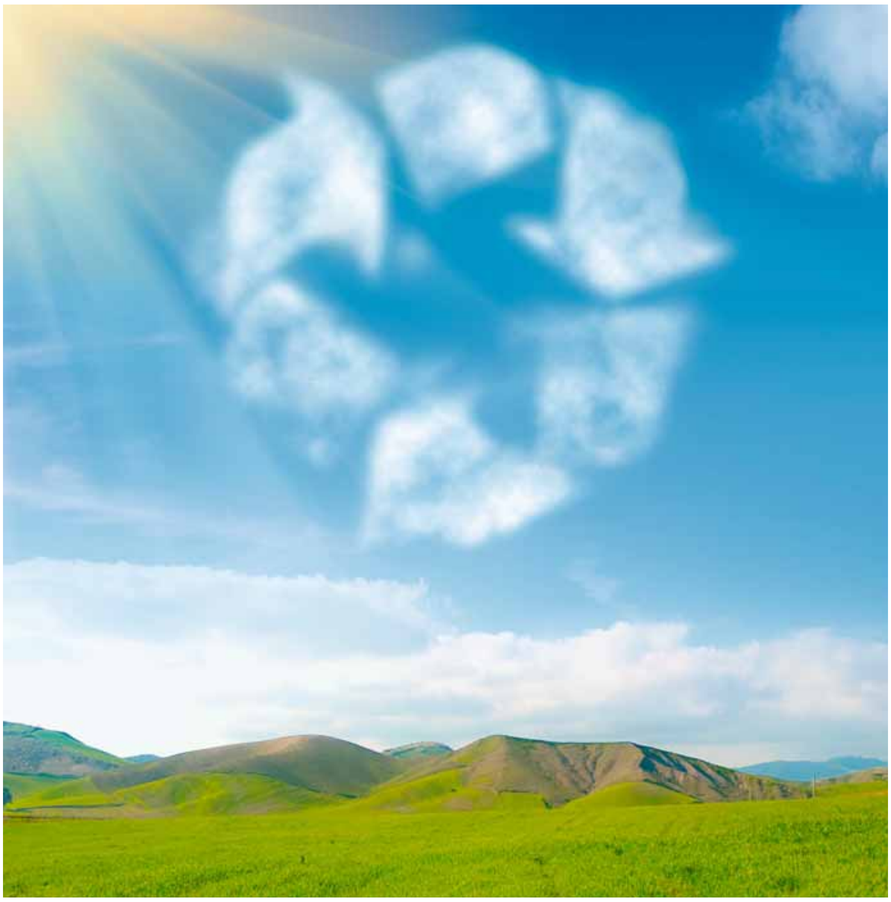
Footnotes

6) A cenosphere is a lightweight, inert, hollow sphere filled with inert air or gas, typically produced as a byproduct of coal combustion.

7) Varistor – a type of resistor with significantly non-linear current-voltage characteristics.

8) Sintering is a method for making objects from powder, by heating the material below its melting point until its particles adhere to each other.

10 Products after wrong recycling procedure



atively new, there is no commercial method for the efficient recycling of used surge arresters.

ABB has patented techniques to reutilize thermoset components.

Investigations have been made for possible ways in which to recycle LSR insulation. Decomposition methods for silicone rubber materials are limited. The most common disposal method is combustion (incineration). However, combustion of silicone rubbers is associated with temperatures in excess of 900 °C, which may result in the emission of the heavy metals. The silicone rubber itself has a relatively high combustion heat (17,000 kJ/kg) in a range not so far off that of hard coal (ranging from 25,000 to 30,000 kJ/kg).

Considering all recycling criteria, laboratory tests were performed using the pyrolysis process to thermally degrade the silicone. The same experimental setup used for the epoxy waste was employed. Different temperatures were tested to optimize the process parameters so that good quality internal parts (mostly zinc oxide varistors and other metallic parts) could be recovered for recycling 9. Under non-optimized conditions components were destroyed and could not be reused for any application 10. It should be noted that at this stage in the study no detailed investigations were done to determine the electrical performance of the recycled varistor blocks and their potential reuse.

Long-term perspectives

Investigations made by ABB in laboratory experiments confirm the availability of technologies for reutilizing (recycling) different types of thermoset components. These techniques have been patented by ABB and provide an opportunity for their commercialization. However, to succeed in this endeavor, an appropriate policy regarding the efficient collection of scrap components should be initiated by waste disposal organizations with the strong support of local governments. This will ultimately result in lower quantities of thermoset waste ending up in landfills and a higher proportion of valuable component recovery for reuse by manufacturers.

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