New EU Legislation (WEEE) Compliant Recovery Processes for LCDs

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ABSTRACT

Sustainability from synthesis to final disposal of products will become essential in future. Due to considerable annual LCD growth rates their waste will increase, too. Although being not hazardous, new legislations in Europe ('WEEE' directive) and Japan ('Recycle Law') require LCD reuse, recycling or recovery. Merck presents two economical and ecological recovery processes. In incinerators and metallurgy processes LCDs substitute used raw materials with recovery rates of almost 100%, an example for Product Stewardship and Responsible Care at Merck KGaA.

INTRODUCTION

Although most of the LCD applications, in particular notebook PC, LCD monitors and TV sets are typically long-life products the disposal or recycling at their end of life needs to be considered under new EU directives and an integrated product policy (IPP). Hence, in total about 152.000 tons of LCD panels for the 3 most weight-relevant applications will be sold worldwide in the year 2008. Consequently, several years later - depending on the different life times - corresponding amounts of LCD waste need to be recycled or to be disposed of, but no economical and ecological recovery processes for LCDs have been available until now.

DEFINITIONS AND COMPONENTS OF LCDs

The definition of 'LCD' or 'LCD panel' describes the sandwich composed of the two glass plates with attached polymers (for example polarizers, color filters, optical compensators and protective films) and the sealed liquid crystal mixture in between the two glass plates. This definition does not include the backlight unit, the printed circuit board, the cables and the frame. These are part of the 'LCD Module'.

Polarizers are usually composed of polycarbonate. Their thickness is typically about 200 nm. The orientation layer consists of a polyimide, which is about 30 to 100 nm thick. The ITO–electrode is also about 30 to 80 nm thick and the glass plates used for LCDs have a thickness of 0.4 to 1.1 mm.

Liquid Crystals are used as mixtures typically containing up to 25 single compounds, sometimes even more. The mixtures are composed of chemically quite similar compounds some of which only differ in their alkyl or alkoxy side chains by varying numbers of carbon atoms (so-called homologous compounds). The quantity of LCs in LCDs nowadays is only about 0.5 mg per cm^2.

Over 95% of the laptop computer, notebooks and monitors use a backlight unit some consisting of gas discharge lamps still containing mercury.

Calculations (1) show that the content of LCs in an LCD with areas $\geq$ 100 cm^2 is $\leq$ 0,1 %, and in relation to an LCD module or even to an electronic device fare below 0,1%. As an example a Laptop with a 15-inch screen and a weight of 2.5 to 1,5 kg contains 0,02 to 0,03 % LCs by weight.

LCD PANEL WEIGHT ESTIMATION FOR 2008

In 2004 about 70 Mio LCD monitors (2) will be sold, and their number is expected to increase to about 130 Mio in the year 2008, representing a CAGR of about 17 % (comparison for CRT monitors: 2004: 65 Mio; 2008: 12 Mio). Likewise notebook PCs will increase from 45 Mio in 2004 to 78 Mio, in 2008 (CAGR = 15 %) and LCD TVs from 10 Mio in 2004 to 56 Mio in 2008 (CAGR = 54 %). In the same period CRT TVs will increase only marginally from 155 Mio in 2004 to 165 Mio - in 2008 but by no means be replaced completely by LCD TVs, even not in the more distant future.

The average area diagonals of LCD monitors, notebooks and LCD TVs and the corresponding weight of the LCD are contained in the table below, together with an estimation of the weight of LCDs worldwide in the year 2008. The definition of 'LCD' or 'LCD panel' is given in the next paragraph. A 17-inch LCD with glass of 0.8 mm thickness weights approximately 400 g at an area of approximately 139 $inch^2$. From these figures the areas of 15 inch (108 $inch^2$) and 30 inch (385 $inch^2$) LCDs were calculated assuming an aspect ratio of 4:3 for 15 inch and 17 inch for the notebook respective monitor LCDs and of 16:9 for the 30" TV-LCD.

Year 2008 World	LCD monitors	Notebooks	LCD TVs
Average LCD area diagonal	**17“**	**15“**	**30“**
Average LCD weight (g)	**400**	**320**	**1.110**
Numbers produced in 2008 (Mio)	**130**	**78**	**56**
Total weight LCD panels (t)	**54.000**	**25.000**	**72.000**

Fig. 1 LCD panel weight for 3 top applications

An estimation for sold LCD weight panels in the year 2008 (2)

SAFETY OF LIQUID CRYSTALS (LCs)

Merck and its Japanese competitors perform toxicological tests (3) with liquid crystals already in the development stage as precautionary measures according to the principles of ‘Responsible Care’ and ‘Product Stewardship’. Toxicological testing is part of the product market introduction strategy for liquid crystals at Merck KGaA (1).

Toxicity is the capacity of a chemical to cause adverse effects, i.e. functional or structural changes, to a living organism. Toxicity is dependent on the dose administered, as already Paracelsus (1493-1541) found: ‘All substances are poison, only the dose makes that a substance is not a poison’. Toxicological studies are designed to reveal such hazardous properties and to provide data for risk assessment purposes.

To find possible hazardous properties, acute toxicity studies, skin and eye irritation studies and bacterial mutagenicity tests were performed with many liquid crystals (1,3). Additionally, information on skin sensitization, long-term and aquatic toxicity (4), biodegradability and bio-accumulation is available for a few LCs. Data from these studies are used in human health and hazard evaluation, environmental risk assessment and serve as basis for classification and labelling of the substances.

Merck has committed itself to perform toxicological tests with liquid crystals already in the development stage as precautionary measures according to the principles of ‘Responsible Care’ and ‘Product Stewardship’. It is part of our sales policy that acutely toxic or mutagenic substances would not be introduced into the market (6). All toxicological studies were preformed according to recent international guidelines (OECD, EU) and followed the national regulations for animal welfare as well as the worldwide acknowledged principles of ‘Good laboratory practice’ (GLP).

The toxicological test methods carried-out at Merck such as the determination of the acute oral toxicity, the assessment of effects on skin and eye and of the bacterial mutagenicity are described in detail in a corresponding brochure (1), as are eco-toxicological investigations.

Since most of the environmental pollutants enter the environment via wastewater, the aquatic compartment is in the focus of eco-toxicological testing. Aquatic organisms used for a first indication of environmental effects of chemicals are i.e. fish, water flea, algae and bacteria. These are exposed to the test compounds dissolved in the test medium and the results are expressed as median lethal concentration (LC_{50}) or median effect concentration (EC_{50}). Liquid crystal materials did not show any adverse effects on water flea (daphnia), algae and bacteria up to the limit of water solubility (4).

Factors such as chemical stability, adsorption and biodegradability influence the concentration and fate of chemicals in the environment. Degradability of LCs by bacteria was assessed in ready biodegradability tests, which are stringent tests providing limited opportunity for biodegradation. Depending on the structure, LCs showed biodegradation rates from 0 to 55%.

Liquid crystals marketed have no acutely toxic or mutagenic properties and are therefore classified as non-hazardous materials according to EU Directive 2000/532/ EC.

Furthermore, eco-toxicological investigations revealed that LCs also are not harmful for aquatic organisms. This is in agreement with the statement of the German Federal Environmental Agency of 28th August 2000 (6).

LEGISLATION AND CLASSIFICATION

The EU adopted the new EU directives 2002/96/EC on ‘Waste of Electrical and Electronic Equipment (WEEE)’ and 2002/95/EC on the ‘Restriction of the Use of Hazardous Substances in Electrical and Electronic Equipment (RoHS)’ on 27th January 2003. The member states have to implement the directive into national law by 13th August 2004 and establish a collection system from households by 13th August 2005.

WEEE Directive

The purpose of the WEEE directive is the prevention of electronic and electrical waste and in addition, the reuse, recycling and other forms of recovery of such waste so as to reduce the disposal of waste.

For the categories 3 and 4 (IT, telecommunication

and consumer equipment) the targets of 75% for recovery and 65% of component, material and substances reuse and recycling per appliance have to be achieved by 31st December 2006.
With respect to LCDs WEEE requires that those of a surface > 100 cm^2 and all those back-lighted with gas discharge lamps have to be removed from collected electrical and electronic waste.

To fulfil the targets of the WEEE directive of 75% for recovery and of 65% for reuse and recycling per appliance a recovery is required for LCDs (7). In the future, at least in Japan and Europe LCD monitors will have to be recovered or recycled due to this legislation.

RoHS Directive

The purpose of the RoHS directive is a restriction of hazardous substances in electronic and electrical equipment in order to contribute to the protection of human health and the environment. From 1st July 2006 on, new electrical and electronic equipment put on the market may not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

Liquid Crystals mixtures supplied by Merck do not contain any of the substances mentioned in the RoHS directive in detectable amounts (5).

European Waste Classification

The EU Directive 2000/532/EC of 3rd May 2000 established a harmonized list of waste with code numbers and a definition for hazardous waste with detailed criteria: one or more substances classified as very toxic, carcinogenic or mutagenic at a total concentration of ≥ 0,1 % and classified as teratogenic at a total concentration of ≥ 0,5%.
Applying these criteria to LCDs proves that those without the backlight are no hazardous waste according to the EU Directive 2000/532/EC and can be classified in the European Waste Catalogue under the waste code number 16 02 16 (components removed from discarded equipment other than hazardous components). This is in accordance with the directive of the Association of the German Federal States for Recovery/ Recycling/ Disposal of used electronic devices with technical requirements and a classification for LCDs, published in 22nd May 2004.

REUSE, RECYCLING & RECOVERY

Basic considerations

To fulfil the targets of the WEEE directive of 75% for recovery and 65% for reuse and recycling per appliance a recovery is required for LCDs. In future the ratio between LCD and LCD module or Laptop PC will increase due to the reduced weight for the electronic device.

'Recycling' means the reprocessing in a production process of the waste materials for the original or for other purposes. But this excludes energy recovery, which means the use of combustible waste as a means of generating energy through direct incineration with or without other waste but with recovery of the heat.

'Recovery' means any of the applicable operations provided in Annex IIB of the Directive 75/442/EEC.

'Disposal' means any of the applicable operations provided in Annex IIA of the Directive 75/442/EEC (the collection, sorting, transport and treatment of waste as well as its storage and depositing above or under ground).

In the future at least in Japan, Europe and may be in China due to the legislation LCD monitors have to be reused, recovered or recycled. Therefore a 'Recycling' or 'Recovery' process is of high interest for the electronics industry.

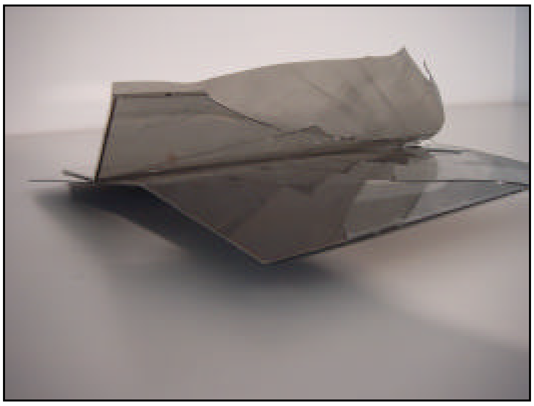

Fig. 2 LCD
LCD with separated glass plates and plastic foils

Reuse of LCD Modules

The reuse of LCD modules is possible as replacement for out of order LCD modules and widely used at least in Third World Countries. In future, this will be only a marginal proportion due to the rapid development of higher performance LCDs.

Evaluation of a Recycling Process for LCs

An evaluation of a 'Recycling' process for reuse of the LCs in LCDs shows no economical benefit.

An LC Mixture typically contains up to 25 or more components. Theoretically, reclaiming the LC mixtures from waste LCDs would yield a mixture containing a huge variety of LCs from all LC producers. For reuse, LCs have to be extremely pure (´electronic grade´). Therefore, this reclaimed mixture of in the worst case up to about 500 different LCs would have to be separated into the single components and be purified afterwards. The costs for quantitative separation and purification are higher than those for newly synthesized LCs, not considering the complex patent situation.

LCD Recovery Process: Incineration

At the high temperatures during the incineration (see Figure 3) of aggressive and hazardous industrial waste the wall of the incinerator will be corroded soon. Additives containing silica are widely used to generate a thin silica layer to protect the wall. Many trials in practice have shown that LCDs can be used as a substitute for silica containing materials.

In addition, the plastic foils of the LCDs are used during the incineration process to produce heat energy. A calculation demonstrates that the energy of the plastic foils is sufficient to melt the glass of the LCD.

Due to the substitution of the raw material by LCD glass and heat generation from the LCD plastic foils this process is considered a 'Recovery Process' with a recovery rate of approximately 99%.

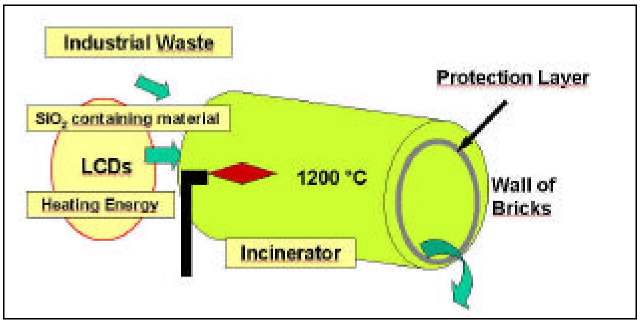

Fig. 3 Incineration Process

LCD Recovery Process: Metallurgy Processes

Some metallurgy processes (see Figure 4) for the production or purification of metals with high temperatures are using melting sand in order to separate the noble metals from the base metals. To avoid the formation of metal oxides, reduction agents - like carbon containing products - have to be added.

Many trials in practice have shown that the glass of LCDs can be used as a substitute for the melting sand or Silica containing materials and the plastic foil of the LCDs can be used as a substitute for the coal.

Due to the substitution of the used raw materials 'silica and coal' by LCDs this process is considered a 'Recovery Process' with a recovery rate of approximately 99%.

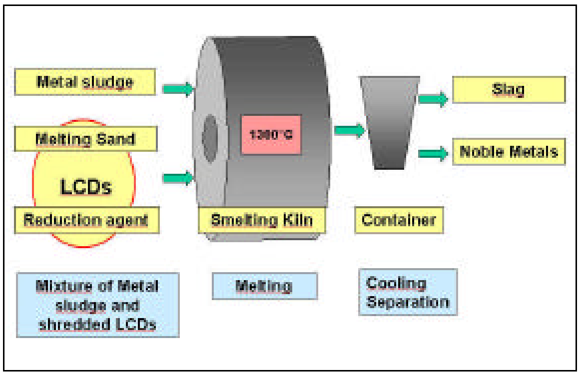

Fig. 4 Metallurgy Process

FINAL REMARKS

Merck KGaA is a member of the Responsible Care Initiative of the Chemical Industry in Europe and feels responsible for its products and the environment from the development until the final recycling, recovery or disposal. Therefore, apart from the intensive toxicological and eco-toxicological testing carried-out by Merck for numerous liquid crystals (1,3) and the self-commitment not to introduce acutely toxic or mutagenic substances into the market (5) Merck has engaged itself into this subject of LCD recycling resp. recovery. This is particularly remarkable since liquid crystals represent only a minor quantity and cost share of the entire LCD.

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