Chemistry for Sustainable Recycling: One course in our master program about sustainable chemistry, SU, Stockholm

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Abstract: The newly developed course (7.5 hp) in ”Chemistry for Sustainable Recycling” gives an overview and chemistry background on subjects related to a few different recycling projects. The course is composed of lectures and four different lab project (3 days each) with a follow up seminar.

1. Recycling of metals from E-waste, PCB (Al, Au and Cu).
2. Recycling of batteries (Litium, Cobalt, Manganese and NiMH).
3. Recycling of plastic (PET)
4. Recycling of phosphate from wastewater sludge and comparison with horse manure.

Many recycling processes do involve several chemicals where security issues are very important. A long-term goal would be to minimize the environmental impact as well from chemicals as the consumption of energy. Lab procedures in this very course do not exactly mimic industrially applicable processes in many cases but are intended to demonstrate important chemistry concepts.

Keywords: recycling, sustainability, analysis

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1 Recycling of precious metals from E-waste

Gold and copper were recovered from crushed E-waste in different forms (Akcil et al., 2015; Wu et al., 2017). Gold was precipitated as metal powder by reduction of $AuCl_4^-$(aq) complexes. Exactly if the complexes had this composition is a bit uncertain since we had several different complexes predicted from thermochemical calculations. This was also an opportunity to question the exactness and quality of databases with thermodynamic information. Our software Medusa (Puigdomenech, 2020) had several gold complexes not documented in some articles we looked up from University library for background information.

1.1 Procedure for extraction of Cu and Au

The recovery of metals from the finely cut E-waste was divided in two steps.

- Firstly: dissolution of Cu with nitric acid, HNO_3(aq). Not very environmentally friendly, but since this course was meant to demonstrate some principles and predictions how to construct processes from basic chemical knowledge this was accepted.
- Secondly: The residues of Au were dissolved in aqua regia, filtered, diluted, and partly neutralized before the reduction of the gold complexes were done with ascorbic acid.

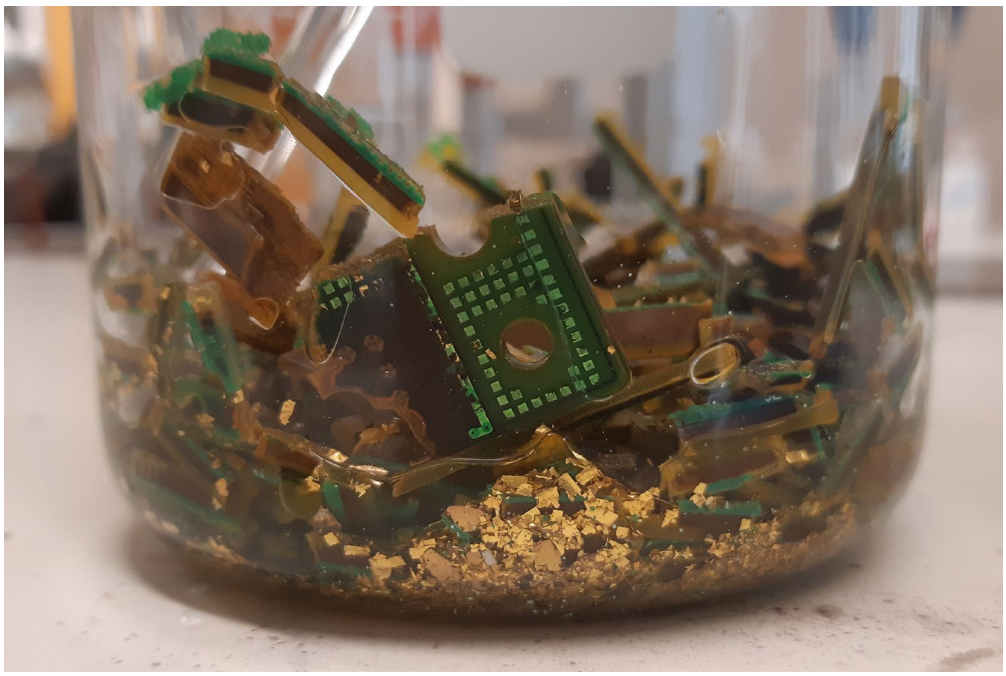

Figure 1. Gold flakes separated from the PCB by dissolving Cu layers in nitric acid solutions.

2 Recycling of critical metals from old batteries

An attempt to recover Cobolt and Lithium from old Lithiumbatteries (LiB) were done by dissolving in acid media (Ekberg & Petranikova, 2015). However it turned out to be difficult to solubilize the cobalt compound, even though a reducing agent (ascorbic acid) was used. Also, it was problematic to separate the Li content since it occurred as a soluble salt. The analysis of Cobalt was straightforward in SEM nut Li was difficult to quantify.

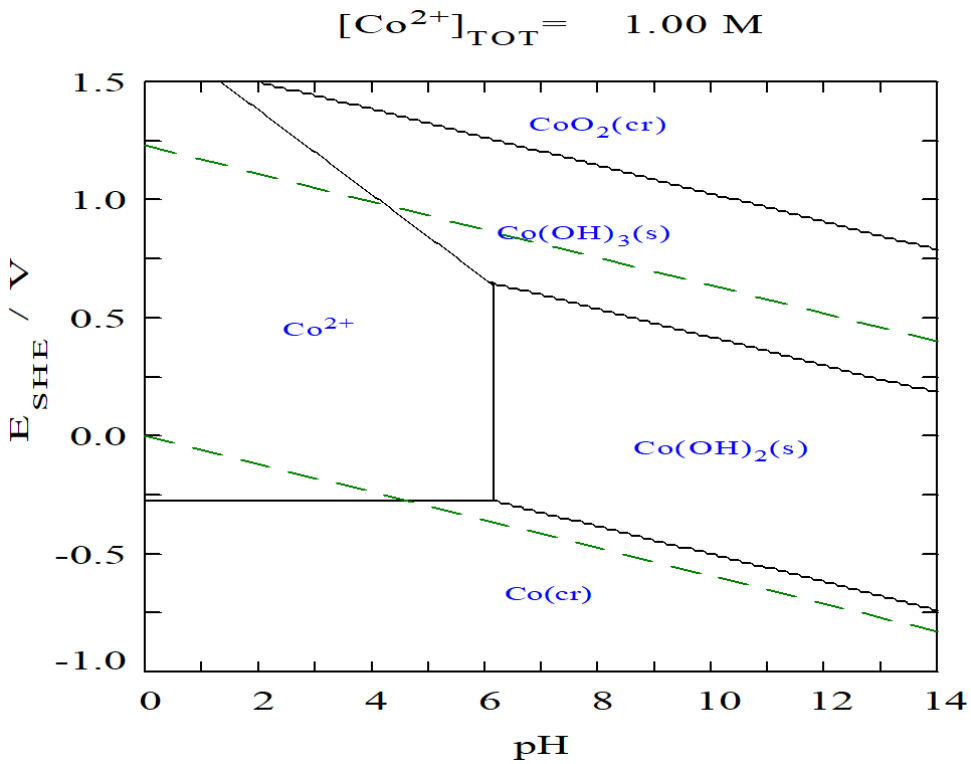

Figure 2. Pourbaix diagram for Cobalt

3 Recycling of plastics from PET bottles

Polyethylenetherephtalate, PET is a common plastic material used for various containers and bottles for food. Since it is an ester, it could be hydrolysed in basic solutions. Various conditions were tested, ambient pressure and boiling as well as higher pressures and temperatures in autoclaves. In general, the result was that higher temperature and thus higher pressure resulted in more complete depolymerization. The pure terephthalic acid was identified by PXRD and later used together with recycled Al cans in an attempt to produce an Al-MOF (Panda et al., 2020).

Figure 3. PET plastic and autoclaves

4 Recycling of phosphate from various sources

Phosphor is considered as a critical element, mainly for its importance as a nutrient with limited resources in the world. Two different sources of phosphate were investigated: wastewater sludge and traditional horse manure. Both samples were investigated with similar methods. Dry weight content, calcination and checking of P content in SEM. Large amounts of Fe and Si were detected in wastewater sludge and horse manure, its seems that horses eat soil… Traditional phosphor analysis with molybdenum blue complexes using spectrophotometric analysis were also done as a complement to SEM analysis. The solid calcined waste was analyzed with PXRD and two Fe-phosphates were identified. From horse manure mainly SiO_2 was identified.

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