

## **BIODEGRADATION OF USED MACHINE TOOL CUTTING FLUIDS**

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### **ABSTRACT**

The loss of an agreed route for the disposal of used machine tool cutting fluids prompted the development of a new disposal process based on biodegradation, which has the potential to convert machine tool cutting fluids to forms more suitable for disposal as aqueous or solid waste. The feasibility of biodegradation was demonstrated through external research contracts. Three systems were examined, i.e. a model activated sludge system, a biofilm system incorporated in a biotower and a tank bioreactor. Significant biodegradation was reported for each system. Consequently, AWE installed an 80 litre tank bioreactor in a non-radioactive area to optimise the conditions for biodegradation and to select suitable methods for downstream treatment.

The micro-organisms performing the biodegradation were selected from the natural population in used, non-radioactive machine cutting fluids held at AWE awaiting disposal. When established, they achieved a significant biodegradation (at least 60%), producing carbon dioxide and biomass. Ultrafiltration of the output of the bioreactor concentrated the biomass and residual organic material. The organic content of the permeate from ultrafiltration was further reduced to the standard for discharge to the environment by passage through a carbon filter.

### **INTRODUCTION**

During metal machining, a cutting fluid is sprayed onto the worked surfaces to lubricate, clean and cool the contact areas. Recirculation of the cutting fluid leads to an accumulation of metal and machine oil. AWE has instigated an Integrated Coolant Management System to deal with waste cutting fluids from the machining of special nuclear materials (as presented at Waste Management 98(1)).

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A novel disposal route for used coolants is being developed as part of this system because the previous disposal route has been withdrawn. The requirements of any new disposal route are that it should fulfil AWE's environmental and health and safety commitments and be acceptable to the agencies that regulate AWE's activities, i.e. the Environment Agency and the Nuclear Installations Inspectorate.

The machine cutting fluid under study is Solcut BR. It contains mineral oil, which is suspended / emulsified in water with anionic and non-ionic surfactants, and a phenolic biocide, which is incorporated to prolong the in-use efficacy of the cutting fluid by inhibiting microbial growth. The mixture of organic material, fissile material and water in used cutting fluid is not readily stabilised in a form suitable for long term storage (1). Cementation after adsorption onto clay granules was possible, but the volume of oil stabilised was only about 1% of the package. Separation of the emulsion followed by immobilisation of the oil on polymers was not possible. The immobilised oil did not meet the pressure and leach criteria for storage, and the water after removal of the oil contained high concentrations of chloride and organic material.

It was recognised that the propensity of cutting fluids to biodeteriorate during use may offer a means of waste treatment. Thus, AWE commissioned 3 separate studies of the feasibility of applying biodegradation to the disposal of Solcut BR. This paper summarises the results of the feasibility studies and it describes AWE's experience of establishing a bioreactor system to pursue the development of biodegradation.

## **METHODS**

### **External Feasibility Studies**

Each feasibility study examined the same sample of Solcut BR (as analysed in Tables I and II) but used different systems as outlined below.

#### **(i) Model Activated Sludge Plant**

This was a 10 litre vessel that was equipped for stirring and aeration. It contained 455 ml used Solcut BR (nominally 10%) diluted to 10 litres with water used to dilute samples for the determination of Biological Oxygen Demand and it was seeded with activated sludge at 1000 mg mixed liquor suspended solids (MLSS)/l. The MLSS were taken from an activated sludge plant treating industrial waste waters from the production of various types of mineral oils. Nitrate and phosphate nutrients were not added.

#### **(ii) BioFilm System**

This was a Novacell water treatment system (capacity 50 litres), which incorporates a fixed film biotower. A solution of 10 litres of used Solcut BR and 40 litres of a nutrient solution were recirculated around the system. Citric acid was added to maintain a pH between 6.5 and 7.5 and the temperature was maintained at 27°C. The operators used a proprietary source of micro-organisms and nutrients.

(iii) Tank Bioreactor

This was a 100 litre stainless steel vessel that was mixed and aerated by passing air at 5 l/min through an airstone positioned at the bottom of the vessel. The vessel was equipped with in-line probes for pH, dissolved oxygen and temperature. A probe in the exhaust gas monitored carbon dioxide. The bioreactor, which was operated in batch mode, contained used Solcut BR (diluted in tap water to a nominal concentration = 1%), sodium nitrate (364 g), and potassium dihydrogen phosphate (29 g). The mixture was aerated for 1 day before inoculation with 90 ml of a culture of micro-organisms grown from those present in the sample of used Solcut BR provided. The inoculum had been grown in 100 ml of a nominally 2% dilution of used Solcut BR enriched with nitrate and phosphate in a 100:10:1 molar ratio C:N:P. The growth medium was contained in a 250 ml conical flask and shaken at ambient temperature for 6 weeks.

**Biodegradation Trials at AWE**

The tank bioreactor installed at AWE was an Applikon Bioclave 110, having an 80 litre working volume. The liquid was stirred at 200 rpm and aerated through a sparge bar with air at 5 l/min (unless otherwise stated). It was equipped for monitoring dissolved oxygen (Broadley James Oxyprobe Model 20 Dissolved Oxygen Transmitter), pH and temperature (Broadley James Model 10 pH Transmitter), and the concentration of carbon dioxide in the outlet gas (Crowcon Deltagas). Biodegradation was performed at ambient temperature, which was around 20 - 25 °C for the trials shown.

**Growth of Micro-organisms in Dilute Solcut BR**

Growth Media

Growth of micro-organisms from Solcut BR was initially encouraged in 0.5% unused Solcut BR diluted in demineralised water supplemented with 1.82 g/l sodium nitrate and 0.15 g/l potassium dihydrogen phosphate. The molar ratio of C:N:P in the medium was estimated to be 100:10:1 assuming that Solcut BR is 80% w/w carbon. Subsequent growth media were prepared as above but with a stock sample of Solcut BR that had been worked at a nominal concentration of 10%. Later analysis of the organic material in this stock recorded a Total Organic Carbon (TOC) = 36,000 mg/l and a Chemical Oxygen Demand (COD) = 190,000 mg/l. Comparison of these values to the values found for unused Solcut BR (TOC =  $7 \times 10^5$  mg/l, COD =  $2.6 \times 10^6$  mg/l) suggests that the concentration of this solution was about 6%. The trials in the bioreactor started with dilutions of either this nominally 10% worked solution or one worked at 2% nominal concentration (TOC = 9600 mg/l, COD = 50,000 mg/l). Both had been derived from the same stock of unused Solcut BR. The nominally 2% stock was diluted 4 fold in demineralised water to start the first AWE trial (Figure 2). The nominally 10% stock was diluted in tap water to start the trials shown in Figures 3 and 4.

**Enrichment of Natural Micro-organisms in Solcut BR**

Before starting the biodegradation in the bioreactor, the microbes present in 4 samples of used Solcut BR (of different ages from 1 year to > 3 years) were re-activated by inoculating 1 ml of a sample into 100 or 200 ml of a growth medium prepared from unused Solcut BR (as

described above). The media were shaken gently in 200 or 500 ml conical flasks at room temperature. Motile bacteria, which were small and coccoidal, developed from all 4 samples within 3 days. After 10 days, 10 ml aliquots from each sample were added together to 2 x 250 ml of a batch of a growth medium prepared from worked Solcut BR and held in 1000 ml conical flasks. After shaking for a further 10 days at room temperature, these sub-cultures and the initial cultures were pooled to start the first biodegradation trial. With the successive trials in the bioreactor (runs 1 - 5), there was a carry-over of about 2 - 3 litres of biotreated fluid, which contained micro-organisms, from the previous run.

### **Monitoring Microbial Activity**

Microbial growth was monitored by microscopic observation and by measurement of the dry weight of material recovered by centrifugation. Duplicate 10 ml samples of the bioreactor fluids were centrifuged at 8000 rpm in a Jouan centrifuge (model BB VVV). The supernatant liquid was removed by decantation and the pellet was transferred to a weighed aluminium cap using demineralised water. The cap plus centrifuged pellet was dried at 105 °C for 2- 3 days and weighed.

The extent of biodegradation in Figure 1 was monitored by measuring TOC and COD using standard waste water methodology. Otherwise TOC, COD and phenols were measured using Dr Lange Test kits LCK 381, LCK 380, LCK 014, LCK 114 and LCK 345 according to the manufacturer's instructions.

### **Downstream Processing of Bioreactor Output**

The output from the bioreactor (about 75 litres) was filtered through a Membrex ESP 50 portable ultrafiltration unit equipped with a 0.1 micron polyacrylonitrile membrane with a hydrophilic coating. This produced about 73 litres of permeate and 2 litres of retentate, which contained concentrated biomass, precipitated material and residual oils. The permeate from the ultrafilter was passed directly through a column of activated charcoal (Jacobi Carbons).

## **RESULTS AND DISCUSSION**

### **Composition of Solcut BR**

Solcut BR was formulated by Houghton Vaughan in the UK to contain 70 - 80 % refined mineral oil. Worked solutions of Solcut BR present a high Chemical Oxygen Demand (COD) when added to waste water. A working dilution of 10 % has a COD = 260,000 mg/l and a Total Organic Carbon (TOC) content = 70,000 mg/l prior to use.

The broad groups of organic components present in used Solcut BR were identified during the feasibility studies (Tables I and II). The mineral oil consisted mainly of branched aliphatic and cyclic hydrocarbons. The surfactants were petroleum sulphonates, fatty acids, tall oil fatty acids and ethoxylated octanoic acid. The formulation also contained the biocide "cresylic acid", which is a mixture of the isomers of cresol, xylenol and ethylphenol from coal tar (2).

The literature gives some guidance on the expected biodegradability of these compounds (Table 1).

Table I Expected Biodegradability of the Organic Components Detected in the Batch of Used Solcut BR Examined in the Feasibility Studies  
(qualitative analysis performed by MScan, Ascot, UK. (3))

| Component of Solcut BR                                                 | Biodegradability                                | Reference       |
|------------------------------------------------------------------------|-------------------------------------------------|-----------------|
| <b>Hydrocarbons</b>                                                    |                                                 |                 |
| n-aliphatic alkanes                                                    | easy                                            | (4)             |
| cyclic aliphatic alkanes                                               | easy - cyclohexane- to difficult                | (5)<br>(6)      |
| branched aliphatic alkanes                                             | difficult - if highly branched                  | (4)             |
| aromatic - single ring                                                 | easy - benzene, phenol                          | (4)             |
| polyaromatic                                                           | moderate - 2 or 4 rings to difficult - >4 rings | (4), (7)<br>(8) |
|                                                                        |                                                 |                 |
| <b>Surfactants</b>                                                     |                                                 |                 |
| alkylbenzene sulphonates                                               | easy                                            | (5)             |
| bicyclicnaphthenaromatic sulphonates                                   | moderate                                        | (5)             |
| tricyclicnaphthenaromatic sulphonates                                  | ?                                               |                 |
| tetracyclicnaphthenaromatic sulphonates                                | ?                                               |                 |
| oleic, linoleic, linolenic acids                                       | easy                                            | (5)             |
| rosin acids (dehydroabietic, abietic acids)                            | easy ?                                          | (5)             |
| ethoxylated octanoic acid                                              | easy                                            | (5), (9)        |
|                                                                        |                                                 |                 |
| <b>Cresylic Acid</b>                                                   | easy to difficult depending on concentration    | (4)             |
| methylphenols (ortho, meta, para-cresol)                               | easy to moderate                                | (4), (10)       |
| xlenols (methylcresols)<br>2,3; 2,4; 2,5; 2,6; 3,4; 3,5 dimethylphenol | easy to moderate ?                              | (11), (12)      |
| ethylphenols                                                           | ?                                               |                 |
| trimethylphenols                                                       | moderate - difficult ?                          | (13), (12)      |

The straight chain fatty acids (oleic, linoleic, linolenic), the ethoxylated octanoic acid, and the n-alkanes are readily biodegradable, although biodegradability of the n-alkanes decreases with increasing chain length. The rosin acids are derived from tall oil, which is a by-product of the timber industry. The rosin acids are considered to be biodegradable, although the large lignin polymers are generally recalcitrant.

When alkylbenzenesulphonates were first introduced, their biodegradation was found to be impeded by the presence of methyl branching in the hydrocarbon chain (4). Molecules with a penultimate quaternary carbon as  $C-(CH_3)_3$  were particularly recalcitrant. The detergent industry moved over to the synthesis of linear alkyl benzene sulphonates when these problems were encountered in the 50's. Thus, it is likely that the alkyl benzene sulphonate surfactants in Solcut BR are biodegradable.

The branched chain and polyaromatic components of the hydrocarbons and surfactants would be expected to be more recalcitrant than the straight chain alkyl components. Compounds containing one or two aromatic rings are generally readily biodegradable (unless they are substituted with xenophore(s)). Polyaromatics are generally more recalcitrant but they can be degraded under laboratory conditions.

Although the analysis of Solcut BR revealed the presence of branched and cyclic petroleum hydrocarbons, it did not indicate the nature of the branching and it did not quantify the amounts of the different types of hydrocarbon. Thus, it was not possible to estimate the amount of hydrocarbon that would be expected to be recalcitrant.

The cresylic acids are present in the Solcut BR formulation to inhibit microbial degradation of the in-use solution but they are not completely effective. The literature suggests that cresylic acid can be biodegraded but its ease of biodegradation will depend on its composition (Table I). Kar et al (10) found that meta-cresol or para-cresol were biodegradable at 800 ppm. However, the dimethyl and ethyl phenols are more biocidal than the methyl phenols (cresols) (2) and may be less biodegradable.

A further factor that could influence the biodegradability of Solcut BR is its metal content and so the solution that was examined in the feasibility studies was analysed for metals (Table II). In general, heavy metals inhibit microbial growth when present at ppm concentrations (15). The feasibility studies treated dilutions of the used Solcut BR which would have reduced the potential for metal toxicity. Moreover, microbial growth on Solcut BR would have been encouraged by the presence of some of these metals, e.g. potassium, magnesium, iron, zinc, and manganese (15).

Table II Quantitative Analysis of the Batch of Used Solcut BR Examined in the Feasibility Studies

(analysis performed by Environmental Impact Analysis Group, University of Derby (14))

| Component              | Concentration (mg/l) | Component | Concentration (mg/l) |
|------------------------|----------------------|-----------|----------------------|
| Organics               |                      |           |                      |
| Total Hydrocarbon      | 56,200               |           |                      |
| Chemical Oxygen Demand | 138,000              |           |                      |
|                        |                      |           |                      |
| Metals                 |                      | Metals    |                      |
| Calcium                | 107                  | Arsenic   | 0.038                |
| Magnesium              | 50.7                 | Cadmium   | 0.005                |
| Iron                   | 1.88                 | Chromium  | 0.062                |
| Manganese              | 0.079                | Lead      | 0.507                |
| Potassium              | 231                  | Mercury   | 0.006                |
| Zinc                   | 0.907                | Selenium  | 0.156                |
| Copper                 | 3.46                 | Nickel    | 0.612                |
|                        |                      | Aluminium | 0.161                |
| pH                     | 8.4                  | Sodium    | 89.1                 |

### **Summary of the Three Feasibility Studies**

Each feasibility study had a different approach to the examination of the biodegradation of Solcut BR. One study examined the cutting fluid as a sewage treatment plant would examine a novel waste stream. The second study treated the cutting fluid in a fixed film biotower. The third study treated the cutting fluid in a 100 litre tank bioreactor with micro-organisms derived from Solcut BR.

#### **(i) Model Activated Sludge Plant**

In this system the mixed liquor suspended solids (MLSS) taken from an activated sludge plant treating oily industrial waste waters were shown to reduce the content of Dissolved Organic Carbon (DOC) in solutions of Solcut BR by 60% in 9 days. The reduction in COD was similar but the measurements were more variable than the measurements of DOC. This study followed the standard methodology for the water industry and was concerned with the removal of water soluble organic material. It did not relate the loss of water soluble material to the loss of oil and it did not measure the production of carbon dioxide.

## (ii) BioFilm System

A 5 fold dilution of used Solcut BR was recirculated over the biofilm in the biotower for several weeks. The hydrocarbon content and COD of the recirculated liquid fell to 1100 and 9300 mg/l after 1 week, reductions of 90 % and 66%, respectively (based on the values shown in Table II). After 5 weeks, the values for hydrocarbon and COD were 108 and 1450 mg/l, reductions of 99% and 95% respectively. Although these reductions were encouraging, the study did not estimate how much of the organic material was removed by adsorption onto the biomass and packing material in the biotower and how much was released as carbon dioxide.

## (iii) Tank Bioreactor

The tank bioreactor, which was operated at ambient temperature around 16 °C, achieved an 89% reduction of TOC from 830 to 90 mg/l. This was paralleled by an 86% reduction of COD from 3100 to 440 mg/l. Most of the TOC and COD was removed during the first 5 days (Figure 1).

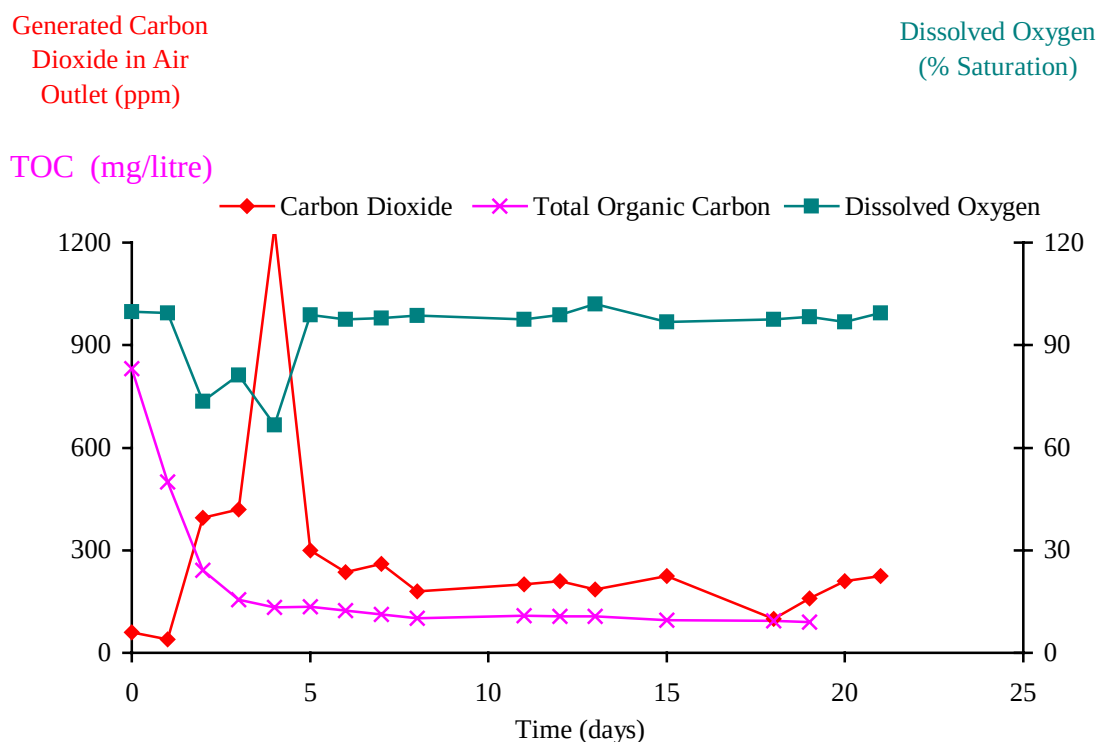


Figure 1 Feasibility of Biodegradation of Solcut BR in 100L Bioreactor

The loss of TOC was accompanied by an output of carbon dioxide and a consumption of oxygen (as shown by a reduction of the concentration of oxygen dissolved in the bioreactor liquid). The pH of the mixture was generally 8.4 - 8.5, falling temporarily to 7.8 during the peak of carbon dioxide production.

The petroleum sulphonates, rosin acids and ethoxylated octanoic acid components of used Solcut BR were not detected after biotreatment. Traces of a compound tentatively identified as oleic acid were detected but none of the other fatty acids were detected. Hydrocarbons were present at 4 mg/l and so made only a small contribution to the residual TOC of 90 mg/l. Phenolic compounds were detected at 15 mg/l. Thus, it was concluded that the phenolic biocide had probably not been degraded to the same extent as the other components of Solcut BR. The identity of the other compounds that contributed to the residual TOC was not established, although there was some evidence for presence of C<sub>6</sub> and C<sub>8</sub> carboxylate anions.

This study did not perform a mass balance on the fate of the organic carbon added to the bioreactor. It was estimated from Figure 1 that the amount of carbon liberated as carbon dioxide constituted about 20% of the TOC added to the bioreactor. About 10 % of the TOC remained in the biotreated liquid. From day 5 a floating flocculated layer of biomass was observed which started to break up at about 19 days. The fact that it floated indicates that it was associated with oil. It is probable that the 70% of the added carbon unaccounted for was associated with the biomass.

### **Experience Establishing Biodegradation at AWE**

The above results encouraged AWE to install a bioreactor in a non-radioactive area in order to pursue the development of biodegradation. The aim was to optimise the biodegradation step and to develop the processing required to stabilise the output from the bioreactor as waste.

It was decided to install a stirred tank bioreactor rather than a biotower. The advantages of the stirred tank are its greater oxygen transfer rates and the ability to take representative samples so that a mass balance can be performed. The following parameters were monitored during the trials at AWE:- carbon dioxide output, concentration of oxygen dissolved in the bioreactor liquid, and the concentrations of TOC, COD, phenols and biomass.

The AWE trials of biodegradation exploited the micro-organisms present in used Solcut BR. The trials started with Solcut BR diluted in demineralised water giving a TOC = 3100 mg/l and COD = 9100 mg/l. This solution was fortified with 2.83 g/l sodium nitrate and 0.45 g/l of potassium dihydrogen phosphate nutrients. The AWE bioreactor was operated with stirring at an ambient temperature around 25°C (i.e. under conditions that were expected to be more conducive to microbial growth than those used in the feasibility study). The patterns of carbon dioxide and oxygen consumption observed were similar to those observed in the feasibility study except that the initial production of carbon dioxide occurred in 2 peaks (Figure 2). As expected, each peak was associated with a reduction in the amount of oxygen in solution in the bioreactor. The occurrence of 2 peaks indicates that the microbial culture in the bioreactor initially had the capacity to metabolise one set of compounds in Solcut BR but that it had to adapt to metabolise further compound(s).

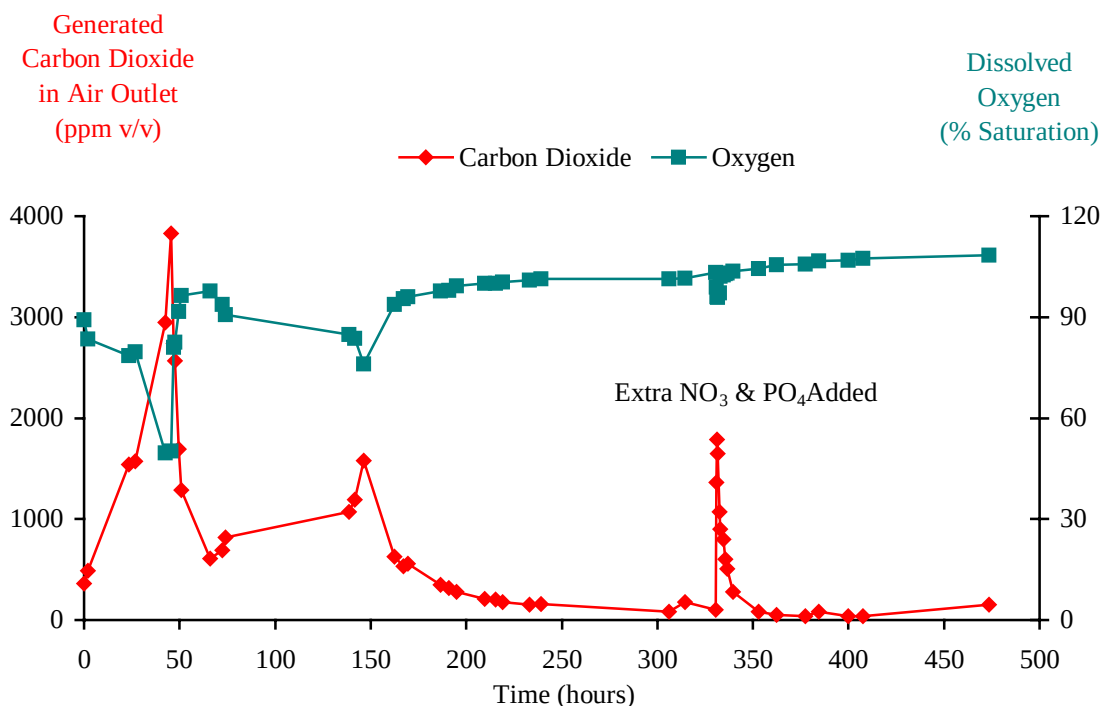


Figure 2 First AWE Trial of Biodegradation of Solcut BR

However, the amount of carbon dioxide produced was only about 10% of the amount of organic carbon added and there was no measurable loss of TOC and COD. The addition of extra sodium nitrate (1.41 g/litre) and potassium dihydrogen phosphate (0.23 g/l) after 330 hours did not stimulate further activity. The transient release of carbon dioxide upon addition of the salts is ascribed to the fall in pH from 7.95 to 6.9.

Two subsequent trials (runs 2 and 3) were performed. Run 2 started with a 2.5% nominal concentration (actual COD = 46,000 mg/l). Run 3 started with a 0.5% nominal concentration (actual TOC = 3,600 mg/l, COD = 14,000 mg/l). The Solcut BR for run 3 was derived from several different old samples. Both runs showed the initial peaks of carbon dioxide production and associated oxygen consumption but neither produced a measurable loss of organic material. After the first peaks of carbon dioxide production, microbial activity in run 3 was not revived by the addition of :- 4 mg/l ferrous sulphate, 8 mg/l calcium chloride, 110 mg/l magnesium sulphate, 50 mg/l yeast extract, 2.2 g/l ammonium sulphate, and a further 0.46 g/l potassium dihydrogen phosphate (data not shown). Likewise, it was not stimulated by increasing or decreasing the mechanical action due to the stirring and air flow and by lowering the pH to about 6.

When possible reasons for the differences in bioreactor performance at the 2 sites were examined, it was realised that the feasibility study shown in Figure 1 had started with a lower

concentration of organic material than the AWE trials. Furthermore, the Solcut BR had been diluted in tap water rather than in demineralised water. It was argued that a lower concentration of Solcut BR may be less inhibitory to those microbes that would perform the biodegradation of the less readily degradable compounds. Thus, for the fourth run Solcut BR was diluted to a nominal concentration of 0.1% in tap water (hardness about 260 ppm as  $\text{CaCO}_3$ ) similar to that used in the feasibility study. The concentrations of the other nutrients were those used in the feasibility study (i.e. 3.64 g/l sodium nitrate and 0.29 g/l potassium dihydrogen phosphate). Starting with a lower concentration of Solcut BR (actual TOC = 540 mg/l and COD = 2400 mg/l) stimulated biodegradation. There was a further peak of carbon dioxide production at 15 days (10 days after the initial burst of activity) (Figure 3). This activity was associated with a measurable increase in the concentration of biomass in the bioreactor from <0.1 to 0.5 g/l and a measurable loss of TOC and COD (Figure 3).

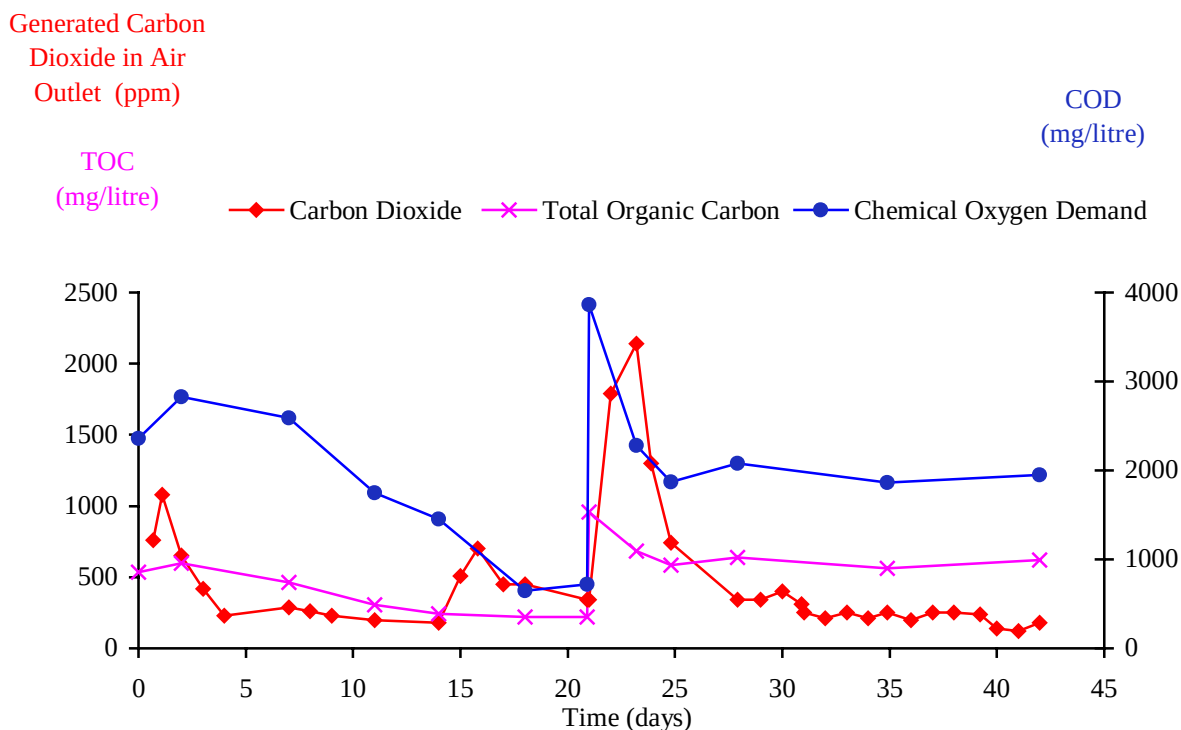


Figure 3 AWE Runs 4 and 5 Establishing Biodegradation of Solcut BR

It was thought that the metabolic capability of the microbial culture had been extended during run 4. A second addition of Solcut BR was made after 21 days, which increased the TOC by 734 mg/l and the COD by 3100 mg/l). This was supplemented with 0.92 g/litre sodium nitrate and 0.15 g/l potassium dihydrogen phosphate (Figure 3). The second addition Solcut BR (at the start of run 5) was degraded more quickly than the first addition: the extent of biodegradation achieved after 7 days (50 % reduction of TOC, 63% reduction of COD) was similar to that

achieved at the end of run 4. The total reductions of TOC and COD 21 days after the second addition of Solcut BR were 55 % and 65 % respectively.

Run 6 was started with the same conditions as run 4 except that it was seeded with the mixture of biomass, associated material and oil that had been concentrated from previous runs by ultrafiltration. Stirring was applied for only the first 11 days, which was the period of greatest microbial activity. Thereafter, aeration alone was sufficient to maintain a dissolved oxygen concentration > 60 % air saturation.

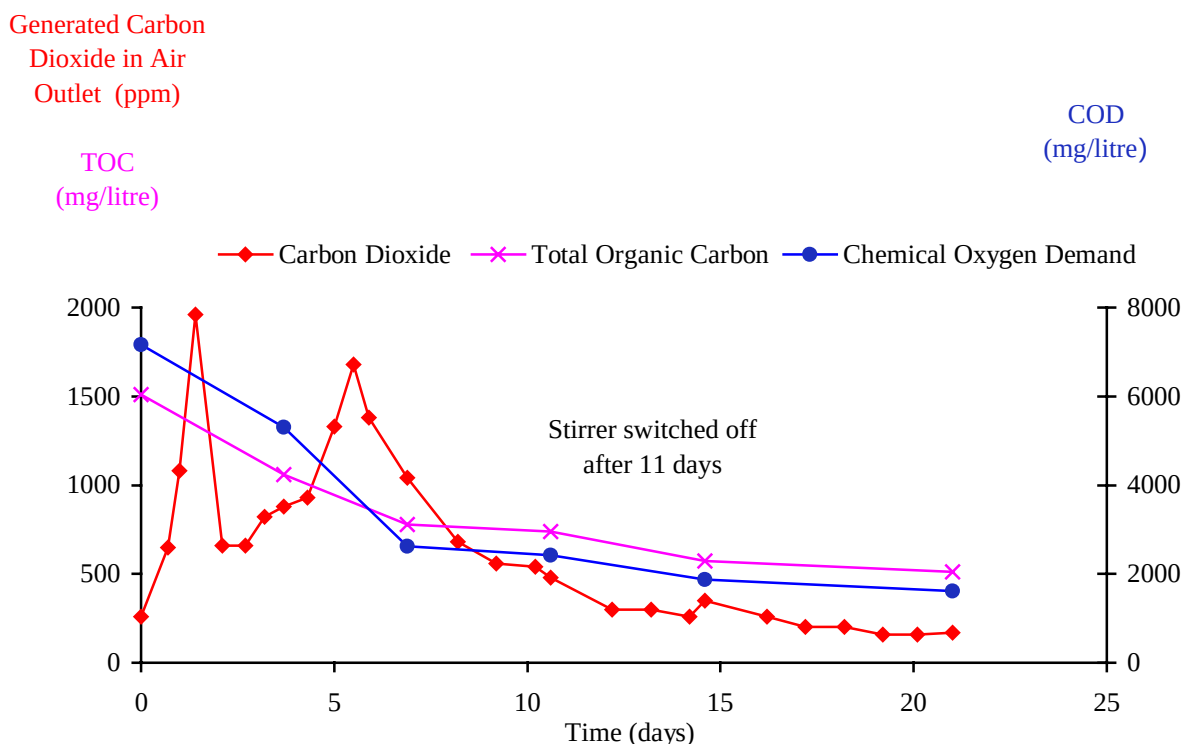


Figure 4 AWE Run 6 - Showing Biodegradation of Solcut BR

The extent of biodegradation was similar to that achieved in runs 4 and 5 (66% reduction of TOC, 77% reduction of COD). The concentration of phenols was reduced by 85% from 24 mg/l to 3.6 mg/l.

The organic carbon added to run 6 was converted approximately equally to carbon dioxide or biomass and associated material or residual “solubilised” organic material that did not sediment upon centrifugation (Table III). Carbon dioxide did not accumulate in the biotreated liquid as inorganic carbon, being removed in the air stream.

Table III Conversion of Carbon During Biodegradation at AWE

| State of Carbon       | Parameter                                                 | Time (days) |        |       |       |       |       |
|-----------------------|-----------------------------------------------------------|-------------|--------|-------|-------|-------|-------|
|                       |                                                           | 0           | 4      | 7     | 11    | 15    | 21    |
| Solution/<br>Emulsion | Total Amount of Organic Carbon (grams)                    | 121         | 84.5   | 62.4  | 59.2  | 45.9  | 41    |
|                       | TOC as % of Added Carbon                                  | 84 %        | 58.6 % | 43 %  | 41%   | 32 %  | 28 %  |
|                       | Total Amount of Inorganic Carbon (TIC) (grams)            | 9.4         | 11.2   | 9.2   | 8.1   | 7.4   | 8.5   |
|                       | TIC as % of Added Carbon                                  | 6.5 %       | 7.8 %  | 6.4 % | 5.6 % | 5.1 % | 5.9 % |
| Carbon Dioxide        | Total Amount of Carbon Removed as CO <sub>2</sub> (grams) | 0           | 11     | 25    | 34    | 39    | 46    |
|                       | CO <sub>2</sub> Carbon as % of Added Carbon               | 0           | 7.6 %  | 17 %  | 24 %  | 27 %  | 32 %  |
| Biomass               | [Biomass] (g dry wt/litre)                                | 0.25        | 0.5    | 1.55  | 1.5   | 1.45  | 1.3   |
|                       | Amount of Carbon as Biomass (grams)                       | 14          | 22.7   | 69.6  | 60.8  | 47.8  | 35    |
|                       | Biomass Carbon as % of Added Carbon                       | 9.7 %       | 16 %   | 48 %  | 42 %  | 33 %  | 24 %  |
| Total Carbon (grams)  |                                                           | 144         | 129    | 166   | 162   | 140   | 131   |
| Accounted For (%)     |                                                           | 100 %       | 89 %   | 115 % | 112 % | 97 %  | 90 %  |

Extending the run to 54 days increased the conversion of TOC to carbon dioxide to 50 % but without affecting the reduction of “solubilised” TOC.

### **Downstream Processing of the Biotreated Liquid**

The residual dissolved/dispersed organic material and biomass in the biotreated fluid will require further processing before disposal as waste. It is envisaged that the generated biomass and any residual oil will be removed from the aqueous stream by ultrafiltration (UF). A trial of ultrafiltration using the output from run 6 demonstrated that UF can remove biomass and associated material as a concentrated UF retentate (Table IV). Part of the biomass concentrate from the ultrafilter could be recycled to the bioreactor to increase biodegradation rates. Possible routes for the disposal of surplus biomass are being pursued.

Table IV Efficacy of Ultrafiltration and Carbon Filtration of the Bioreactor Output

|               | Stage of Downstream Processing |        |             |     |                 |     |
|---------------|--------------------------------|--------|-------------|-----|-----------------|-----|
|               | UF Retentate                   |        | UF Permeate |     | Carbon Filtrate |     |
| COD<br>(mg/l) | Min                            | 4,700  | Min         | 580 | Min             | 5.2 |
|               | Max.                           | 53,000 | Max.        | 700 | Max.            | 6.2 |
|               |                                |        | Combined    | 610 |                 |     |

The UF permeate contained a significant amount of dissolved organic material that would preclude its discharge to the environment. However, the majority of this organic material was removed by passage through a carbon filter, which yielded an effluent that met the environmental discharge limit of 20 mg COD /l (Table IV).

## CONCLUSION

The work described in this paper shows that biodegradation can be applied to the disposal of used Solcut BR cutting fluid. Biodegradation converted an appreciable amount of the organic material in the Solcut BR into carbon dioxide. The organic material that remained after biotreatment could be separated by ultrafiltration into an-oil free aqueous stream and a biomass concentrate. The organic material that was dissolved in the oil-free aqueous liquid could be removed by carbon filtration so that the liquid met the limits on COD (= 20 mg/l) for discharge to the environment. It is expected that, when the process is transferred to treat Solcut BR containing special nuclear material, both the aqueous stream and the biomass will contain fissile material. The aqueous stream should be suitable for treatment along with the normal radio-active effluent. Possible methods for the stabilisation of the biomass are being examined.

Biodegradation has the potential to convert an oily material, that is difficult to treat by conventional means, into forms that are more amenable to waste stabilisation. The development work is continuing to improve the efficacy of the biodegradation step and to extend the scope of biodegradation to other organic waste materials from nuclear processing.

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