International Council for the Exploration of the Sea

CM 1974 / E : 10
Fisheries Improvement Committee

Review on scientific aspects of sea disposal of red mud

by

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Introduction

Two papers on the effects of red mud on marine organisms have been presented to the I.C.E.S. (DETHLEFSEN 1972, WILSON and BLACKMANN 1973). These papers reported results of Great Britain and the Federal Republic of Germany with the industrial waste, which were obtained during routine and experimental dumping as well as by laboratory work. The presentation of these papers was followed by intensive discussions in the course of which it appeared to be necessary to review the scientific literature on sea disposal and literature on results of laboratory work on the effects of red mud on marine organisms. The author of this report was asked to take up this task.

The waste

Red mud which is a by-product in the reduction of bauxite to Al_2O_3 has been described in its physical and chemical characteristics by DETHLEFSEN and ROSENTHAL 1973, ROSENTHAL 1971, BAUDART 1967, HEGENBARTH 1973, WILSON and BLACKMANN 1973 and from these descriptions it is quite obvious that this waste is not at all uniform. Physical and chemical differences depend on the origin of the bauxites, on the pretreatment, on processing, and on storage of the slurry.

These variations are specially marked in the pH of the liquor which ranges from 9.8 - 12.4, specific gravity from 1.22 - 1.87, % of solids 26% - 55%, contents of iron oxide 20% - 50%, particle size 50% 18 - 300 um (Australian bauxite), 50% 5 - 10 um (French Ghana bauxite).

The processing procedure following the Bayer process is briefly described by WILSON and BLACKMANN 1973. The main steps are crushing of the ore followed by washing and extraction of Aluminum with caustic soda. This last step forms the insoluble residue, the red mud. The quantities of the wastes produced per year in different countries are 800,000 tons (net weight) for one plant in Germany, 1,4 mio tons in France and 40,000 tons in Great Britain.

There are different countries who are at present discharging the red mud into the sea as for instance Japan, Jamaica, Italy and U.S.A., but scientific monitoring of possible effects of such discharges was carried out only in France, Great Britain and in the Federal Republic of Germany where an experimental dumping of altogether 15,ooo tons red mud was accomplished.

France

Since May 1967 a discharge of red mud 1,4 mio to/per year has been carried out by Pechiney, a factory which is located near Marseille in the bight of Cassis.

The red mud is pumped via pipeline of 7 km into a canyon at a depth of 330 m, this canyon is declining to 2,000 m. The hydrographic situation of this canyon appears to be extremely suitable for this discharging project because of the absence of strong currents. Besides that this area had no importance for local fisheries and the procedure of dumping does not interfere with amenities. So the changes in chemistry of waters are restricted to this rather small area. The highly alkaline liquor (pH 12) is neutralized, when it is mixed with sea water. The temperature of the waste is 35°C at the entrance to the pipeline and 22 - 25°C at the outlet. An important factor is that the red mud is not welled up to the surface.

Great Britain

For a period of 6 years a total amount of 300,000 tons of red mud produced in South Wales has been disposed of in the Newport Deep of the Bristol Channel. This area is characterized by very fast water currents which are 3.7 - 5.9 Km/h with a tidal range of 13 m, which guarantees high turbulence.

The red mud discharged into this area has been stored in land basins and was resuspended in water before being loaded into the discharge vessel. When this slurry was pumped overboard with 1,500 metric tons/h a high dilution rate was achieved. This very rapid dispersion in combination with fast currents did not lead to any accumulation of red mud in the sediments and no damages to fisheries were noted (WILSON and BLACKMANN 1973, DAVIES 1972).

Germany

In Germany an experimental dumping was carried out in an area which has been selected by German authorities particularly because of poor fishery activities. The hydrographic situation found in this area ($55^{o}5'$ N, $05^{o}30'$ E) is completely different from the two mentioned above.

The currents are rather weak compared with the Bristol channel, so a rapid mixture cannot be achieved, a continuous layer of red mud on the bottom was the result. But in comparison to the situation in the bight of Cassis the currents are still too strong as to allow a complete settlement in a very restricted area.

Chemical and physical behaviour of the waste when it is discharged.

As already said above, the chemical and physical behaviour of the waste is strongly influenced by hydrographic parameters at the dumping point.

High turbulence will lead to rapid neutralization and high dilution, so that silt contents will not be much different from what is normal in the respective area (WILSON and BLACKMANN 1973).

Absence of turbulence will favour a complete settlement of red mud particles and an inlet at a depth of 330 m will restrict chemical reactions to bottom waters (BOURCIER 1969).

Red mud mainly consists of natural minerals which are not soluble, so the major part of the waste is inert, but the liquor in which these particles are suspended undergoes quite a lot of chemical reactions. When contacting sea water a precipitate is formed consisting of yellowish-white flakes which are heavily hydrated. BAUDART and ZIBROWIUS (1973) describe this reaction:

$2\ (OH)^- + Mg^{++} = Mg\ (OH)_2$, but they say that the quantities of Mg fixed by this reaction are negligible for the open sea.

NAUKE (1973) found by X - ray - fluorescence analysis that the precipitates consisted of Al^{+++}, Fe^{++}, Ca^{++}, Cl^- and S^{--}, 15,6% of the total precipitate being Al_{203}.

A decrease of the Mg-contents of sea water at the point of inlet was measured in the bight of Cassis (GAUGENHEIM et al 1965).

Settlement and spreading of red mud.

Due to the high specific gravity the red mud sinks to the bottom immediately after being dumped, a small amount remains suspended and gives the surface layers of the dumping area an intensive red colour.

This colouring is more intensified when the dumping vessel starts to clean her tanks.

In the German dumping experiments altogether 15 000 t of red mud were discharged in portions of 1 000 t each in a time of 20 days.

The settlement and the distribution of red mud was investigated by means of Van-Veen grabs and the results were unexpected. When 15,000 t had been released a closed red mud layer was found in a rather large circle around the dumping point. Considerable amounts of red mud were drifted about 3 miles East and about 10 miles North-

west from the dumping point. Altogether red mud was found in an area of 250 km^2. This area was growing from dumping to dumping and a severe accumulation of red mud in the sediments occurred.

This behaviour of red mud was not at all acceptable because it was very probable that after a certain time of dumping a large area would be covered by a closed red mud layer thus endangering the bottom fauna.

Biological investigations

Investigations on the effects of red mud on marine organisms were conducted in France, Great Britain and Germany.

The results of German and British experiments which were presented to the I.C.E.S. in 1972 and 1973 were in good correspondence. The animals tested are listed in the table. Especially the comparative tests of WILSON and BLACKMANN 1973 were able to show differences of toxicity depending on the origin of the red mud. So the toxicity of German red mud (Weipa bauxites) was slightly higher than material from Great Britain.

All organisms tested showed more or less marked effects when they were exposed to red mud.

Damage on algae was mainly caused by mechanic effects of red mud particles, which are coagulating and coprecipitating with the algae thus reducing their individual numbers (Kayser 1973).

Filter feeders ingested the red mud which passed the intestinal tracts of test animals thus acting on the energy budget of the organisms (WILSON and BLACKMANN, 1973, WINTER, 1970, PAFFENHÖFER, 1972).

An-other effect on organisms was that red mud adhered on body surfaces of fishes, on gills of brown shrimp and on membranes of herring eggs (ROSENTHAL 1971). These adhering red mud particles resulted in marked physiological effects as were demonstrated by HALSBAND and HALSBAND (1971).

The food intake of plankton organisms like Beroe gracils (GREVE and KINNE 1971) and the copepod Calanus helgolandicus (PAFFENHÖFER 1971-1972) was interfered by the presence of red mud.

Benthic echinoderms which were covered by red mud layers also showed red mud particles adhering to their body surfaces, they were only very slowly able to free themselves from this red mud, when they were replaced in clean water.

To repeat the most striking effects:

1) Mechanical interference.
2) Adhesive properties of red mud.
3) Toxic effects of the liquor in high concentrations.

French investigations on the influence of the liquor in which red mud is suspendend on larvae of echinoderms gave no indication of damaging effects although these larvae are known to be extremely sensitive to changes in pH (GAUGENHEIM et al 1965).

The results of investigations on the bottom fauna in the area of experimental dumping were inclusive due to the short period in which the observations could be made.

APELT (1971) and RACHOR (1971) were not able to attribute changes in the fauna of the dumping area to ongoing dumping activities, but they did not even expect that, because the knowledge of the status quo before dumping was very poor and a catastrophic effect of the red mud on the bottom fauna was not expected.

But the investigations of BOURCIER (1969) and BOURCIER and ZIBROWIUS (1973) clearly demonstrate what happened to the bottom organisms, when they were exposed to red mud for prolonged periods.

At the axis of the canyon where a depot of rather fluid red mud had been built up bottom organisms were completely eliminated.

At the lateral zones of this area where red mud layers of some mm were found the benthic life did not show obvious signs of harm by red mud. In this special case the elimination of benthic organisms from a restricted area was not dramatic because the population

density is normally very low so that no se-vere disturbance of the ecological equilibrium would be the result.

Conclusions

The experiences of laboratory work and dumping projects show that the waste is slightly toxic, which holds true especially for the liquor in which the red mud particles are suspended.

Mechanic effects would disturb benthic organisms when complete layers of red mud are formed after dumping. These layers are formed when no high dilution can be achieved during dumping. High dilution is supported by high turbulence of water in the dumping area. Water without this turbulence would allow the red mud to settle down to the bottom. Weaker currents would distribute the red mud to a rather large area thus forming a thinner layer of red mud, which still would be thick enough to eliminate benthic life from this area.

Elimination of benthic life is acceptable in areas with normally very poor individual numbers but can not be accepted in areas with high population density and considerable fishery activities in the vicinity.

These few remarks may indicate, that there is no general answer to the question of whether red mud can be safely disposed of into the sea.

Regarding the low toxicity, the high quantities of solid, insoluble material in the waste and its adhesive properties, consideration of whether the waste can be dumped or not should be made with extreme care.

Basic factors for these considerations are given in two papers; 1. by PORTMANN and WILSON 1973, 2. by ROLFE 1973, who gave scientific outlines of factors to be considered in assessing the suitability of wastes for disposal and in the selection of a dumping ground.

The different decisions of German, British and French authorities mainly have their reasons in hydrographic and topographic differences of the dumping sites and in future it will depend on these factors too, when for example Norwegain authorities have to decide whether or not red mud can safely be disposed of in a fjord at the Norwegian coast.

Summary

A review of effects of red mud on marine organisms is given. Dumping projects in the Bristol Channel, the Bight of Cassis and in an area near Helgoland (North Sea) are compared in the light of hydrographic and topographic differences. It is concluded that there is no general answer to the question of whether red mud can safely be disposed of into the sea because every single case needs a special evaluation.

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Table 1

Organisms which were exposed to red mud in the laboratory

F.R. Germany

Organisms	Author	Organisms	Author
Dunaliella euchlora	Halsband und Halsband 1971	Scrobicularia plana	Wilson and Blackmann 197
Monadina	Dethlefsen 1972	Cardium edule	Wilson and Blackmann 197
Protococcus spec.	Halsband und Halsband 1971	Mytilus edulis	Wilson and Blackmann 197
Coscinodiscus granii	Kayser 1971, 1973	Crangon crangon	Wilson and Blackmann 197
Chaetoceros socialis	Kayser 1971, 1973	Agonus cataphractus	Wilson and Blackmann 197
Prorocentrum micans	Kayser 1971, 1973	Solea solea	Wilson and Blackmann 197
Mytilus edulis	Winter 1970		
Pleurobrachia pileus	Greve 1972		
Beroe gracilis	Greve und Kinne 1971 a		
Asterias rubens	Greve und Kinne 1971 b		
Echinocardium cordatum	Greve und Kinne 1971		
Ophiura albida	Greve und Kinne 1971		
Ophiura texturata	Greve und Kinne 1971		
Psammechinus miliaris	Greve und Kinne 1971		
Eupagurus bernhardus	Greve und Kinne 1971		
Calanus helgolandicus	Paffenhöfer 1972 a, b		
Crangon crangon	Halsband und Halsband 1971		
Pleuronectes platessa	Halsband und Halsband 1971		
Anguilla anguilla	Halsband und Halsband 1971		
Clupea harengus	Rosenthal 1971		