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E. T. Premuzic, M. S. Lin and J. Z. Jin

**Department of Applied Science
Biosystems and Process Sciences Division
Brookhaven National Laboratory
Upton, NY 11973**

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DEVELOPMENTS IN GEOTHERMAL WASTE TREATMENT BIOTECHNOLOGY

E. T. PREMUZIC, M. S. LIN and J. Z. JIN

Brookhaven National Laboratory, Biosystems and Process Sciences Division,
Department of Applied Science, Upton, NY 11973, USA

Abstract- Disposal of toxic solid waste in an environmentally and economically acceptable way may be in some cases a major impediment to large geothermal development. The major thrust of the R&D effort in this laboratory is to develop low-cost processes for the concentration and removal of toxic materials and metals from geothermal residues. In order to accomplish this, biochemical processes elaborated by certain microorganisms which live in extreme environments have served as models for a biotechnology. It has been shown that 80% or better removal of toxic metals can be achieved at fast rates (e.g., 25 hours or less) at acidic pH and temperatures of about 60°C. There are several process variables which have to be taken into consideration in the development of such biotechnology. These include reactor size and type, strain of microorganisms, biomass growth, temperature, loading concentrations of residual geothermal sludge, and chemical nature of metal salts present. Recent data generated by the research and development effort associated with the emerging biotechnology will be presented and discussed.

INTRODUCTION

Studies in this laboratory (Premuzic and Lin, 1989a,b; 1991a,b,c) have shown that a technically feasible and environmentally acceptable biotechnology for detoxification of geothermal residual sludges depends on several parameters. These include properties varying from reactor size and sludge loading to the chemical nature of salts and process temperature, all essential in the determination of cost-efficiency of the bioprocesses considered. The bioprocess investigated is based on biochemical solubilization of metals. Multi-element analyses of solubilization rates have consistently shown that in the initial phase, between 80%-90% of metals are transferred from the solid to liquid phase. Routine analyses were conducted by the use of Induced Coupled Plasma-Mass Spectrometry (ICP-MS) capable of a simultaneous detection of 70 metals (including isotopes) with sensitivity in ppm range (Date and Gray, 1989). Typical analytical results are given in Figure 1 for mercury and lead before and after biotreatment. Examples of rates of metal solubilization are given in Figures 2 and 3 for boron and copper. Similar results have been obtained with other metals including such metals as arsenic, mercury, radium, thorium, uranium, etc., which are present in some types of geothermal sludges. In the examples given, two types of bioreactors, tank and fluidized bed to be discussed later, have been compared.

The choice of a bioprocess was based on the following consideration. There are circumstances in which large quantities (i.e., tons) of a process end-product or by-product are produced containing small amounts (i.e., ppm) of materials which may be subject to environmental regulation and/or the materials are valuable, which would make their recovery advantageous. In such circumstances, conventional technologies for solubilization are by and large

Figure 1. ICP-MS Analysis for Mercury and Lead. 'A' before and 'B' after Biotreatment.

Figure 2. Rate of Copper Solubilization from Geothermal Residual Sludges.

Figure 3. Rate of Boron Solubilization from Geothermal Residual Sludges.

not suitable because of technical, economical and environmental reasons. Geothermal residual sludge, a by-product of geothermal power generation, falls into this category. In the Salton Sea area of California, USA, a 50 MW plant produces typically about 2,500 Kg/h of such sludge. The disposal costs of such sludge are increasing and therefore adding to the overall cost of geothermal power-production. For example, in 1985, the average cost of disposal for this type of sludge was two hundred dollars per ton because it contained toxic metals (e.g., copper, arsenic, etc.) compared to seventy-five dollars per ton for non-hazardous waste (Dobryn et al., 1986). An 80% reduction in the original concentration of the metals brings the material to be disposed of well within the range of non-hazardous waste. Thus, the biochemical process chosen represents about a 60% savings. It is to be understood, however, that the cost of disposal and long term liabilities are continuously increasing while the available space for disposal is diminishing. For example, at Brookhaven National Laboratory (BNL) disposal of a similar sludge cost \$500 per ton in 1991. The corresponding non-regulated waste disposal cost was \$100 per ton. If the sludge contains in addition to chromium and lead, say radium, then it has to be shipped at a cost of \$400 per cubic foot or \$14,000 per cubic meter. On the other hand, removal of the metals leaving radium alone produces waste costing \$76 per cubic foot or \$2,700 per cubic meter to dispose of, or \$10,800 and \$2,052 per ton respectively, representing a five-fold saving already achievable on a laboratory scale. Optimization of particular streams within the bioprocess, choice of bioreactors, construction materials and other process variables, allow for additional savings in the overall process. Some of these savings will be discussed in this paper.

EXPERIMENTAL

A flow diagram for a typical biochemical waste treatment plant in which a fluidized bed and agitated tank bioreactor can be interchanged is given in Figure 4. The process configuration shown in the flow diagram serves as the basis of studies which compare key process variables including types of bioreactors, flow rates, solid loading, filter type and size, and construction materials.

RESULTS AND DISCUSSION

Preliminary studies in which various sludge loadings have been considered have shown that an increase in the loadings of solids in the bioreactor will (i) decrease the consumption of bacteria culture (stream 2); (ii) decrease the flow rate at the reactor exit (stream 4); (iii) decrease the consumption of calcium hydroxide (stream 8); and (iv) decrease the quantity of final fluid (stream 9). Thus, at 40% loading which appears to be a practical, working concentration, the flow rates for various streams are given in Table 1. In this particular scenario, microbial nutrients are in solution and are recyclable. Since they also represent inorganic salts found in the sludge, the use of indigenous salts with inorganic nutrient addition is being considered. A number of bioreactors are also being contemplated. For the purpose of this discussion, the fluidized bed and agitated tank type bioreactors will be examined only.

Table 1
Biochemical Waste Treatment Plant Stream
Summary of Flow Rates at 40% Loading

Stream No.	Description	Flow Rate Kg/h	Amount of Solids %
1	Geothermal Sludge	2329	53.5
2	Bacterial Culture	1895	0
3	Filtrate, Recycle	1075	0
4	Reactor Exit	5299	23.5
5	Filter Cake	2329	53.5
6	Neutralization Drum Feed	1895	0
7	Water and Nutrients	-	0
8	Ca(OH) ₂	9.9	100
9	Reinjection Liquid	1790	0
10	Regulated Filter Cake	114	16
11	Neutralization	1905	1.0

A fluidized bed bioreactor works on the principle that gas bubbles entering the bottom of a reactor can mix solid-liquid mixtures and disperse gas into the liquid media. Airlift bioreactors produce uniformly mixed fluids. However, given a 65% solids (by volume) 2329 Kg/h sludge, a retention time of 24 hours, the reactor would have to handle 144,000 liters of a 40% solids (w/v) sludge slurry. Costs of air compressors for a fluidized bed bioreactor, which can handle such quantities, come as high as \$500,000 and up. The estimated cost of a bioreactor vessel itself is about \$60,000, which is based on the cost for a vertical storage tank without provisions for jacketed heating, port-holes, and air compressor.

The size of an air compressor can be reduced by supplementing the bioreactor's supply gas flow with pressurized steam, a possibility that has to be further explored.

The operations of a fluidized bed bioreactor can also incorporate a cycle scheme of bacteria. When sludge has been treated, a portion of the fluid can be discharged from the bioreactor. The other portion which contains live bacterial cultures can be retained in the bioreactor and fresh untreated

sludge can be added to the bioreactor. The recycle option would reduce the cost of continuously growing new cultures of bacteria in a separate tank. However, there are some limitations to this process previously reported (Premuzic and Lin, 1990).

To increase the solubility of oxygen in water, and hopefully to increase reaction rate, the total reactor operating pressure can be increased (Friday and Portier, 1991; Beck et al., 1987). The purchase cost of the bioreactor itself would increase due to increase in bioreactor wall thickness to handle the higher pressure. However, the operating cost would decrease due to increased reaction rates or decreased retention time.

Agitated tank bioreactors use an impeller to mix the contents of a tank. The impeller creates turbulent flow in the tank, which mixes the solid-liquid-gas phases. In choosing an agitated tank bioreactor one has to consider which type of impeller to use, what kind of geometrically shaped tank to use, and how fast to mix the sludge slurries. Not all impeller-mixers are suitable for all kinds of mixing because different processes have different requirements for the kind of flow, the amount of power, and the amount of fluid shear (Oldshue, 1989). A poor bioreactor design leads to inadequate solids suspensions, low heat transfer rates, and non-uniform gas concentrations in the liquid slurry. There are two types of impeller flows that characterize fluid mixing patterns, axial and radial. Axial flow impellers that are top loaded circulate fluid in the vertical direction, while radial flow impellers circulate fluids horizontally towards the walls of the reactor vessel. While most industrial applications use radial flow turbines with auxiliary sparged gas, axial flow impellers are generally preferred for solids suspensions, although they cannot be used with bottom supplied gas because upward flow bubbles destroy axial flow patterns (Oldshue, 1989). Pitched blades on impellers contribute to axial patterns, whereas flat blades contribute to radial patterns.

Cutting agitation costs means that over-mixing should be avoided by sizing and designing equipment to agitate only as much as is necessary for efficiency (Garrison, 1981). When suspending fine solids, the mixer should provide high flow (pumping) capacity. When mixing gas and liquid, the mixer should provide high fluid shear stress for dispersion of bubbles. However, high flow and high shear cannot be fulfilled at the same time by the same impeller, and combined systems have to be considered.

Heat transfer parameters in an agitated bioreactor should be known beforehand. Factors that affect heat transfers are direct conversion of heat from agitator work, heat generation due to chemical reaction, tank diameter, liquid depth, number of baffles, heat surface (jacket or coils), type of flow (radial or axial), impeller diameter, number of impeller blades, blade geometry and pitch, impeller speed, impeller placement in tank (with respect to heat surface), thermal conductivity of the fluid, thermal capacity of the fluid, and viscosity. Jacket heating is usually cheaper to construct and install on new vessels compared to internal coils which offer less heat transfer surface (Polluzi and Porcelli, 1990). Other aspects of design and construction should also be considered. For example, the impeller should be placed at the mid-point in a bioreactor to optimize heat transfer rates. However, that location is not ideal for solids suspension, where impellers are usually placed near the bottom, a location which has poor heat transfer rates (Oldshue, 1989). In addition to heat considerations, types of impeller and size are also considered and optimized. Using the most up-to-date data, a plant cost vs. waste disposal comparison between 1985 and a 1991 plant designed on the basis of flow diagram in Figure 4, is given in Table 2 (US \$).

Table 2
Biochemical Treatment Plant Costs Vs. Costs of
Treated and Untreated Waste Disposal

Quantity of geothermal sludge to be treated: 2329 Kg/h
Working hours per year: 8000 hr
Total capital cost + start up: \$4,209,000

	1985	1991
Waste Disposal Cost:		
for non-regulated waste (\$/ton)*	75	100
for regulated waste (\$/ton)	200	500
Annual Total Expenses (\$):		
untreated geothermal sludge disposed of directly	4,104,000	10,260,000
Geothermal Sludge Treated:		
by the biochemical process (non-regulated waste disposal cost)	1,539,000	2,052,000
Waste Concentrate (regulated disposal cost)	202,000	504,000
Operating Costs, etc.	1,396,000	1,396,000
Amortized Payment (fixed)	685,000	685,000

* short ton.

Currently, a complementary process is being developed in which the produced aqueous phase is treated to yield a metal concentrate and a drinking water quality product (Premuzic et al., 1992).

CONCLUSIONS

The geothermal residual sludge detoxification biotechnology R&D phase described in this work allows the following conclusions:

1. Fast detoxification rates are achievable.
2. Cost effective processes(es) operate at elevated temperatures and acidic media.
3. Consistent results indicate that toxic metals are removed in the early phases of the treatment.
4. Forty percent sludge loadings can be achieved.
5. Four to ten hour cycles are achievable.
6. The bioprocessed wastes will ultimately be disposed of as non-regulated wastes.

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