MASTER'S THESIS

Bioleaching of heavy metals from anaerobically digested sewage sludge using isolated indigenous iron- and sulphur-oxidizing bacteria

Chan, Lau Chi

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Bioleaching of Heavy Metals from Anaerobically Digested Sewage Sludge Using Isolated Indigenous Iron- and Sulphur-Oxidizing Bacteria

CHAN Lau Chi

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Abstract

Bioleaching has been demonstrated to be a feasible means to remove heavy metals from sewage sludge and the decontaminated sludge could be reutilized for land application safely. The aim of the present study was to develop an efficient and cost-effective bioleaching process to remove metals from sewage sludge with special emphasis on the development of the iron- and sulphur-oxidizing process using isolated indigenous bacteria. The pre-acidification of sludge for the iron-oxidizing process and the residual sulphur in the decontaminated sulphur for the sulphur-oxidizing process limit their application of bioleaching.

Bioleaching was performed on sewage sludge collected from Yuen Long wastewater treatment plant using isolated indigenous iron- and sulphur-oxidizing bacteria, with the addition of iron sulphate and sulphur as energy source in the bioleaching, respectively. The mixtures were shaken continuously in an incubator at 28°C for 16 days and samples were taken at 2 days interval for pH, ORP, Cu, Cr and Zn determination. Finally, the metal speciation, total nitrogen, total phosphorus and organic matter contents in the decontaminated sludge were also measured.

The results showed that both the iron-oxidizing process (with the addition of iron sulphate and inoculation of iron-oxidizing bacteria) and the sulphur-oxidizing process (with addition of sulphur and inoculation of isolated sulphur-oxidizing bacteria) were effective in removing heavy metals from sludge at its indigenous pH without the addition of sulphuric acid. In the iron-oxidizing process, 4 g L^{-1} iron sulphate was enough for obtaining maximum Zn and Cu removal, increasing iron sulphate concentration of 8 g L^{-1} did not show any added advantages on solubilization of these two metals at an 15% (v/v) inoculation of isolated indigenous iron-oxidizing bacteria. A high inoculation rate of 15% (v/v) isolated iron-oxidizing bacteria gave the fastest rate of metal removal efficiency at each of the concentration of iron sulphate added. From the present study, the optimum condition was 15% inoculation of iron-oxidizing bacteria receiving 4 g L^{-1} iron sulphate for the iron-oxidizing process and the maximum metal removal efficiencies were 99%, 86% and 52% for Zn, Cu and Cr, respectively. In the sulphur- oxidizing process, an increase in sulphur concentration from 0.375% to 1.5% resulted in an increase in bioleaching efficiency. At a sulphur concentration of 0.375% required a high inoculation of 15% of isolated indigenous sulphur-oxidizing bacteria in order to reduce the pH to < 2. However, at a high sulphur concentration of 1.5% (v/v) inoculation volume did not have any significant effect on bioleaching efficiency, but had a 2-day earlier kick-start for Cu solubilization. The optimization experiment showed that 15% inoculation of sulphur-oxidizing bacteria receiving 0.75% sulphur achieved 100% of Zn, 88% of Cu, and 43% of Cr removal efficiencies. At the optimum condition, iron-oxidizing process showed a (2 days) faster bioleaching reaction rate in terms of pH reduction and Cr and Cu removal rate was (4-6 days) faster than the sulphur-oxidizing process. Nevertheless, the total Cu removal efficiency in the iron-oxidizing process was 20% lower than that of the sulphur-oxidizing process.

To further improve the metal removal efficiency, the feasibility of co-inoculation of iron- and sulphur-oxidizing bacteria for bioleaching was investigated. The results of co-inoculation experiment showed a significant enhancement on metal removal rate in the sulphur-oxidizing process. The co-inoculation of iron-oxidizing bacteria with sulphur-oxidizing bacteria could shorten the bioleaching time from 12 days to 6 days and 6 days to 2 days for ~50% Cr and ~70% Cu solubilization in the sulphur- oxidizing process, respectively, as compared to single inoculation of

sulphur-oxidizing bacteria. However co-inoculation in the sulphur-oxidizing process required longer time to achieve the same level of metal removal efficiency as compared to its counterpart in the iron-oxidizing process. Other than the rate of metal solubilization, co-inoculation of iron- and sulphur-oxidizing bacteria also improved Cr removal efficiency in both bioleaching processes. The experimental results suggested the beneficial effect of both indigenous iron- and sulphur-oxidizing bacteria in the bioleaching process. Therefore, further work will be needed to evaluate whether the co-addition of iron sulphate and sulphur as energy source in both bioleaching processes will increase the leaching efficiency.

The metal speciation experiment showed that bioleaching caused a significant reduction of Zn, Cu and Cr in the decontaminated sludge which mostly existed in the less available (residual) fraction except Cu in the iron-oxidizing process. The addition of iron sulphate led to the production of jarosite in the iron-oxidizing process and as a result, Cu in the sludge solids was found mainly present in the Fe-Mn oxide phase. Bioleaching also caused a significant loss in nutrients i.e., 21-48% total nitrogen and 31-60% total phosphorous, but the sulphur-oxidizing process resulted in a higher loss of nutrients than the iron-oxidizing process because of the lower pH achieved.

The present study indicated that bioleaching using the iron-oxidizing process receiving 4 g L^{-1} iron sulphate and 15% inoculation of isolated indigenous bacteria could operate without pre-acidification of sludge and it took a shorter bioleaching time of 2 days and on 10 days to achieve the maximum Zn and Cu removal efficiency as compared to the sulphur-oxidizing process with either a single inoculation of sulphur-oxidizing bacteria or co-inoculation of isolated iron- and sulphur-oxidizing bacteria. At the same time, the higher remaining nitrogen and phosphorus concentration in the decontaminated sludge of the iron-oxidizing process made this approach more superior than the sulphur-oxidizing process. However, the impact of biological factors such as the change of *Thiobacillus* population in the simultaneous chemical and biological iron-oxidizing process is still not clear. Therefore, further research is needed to determine the microbial population dynamics during the bioleaching process. The understanding of correlation between the microbial population and metal leaching efficiency will give an indication of the mechanism responsible for the removal of heavy metals which may lead to further improvement of the bioleaching efficiency.

Table of Contents