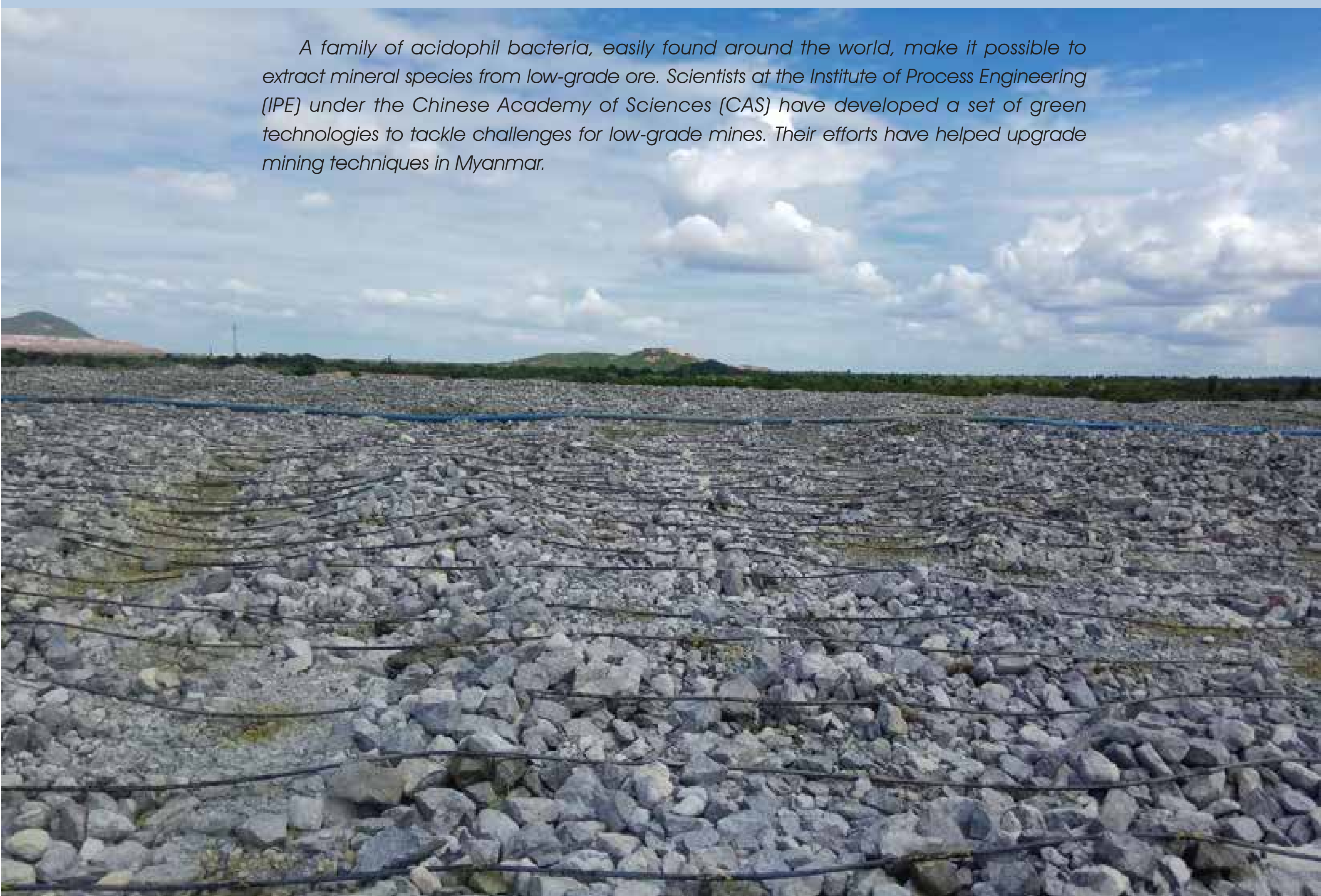
Greener Copper from Low-grade Ore – Catalyzed by Bacteria

By SONG Jianlan (Staff Reporter)

A family of acidophil bacteria, easily found around the world, make it possible to extract mineral species from low-grade ore. Scientists at the Institute of Process Engineering (IPE) under the Chinese Academy of Sciences (CAS) have developed a set of green technologies to tackle challenges for low-grade mines. Their efforts have helped upgrade mining techniques in Myanmar.



A view of the copper mine in Monywa, Sagaing Division of Myanmar. Seen on top of the ore are tiny pipelines that keep dripping solutions for the "leaching" of mineral species. (Photo by JIA Y, IPE)

Myanma Expats in Beijing

"My dissertation has something to do with bacteria," Mr. Htet Aung Phyo, a postgraduate student from Myanmar, told the author in a conversation at the Institute of Process Engineering (IPE) under the Chinese Academy of Sciences (CAS). He got exposure to microbiology when doing his bachelor's degree in materials science back in his home country; still, however, his project looks a bit strange: what can bacteria do for mining?

"My company uses bacteria to extract copper from ore," he explained, "and I am doing a dissertation on the effect of bacteria in mining." This seemingly weird microbial medium, a family of acidophil microorganisms, has connected him, his fellow classmates, and also his employer, to IPE – an institute dedicated to developing green technologies for industrial production.

Htet Aung Phyo has tied a contract with Wanbao Mining LTD, a Chinese enterprise which runs a copper mine in Monywa, Sagaing Division of Myanmar. Meanwhile, he has got a scholarship from the CAS B&R Master Fellowship Program to pursue his master's degree at the University of CAS (UCAS). The latter has supported his study at IPE.

Similar to Htet Aung Phyo, Mr. Pyae Phyo Thu is also currently studying at IPE in the capacity of employees of Wanbao; and with them is Mr. Kyaw Min Soe, an officer from the Myanma Economic Holding limited (MEHL), partner of Wanbao. Focusing on different aspects of mining process, they are doing research in a kind of green mining method under the supervision of Prof. RUAN Renman at IPE. Enabled to extract targeted mineral species from low-grade ore with aid from a family of acidophil microorganisms, this novel method is called "bioleaching."

Joining them is Mr. Aung Kyaw Phyo, a staff of the Ministry of Environmental Conservation and Forestry (MECF) of Myanmar, and his colleague Ms. Su Su Naing. "My dissertation is on the floatation, a kind of metallurgic technique to separate different species in mining," said Pyae Phyo Thu. And his MECF colleague, Su Su Naing, is doing a dissertation on ore characterization, with a focus on copper ore related with clay minerals. "We have different types of clays in Monywa Mine," she said, "and the existence of clays in mines reduces the recovery of the ore. We need to process the ore with adequate techniques to reduce the affect of clay minerals to the heapleaching permeability, and increase the extraction rate."

Students from Myanmar studying at IPE. (Photo by SONG J, *BCAS*)

"We need to tackle some other challenges to upgrade the mining techniques in our country, which are now out of date and cannot meet the need to extract minerals from low-grade ore. That's why we came here," said Kyaw Min Soe.

Bacteria in Ore

At IPE, Htet Aung Phyo and his fellow classmates learn how to culture and optimize the community of the acidophil bacteria to maximize the efficiency of mining, or the extraction rate of mineral species. "In Myanmar," he said, "after mining for years, the ore on the site for which I am working have become low-grade, and this need more efficient microbial activity in the heap bioleaching process. Here I've learnt how to promote it in the bioleaching heaps."

At a lab led by Prof. RUAN, he learns how to design and induce a selective evolution in the bacteria community via manipulating the interplays between different microbial species and strains, hence achieving the desired dominance of certain ones in the culture. "Some strains are not helpful in leaching," he added, "therefore tuning the culturing conditions we can also control the growth of the unwanted ones."

"Such kind of acidophil bacteria are widely distributed across the world, including Myanmar," introduced Prof. RUAN, who has been working on heap bioleaching, a kind of biologically aided method for mining for decades. "It's totally natural," he affirmed.

With this special mining method, they managed to reduce their environmental impact down to a desirably low level, and meanwhile achieve an extraction rate much higher than traditional methods. Due to the low costs, low consumption of energy, and high extraction rate, their techniques are particularly suitable for low-grade ores, which would otherwise be unprofitable for commercial mining.

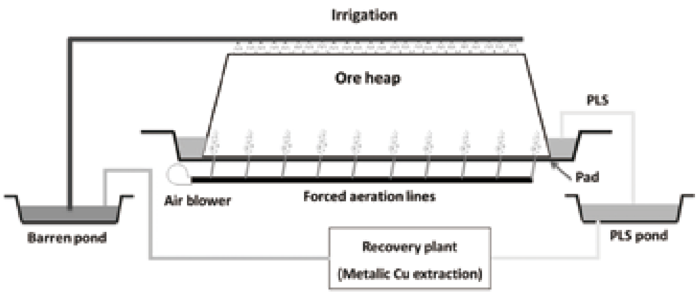
"You don't even need to feed them, they are totally self-sustainable," RUAN explained to the author the role of such microbial "agents" in the bio-chemical reaction. "They produce Fe^{3+} in their own cells, and this can react with CuS_2 in the copper matte, and as a result give off Fe^{2+} and Cu^{2+}. The Fe^{2+} released by the bacteria can later lose an electron in sulfuric acid, and in return give off water (H_2O), and Fe^{3+} – exactly what they have given out in the reaction with CuS_2 – again." RUAN grasped over a sheet of paper and could not help drawing a reaction chart for the author. "This forms an endless circle," concluded RUAN, "Hence they don't need to eat – or you can say they eat what they produce themselves, if you like."

"Originally the copper matte ore mainly contains Cu_2S, and is relatively easier to treat in mining," Mr. GAO Hongshan, Chief Engineer of Wanbao, introduced to the author in a conversation at his office in the south of Beijing City. GAO has been in partnership with RUAN for a long time. "Gradually, however, due to certain conditions in the environment, in secondary ore beds, the ore becomes more and more compact and impermeable. This frequently happens," he said. "Simply put, acidophil bacteria help pre-oxidize the ore a little bit, and make it easier to react with the agents in the leaching solutions, which help dissolve the target mineral species. In this case, the ore becomes suitable for treatment of heap bioleaching," GAO said.

Less Is More

For heap bioleaching, a solution containing certain chemical agents is sprayed or dripped from the top of the ore heap, in the hope of dissolving the target species into the liquid. After a certain time period – in some cases it takes years – the solution infiltrates the ore layers in the heap and arrives at the bottom, where an impermeable base is built with pipelines to collect and drain the solution for further treatment. By this time, the solution has dissolved different mineral species from the solid ore, and through some chemical reactions the target mineral species can be recovered from the solution and further be purified. Sometimes a double-bed base is set to prevent leakage of solution, which can be potentially toxic to the environment – after all, it is generally acid and, by arrival at the base it has carried different metal species and impurities.

Heap stacking equipment at the mining site of Monywa.



Schematic of a typical copper sulphide heap leach circuit (J. Petersen, *Hydrometallurgy* 2015)

Therefore, a magic of this microbial catalyst is its ability to pre-oxidize and sulfurize the ore and provide it with better chance to react with the leach solutions. This contributes to a higher recovery of target mineral species.

However, this does not mean the more thriving the bacteria community is, the better. "You need to optimize it, sometimes to curb their urges to grow," RUAN emphasized. "Unless they would produce too much sulfuric acid – don't forget that they produce sulfuric acid when growing. If this overdose of acid is not neutralized adequately, it could be disastrous to the environment. You must reduce the harmful influence on the environment, ideally, to zero, therefore it is important to keep their growth rate at a reasonable level."

The rainy climate of Myanmar deteriorates the problem, raising the risk of acid leakage into the environment. All this demands sophisticate and reliable handling of acid.

The technical team at the joint lab in Monywa. (Photo by JIA Y, IPE)

"Manipulating the culturing conditions, for example the temperature, acidity, and concentrations of the agents in the solution, we can obtain an optimal community for mining," said Htet Aung Phyo. "But we need to know which strains do the best for certain mineral species, and how they respond to the nuances of different conditions, like temperature and acidity."

The techniques to optimize the composition of a microbial culture, including the knowhow of temperature and acidity control, dominate his study and experiments at IPE.

Green Mining

"What RUAN has made a big difference in this field is, he is the first one in the world to have invented an acid-free method to trigger bioleaching in the heap," GAO showed the author a certificate of technical assessment, praising highly of his cooperator's contribution.

Traditional heap bioleaching produces iron sulfate and sulfuric acid. Even worse, to trigger the reaction circle in bioleaching process, an acid "starter" is needed. These in combination pose stress on the environment, and efforts to neutralize this acid greatly increase the costs of mining.

"You might be surprised by the amount of sulfuric acid produced by traditional leaching process," RUAN told the author, when writing on the paper the chemical formula. "A mine could produce a million tons of sulfuric acid a year; this costs around 100 million dollars to neutralize," he continued.

To reduce the harmful impact on the environment, RUAN and his colleagues have invented a series of techniques to control the acidity of the mining process. According to assessment given in peer-reviewed papers, the acid released from his version of heap bioleaching is as low as only 15% of what traditional mining processes do.

On a whole, the environmental impact produced by RUAN's bioleaching process is considerably lower than traditional mining and metallurgical processes. It consumes much less water and energy, accounting for only 38.35% and 12.85% of what consumed by conventional mining. On the other hand, the greenhouse effect of this novel process is also much lower. Emissions of greenhouse gases from this process can be as low as about 37.50% of traditional processes.

GAO's company has joined RUAN's group for long-term technical cooperation to deal with acid problem in Monywa, and their efforts have led to the successful application of RUAN's water-based starter at a large-scale mining site. This site is now operating smoothly, producing about 100 thousand tons of copper a year, well up to the pre-designed capacity.

"In actual operation, technical issues might pop up from here and there, and you need to modulate the working conditions and parameters from time to time. Therefore, we set up a joint lab on the site in 2013," GAO introduced. "Actually, we started our cooperation much earlier," he continued, "It can be traced back to 2003. Since then we have been very good friends."

"Yes, we had some hard time at the beginning of the project," said Dr. JIA Yan, an associate professor with RUAN's lab who heads a technical team at the joint lab in Monywa. "But the whole team worked against all the odds, and all this paid off when we saw the first piece of cathode copper turned up on the production line," he said.

Green technology from IPE has fueled the booming local economy. (Photo by JIA Y, IPE)

Sustainable Future

Aung Kyaw Phyo, out of instinct concern about the environment as an inspector of the Ministry of Environmental Conservation and Forestry of Myanmar, focuses his study and research at IPE mainly on the environmental impact of mining. "My idea is to learn the best techniques here and use them when I am back to Myanmar," he said, "the best techniques that would not impact the environment."

What he learns includes techniques involved in closing a mine.

To conserve the environment, in Myanmar mining companies are required to restore the mining sites to their original status, so as to reduce the environmental impact to as minor as approximately zero. This demands a series of complicated treatment in the soil, dislocation or treatment of the heaps of spent ore, and even growing of forests. What he has learnt at IPE will help him get prepared for current and future closure of mines in Myanmar.

"Some mines have been exploited for decades and got to the point of closure," he said. "Some others are following, one to be closed in one or two years, and some in longer a time. All in all, I will get a lot to do when I am back there," he added.

The successful application of IPE's green technology in Monywa has bore fruits. The environmental impact has met the environmental protection standards formulated by the European Union and the United States (ROHS and EPA standard); and the technology has revitalized the local economy by creating employment opportunities.

"I've been working for the joint lab in Monywa for about five years," said JIA. "Over the past years, the infrastructure has become better and better. The roads have been repaved and more and more new buildings have appeared in the neighborhood. The local people are getting rich."

Many farmers in the nearby countryside have got jobs on the mining site, living in new buildings constructed by the company. A new town has taken shape, so is a commercial area. According to statistics, the mining site has offered about 5,000 jobs, and further added 5,000 more jobs to the upper- and lower-stream industries for the local economy.

"We are confident that we will earn better salaries when we are back to Myanmar," said Kyaw Min Soe and his fellows. "But a brighter future in vision is even better than that," asserted Kyaw Min Soe with a bright smile.