The copper microbe

Would bacteria become workhorses of the future?

S ANANTHANARAYANAN

Micro-organisms drive the process of fixing nitrogen from the air, the Earth's largest chemical process, which enriches soil and sustains all vegetation. Within the bodies of living things, processes on the land and sea, and in laboratories and factories, micro-organisms perform myriad tasks. It is estimated that the workforce of bacteria on Earth numbers five million trillion trillion (or 5×10^{30}). Could this resource be used to simplify or replace current, polluting industrial processes?

A paper in the journal, *Science Advances*, by Louise Hase Gracioso, Janire Peña-Bahamonde, Bruno Karolski, Bruna Bacaro Borrego, Elen Aquino Perpetuo, Claudio Augusto Oller do Nascimento, Hiroki Hashiguchi, Maria Aparecida Juliano, Francisco C Robles Hernandez, Debora Frigi Rodrigues, from the University of São Paulo, the Federal University of São Paulo, the University of Houston and JEOL Limited, an enterprise in Tokyo, suggests that it can be done. They propose an application where bacteria are harnessed to undertake extraction of metallic copper from its compounds, an industrial process that consumes energy and uses toxic reagents.

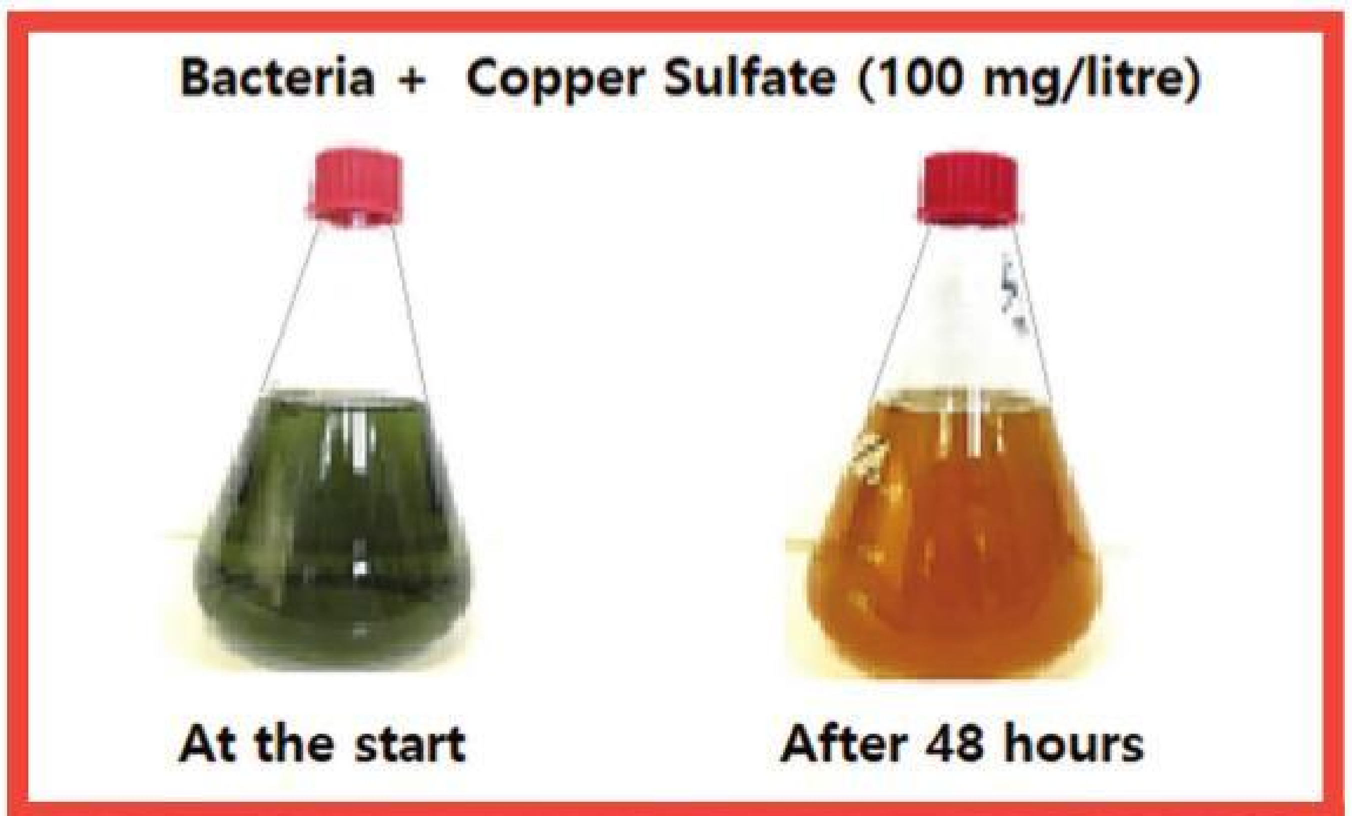
Copper is a pivotal material of the modern world. As it is relatively easy to extract from the ore, copper has been used since prehistoric times. With the discovery of electricity, however, its consumption has skyrocketed, in power lines, generators, motors and transformers. And the future of copper mining? Although abundant in the crust of the Earth, only a fraction is within reach, and copper that is mined would suffice only for 50-60 years. For this reason, a method that could tap the distributed sources of copper may be what we need, quite apart from current methods of extraction being energy intensive and polluting.

While it is true that copper exists in nature as a metal, most of it is in ores, in combination with other elements, or mixed with impurities. The extraction from ore is a two-step process. The first is to grind, sift and roast the ore in hot air, to get rid of sulphur. It is then melted and treated with fluxes, to get it to a workable state. The final process is purification with the use of electricity. While all processes consume energy, the last, to attain high purity, is truly energy intensive.

The ingots of partly refined copper are immersed in an electrolyte, a conducting solution of copper sulphate, and a current is passed from the copper ingot to a rod of pure copper. The copper atoms in the ingot pass into the medium and collect at the opposite end. Other metals that are present do not participate and collect as a sludge, and the copper is purified.

Another method of extraction is to draw out the copper from the ore by bathing the ore in sulphuric acid. The copper dissolves into a copper sulphate solution, from which copper is recovered as before. This method can be used with low quality ores, but the high cost of extraction by electricity remains.

Yet another method, one which does not consume energy, is to extract copper by biological means. As copper combines only feebly with other elements, milder heat and action of microbes can liberate metallic copper. Microbes that seek oxygen in copper salts have hence evolved to be copper-tolerant, and much of natural, free copper may have come through this route. There are already places where bacteria are employed, along with chemicals and electrolysis, to improve the content of low-grade ore which is otherwise discarded as waste.



Bacterium in the mine

The work that the group writing in *Science Advances* has done is to identify a copper-resistant bacterium which is able to get at metallic copper from the ores, "naturally under aerobic conditions eliminating toxic solvents." The group has used a sophisticated electron microscope technique and shown "that microbes in acid mine drainages can naturally extract metal ions, such as copper, and transform them into a valuable commodity"

The paper points out that copper finds applications in light sensitive, electro-chemical cells, sensors, solar cells, inks, varnishes, and, as copper is toxic to many microbes, in antimicrobial coatings. Copper, in the form of single atoms just released from copper compounds, even more than in the form of nanoparticles, is also effective for special applications, as in catalysts, where it forms short-lived combinations with reagents, or to "dope" materials as a trace impurity. Creating copper atoms in this form, however, involves tedious processing and needs toxic chemicals. There are studies where it has been done with the help of bacteria or fungi, the paper says, but they need the support of additives.

In the current study, the authors examine a bacterium, found in copper mines, which is able to generate atomic copper without the use of toxic solvents or energy. Atomic copper that was isolated in copper mines in a region in Brazil suggested that micro-organisms could extract metal atoms from the environment, the paper says. And this implied also that microbes could clear sites that are contaminated by copper.

That the bacterium concerned could do this, the paper says, was first shown visually, by the change in the green colour of the bacteria growth medium, which contained copper sulphate. In 48 hours, the mixture changed from green to orange -- indicating the presence of metallic copper. Sophisticated electron microscopy then showed that the orange mixture contained copper, and in the form of separate atoms.

In electron microscopy, what is shone through the sample is not light, but a beam of electrons. Just as light, in the case of interaction with a solar cell, for instance, behaves like a particle or a "photon", particles like electrons can exhibit wave behaviour, and those waves are of extremely short wavelengths. The result is that the electron microscope can make out details at extremely small dimensions – good enough to show that the particles in the sample have the dimensions expected of copper atoms.

The mechanics of how the bacteria went about this process was studied with the help of proteins that were expressed by the bacteria, when in the presence of copper sulphate and otherwise. While 562 proteins were there when there was no copper sulphate, 458 proteins were expressed when copper sulphate was present. Of the 458 proteins, 313 were also there among the 562, but the remaining 145 proteins were expressed only in the presence of copper sulphate. Analysis of those unique proteins then led to an understanding of what brought about the extraction and stabilising of the copper atoms.

That the bacteria from the copper mine are able to isolate copper atoms opens "up exciting strategies to produce in large-scale atomic copper via sustainable manufacturing and at low cost for existing and future applications," the paper says." And the beginning of a field of research into using microbes to extract other metals for applications in science, technology, engineering and medicine, the paper says.

The writer can be contacted at response@simplescience.in

PLUS POINTS

Chernobyl clean-up

On the 35th anniversary of one of the world's worst nuclear disasters, new research has been published that could help to contain and clean up the most dangerous radioactive materials that still remain at the site in Chernobyl.

The study, led by Claire Corkhill from the University of Sheffield's department of materials science and engineering, has employed a new approach of using ultrabright x-rays to better understand the hazardous waste that has been left behind inside the nuclear reactor.

The technique provides proof of concept for the first time that using ultrabright x-rays can yield rich chemical information on some of the most dangerous materials left at Chernobyl and provide a safe way of analysing them. Using ultrabright x-rays has also enabled the team to forensically unravel how nuclear fuel at the site transformed into a lava-like substance immediately after the disaster, which has solidified in large masses and are obstructing decommissioning efforts.

The researchers studied simulant Chernobyl material with two of the world's brightest microscopes – called x-ray synchrotrons – in Switzerland and the U S. They were able to measure very small samples of their material and identify uranium-containing features that were one twentieth of the size of a human hair. By building 2D chemical images of the uranium features, the team were able to reconstruct the timeline of events that occurred in the moments immediately after the accident, during the formation of the melted down nuclear fuel. Testing the technique on the simulant Chernobyl material has provided proof of concept that the method could be used to safely analyse real samples from Chernobyl like never before.

Corkhill, Engineering and Physical Sciences Research Council early career research fellow and reader at the University of Sheffield, said, "Like a forensic analysis of a crime scene, the chemical analysis performed on our simulant materials allowed us to piece together the last moments of the Chernobyl nuclear fuel as it melted together with other components in the reactor to form a volcanic-like lava. Our analyses are consistent with the limited data available on real samples, which is extremely exciting."

The study, "Safely probing the chemistry of Chernobyl nuclear fuel using micro-focus X-ray analysis", is published in the *Journal of Materials Chemistry A*.

Purifying salt

Researchers at the Indian Institute of Technology-Guwahati have developed a microfiltration process to remove micro-plastics from seawater in order to prevent the inclusion of plastic residues in edible salt extracted from it. Kaustubha Mohanty and Senthilmurugan Subbiah, department of chemical engineering, IIT-Guwahati, have recently published the results of this research in the journal *Environmental Technology & Innovation*, in a paper co-authored by their research scholar, Naveenkumar Ashok Yaranal.

Research performed in East Asia has shown that 90 per cent of the table salt brands sampled worldwide have micro-plastics. Another study by IIT-Bombay showed that eight brands of Indian sea salt were contaminated with micrometre-sized particles of polyesters, polyethylene terephthalate, polyamide, polyethylene and polystyrene. Micro-plastics ingested by humans can disrupt hormones, leading to infertility, and cause nervous system problems, and even cancer.

While there have been many studies to identify and quantify micro-plastics in various food products, including salt, there have been fewer attempts at finding ways to remove them. The IIT-Guwahati team has, for the first time, shown efficient removal of micro-plastics from synthetic seawater using hollow fibre microfiltration membranes.

"In our hollow fibre membrane filter, hundreds of tiny straw-like tubes are bundled together to create a filter matrix," explained Mohanty. The walls of the tubes are filled with microscopic pores, and when water is passed through the tubes, the micro-plastics are trapped inside, thus freeing water of this pollutant.

Hollow fibre membranes are already used extensively in daily life applications such as reverse osmosis pre-treatment, industrial water/wastewater, juice processing and other biotech applications, including in dialysis membranes used for kidney ailments.

NEW GENERATION OF COSMIC EXPLORERS

Space tourism – 20 years in the making – is finally ready for launch

Dennis Tito

WENDY WHITMAN COBB

For most people, getting to the stars is nothing more than a dream. On 28 April 2001, Dennis Tito achieved that lifelong goal – but he wasn't a typical astronaut. Tito, a wealthy businessman, paid (US) $20 million for a seat on a Russian Soyuz spacecraft to be the first tourist to visit the International Space Station. Only seven people have followed suit in the 20 years since, but that number is poised to double in the next 12 months alone.

The National Aeronautics and Space Administration has long been hesitant to play host to space tourists, so Russia – looking for sources of money post-Cold War in the 1990s and 2000s – has been the only option available for those looking for this kind of extreme adventure. However, it seems the rise of private space companies is going to make it easier for regular people to experience space.

From my perspective as a space policy analyst, I see the beginning of an era in which more people can experience space. With companies like SpaceX and Blue Origin hoping to build a future for humanity beyond Earth, space tourism is a way to demonstrate both the safety and reliability of space travel to the general public.

Development of space tourism

Flights to space like Tito's are expensive for a reason. A rocket must burn a lot of costly fuel to travel high and fast enough to enter Earth's orbit.

Another cheaper possibility is a suborbital launch, with the rocket going high enough to reach the edge of space and coming right back down. While passengers on a suborbital trip experience weightlessness and incredible views, these launches are more accessible.

The difficulty and expense of either option has meant that, traditionally, only nation-states have been able to explore space. That began to change in the 1990s as a series of entrepreneurs entered the space arena. Three companies led by billionaire chief executive officers have emerged as the major players – Virgin Galactic, Blue Origin and SpaceX. Though none have taken paying, private customers to space, all anticipate doing so in the very near future.

British billionaire Richard Branson has built his brand on not just business but also his love of adventure. In pursuing space tourism, Branson has brought both of those to bear. He established Virgin Galactic after buying SpaceShipOne – a company that won the Ansari X-Prize by building the first reusable spaceship. Since then, Virgin Galactic has sought to design, build and fly a larger SpaceShipTwo that can carry up to six passengers in a suborbital flight.

The going has been harder than anticipated. While Branson predicted opening the business to tourists in 2009, Virgin Galactic has encountered some significant hurdles – including the death of a pilot in a crash in 2014. After the crash, engineers found significant problems with the design of the vehicle, which required modifications.

Elon Musk and Jeff Bezos, respective leaders of SpaceX and Blue Origin, began their own ventures in the early 2000s. Musk, fearing that a catastrophe of some sort could leave Earth uninhabitable, was frustrated at the lack of progress in making humanity a multiplanetary species. He founded SpaceX in 2002 with the goal of first developing reusable launch technology to decrease the cost of getting to space. Since then, SpaceX has found success with its Falcon 9 rocket and Dragon spacecraft. SpaceX's ultimate goal is human settlement of Mars – sending paying customers to space is an intermediate step. Musk says he hopes to show that space travel can be done easily, and that tourism might provide a revenue stream to support development of the larger, Mars-focused Starship system.

Bezos, inspired by the vision of physicist Gerard O'Neill, wants to expand humanity and industry not to Mars, but to space itself. Blue Origin, established in 2004, has proceeded slowly and quietly in also developing reusable rockets. Its New Shepard rocket, first successfully flown in 2015, will eventually offer tourists a suborbital trip to the edge of space, similar to Virgin Galactic's. For Bezos, these launches represent an effort at making space travel routine, reliable and accessible to people as a first step to enabling further space exploration.

Outlook for the future

Now, SpaceX is the only option for someone looking to go into space and orbit the Earth. It currently has two tourist launches planned. The first is scheduled for as early as September 2021, funded by billionaire businessman Jared Isaacman. The other trip, planned for 2022, is being organised by Axiom Space. The trips will be costly, at $55 million for the flight and a stay on the International Space Station. The high cost has led some to warn that space tourism -- and private access to space more broadly -- might reinforce inequality between rich and poor.

Blue Origin's and Virgin Galactic's suborbital trips are far more reasonable in cost, with both priced between $200,000 and $250,000. Blue Origin appears to be the nearest to allowing paying customers on board, saying after a recent launch that crewed missions would be happening "soon." Virgin Galactic continues to test SpaceShipTwo, but no specific timetable has been announced for tourist flights.

Though these prices are high, it is worth considering that Tito's $20 million ticket in 2001 could pay for 100 flights on Blue Origin soon. The experience of viewing the Earth from space, though, may prove to be priceless for a whole new generation of space explorers.

The writer is professor of strategy and security studies, US Air Force School of Advanced Air and Space Studies. This article first appeared on www.theconversation.com