The Feasibility of Thailand Lunar Simulant(TLS-01) Biomining †

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† Presented at the 2nd Innovation Aviation & Aerospace Industry - International Conference 2021, 28-30 June 2021; Available online: https://iaai-2021.sciforum.net, https://iaai.asia/

Published: 1 July 2021

Abstract: The Lunar Mission has been affected by the different conditions from Earth, such as gravity, air pressure, temperature, lunar regolith, and others. As a part of the nuclear fusion project known as the mini sun on earth, Helium-3 is a fuel source from the moon. The clean energy will be used for extracting water, construction materials, fertilization, lunar agriculture and sustainable living. The ore processing and extraction require further study. The samples of lunar regolith investigated from the Apollo project have been used to create lunar regolith simulant from Earth resources in various locations, such as the USA, Europe, India, Russia and Thailand. The Thailand Lunar Simulant (TLS-01) in this research is reported with four parameters as physical properties; chemical composition, mineralogical characteristics, particle size distribution and the progress of mineral extraction by biomining methods. The results show that the basalt rock from Trad province can be used for the simulant material. The biomining can extract the necessary elements from the lunar regolith simulant, which are sodium, magnesium, iron, aluminum, titanium and silicon.

Keywords: Thailand Lunar Simulant (TLS-01); biomining; lunar soil; regolith

1. Introduction

The Space Research Organization (SRO) in Thailand and the Geo-Informatics and Space Technology Development Agency (GISTDA) not only have been working on the remote sensing and technology development of satellites, but have also been developing space technology with other organizations, such as the contract for robotic technology for lunar missions [1]. The contract is under the Commercial Lunar Payload Services (CLPS) with NASA [2]. The lunar projects have been investigated in many ways, including "Lunar Mining", for a better understanding of the basic and advanced geochemistry, science and engineering in the lunar environment [3]. Therefore, the lunar regolith that requires the smallest amount of resources from the Earth with the highest lunar utilization is a question of interest, as in this preliminary project. The lunar regolith is essential for the study of various related topics, but the lunar regolith quantity is small and has an expensive price [4]. The lunar simulant samples are the solution in standard laboratory tests, such as JSC-1 by NASA [5] and the Johnson Space Center, Lunar Highlands Simulant (LHS-1) by the University of Central Florida [6], FJS-1 by Shimizu Corp. for JAXA [5], LSS-ISAC-1 by ISRO and ISAC in India [7] and TLS-01 by the Space Zab Company.

2. Literature Review, Materials and Methodology

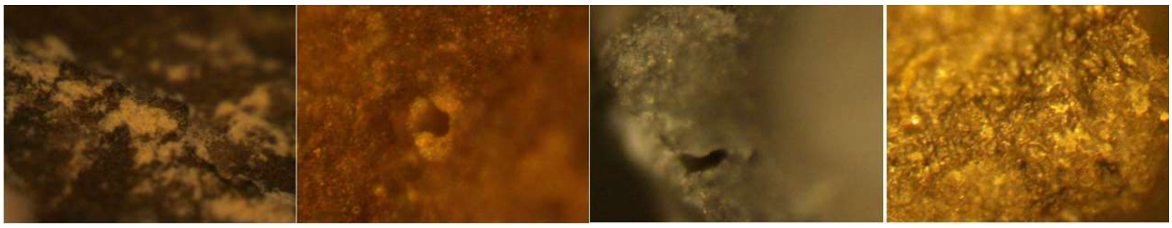
The space gravity conditions on the ISS have been successful for testing microbials for basalt rock sample extraction. The results found that microbial workings in space were no different from the laboratory conditions [8]. In this preliminary project, it is shown that Acidothiobacillus bacteria propagations can survive under the TSL-01 environment. Sulfur and water were added as microbial culture nutrients. The biomining work by the invisible miners, for 24 h without holiday and welfare under suitable conditions, can extract various elements from TSL-01 [9]. After the electrolysis of the elements from sulfate solution, the water and sulfur can be recycled to use for biomining again.

The TLS-01 was prepared from the basalt from Trad province in Thailand, as shown in Figure 1a. The physical properties are presented as density 1.065 g/cm^3 and angle of repose 29 degrees. The main mineralogical classifications were 35.4% plagioclase, 23.5% pyroxene, 14.5% ilmenite and 20% quartz. The elemental compositions as related to the minerals were 15.7% Al, 2.795% Na, 6.833% Fe, 3.7965% Mg, 4.381% Ca, 1.1557% Ti and 23.24% Si. The TLS-1 particle size was sieved under a 100 mesh size.

Acidothiobacillus ferrooxidans DSM11477[10] and *Acidothiobacillus thiooxidans DSM14887*[11] were cultured for this experiment. Over the 14-day-long leaching process, a microscope with 1000X magnification was used for observations every 48 hrs. The solute leaching liquid was filtered, then the filtered liquid was evaporated. The product crystals appeared after evaporating. The sample was tested by the X-ray fluorescence spectrometer.

3. Experimental Results and Discussion

The TLS-01 was clearly corroded on the plagioclase and pyroxene texture. However, the quartz grain articles had no effect on the medium. Some quartz grain fell off from the plagioclase fixation, as shown in Figure 1b. Some plagioclase particles were dissolved but the surrounding quartz crystals still retained the porous structure of quartz, as shown in Figure 1c. The corroded TLS-01 surface was shown to be almost a silicate crystal surface. It is quite clear that there was no plagioclase or pyroxene surface at 14 days, as shown in Figure 1d. Finally, the corroded particle samples were broken again, and the pyroxene texture was still found inside. Therefore, the fine particles or high surface area were the key to the leaching.

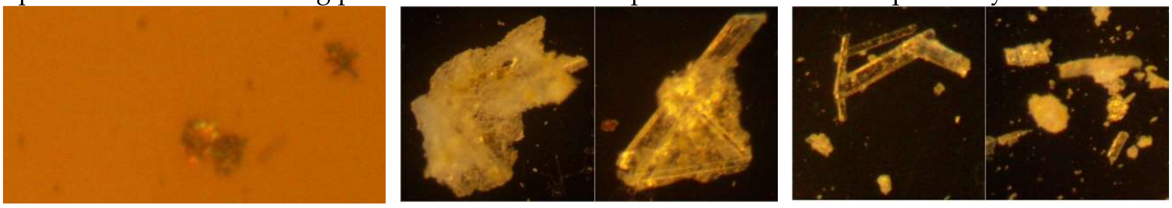


(**a**) (**b**) (**c**) (**d**)

Figure 1. The Thailand Lunar Stimulant (TLS-01) surface as: (**a**) the non-leached original TLS-01 surface; (**b**,**c**) the hole on the TLS-1 surface, at 14 days; and (**d**) the leached TLS-01 surface at 14 days.

The two types of microbial can survive in the TLS-01 with medium. Over fourteen days the medium was sampled under a microscope. The captured picture from the video provided in Figure 2a presents the bacteria moving in video, bacterial shapes, bacterial density, bacterial velocities in the medium in video, bacterial size, the new crystal products as shown in Figure 2a–e, the medium color, the residual samples and the changing of the sample surface.

The evaporated residual resulting from the paper filter passing liquid was analyzed by XRF. The elemental composition was 5.3% Fe, 3.03% Ca, 2.85% Al, 1.01% K, 0.3% Ti and 8.14% Si. The new product crystals found gypsum ($CaSO_4 \cdot nH_2O$) with the covering of other sulfate products, as shown in Figure 2b. The gypsum polycrystal with ferrous sulfate heptahydrate ($FeSO_4 \cdot nH_2O$), as shown in Figure 2c, and aluminum sulfate hydrate ($Al_2(SO_4)_3 \cdot nH_2O$), as shown in Figure 2d, and other complex sulfate crystals were found in the dry products, as shown in Figure 2e. The residual particles on the paper filter after the leaching process were the TLS-01 particles and the fine quartz crystals.



(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 2. The medium and the new products from TLS-1 biomining: (**a**) the microbial and the mineral crystal product in the medium; (**b**) complex sulfate-bearing crystals; (**c**) calcium sulfate dihydrate (gypsum) polycrystal with a single ferrous sulfate crystal at the left; (**d**) calcium sulfate hydrate complex crystals with two aluminum sulfate hydrate crystals at bottom-left; and (**e**) polysulfate crystals.

In general, the bacterial oxidation on the sulfide minerals is caused by the attached bacteria leaching process. The non-contact leaching can degrade the volcanogenic mineral, also [12]. Next, the stability leaching process passed well, and the sulfate products appeared. After that, the bacteria can use contact leaching on the new products, such as gypsum. Then, they will use the cooperative leaching process.

4. Conclusions and Future Works

A. ferrooxidans and *A. fhiooxidans* can grow on TLS-01. The corrosion process of TLS-01 starts from the surface. The quartz particles are not eroded by the leaching. The evaporated liquid shows the sulfate products. The products are efficient to use in water extraction, building materials, soil nutrients, plant growing and cycle living in the lunar environment.

Moreover, the sulfuric acid environment has a dehydrating property as it fixes the water molecules. The TLS-01 size reduction is caused by the corrosive effect from the acid, and the crystals forming in the small particle pores [13].

Directions for future work are the cyanobacterial culture for hydrocarbon methane production, the recycling of materials for bacterial culture, and the study of the other parameters of the lunar environment such as temperature, pressure, UV concentration, etc.

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