Study on Renewable Energy System based on Mars Resources

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Abstract: This project discussed the technical feasibility and comprehensive utilization of resources and energy on Mars, which may have applications in the Mars exploration. Renewable fuel cell system could convert solar energy into chemical energy, electric energy and heat energy with the medium of recycled water, hydrogen and oxygen. In this project, a renewable energy system was designed based on fuel cell and water electrolyzer. Thereafter, the performance of the regenerative fuel cell was tested. The result shows that the power generation efficiency of the regenerative fuel cell was 65.41%, and the electrolysis efficiency was 90.2%. Meanwhile, the purity of hydrogen and oxygen were over 99.99% and the conductivity of water was lower than 5.0μS/cm.

1. Introduction
It is widely recognized that Mars exploration has the characteristics of long period and far distance. Since core technologies such as orbiting, landing and roving exploration have been developed, the high-cost and poor techniques of this project remains uncovered. From the late 1980s, America’s space agency (NASA) conducted a series of researches on in-situ resource utilization (ISRU) of Mars[1-3]. The results they have obtained including preparing the propellant, water, oxygen, food and energy. With the full use of Mars resources, the cost and risk of the exploration would be reduced. And meanwhile, more tough missions would be achieved with ISUR compared with recent techniques[4].

2. Design strategy
2.1. Availability analysis
2.1.1. Solar energy
Solar radiation intention on Martian atmosphere was 493~717W/m², the average value was 589W/m², which was about 42% on earth[5]. In addition, atmosphere and dust further decreased the intensity of the sun’s rays on Martian surface. The concrete distribution varied with longitude and latitude. The blue band on Mars was weaker than earth, while the red band and infrared wavelengths were stranger[6]. The spectra on Martian surface was tested by the spectrometers on the Spirit and the Opportunity.

Researchers have calculated the distributions of solar energy radiation resources in Martian atmosphere. The data shows that martian could achieve 5.17*10⁶J/m² solar energy every Mars year compared with geostationary satellites. And Martian surface around the equator could get
2.953*10^9 J/m^2 energy in the orbital period, considering the factors of atmospheric scattering, transmission and sandstorm, which had the largest solar energy[7].

2.1.2. Water-ice resources
Water resources was the foundation of long-time exploration and migration in the future. Space exploration shows that water existed in the form of water-ice, which could be observed in Arctic ice covered on Martian surface. In addition, abundant water-ice normally present in Antarctic and surface at the warm latitude[8,9].

2.1.3. Atmosphere resources
The results from the probe indicate that the Martian atmosphere is consist of 95.3% carbon dioxide, 2.7% nitrogen, 0.13% oxygen and small amounts of oxygen. Carbon dioxide could be transferred into synthetic hydrocarbon fuels and release large amounts of energy. Meanwhile, the oxygen produced could be used to support life system and the N₂ and Ar could be used as the gas buffer.

2.1.4. Water electrolysis technology
Water electrolysis is an important method to prepare hydrogen and oxygen on a large scale. The oxygen generation system with water electrolysis have already been launched on space shuttle. Meanwhile, Hydrogen energy is also a kind of high efficient secondary energy. SPE electrolysers decompose pure water into hydrogen and oxygen. And the charge transfer steps in between the electrodes and ion charge, namely hydrogen ion which crossed the proton exchange membrane (PEM) got electronic from the cathode, reductive into hydrogen. Oxygen Evolution Reaction (OER) took place at Hydroxyl ions by losing electrons[10].

2.1.5. Fuel cell technology
The way a fuel cell works is basically the opposite of an electrolysis cell. Fuel cell normally uses fuel as source, such as hydrogen, and an oxidant to create electricity from an electrochemical process. Hydrogen and oxygen were subjected to oxidation-reduction reaction, transporting protons from the positive to the negative electrode. In the 1960s, fuel cell was first used in NASA's Apollo spacecraft as assistant power.

2.2. Energy comprehensive utilization technologies
Considering system constitution of Mars base, energy comprehensive utilization model was designed, as shown below. The model involved material utilization and energy exploitation. Resources mainly include hydrogen, oxygen and water. And energy always include electric energy and thermal energy.

Figure 1. A schematic of renewable energy comprehensive utilization
2.2.1. Resources for ECLSS
Solar power was used for supplying loads in ships during light periods, charging batteries and store energy. Water electrolyser uses electricity from bus to generate hydrogen and oxygen, which is provided to environmental control and life support system (ECLSS). Oxygen is available for astronauts breathe. Hydrogen combined with carbon dioxide reduction systems could be used to degrade carbon dioxide which is collected from the atmosphere, generating carbonic oxide and water. Fuel cell transmuted hydrogen and oxygen to electricity and water at night. Water could be drunk by astronauts and realized that secondary utilization combined with water-management system after filtering and purifying. The efficient use and recycling of resources could be realized by reasonable design of renewable fuel cell system (RFC) and ECLSS interfaces.

2.2.2. Energy for thermal control system
Waste heat could be introduced into subsystem as a resource. During light periods, the efficiency of water electrolyser which converted solar energy into chemical energy was reasonably high. Thus, it produced less heat requirements of thermal insulation and lessen the burden on thermal control system. At night, fuel cell would produce equal amounts of heat while generating power. Thermal energy was transported to thermal control system to sustain the system temperature by heat exchanger and thermal storage devices. This method reduced extra volume and weight of thermal control system. Besides, it improved the efficiency of energy utilization.

3. Renewable fuel cell system
Renewable energy system was studied based on the external interface and function. It is consist of a 3kW water electrolyser, a 3kW fuel cell, gas management unit, water management unit, thermal management unit and electronic control unit. The renewable fuel cell energy system was achieved via optimal design and test. The principle prototype of renewable fuel cell was shown in figure 3.
Figure 3. Schematic diagram and the principle prototype of renewable fuel cell

Water electrolyser: converting solar energy into chemical energy and thermal energy by electrolyze water. Fuel cell: converting the chemical energy of the hydrogen and oxygen directly into electricity and thermal energy and reforming water. Gas management unit: the storage space available for system stress of hydrogen and oxygen. Water management unit: the reaction product water collection and storage. Thermal management unit: providing external heat source to all the thermal control point via the water circulating system. Electronic control unit: ensure that the control system has run stably and credibly, satisfied field real control need and proved to have good power, temperature and pressure conditions.

3.1. Water electrolysis performance

Water electrolyser was design to provide 3kW@3.5MPa. The pressure and temperature were maintained stable within a band from the set point. Input current and voltage values were recorded by potentiostatic method. Water electrolyser operated at constant voltage operation, the average voltage and current were 49.21 V and 61.00 A. The input power of Water electrolyser was 3001.81W. The stack gave a current density of 500 mA/cm² at an average cell voltage of 1.64V. The electrolysis efficiency could exceed 90.24%.

\[ \eta_{el} = \frac{1.48 \cdot V}{1.64} \times 100\% = 90.24\% \]

Figure 4. Water electrolysis performance: input power (left) and polarization curve (right)

3.2. Electricity generation performance

Fuel cell output power was tested after the pressure and temperature were maintained stability within a band from the set point. The output current and voltage at 63°C, 2.10 bar were 80.25A and 37.64, and
the output power was 3020.61W. when the stack on the condition of 200 mA/cm², 0.80 V, the generating efficiency was 65.41%.

![Figure 5. Fuel cell performance: output power (left) and polarization curve (right)](image)

### 3.3. Gas purity

The purities of hydrogen and oxygen in both primary gas and purified gas were measured, as shown in table 1. Hydrogen generated by water electrolyser contained much oxygen and oxygen generated by water electrolyser had a small amount of hydrogen. The purities of hydrogen and oxygen after purification could reach up to 99.99%.

| Gas      | Process         | Value    |
|----------|-----------------|----------|
| Hydrogen | Before purification | 99.95%   |
|          | After purification | 99.999%  |
| Oxygen   | Before purification | <98%     |
|          | After purification | 99.996%  |

### 3.4. Water purity

The reaction product water of renewable fuel cell was collected and filtered. Tests indicated that water had a pH of 7. The water conductivity was decreased under 5.0 μS/cm by passing the water through ion-exchange columns.

### 4. Conclusion

Mars resources (solar, atmosphere and water-ice) and technologies were investigated in recent decades. The high efficient techniques must be developed for energy comprehensive utilization. Renewable fuel cell system is one of the key factors for ISRU and energy recycling. The results showed that water, gas, heat and electricity could be used and transformed by renewable fuel cell system. Thereafter Solar energy is stored as a chemical energy (such as hydrogen and oxygen) and could be released by the form of electrical energy and thermal energy. In addition, hydrogen could be used to transform carbon dioxide to methane and water. Meanwhile oxygen could be used to life support system, and water could be used as reaction media through environment control system, life support system and energy system.

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