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An Analysis of Solar Distillation Technology for Mars Colonization

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ABSTRACT

Aiming to analyze the practicality of distilling water on Mars, this research article studied vacuum membrane distillation and its ability to be utilized on Mars. Areas of study includes estimating water needs on Mars, analyzing existing water bodies on Mars, examination of vacuum membrane distillation technology, and more. It was concluded that vacuum membrane distillation is a technology possible to be utilized on Mars and could potentially distill enough water to support a Martian mission.

Introduction

Colonization of Mars has been a goal for humans for some time now. Mars is the only planet other than Earth in our solar system that possesses all the raw materials needed to support life and human civilization [1]. Considering that some natural resources are overexploited on Earth, it may be useful to explore other planets in our solar system. In order to build a habitat on Mars, certain vital elements for life need to be established. Water is a component crucial for human life, but water exists in different forms on Mars than on Earth. Most of the water on Mars exists in ice rather than liquid water, so for water to be utilized on Mars, purification must take place. Distillation allows liquid water to be separated from nonvolatile solids and it allows almost a full separation that raises the concentration of water significantly [2]. Water distillation is the process of vaporizing and recondensing water to leave behind impurities. Utilizing substances' specific heat, heating and cooling allows the concentration of the desired substance to increase by leaving out unwanted substances. Currently on Earth, distillation is used in situations such as desalination, making liquified gasses from air, and oil refining.

Aiming to replicate current distillation models on Mars, methods including vacuum membrane distillation (VMD) and air gap membrane distillation (AGMD) were studied and compared. Vacuum membrane distillation separates substances at a lower pressure than atmospheric distillation, allowing for substances to be vaporized at a temperature lower than their normal boiling points [3]. Distillation models utilize solar radiation in boiling and condensing water, and the calculation process involves different inputs, including the Sun's zenith angle, hour angle, diffuse radiation, and total intensity received. Using a current performance model, the process of predicting total solar radiation intensity received was reproduced to understand how each variable contributes to the outcome fully [4]. VMD models were studied to better understand the performances of such models, including how they work and what inputs may need to be changed in order to apply the model on Mars.

Estimates of Water Needs on Mars

Based on existing data and approximations of water needs on Earth, an estimate of water needs on Mars was calculated, accounting for a person's daily needs and uses of water as well as the need for water for plantation. A conservative estimate of 50 gallons of water per person per day accounts for [5]:

- Drinking water: 1 gallon

- Hygiene: 2.5 gallons
- Shower: 20 gallons
- Toilet: 18-24 gallons

Water is also needed for agriculture such as potatoes and other vegetables. For example, for every 100 potatoes, 1 gallon of water is needed every week for potato plantation year round [6].

Combining these individual needs, an estimate for the total amount of water needed is 400 gallons per week or approximately 1600 L/week.

The Existing Water On Mars and The Treatment Needs (From Existing Water and Water Recycling)

Existing water on Mars exists mainly in the form of ice, lying under ice caps in the North and South polar ice caps [7-8]. The volume of ice in the North and South polar ice caps on Mars is similar to the volume in the Greenland ice sheet, which is 2,900,000 cubic kilometers. Since water mainly exists in the form of ice, the process of distillation may require more energy as water will need to transform from ice to water vapor. This need for more energy is due to the fact that the higher temperature the water intake is, the better the model performance is [4].

Some ice on Mars is mixed with carbon dioxide, and other bodies of water contain salt. Distillation is needed to purify such water so that it may be used by crew members or future populations on Mars. For example, salt (NaCl) is heavier than water (H_2O), so by the process of distillation, NaCl may be eliminated. The recycling of water should also be considered as water on Mars is of a limited amount compared to water on Earth. Distillation will help with the process of recycling as it will allow for substances polluting the water or containing minerals that should not be accessed by humans to be eliminated before being reused.

VMD Technology

Water distillation is the evaporation of water. Because substances have different boiling points, certain components, such as water, may be extracted, leaving behind other components with a higher boiling point. Vacuum distillation lowers the boiling point of water, thereby increasing the vapor pressure of water. Dalton's law states that the total pressure exerted is equal to the sum of all the partial pressures exerted by different components [9]. When the vapor pressure of water is increased, the total pressure of the liquid mixture, by Dalton's law, increases as well. The difference in pressure between the inlet and the permeate side (see figure 1) creates a concentration gradient, vaporizing water more efficiently.

The VMD system is depicted in Figure 1. The absorber plate absorbs solar radiation through the glazing cover, minimizing heat loss, and the temperature rises inside the feed water model, vaporizing some of the feed water, and then collecting liquid water on the permeate side. Through this process, water is purified and other substances are left behind in the feed water due to a different specific heat or chemical property than water.

The VMD model applies vacuum on the permeate side of the membrane distillation model so that more water vapor is generated. The VMD model is one of the most accessible membrane distillation models to control, as the vacuum pressure may be adjusted based on specific measurements to ensure that the system is controllable. By maintaining low pressure on the permeate side of the distillation model, a gradient is created, allowing water vapor to enter the permeate side, leaving other substances behind.

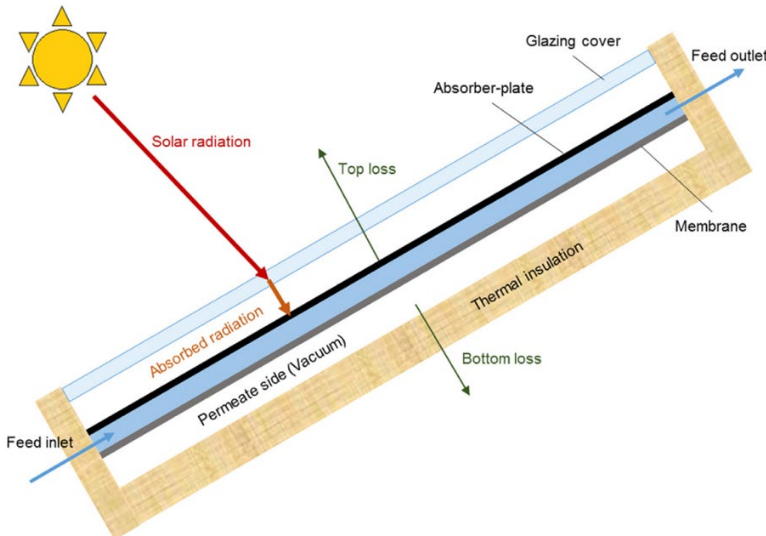

Figure 1. Cross-sectional view of VMD model demonstrating how solar radiation is utilized as an input [4].

Differences Between Martian and Earth Solar Radiation + Impact On VMD

Mars and Earth have different distances from the Sun and, therefore, different solar radiations. The average solar radiation on Earth is approximately 1380 W/m^2, whereas the average solar radiation on Mars is only 590 W/m^2 (difference in altitude, atmospheric conditions, cloud coverage, and ground surface reflectivity may affect the exact solar radiation the model receives). This difference in solar radiation will affect the efficiency of the VMD model since the model makes use of solar radiation to vaporize water. The process of vaporizing water may take longer as a result of less solar radiation, and the amount of water able to be vaporized may also be reduced.

Estimates for VMD Equipment for a Martian Mission or Colony

To better estimate VMD equipment needed for a Martian mission or colony, results from Q. Ma et al.'s 2022 paper [4] was taken. That work evaluated the efficiency of the VMD model on Earth and recorded the amount of water able to be distilled by VMD panels. The VMD model used in Q. Ma et al.'s research was an integrated solar VMD model, the same as the VMD model discussed in this paper. Q. Ma et al's research was conducted over a series simulations without controlling a set temperature, which is to best replicate situations on Earth [4]. The paper's results stated that "the daily water production reached 8 kg m^{-2} where [the gained output ratio] attained above 0.71 without the heat recovery from condensation during a 12-h operation and with a specific pumping energy consumption around 239 kWh m^{-3}" [4].

Based on the conclusion from [4], an adjustment was made to better replicate the environment on Mars. Assuming a six person Martian mission crew, 2400 gallons (2400 gallons x 3.79 kg/gallon = 9096 kg) of water is used per week (approximately 1300 kg per day). Based on the reported efficiencies this would require 162.5 m^2 of VMD panel, if the efficiency of VMD is identical as on Mars. Because the maximum solar radiation on Mars is 590 W/m^2, which is 42.75% as to the solar radiation on Earth, the size of the VMD panel needed should be divided by 42.75% as well, which results in approximately 380 m^2 of the VMD panel.

A Martian day is 24 hours and 37 minutes, which is 102.57% the day length on Earth. Accounting for the day length, the approximate size of the VMD panel would be 380 m^2/1.0257, which is 370.5 m^2. Based on existing calculations, a mass estimate for the VMD model is as follows:

- Typical thickness of insulation varies between 2.54 and 6.35 cm, a mean of 4.445 cm is used, multiplied by the area, 370.5 m^2, the volume is 16.47 m^3. The glass volume is assumed to be the same as the insulation.
- The density of insulation is around 40 kg/m^3, so the mass for insulation is calculated to be 658.8 kg.
- The density of glass is 2500 kg/m^3, so the mass for glass is calculated to be 41175 kg.
- Assuming the membrane has a thickness of 1 mm and a density of 2g/cm^3, the area remains the same (370.5 m^2), the mass of the membrane is 0.000741 kg.

Water may need to be stored as this calculation is an average, meaning some days more water will be distilled and other days less. Calculations were made based on average inputs, and certain variables may be different based on specific location of a Martian mission or colony. For example, the efficiency of a VMD panel is assumed to be the same as on Earth, however, because the solar radiation on Mars is often received along with high intensity cosmic radiation, which contains multiple types of ionizing radiation, the amount of solar radiation able to be received and utilized by VMD panels may be more limitimed than assumed [10]. Different altitudes may also affect the efficiency of the VMD model; some of the possible locations for a Martian landing are discussed in the following section.

Possible Locations for Martian Mission Landing

High altitude for a Martian mission offers promising solar radiation exposure, increasing VMD efficiency.

Based on NASA's 2015 workshop on potential sites for NASA's Mars 2020 Rover landing, some possible locations for a Martian mission landing are as follows:

- Columbia Hills, Gusev Crater; altitude around 82 m
- Eberswalde; altitude around -1350 m
- Jezero Crater; altitude around 2700 m
- Nili Fossae; altitude around -60 m

NASA's Mars 2020 Rover landed on Jezero Crater, where signs of water and lakebed sediments were found. If water is confirmed to be bountiful around the Jesera Crater area, a Martian mission will benefit from landing around the area as well, given that the altitude is quite high, offering promising solar radiation exposure.

Conclusions

VMD is a possible solution for water production on Mars because it utilizes in-situ resources such as solar radiation to distill water from other substances efficiently and because its size is practicable for a Martian mission. Using approximately 370.5 m^2 of VMD panel, 2400 gallons of water can be distilled per week to support six Martian mission crew members for their daily water needs and agriculture. The total weight needed to be brought to Mars to build a VMD system is around 41834 kg, compared to the mass of a space shuttle - over 2 million kilograms- is reasonably practicable. Hopefully, by utilizing VMD technology, Martian missions will have promised access to water.

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