

Mars Terraforming Examples

Chapter 6 (thermodynamic systems, enthalpy, specific heat, calorimetry, Hess' Law, heat of formation)

Thermodynamic Systems

Terraforming Mars will require many things, but most of all, it requires energy. Nuclear power plants brought from Earth will provide some energy but most energy will come from the Sun. Plants will absorb light in order to convert CO₂ to O₂. Orbiting mirrors will collect solar energy and focus the sunlight onto a small area in order to melt frozen CO₂ and ice. Once water and a thicker atmosphere appear on Mars, clouds will form and these will reflect some of the sunlight back into space. Would all this make Mars a closed open or isolated system?

(Mars is a closed system. Energy can enter and leave but not mass. On the other hand, if the materials brought from Earth to Mars are considered, Mars would be an open system since mass is entering the system.)

Enthalpy

1. Consider the following processes.

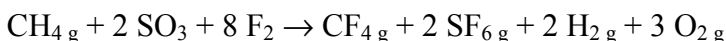
Greenhouse gases absorb sunlight and prevent the heat from escaping back into space.

This will cause the temperature on Mars to change from -60 °C to 5 °C. If all of Mars is the system, is this process endothermic or exothermic? (endothermic)

The factory that creates the greenhouse gases requires power from a small nuclear reactor. Is the process of making the greenhouse gases endothermic or exothermic? (endothermic)

Rocket propellants such as CH₄/O₂ and H₂/O₂ mixtures react and produce enough energy to move spaceships away from Earth and towards Mars. Is the burning of propellant an endothermic or exothermic reaction? (exothermic)

2. The following reaction might be used to generate the greenhouse gases needed to warm Mars:



$$\Delta H_{\text{rxn}} = -2485 \text{ kJ}$$

Endothermic or exothermic? (exothermic)

What is ΔH_{rxn} per mole of F₂ g used? (-310.6 kJ/mol F₂)

Earlier, we said that the production of greenhouse gases would require power from a small nuclear reactor because the production of gases was an endothermic process. So why is the above reaction exothermic?

CO₂ and SO₃ can be found on Mars but we haven't considered how we will make F₂ g and CH₄ g. Fluorine gas does not exist in the Martian atmosphere and it must be produced from CaF₂ rocks. The reaction is:

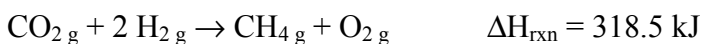


Is this reaction endothermic or exothermic? (endothermic)

How much energy is required to make the 8 moles of F₂ g needed for the production of SF₆ and CF₄?

$$(8 \times 1228 = 9824 \text{ kJ})$$

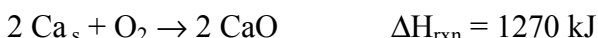
CH₄ will have to be made also. Starting with CO_{2 g} in the atmosphere and H_{2 g} brought from Earth or produced in other reactions, the production of methane occurs by the reaction:



Is this reaction endothermic or exothermic? (endothermic)

Which process requires less energy, production of a mole of F₂ or CH₄? (CH₄)

Even though production of greenhouse gases will require lots of energy, there is a silver lining to this whole process. The reactions make O₂ and Ca metal, which can react in an exothermic reaction:



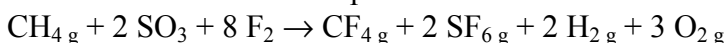
If 4 moles of oxygen gas and 8 moles of Ca metal are combined, how much energy is released when they react?

(5080 kJ)

Specific Heat

SF₆ and CH₄ are greenhouse gases that will be produced on Mars to help raise the temperature. An insulated reactor will contain F₂, CO₂ and SO₃ gases heated to 40 °C.

The reaction that will take place is:



Since the outside temperature on Mars will be -60 °C initially, energy must be supplied to heat the reactants to 40 °C. If stoichiometric amounts of reactants are placed in the reaction chamber, how much energy is needed to warm the reactants from -60 °C to 40 °C? The specific heat of each material is provided below. Assume that the reaction chamber is well insulated and so there is no heat loss.

$$s(\text{CH}_4\text{g}) = 9.82 \text{ J}/(\text{g } ^\circ\text{C})$$

$$s(\text{SO}_3\text{g}) = 0.634 \text{ J}/(\text{g } ^\circ\text{C})$$

$$s(\text{F}_2\text{g}) = 0.824 \text{ J}/(\text{g } ^\circ\text{C})$$

(509 J/°C for combined reactants, 50.9 kJ for 100 °C temperature change.)

Calorimetry

1. One significant difference between Earth and Mars is that there are no fossil fuels on Mars. Space vehicles that return to Earth from Mars will have to be very fuel-efficient. As a scientist at NASA, you are asked to determine the enthalpy for the combustion of each of the following fuels using a bomb calorimeter. All the fuels will react with excess oxygen at 278 K.

The calorimeter contains 1000 g of H₂O and has a calorimeter constant of 11.3 kJ/°C.

Three experiments were performed and the temperature changes noted:

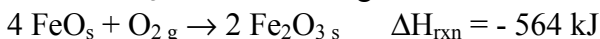
material	ΔT (°C)	reaction
1.15 g H _{2 g}	14.3	H _{2 g} + 1/2 O _{2 g} → H ₂ O _L
1.50 g CH _{4 g}	7.3	CH _{4 g} + 2 O _{2 g} → CO _{2 g} + 2 H ₂ O _L

Determine $\Delta H_{\text{rxn}}/\text{mol}$ fuel (either $\text{CH}_4 \text{ g}$ or $\text{H}_2 \text{ g}$).

(For the combustion of $\text{H}_2 \text{ g}$, $q = -161.6 \text{ kJ}$ for 1.15 g or -283.3 kJ/mol . Since $\Delta n = -1.5/\text{mol H}_2$ and $\Delta H = q + RT\Delta n$, $\Delta H = -286.8 \text{ kJ/mol}$.

For the combustion of $\text{CH}_4 \text{ g}$, $q = -82.5 \text{ kJ}$ for 1.50 g or -879.9 kJ/mol , $\Delta n = -2/\text{mol CH}_4$, $\Delta H = -884.5 \text{ kJ/mol}$.)

2. As plants convert CO_2 to O_2 , some of the oxygen will react with minerals and oxidize them. For instance, both FeO and Fe_2O_3 are found on Mars. FeO can react with O_2 to make Fe_2O_3 in the following reaction:



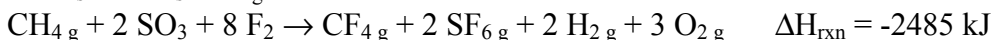
Since O_2 is a gas, this reaction will only occur on the surface of a FeO rock.

If a 5.05 kg chunk of FeO is exposed to O_2 , what will be the temperature change of the rock due to the oxidation of 20.07 g of FeO on the surface? Since most of the rock remains FeO , assume that $s_{\text{soln}} = s(\text{FeO}) = 1.40 \text{ J}/(\text{g } ^\circ\text{C})$. Assume that all the energy released from the oxidation reaction is absorbed by the rock.

($\Delta H_{\text{rxn}} = -564 \text{ kJ}$ for $4 \text{ mol FeO} = 141 \text{ kJ/mol FeO} = 1.96 \text{ kJ/g FeO}$. For 20.7 g FeO , $\Delta H_{\text{rxn}} = 40.6 \text{ kJ}$. $\Delta T = 5.74 \text{ K}$.)

Hess' Law and Heat of Formations

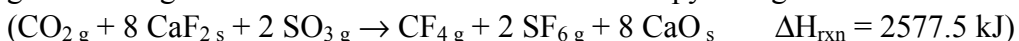
The production of greenhouse gases (CF_4 and SF_6) on Mars may require the following reactions:



Energy is also released when oxygen reacts with calcium metal:



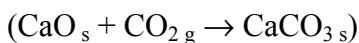
Write the overall, balanced reaction so that the only products made are desired greenhouse gases and CaO and determine the enthalpy change.



Use heat of formation data to verify the results of the Hess' Law problem.



Another process can be added that converts CaO to CaCO_3 . Write the reaction that could occur.



If $\Delta H_f(\text{CaCO}_3 \text{ s})$ is -1207 kJ/mol , does converting CaO to CaCO_3 help reduce the energy requirements of this reaction?

(Yes, the production of $8 \text{ moles CaCO}_3 \text{ s}$ releases 1428 kJ , lowering the total reaction enthalpy to 1149.5 kJ .)