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A1_9 Terraforming Mars: CO_2 Combustion

W.H.A. Longman, K. Flatt, S. Turnpenney, M. Garreffa

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

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Abstract
This report examines the feasibility of transporting coal from the Earth to Mars to increase the Martian atmospheric density. This is done by releasing CO_2 through combustion, which would terraform the planet. It was found that this was unfeasible due to the large values required: 3.15 x 10^{19} kg of coal and 1.97 x 10^{27} J of energy to transport it outside of the Earth's gravitational potential.

Introduction

As the Earth's population increases, the need to colonise other planets to ensure humanity's long term survival grows. A primary target is the planet Mars.

The hypothetical process of terraforming Mars is the deliberate changing of the Martian climate with the goal of making the surface more hospitable to human habitation and colonisation. There are several methods that potentially could achieve this, such as using orbital mirrors to increase the surface temperature [1] or placing coal from Earth on the Martian surface to produce CO_2 through combustion which would increase the atmospheric density to that similar to Earth. This is the process considered in this report. This would eliminate the present need for a pressure suit, making Mars more hospitable. The two parameters calculated in this are the mass of coal required and the amount of energy needed to transport this to Mars.

Volume of the Martian atmosphere

We model the Martian atmosphere as a thin shell of height ΔH. Figure 1 shows the vertical density profile for Mars, and from this we can see that there is a sharp fall in density around 60 km. This is hence the value we use for ΔH. For a thin shell of total radius R, the volume is given by $4\pi R^2 \Delta H$. Using R = 3390 km for the radius of Mars [2], we hence find that the volume is 9 x 10^{18} m^3.

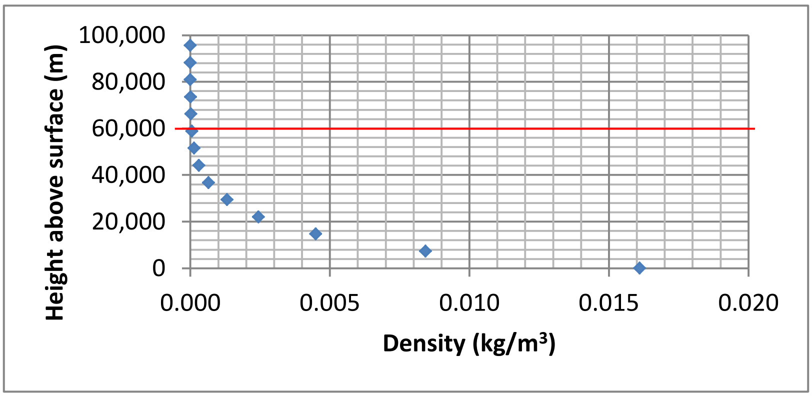

Figure 1: Vertical density profile of the Martian atmosphere. [3] The red line indicates the assumed abrupt boundary of the Martian atmosphere (60 km).

Required Mass of Coal

Assuming that the Martian atmosphere is an ideal gas, the equation of state will be $PV = Nk_BT$ (where P is pressure, V is volume, N is the number of molecules, K_B is the Boltzmann's constant and

T is the temperature). Given constant volume (V = Volume of Martian atmosphere = 9 x 10^{18} m^3) and temperature (T = Average temperature of Martian atmosphere at present = 218 K [4]), and that the Martian atmosphere current pressure is 600 Pa [5], we calculate N_1, the number of molecules at present. This was done by rearranging the ideal gas law and the result was N_1 = 1.79 x 10^{42}.

From the ideal gas law, there is a linear relationship between pressure, P and the number of molecules, assuming constant volume and temperature. We hence find

$$\frac{P_1}{P_2} = \frac{N_1}{N_2} \quad , \tag{1}$$

where P_2 is the pressure required, 1 atm. N_2 was hence calculated to be 3.02 x 10^{44}. Next, by subtracting N_2 by N_1 the number of (CO_2) molecules added by this increase in pressure can be calculated to be 3.00 x 10^{44}.

The molar mass of CO_2 (0.04401 kg/mol [6]) can be divided by Avogadro's number (6.022 x 10^{23} mol^{-1}) to find the mass of one CO_2 molecule which was found to be 7.31 x 10^{-26} kg. The total mass of CO_2 found is hence 2.19 x 10^{19} kg.

By finding that hard coal produces 0.34 kg of CO_2 per kWh [7] and that 0.49 kg (1.09 pounds) of coal generates a kWh [8] it therefore can be stated that 0.49 kg of coal burned releases 0.34 kg of CO_2 and hence giving a (coal mass/CO_2 mass released) ratio of 1.44. Multiplying the total mass of the CO_2 produced with the ratio gives the total mass of coal that would need to be burned to release the required CO_2 (and hence transported to Mars) which is 3.15 x 10^{19} kg.

Energy to transport coal to Mars

There are many steps which control the energy required to transport an object to Mars, however the dominant factor would be the energy required to take the object out of the Earth's gravitational field. The energy required to transport this coal is hence

$$E = \frac{1}{2} M v_E^2 \quad , \tag{2}$$

where M is the total mass calculated above and $v_E = 11.2$ kms is the Earth's escape velocity. We hence find the energy required to transport this amount of coal to Mars will be approximately 1.97 x 10^{27} J. To put this into perspective, the SpaceX Falcon Heavy which is the world's most powerful rocket has a payload capability to Mars of 13,200 kg [10] which means it would take 2.39 x 10^{15} launches to deliver the coal.

Conclusion

From the calculations above it is clear that transporting coal from Earth to Mars to increase the Martian atmospheric density (by releasing CO_2 through combustion) in order to terraform the planet is unfeasible. Hence, terraforming Mars must be done by using the resources already on the planet to increase the density and temperature through the greenhouse effect.

References

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