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INVESTIGATION OF THE USE OF THE LUNAR SURFACE LAYER TO STORE ENERGY FOR GENERATING POWER DURING THE LUNAR NIGHT

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Page 7: The values of thermal conductivity (cal/(sec)(cm)($^{\circ}$C)) in the third column of table I should be 8.26×10^{-6}, 1.98×10^{-4}, 6.61×10^{-4}, and 4.96×10^{-3}.

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SUMMARY

The lunar surface layer was analyzed as a heat-storage material for an electric power conversion system to be used during the lunar night. A solar concentrator and a surface heat exchanger with a coating having a high ratio of solar absorptivity to thermal emissivity were used to increase the thermal input to the storage bed during the lunar day. A Rankine cycle system was selected as the conversion device and the boiling temperature of the cycle was varied from 560° to 760° R (311° to 422° K).

To cover a range of possibilities, four postulated surface layer materials were considered; dry sand in a vacuum, pumicite, basalt lava, and basalt rock. For a powerplant conversion efficiency of 0.135, the required specific storage bed area for basalt rock was approximately 400 square feet per kilowatt electric (37.2 m^2/kW_e) for a boiling temperature of 560° R (311° K) more than 2 times as large for basalt lava, more than 6 times as large for pumicite, and about 40 times as large for dry sand.

The effects of raising the cycle boiling temperature were investigated for the two best storage materials, namely, basalt rock and basalt lava. Operation at higher boiling temperatures reduced radiator area, but at the expense of a larger storage bed. The specific bed areas increased approximately 20 to 30 percent for each 100° R (55.5° K) increase in boiling temperature for both materials. Additionally, the boiling temperature of 760° R (422° K) was achievable only when the storage bed was preheated at least 2 lunar days before heat was removed for the first power period.

Throughout the study assumptions favorable to the thermal energy storage device were used. A rough estimate indicated that the specific weight of a thermal-storage-device - solar-cell combination was of the same order of magnitude as that of a solar-cell - regenerative-fuel-cell system or the isotope Brayton system. Additionally, there are formidable problems resulting from the large reflector, radiator, and surface heat-exchanger areas involved. Therefore, it was concluded that the possibility of developing an attractive thermal-energy-storage device using this concept does not appear promising.

INTRODUCTION

In competition with isotope Brayton or nuclear reactor systems is the use of solar cells for generating electric power on the moon. Because the moon undergoes alternating 354-hour periods of sunlight and total darkness, a power generation system is needed in order to provide electric power during the dark periods and thus complement the use of solar devices during the sunlit periods. Regenerative fuel cells are possible energy reservoirs, but these are relatively heavy. Another approach is to heat a storage bed during the lunar day and withdraw the stored thermal energy during the lunar night for use in a power generation system. The purpose of this study was to devise such a storage device and evaluate its feasibility.

The basic philosophy in the analysis was to use indigenous lunar materials for the thermal-storage material because of the prohibitive weights involved in transporting heat-storage materials to the moon. There is, of course, considerable doubt about the nature of the lunar surface layer, its origin, and its thermal and mechanical properties. References 1 to 5 discuss suggested models for the lunar surface layer and the physical and thermal properties of postulated lunar materials. In addition to these sources, recent information about the surface thermal properties is contained in references 6 and 7, which report the findings of the Surveyors I and III soft landings at two different sites on the Moon.

Although the characteristics of the lunar-surface-layer thermal-storage device will be dependent on the properties of the storage material, its feasibility and attractiveness can be evaluated by considering several postulated materials which cover the range of anticipated lunar material properties. Four materials were used in this study: dry sand, pumicite, basalt lava, and basalt rock. The rationale used in selecting these materials was the following. The thermal properties of dry sand in a vacuum were chosen as a likely lower limit of interest for possible lunar materials. These values have been experimentally determined and are reported in reference 1. As a likely upper limit the thermal properties of solid basalt rock were chosen. Two postulated materials with thermal properties intermediate to those of sand and solid basalt rock, pumicite and basalt lava, were selected to investigate more extensively the merit of the proposed scheme. The thermal properties for these two materials have likewise been experimentally determined and are found in reference 2. Unpublished results from the alpha scattering experiment on Surveyor V indicate that the lunar soil has a basaltic composition.

SYMBOLS

A area, ft^2; m^2

A_R prime radiator area, ft^2; m^2

B width of thermal storage bed, ft; m

c_p storage material specific heat, Btu/(lb)(°R); J/(kg)(°K)

k storage material thermal conductivity, Btu/(hr)(ft)(°R); W/(m)(°K)

L length of storage bed, ft; m

M reflector wdith, ft; m

P electric power, W

Q heat transferred, Btu/hr; W

T temperature, °R; °K

x distance below bed surface, ft; m

ϵ_{eff} effective emissivity

ρ storage material density, lb/ft^3; kg/m^3

σ Stefan-Boltzmann constant, 0.1713×10^{-8} Btu/(hr)(ft^2)(R^4); 5.669×10^{-8} W/(m^2)($°K^4$)

Subscripts:

b bed

HX surface heat exchanger

n night

R radiator

LUNAR STORAGE-BED CONCEPT

The energy-storage scheme which evolved is shown in figure 1. A fin-and-tube heat exchanger is placed on the surface of the Moon, the lunar surface to be used having been previously cleared of any unwanted dust or rubble which might be present. The top surface of the heat exchanger has a coating with a high solar absorptivity and a low thermal emissivity in order to increase the net energy stored. A flat reflector is used to increase the solar flux incident on the bed. The reflector is pivoted at the edge of the bed and tracks the sun in a manner which maximizes the total solar flux incident on the bed.

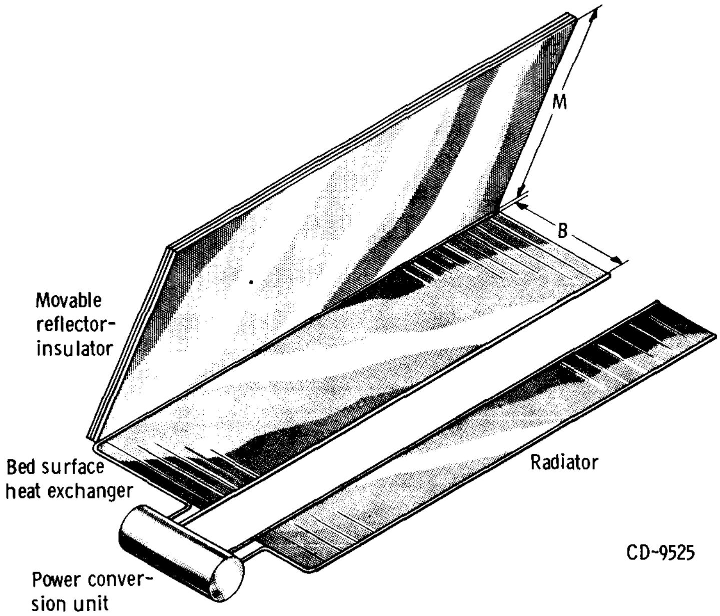


Figure 1. - Lunar surface layer heat storage system.

Conversion System

A Rankine-cycle powerplant was selected for the conversion system because of its good thermal efficiency at high ratios of heat rejection temperature to peak cycle temperature. The closed Brayton cycle was not used because the low heat-rejection temperature required for reasonable cycle efficiency would result in excessively large radiator area. Direct energy conversion devices were not considered because of their inherently low conversion efficiencies.

Storage-Bed Operation

The basic operating scheme is depicted in figure 2. During the lunar morning, the plane reflector tracks the Sun as it rises. At noon, the reflector is transferred from one side of the bed to the other, and the tracking operation continues until the sun sets. The reflector is then laid horizontally across the bed in order to act as a radiation shield against heat loss during the lunar night.

During the lunar night, a two-phase fluid at a boiling temperature lower than the bed temperature is passed through the heat exchanger, which covers the bed. Radiation is assumed as the mode for heat transfer to the heat exchanger from the bed surface because the lunar surface is expected to be irregular, and therefore a good heat-conduction path from the bed surface to the heat exchanger would be difficult to establish. The

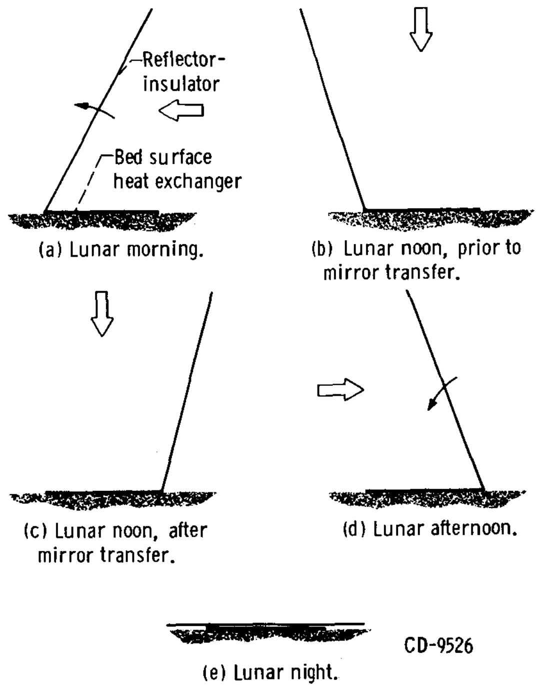


Figure 2. - Thermal-storage system operation. (Arrows indicate direction of solar rays.)

working fluid, after passing through the heat exchanger, flows through the rest of the Rankine system, and electric power is generated. In order to increase the temperature level of the bed, the bed can be preheated for longer than 1 lunar day before power is first drawn, providing that mission requirements allow this. This heating-soaking mode of operation can be effected by maintaining the lunar day operation but allowing the bed to remain dormant during the lunar night with no heat extraction except radiation heat loss from the surface.

ANALYSIS

Mathematical Model of Storage Bed

Transient, one-dimensional heat flow within the bed was considered. A finite-difference numerical approach was used. This mathematical representation of the storage bed implicitly assumed negligible heat loss along the edges of the designated bed area and an isothermal heat exchanger, that is, no temperature change along the tubes or fins of the heat exchanger. The storage-bed model assumed a homogeneous bed with thermal properties independent of temperature. The bed was assumed to be initially of uniform temperature throughout. Three sets of conditions were used at the surface heat exchanger, one for each mode of bed operation:

(1) Lunar day operation - solar heat input to heat exchanger and radiation from the heat exchanger to the heat-storage-bed surface and to space as a loss with heat exchanger at its equilibrium temperature.

(2) Lunar night operation with power extraction - radiation from the heat-storage bed surface to the heat-exchanger and heat loss to space from the heat exchanger through the insulation. Heat exchanger temperature held constant at working-fluid boiling temperature.

(3) Lunar night operation without power extraction (heating-soaking mode) - radiation heat loss from heat-storage bed surface to heat exchanger and from heat-exchanger to space through insulation, with heat-exchanger at its equilibrium temperature.

Coupled with each of these surface heat-exchanger conditions was the additional condition that negligible heat flow pass through a specified bottom of the bed. This specified bottom was chosen for each case from consideration of the thermal diffusivity of the storage material and the length of time over which the bed would be used. Results were checked to make sure that this boundary condition was, in fact, a reasonable one.

Calculation Procedure

For calculation of the temperature distribution in the bed, the bed was divided into layers, each layer being characterized by a nodal point at the center of the layer. In addition, a zero-heat-capacity nodal point was assumed at the surface of the bed. Each time period (lunar day or lunar night) was divided into small time increments. The size of the depth increments and length of the time increments were chosen from consideration of the storage-bed material properties. For each time increment the temperature distribution was found by first calculating the heat-exchanger temperature and surface temperature of the bed by an iterative procedure using the appropriate boundary condition on the heat exchanger and then progressively calculating the temperature of the bed layers down to the "bottom" layer of the bed, where the condition of no heat flow (a perfectly insulated bottom) was applied.

Once the temperature distribution in the bed was obtained, the net heat per unit area into the working fluid could be found by subtracting the thermal radiation loss to space from the heat conducted to the surface of the bed as is given in the following equation:

$$\frac{Q}{A} = k \left. \frac{dT}{dx} \right|_{\text{bed surface}} - \sigma \epsilon_{eff} (T_{HX})^4$$

The electric power output per unit area can be found by multiplying the net heat per unit area into the Rankine system by its conversion efficiency.

Calculation Inputs

Storage-bed material. - Four materials were selected for investigation as the storage-bed material. They were dry sand, pumicite, basalt lava, and solid basalt rock. They are listed in table I along with their properties as measured in a vacuum environment (refs. 1 and 2). Surveyor I results (ref. 6) show marked similarities between the lunar-surface temperatures and those that would be exhibited if the surface material was assumed to have a thermal inertia $(k\rho c_p)^{-1/2}$ of about 1000 $(^{o}C)(cm^2)(sec^{1/2})/cal$ $(239\times10^4\ (^{o}K)(m^2)(sec^{1/2})/J)$. Reference 7, reporting Surveyor III results, concluded that lunar surface temperatures around noon are compatible with the homogeneous-surface model with thermal inertia greater than 400 (95.8×10^4). It also pointed out that, during the day, surfaces with a thermal inertia greater than 500 (119.5×10^4) would have essentially the same temperature. Thus, it appears that a thermal inertia in the range 400 to 1000 $(95.8\times10^4$ to $239\times10^4)$ would be consistent with the results from Surveyors I and III. From table I it can be seen that only one of the postulated materials, sand, has a thermal inertia that falls within this range. Although the thermal inertias of the others fall below the range indicated by the Surveyors, they may still be considered as possibilities at other locations or as subsurface possibilities.

TABLE I. - PROPERTIES OF POSTULATED LUNAR MATERIALS

Postulated material	Thermal conductivity, k		Density, ρ		Specific heat, cp		Thermal inertia, $(k\rho c_p)^{-1/2}$	
	$Btu/(hr)(ft)(^{o}R)$	$cal/(sec)(cm)(^{o}C)$	lb/ft^3	g/cm^3	$Btu/(lb)(^{o}R)$	$J/(kg)(^{o}K)$	$(^{o}C)(cm^2)(sec^{1/2})/cal$	$(^{o}K)(m^2)(sec^{1/2})/J$
Dry sand	0.002	8.26×10^{-6}	100	1.6	0.21	0.878×10^3	600	143.5×10^{-4}
Pumicite	.048	1.98×10^{-4}	80	1.28	↓	↓	136	32.5
Basalt lava	.16	6.6×10^{-4}	130	2.08	↓	↓	58.5	14.0
Basaltic rock	1.2	4.96×10^{-3}	180	2.89	↓	↓	18.2	4.35

Normal lunar temperature environment. - Based on Earth observations, the lunar surface temperature has been estimated to range from 673^{o} R (374^{o} K) at the sub-solar point to 216^{o} R (120^{o} K) during the dark period (ref. 8). In addition, the subsurface temperatures at depths greater than 3 feet have been estimated to be approximately 440^{o} R (244^{o} K) and constant (ref. 9). For the purpose of this study, the initial storage bed temperature was assumed to be 440^{o} R (244^{o} K) for its entire depth prior to the first heat addition period, this assumption yielding slightly optimistic results.

Heat-exchanger coating. - The heat-exchanger surface coating was assumed to be magnesium fluoride - molybdenum - cerium oxide (MgF_2-Mo-CeO_2) on molybdenum with a solar absorptivity of 0.85 and a thermal emissivity of 0.053 (ref. 10).

Reflector-radiation shield. - The reflector was assumed to have a reflectivity of 0.85. It was assumed that the reflector was backed by several thin sheets separated by vacuum, thereby acting as a radiation shield at night in order to reduce thermal losses from the bed. It was further assumed that enough low-emissivity sheets were used such that the effective night emissivity would have a value of 0.0065.

Solar flux. - The total solar flux incident on the bed is a function of the ratio of reflector width to bed width M/B. An analysis was made for a flat reflector pivoted at the edge of the bed and positioned to give maximum incident flux on the bed. From the results of this analysis, which are presented later in this report, a value of M/B of 1.5 was selected for the study, and the corresponding total incident solar flux as a function of time was used.

Rankine cycle. - The conversion cycle was chosen to operate at a condensing-to-boiling temperature ratio of 0.75 and to have an overall conversion efficiency of 0.135 for the bulk of the study. For one example the cycle temperature ratio was varied to investigate its effect on combined prime radiator and prime storage-bed areas.

In this study, the working-fluid boiling temperature was varied from 560° to 760° R (311° to 422° K). There are a number of fluids, such as ammonia and some of the Freons and light hydrocarbons, that might be used in this temperature range.

RESULTS AND DISCUSSION

Reflector

The relation between the elevation of the Sun above the horizon and the reflector angle yielding maximum energy incident on the storage bed is presented in figure 3 for a flat reflector. The reflector position for maximum incident energy is shown to be a function of the ratio of reflector width to bed width M/B as well as a function of the elevation of the sun. The total solar flux incident on the storage bed as a function of time is shown in figure 4 for several values of M/B, the reflector angle being optimum at each point in time. The solar flux incident on the bed if no reflector were used is also shown in figure 4. The advantage of using a reflector is readily apparent, but the choice of M/B is not. As M/B is increased, the difficulties of reflector construction and deployment increase, and the incremental gain in total incident energy is reduced. On the basis of these considerations, a value of 1.5 was arbitrarily selected for M/B.

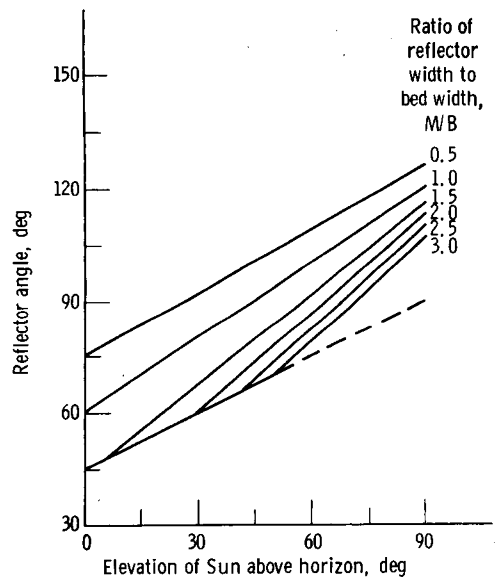


Figure 3. - Relation between reflector angle and Sun angle for maximum incident energy to storage bed.

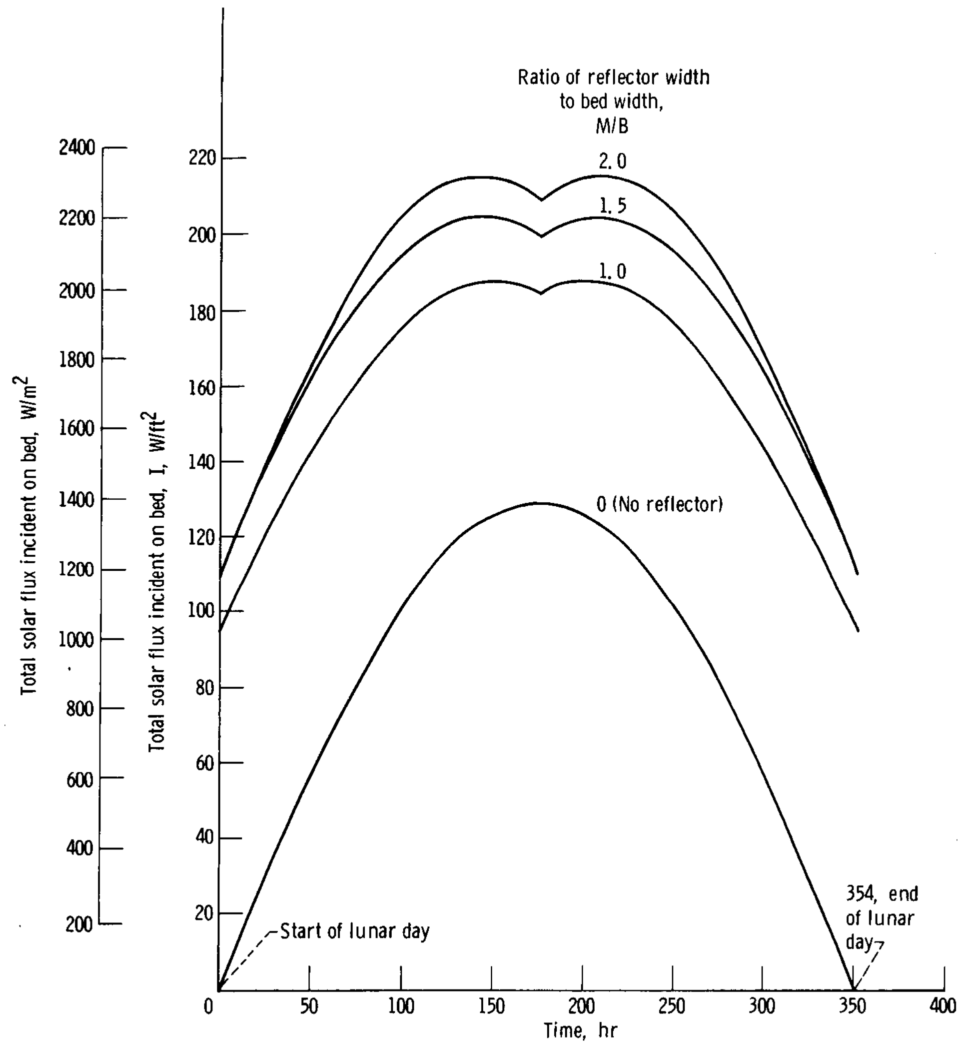


Figure 4. - Total solar flux incident on bed as function of time. Flat plate mirror; mirror reflectivity, 0.85; mirror pivoted at bed edge.

Energy-Storage Bed

Comparisons of storage-bed materials. - The net thermal energy stored by the assumed lunar-surface materials during the first lunar day is compared in table II. The net thermal energy stored by the basalt rock was 2.5 times as large as that stored by basalt lava, 5.5 times as large as that stored by pumicite, and 23 times as large as that stored by sand.

TABLE II. - NET THERMAL ENERGY STORED DURING FIRST LUNAR DAY FOR SEVERAL POSTULATED MATERIALS

	Energy content	
	(kW)(hr)/ft^2	J/m^2
Basalt rock	30	11.63×10^8
Basalt lava	12	4.65
Pumicite	5.4	2.09
Dry sand	1.3	.50

The temperature profiles at sunset after the first heat addition period are shown in figure 5. The surface temperature for basalt rock is in excess of 1200° R (667° K), while the other three materials show surface temperatures of approximately 1350° R (750° K). The sunset temperature profiles of basalt rock and basalt lava are also shown after six heating-soaking periods; the heat has penetrated the bed more than 15 feet (4.57 m) in the case of basalt lava and well over 20 feet (6.1 m) for solid basalt rock.

During the lunar night, heat is removed from the storage bed by radiation from the bed surface to the heat exchanger, which is maintained at a constant temperature, the working-fluid boiling temperature. Figure 6 shows the net thermal power transferred from the basalt-rock storage bed to the heat exchanger at 560° R (311° K) for the first, third, and sixth heat-removal periods as a function of time. The rate of heat transfer decreases with time because the bed surface temperature is decreasing with time while the temperature of the heat exchanger remains constant. It can also be seen that the thermal power increases as the number of power cycles increases. The difference in heat-transfer rate between successive power cycles decreases as the number of power cycles increases, indicating a tendency toward limiting, repetitive cycles.

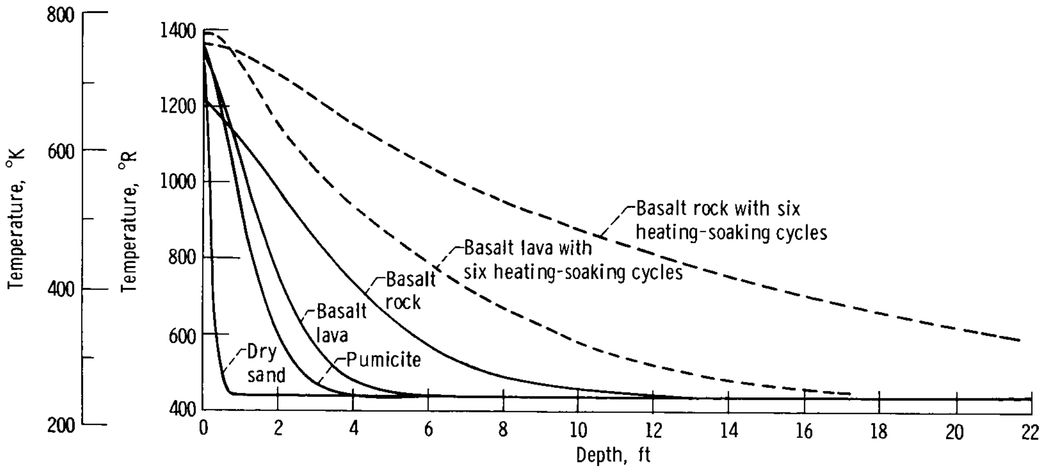


Figure 5. - Temperature profiles at the start of first power cycle for several postulated lunar materials. Mirror reflectivity, 0.85; ratio of reflector width to bed width, 1.5; solar absorptivity, 0.85; infrared day emissivity, 0.053; infrared night emissivity, 0.0065.

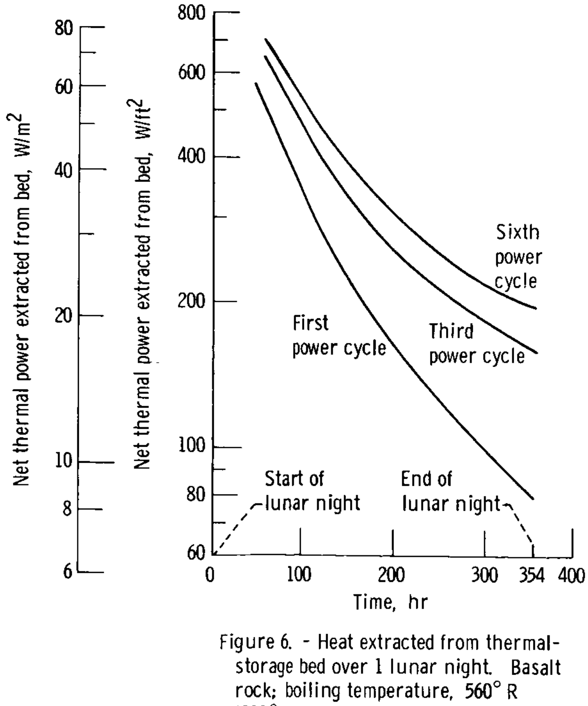


Figure 6. - Heat extracted from thermal-storage bed over 1 lunar night. Basalt rock; boiling temperature, 560° R (311° K); no heating-soaking cycles.

The fact that the heat transferred to the constant-temperature heat exchanger decreases with time may present serious problems to a conversion system designed to operate at a fixed boiling temperature and constant thermal input. If the load demand is approximately constant over the lunar night, some method would be required to handle the excess temperature available at the beginning of the lunar night, such as superheating in the boiler or a shutter between the bed and the heat exchanger. In the absence of such a control, the excess thermal energy removed would either be utilized or rejected to space. For this study, no control device was used, and it was assumed that the useful electrical power generated is that generated at the end of the lunar night; the specific powers presented are based on this assumption.

For the four lunar materials considered, the amount of power that could be generated for each square foot of storage-bed area is shown in figure 7, the conversion efficiency being taken as 0.135.

For the basalt-rock storage bed, the available electric power rose from about 1 watt per square foot (10.76 W/m^2) for the first lunar night to about 2.5 watts per square foot (26.9 W/m^2) for the sixth lunar night. For the sixth lunar night, the specific power was

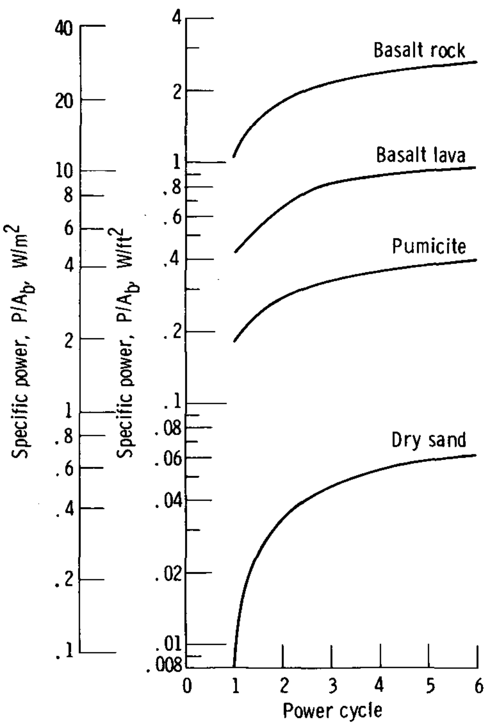
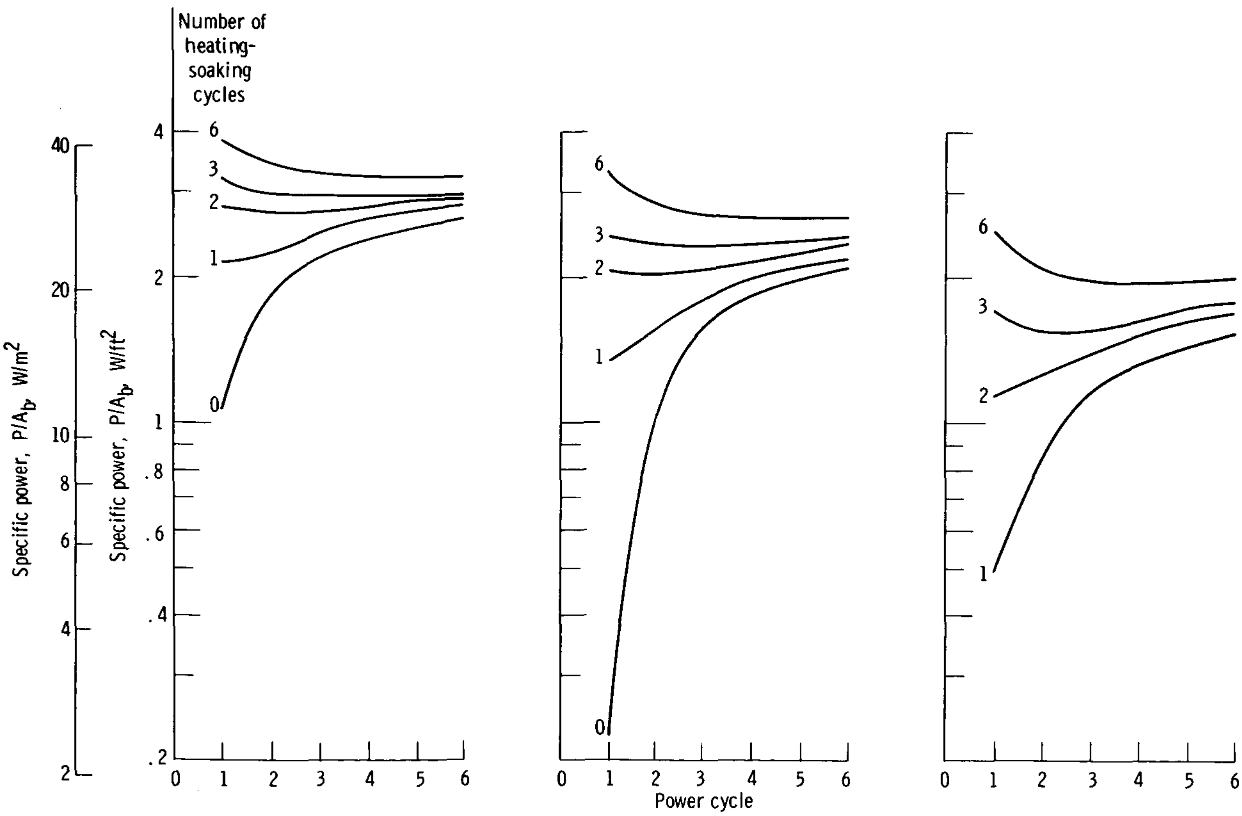


Figure 7. - Variation of electric power generated with time. Boiling temperature, 560° R (311° K); conversion efficiency, 0.135; ratio of reflector width to bed width, 1.5; mirror reflectivity, 0.85; solar absorptivity, 0.85; infrared day emissivity, 0.053; infrared night emissivity, 0.0065.

about 1 watt per square foot (10.76 W/m^2) for basalt lava, 0.4 watt per square foot (4.30 W/m^2) for pumicite, and 0.06 watt per square foot (0.65 W/m^2) for dry sand. Thus, for each kilowatt of electric power the required storage-bed area would be 385 square feet (35.8 m^2) for basalt rock, 1065 square feet (99 m^2) for basalt lava, 2500 square feet (232 m^2) for pumicite, and more than 16 000 square feet (1487 m^2) for dry sand. On the basis of these results the two best materials, solid basalt rock and basalt lava, were selected for further investigation at higher working-fluid boiling temperatures.

Effect of boiling temperature. - To determine the effect of increasing boiling temperature upon storage-bed area and radiator area, calculations were made for a range of working-fluid boiling temperatures. The Rankine cycle temperature ratio, T_R/T_b, was maintained constant at 0.75. Increasing the boiling temperature decreases the size of the radiator required, but the size of the thermal storage bed is affected adversely. Figure 8 shows the effect of increasing the Rankine-cycle boiling temperature from 560° to 660° to 760° R (311° to 367° to 422° K) with basalt rock as the thermal-storage material

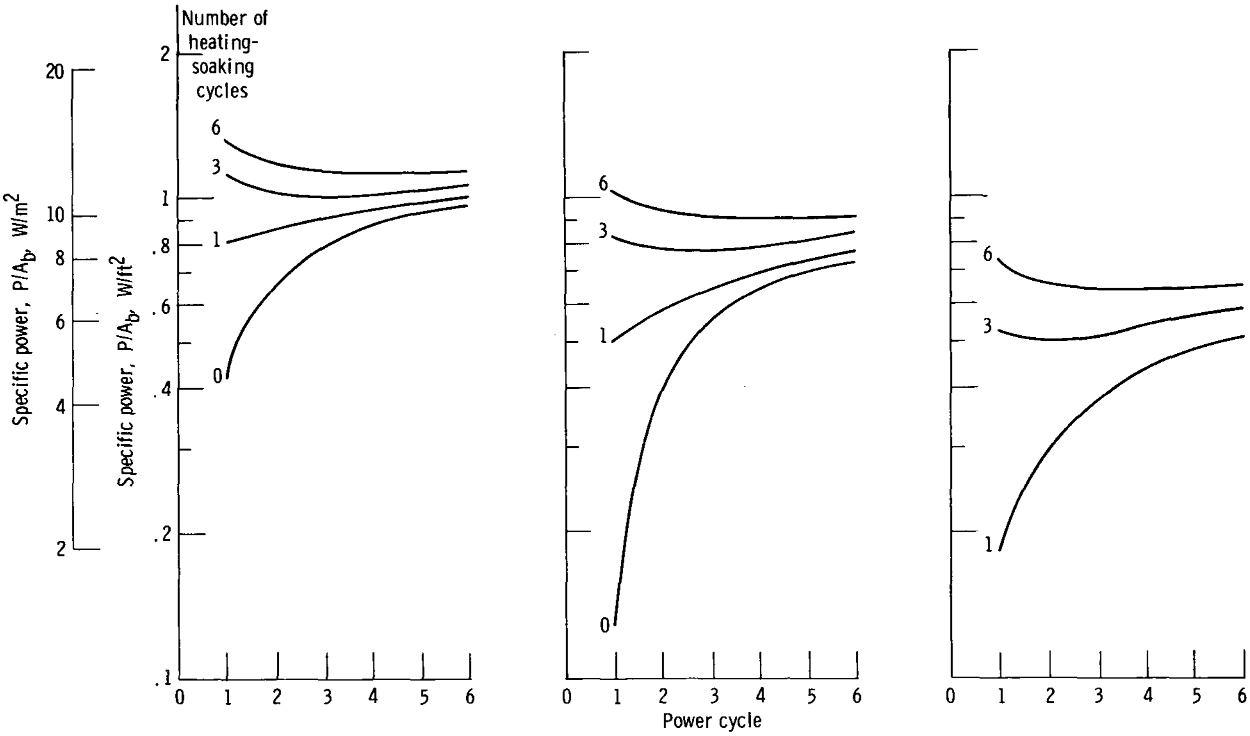


(a) Boiling temperature, 560° R (311° K).

(b) Boiling temperature, 660° R (367° K).

(c) Boiling temperature, 760° R (422° K).

Figure 8. - Variation of electric power generated with time. Basalt rock; conversion efficiency, 0.135; ratio of reflector width to bed width, 1.5; mirror reflectivity, 0.85; solar absorptivity, 0.85; infrared day emissivity, 0.053; infrared night emissivity, 0.0065.



(a) Boiling temperature, 560° R (311° K).

(b) Boiling temperature, 660° R (367° K).

(c) Boiling temperature, 760° R (422° K).

Figure 9. - Variation of electric power generated with time. Basalt lava; conversion efficiency, 0.135; ratio of reflector width to bed width, 1.5; mirror reflectivity, 0.85; solar absorptivity, 0.85; infrared day emissivity, 0.053; infrared night emissivity, 0.0065.

and with as many as six heating-soaking cycles preceding power generation. At the sixth power cycle, which is indicative of equilibrium operation, figure 8 indicates that the electric power generated per square foot of storage bed decreased by 20 to 30 percent for each 100° R (55.5° K) in boiling temperature. Similar curves for basalt lava are presented in figure 9. Here again, increasing the boiling temperature 100° R (55.5° K) decreases the power available per square foot of storage bed by 20 to 30 percent. For both materials, heating and soaking were required to operate the heat exchanger at 760° R (422° K) continuously during the first lunar night. Therefore, with heating and soaking, there is a wider range of boiling temperatures from which to choose, and selection of cycle temperatures would involve a tradeoff between storage-bed size, which increases with increasing boiling temperature, and radiator size, which decreases as boiling temperature is raised. Prime storage-bed area and prime radiator area, which are the areas required for isothermal surfaces, are plotted against boiling temperature $T_{HX,n}$ in figure 10. An actual radiator or surface heat exchanger, such as a fin-and-tube type, would require larger areas than the prime areas presented. The prime radiator areas shown are those required for heat rejection of only the waste heat from the conversion

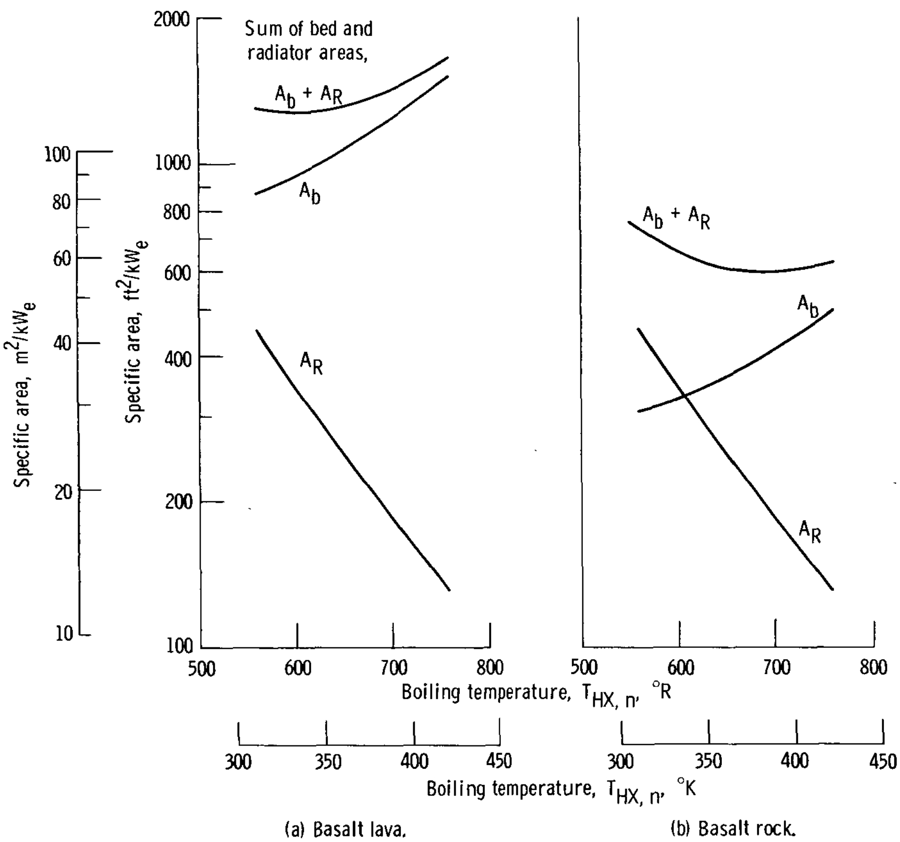
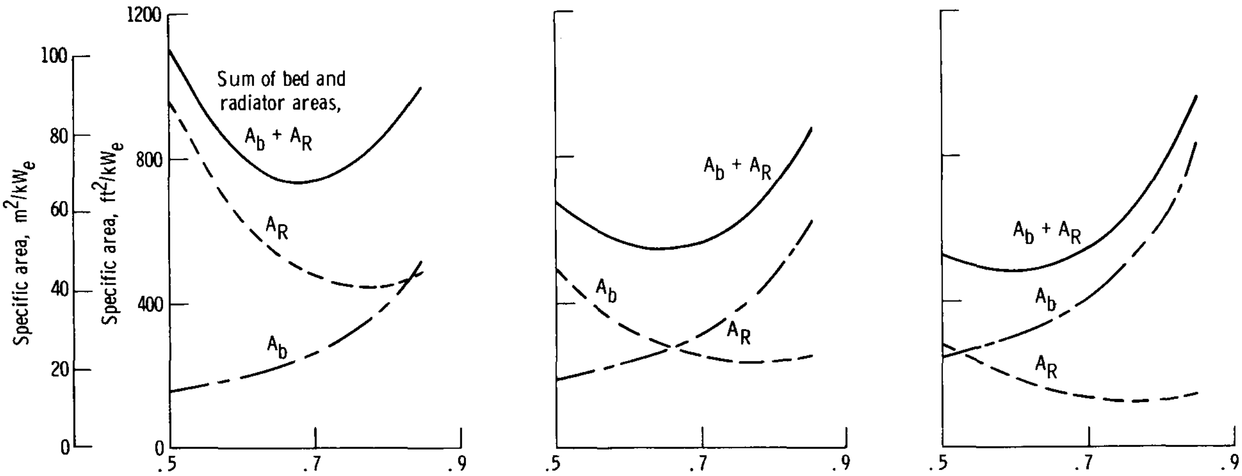


Figure 10. - Effect of peak cycle temperature on prime radiator and storage-bed area. Conversion efficiency, 0.135; radiator temperature, three-fourths of boiling temperature; sink temperature, 0° R (0° K); infrared radiator emissivity, 0.9; ratio of reflector width to bed width, 1.5; six heating-soaking cycles; six power cycles.

system. Figure 10 shows clearly that selection of the best boiling temperature involves consideration of both radiator area and storage-bed area. For a cycle temperature ratio T_R/T_b of 0.75, the lowest combined area for both storage bed and waste-heat radiator is obtained with boiling temperatures in the range 650° to 750° R (361° to 417° K) for basalt rock and in the range 550° to 650° R (306° to 361° K) for basalt lava. For basalt rock, this minimum combined area is 600 square feet per kilowatt of electric power (55.8 m^2). The other storage-bed materials would require larger areas.

Effect of cycle temperature ratio. - Figure 11 shows the effect of varying cycle temperature ratio T_R/T_b for boiling temperatures of 560° to 760° R (311° to 422° K) for basalt rock. For minimum combined area of storage bed and radiator, cycle temperature ratios less than 0.75 are required, especially at the higher boiling temperatures. If both boiling temperature and cycle temperature ratio are varied, the minimum combined area is approximately 500 square feet per kilowatt of electric power (46.5 m^2). It should be restated that the minimum areas presented are for the favorable conditions of



(a) Heat-exchanger temperature, 560° R (311° K).

(b) Heat-exchanger temperature, 660° R (367° K).

(c) Heat-exchanger temperature, 760° R (422° K).

Figure 11. - Effect of cycle temperature ratio upon prime radiator and storage-bed area. Basalt rock; six heating-soaking cycles; six power cycles.

six heating-soaking cycles before the first power is drawn; without this heating and soaking, the combined areas would be larger.

Evaluation. - The merits of the thermal-storage power system must be judged by comparison with its competitors, namely, (1) solar cells plus regenerative fuel cells, and (2) the isotope Brayton power system. Although system endurance and develop ability are the principal measures of merit for such future power systems, they are factors difficult to compare in an analysis such as this one. However, weight estimates can be used to judge whether or not further investigation of a given system is worthwhile.

A competitive power system, whether a solar-cell - regenerative-fuel-cell system or an isotope Brayton system, will weigh of the order of 500 to 1000 pounds per kilowatt of power (226.8 to 453.6 kg/kW) produced, and would produce power continuously during both lunar day and night. The thermal-storage power system analyzed herein is best suited to providing power during just the lunar night. However, use of solar cells in combination with this thermal-storage system would also produce power continuously. Such a solar array might add 100 pounds per kilowatt (45.4 kg/kW), a comparatively small weight, to the thermal-storage system.

The weight of the thermal-storage system is herein estimated by use of the following assumptions:

(1) Radiator weight is 1 pound per square foot (4.9 kg/m^2) of prime area.

(2) The combined weight of heat exchanger, reflector, deployment mechanism and structure, orientation mechanism, and insulation is 2.5 pounds per square foot (12.2 kg/m^2) of storage-bed prime area.

(3) Solar cells for daytime power add 100 pounds per kilowatt (45.4 kg/kW).

(4) The weight of all else in the system may be neglected.

(5) The lunar surface is basalt rock.

(6) The power generated per unit area is that generated at the end of the sixth power period with the bed having been conditioned with 6 heating-soaking cycles before the first power is drawn.

The resulting minimum weight is 1000 pounds per kilowatt of electric power (453.6 kg/kW). If, in order to conserve the heat, the thermal power extracted from the storage bed can be modulated without adding a heavy shutter or other mechanism, this weight might drop to about 700 pounds per kilowatt (318 kg/kW).

Thus, a very optimistic evaluation of the thermal-storage system is required in order for it to be weight-competitive, and therefore a real system is likely to show a weight disadvantage.

CONCLUDING REMARKS

The study shows that the size of the storage bed is strongly dependent upon the properties of the lunar-surface material. Even if the best postulated material is assumed (solid basalt rock), the areas required for the storage bed per kilowatt generated are large. Large storage-bed areas of themselves are probably not limiting, but the associated problems of even larger reflector areas, construction and deployment, fluid pumping power, and protection of the surface heat exchanger against meteoroids are all aggravated by large bed areas. Additionally, a large radiator area is required by the low heat-rejction temperature.

The rough weight estimate made indicated that the entire system would weigh, even under optimistic assumptions, of the same order as a solar-cell - regenerative-fuel-cell system or an isotope Brayton system.

On the basis of this preliminary study, it is concluded that the possibility of developing an attractive lunar-surface power-generation system using this concept does not appear to be promising.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 19, 1967,
120-33-05-02-22.

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