ISRU to harness, store, and transport thermoelectrical energy on the lunar surface to support space habitat

Sharat Chandra[a]

a) Research Scholar at MNIT Jaipur – sharataero@gmail.com

Abstract:- It has been more than 50 years since mankind stepped over the moon for the first time. Outer space has always been a matter of interest for space enthusiasts people to date.

Scientists have been able to send the robots and probes to the moon and mars but satisfying the energy required for these types of equipment are very challenging. Till now the probes sent to the other planet were equipped either with batteries or with a solar panel. Although these are good options as of now these techniques have certain limitations as the batteries have a self-life and solar panels can't be used for a longer duration.

Researches are being carried out to fulfil the requirements of energy for the colonisation of Mars and the moon. One of the promising techniques seems to be is **thermoelectric generators** also called **Seeback generators** and **thermocouples** which can directly convert heat flux (temperature difference) to electricity. As it has been observed and concluded that temperature variation on the lunar regolith is very high i.e. if we go under the surface of the moon the temperature difference of even 100^{o}C can be observed easily. This temperature difference can be converted into electricity.

A thermocouple consists of two wires with different conductivity joined together at two different junctions. When the junctions are maintained at different temperatures the electrons start flowing from higher temperature to the lower temperature junction. The silicon and Silicon carbide can be used as a substrate for the upper and lower surface as their electrical conductivity differs by very high values and the thermocouple wires made up of graphene and silicon carbide can be used as their thermal conductivity is 4000W/m-K and 20.7W/m-K and their electrical conductivity is of the order 100S/m. The small circuits can be fabricated and can be compiled as thermopiles and can be used to increase efficiency.

The one junction of the thermocouple is supposed to be in the outer surface and the other junction to be kept under the surface so the difference of the temperature can easily be attained and this can result in the generation of electricity for further uses.

Introduction:- With this current situation and scenario the energy demand is exponentially increasing and satisfying this is a great challenge for this planet. According to the UN report, the population of the world will spike up to 9.5 billion by 2050. So the energy demand will be very high in the upcoming decades not only on the earth but even in the space sector. Tremendous efforts are going all over the globe to fulfil the requirement of the energy crisis.

Within the next two decades, human is going to set their footprint on Moon and Mars. The use of telerobotics tethered robotic rovers, and other space architectures are being built to support consistent science and commercial operations on the permanently shadowed regions on the Moon, to establish human space habitat for a sustainable and affordable human life settlement, extraction of energy to and from the planetary bodies including asteroids.

Apart from traditional chemical energy solutions like solar photovoltaic cells used on the arrays, rechargeable batteries, and other conventional methods, it is prominent that the ISRU method is cost-effective; simpler with the less hazardous scenario is best to afford consistent, clean, affordable supply of energy to the space habitat. This paper primarily focuses on the engineering methodology to establish an energy solution for future space colonization that supports the ISRU approach.

To expand the human presence beyond the blue planet has become a mandate with the increase in space technology for space tourism, colonization on Moon and Mars. Constructing Moon and Mars bases will require an immense supply of clean, consistent, renewable energy on in-situ surfaces or the lunar regolith. Regolith is the layer of loose material covering the surfaces of the Moon and many other solar system bodies. This porous, granular layer thermally insulates underlying bedrock and absorbs cosmic rays.

Here we present an approach to convert the temperature difference to the electricity on the lunar regolith with the help of thermocouples or thermoelectric generators.

Methods:- Changing the heat flux generated by the temperature difference to the electrical energy over the lunar surface can be a boom to the energy crisis fulfilment and can bring a revolution in this field. The two methodologies which seem promising to change the heat flux to electricity are **thermoelectric generators and thermocouples.**

a). Thermoelectric generator:- A thermoelectric generator (TEG), also called a Seebeck generator, is a solid-state device that converts heat flux (temperature differences) directly into electrical energy through a phenomenon called the *Seebeck effect* (a form of thermoelectric effect).

Thermoelectric generators function like heat engines, but are less bulky and have no moving parts.

Thermoelectric devices can be used to convert the waste heat into power which can be utilised by the rover to charge the battery. The schematic diagram of the TEG has been shown in the below diagram.

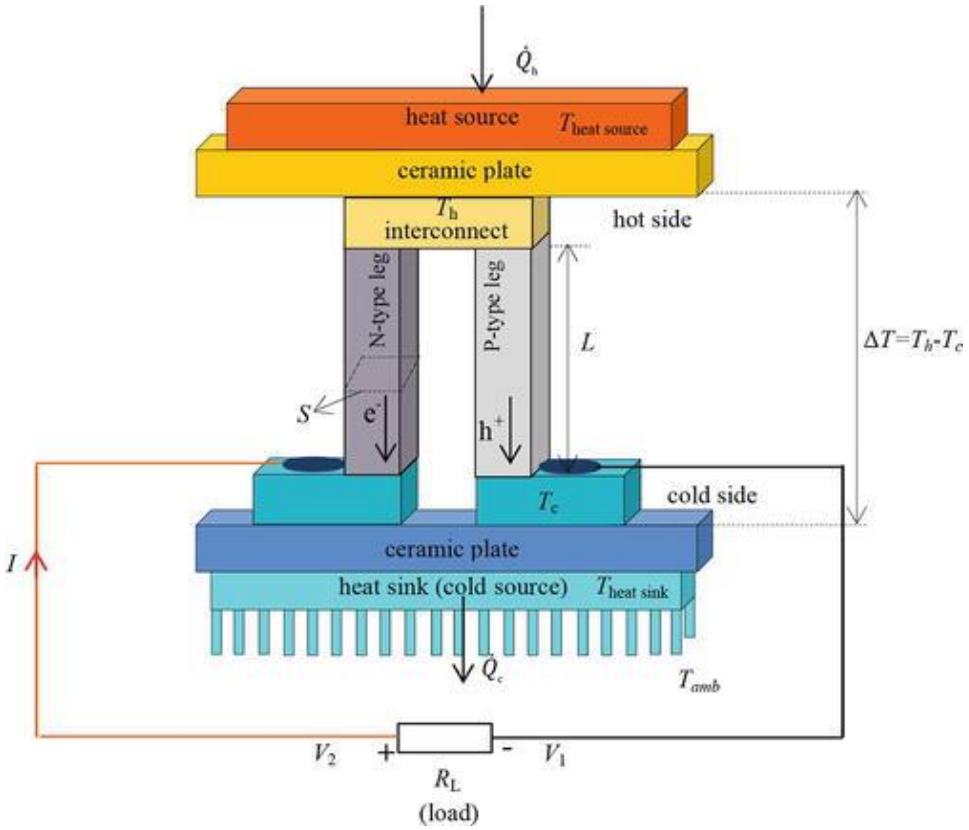


Fig. 1. Thermoelectric generator

Components and Construction:- The heavily doped semiconductors like SiGe(0.661eV), GaSb(0.726eV), InN(0.7eV), InAs(0.17eV), CdSe(1.74eV), PbSe(0.27eV), PbS(0.37eV) can be used as the p & n type after getting doped with the respective elements i.e. either Boron or Phosphorous.
The cross-section area of the p & n-type legs can be taken as 1mm* 1mm.
Height of the legs = 0.8 inch.
The TEG can be connected in parallel to avoid failure. In series, if there is even with a single failure, the whole circuit will be damaged.

b). Thermocouples:- The thermocouple working principle is based on the Seeback Effect. This effect states that when a closed circuit is formed by joining two dissimilar metals at two junctions, and junctions are maintained at different temperatures then an electromotive force (e.m.f.) is induced in this closed circuit.

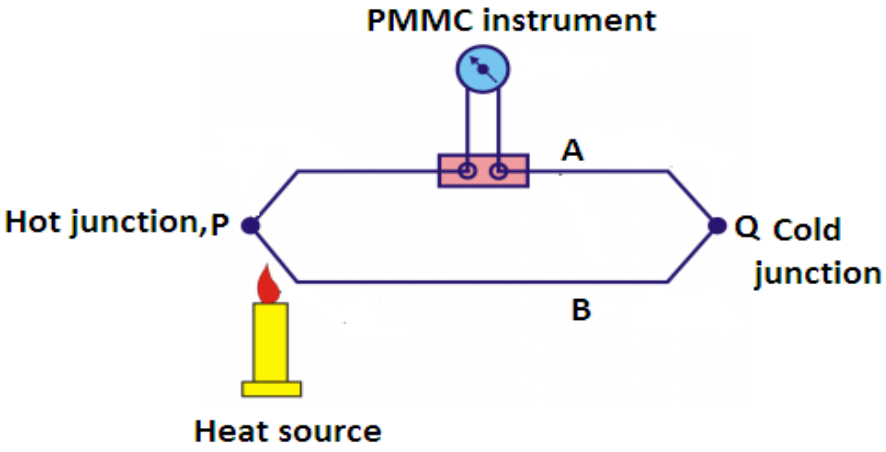


Fig. 2. Schematic diagram of thermocouple

A cable consisting of two wires is completely insulated for each other in which one is carrying the wire with higher thermal conductivity and the other one with lower thermal conductivity. When one end is kept at the higher temperature and another end at the lower temperature the electrons start flowing from higher temperature to the lower temperature.

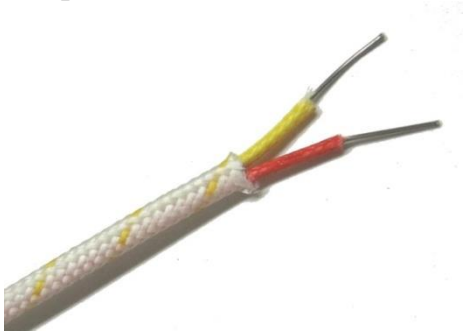


Fig.3. Thermocouple End Point

Temperature distribution on Lunar Regolith:- There is a very thin layer of gases available over the surface. Due to which the temperature varies from -173^{o}C to 127^{o}C during day and night.

As we can observe that there is a huge difference in the range of temperature at the lunar surface. So the difference in the temperature can be used to generate and store the energy for the satellites.

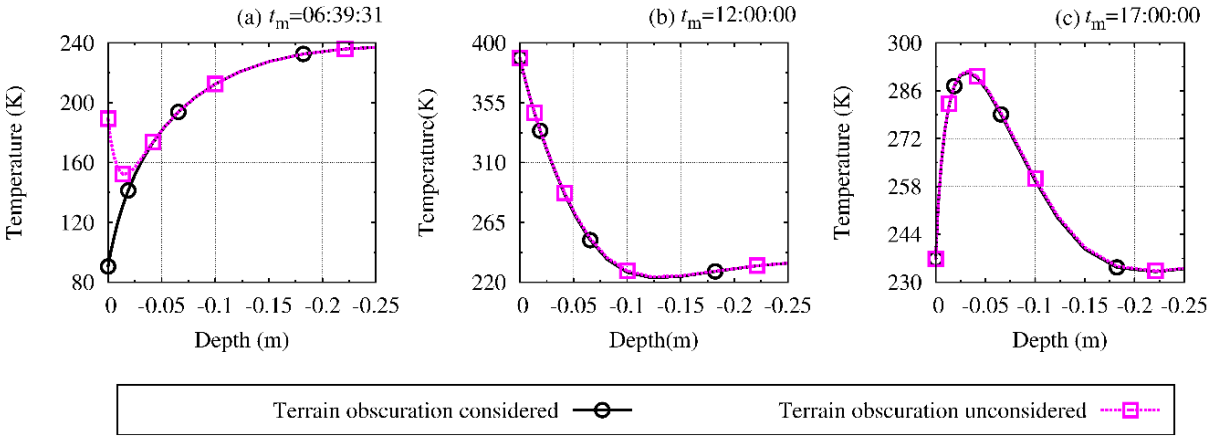


Fig.4. Temperature variation on regolith

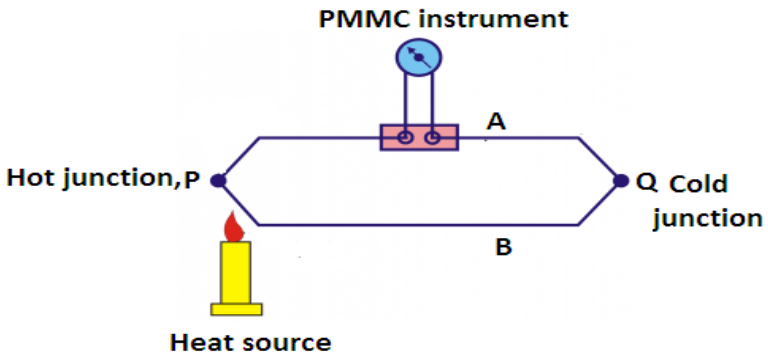
The variation of the temperature along with the depth over the lunar surface along with the time was studied by Apollo 15 and Apollo17 at different times and the graph was plotted for the temperature vs. depth below the surface at different times. From the above diagram, it can be noted that the temperature difference at the surface and the depth of 0.25 metres was more than 100K and even more. So this temperature difference can be easily used for thermoelectric couples and the energy generated can be used to satisfy the other requirements as well.

Major Components and Parts:-

a) The wires are needed with high electrical conductivity but with different thermal conductivity.
b) Graphene with thermal conductivity 4000W/m/K and SiC with thermal conductivity of 20.7 W/m/K can be used as the two wires have a very huge difference in thermal conductivity and significantly they both have the electrical conductivity of the order 10^2S/m.
c) Insulation of the wires is necessary to avoid short-circuiting so the wires can be insulated with Molybdenum or quartz cloth.

Working of the thermocouples:-

The drilling equipment can be attached at the bottom of the rover which can drill the regolith at a particular depth and can drop the wires to the bottom surface and another end of the wire is on the upper surface so the significant temperature difference is maintained easily.



In the above diagram, the junctions are denoted by P & Q, and the temperatures are denoted by T1, & T2. When the temperature of the junction is dissimilar from each other, then the electromagnetic force generates in the circuit.

If the temperate at the junction end turn into equivalent, then the equivalent, as well as reverse electromagnetic force, produces in the circuit, and there is no flow of current through it. Similarly, the temperature at the junction end becomes imbalanced, and then the potential variation induces in this circuit.

The magnitude of the electromagnetic force induces in the circuit relies on the sorts of material utilized for thermocouple making. The entire flow of current throughout the circuit is calculated by the measuring tools.

The electromagnetic force induced in the circuit is calculated by the following equation

$$\mathbf{E = a\,(\Delta\Theta) + b\,(\Delta\Theta)}$$

Where $\Delta\Theta$ is the temperature difference among the hot thermocouple junction end as well as the reference thermocouple junction end, a & b are constants.

Thermopiles:- The different thermocouples can be connected in series to improve the output of the system. The thermocouples connected in series are called **thermopiles** and have greater efficiency than the single thermocouple.

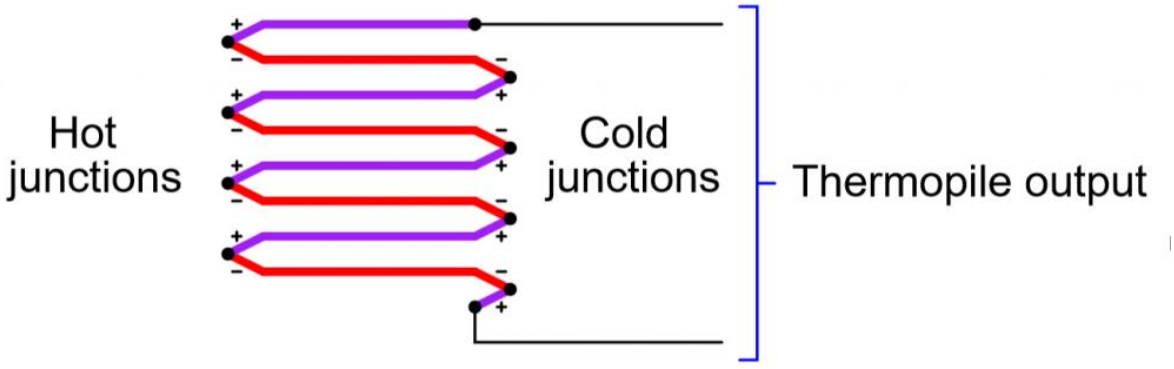


Figure- Thermopile

Fig.6. Thermopiles

A thermopile can be very highly efficient as compared to the single thermocouple as it is connected in the series and can give the output multiple times compared to the single thermocouple.

Tabular data and graphs:- The thermocouple behaviour to temperature have been studied and tabulated the results. The e.m.f generated by the thermocouple at different temperatures have been tabulated.

Temperature difference (°C) versus emf (μV) for thermocouples with 0 °C reference.

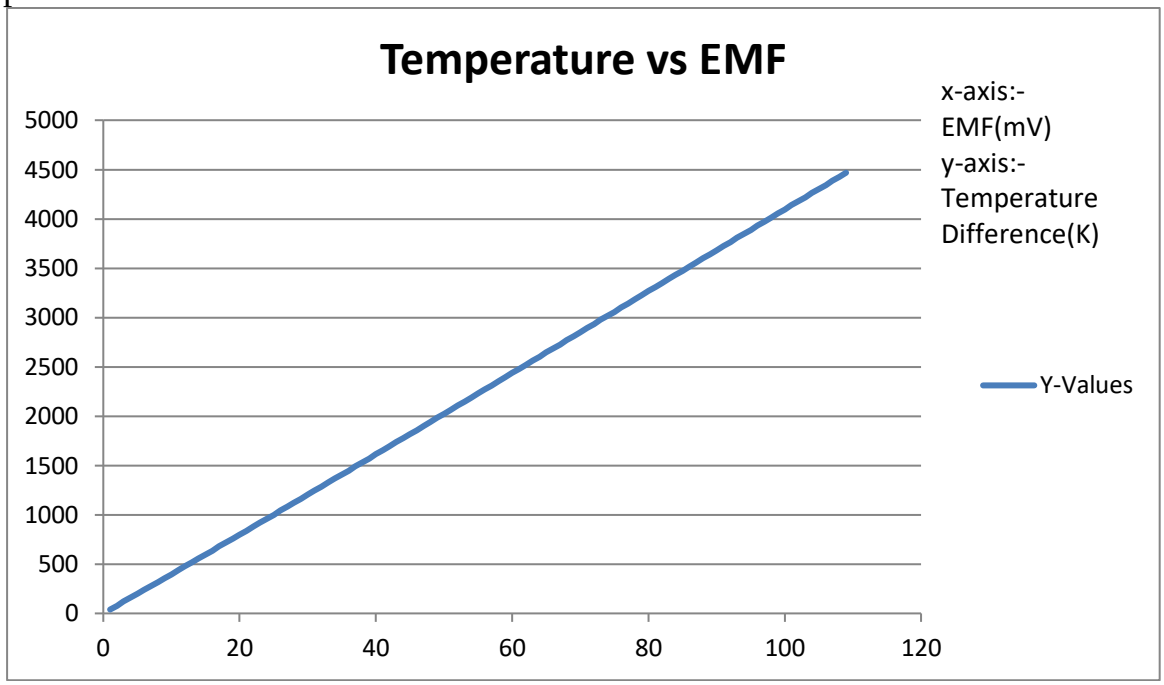
deg C	0	1	2	3	4	5	6	7	8	9
0	0	39	79	119	158	198	238	277	317	357
10	397	437	477	517	557	597	637	677	718	758
20	798	838	879	919	960	1000	1041	1081	1122	1163
30	1203	1244	1285	1326	1366	1407	1448	1489	1530	1571
40	1612	1653	1694	1735	1776	1817	1858	1899	1941	1982
50	2023	2064	2106	2147	2188	2230	2271	2312	2354	2395
60	2436	2478	2519	2561	2602	2644	2685	2727	2768	2810
70	2851	2893	2934	2976	3017	3059	3100	3142	3184	3225
80	3267	3308	3350	3391	3433	3474	3516	3557	3599	3640
90	3682	3723	3765	3806	3848	3889	3931	3972	4013	4055
100	4096	4138	4179	4220	4262	4303	4344	4385	4427	4468

Table: - The Top First Row & Left First Column indicates temperature scales. First Left Column indicates the temperature in units 10C and Top First Row indicates temperatures in units 1C. The remaining cells indicate respective thermocouple output voltage in μV units.

For example, the Temperature is 10°C then from the above table; the equivalent thermocouple output voltage is 397μV. Say now the temperature is 12°C then the output voltage is 477μV.
Similarly, if the temperature is 105°C then from the above table, the thermocouple output voltage is 4303μV. The thermocouple tables will change with the type of thermocouple.

From the above data, we can get the results only up to 109°C and the corresponding output voltage is 4468 μV.
For the further greater output more number of cables can be connected in series.

The plot of standard results of temperature diff. Vs induced emf is shown in this plot:-



Conclusion:- The temperature difference over the lunar surface can be utilized to fulfil the energy requirements and if the society is established then this concept can be used to satisfy the energy requirements of each family on a large scale. The thermopile consists of several thermocouples in series can give a considerable amount of the output voltage.

References

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