King Fahd University of Petroleum and Minerals

Aerospace Engineering Department

Astrodynamics I

(AE 570)

Paper Study

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Introduction

In this report, the paper (Thermal Design of Liquid Droplet Radiator for Space Solar-Power System) is going be discussed in details starting from the objectives and ending with the results. This paper was published on 1 may 2004 by Tsuyoshi Totani, Takuya Kodama, Harunori Nagata and Isao Kudo.
The objective of this paper is to come up with a design of Liquid Droplet Radiator **(LDR)** to take care of the waste heat and remove it from the Space Solar-Power System **(SPS)**. Where the Space Solar-Power System (SPS) is a large structure located at low earth orbit to supply 5 MW of electricity to a power transmission line on earth. So the SPS works as a source of energy that generates electric power from solar energy in orbit, concerts the power into microwaves, and then transmits the microwaves to earth. The SPS can generate electric power regardless of the weather; can utilize the inexhaustible solar energy, and does not release carbon dioxide in the process of power generation system that is able to supply electric power semipermanetly and stably in an environmentally friendly manner.
However, discarding the large quantities of waste heat is one of the technical issues that must be considered to realize large space structures that handle high power (from megawatt to gigawatt order), such as the SPS. The LDR is an important candidate for resolving this issue. Its lightweight structure, high resistance to meteorite impacts, small strong volume requirement at lunch, and easy deployment in space make it a very attractive heat removal system for the SPS.

Paper Nature:

➔ The first element in this report is about LDR and its operation.
➔ The second element is about Microgravity Experiment.
➔ The third element is to study two models of the SPS. The first model is called the Photovoltaic Power Generation System **(PVPS)**, and the second model is called the Solar Dynamic Power Generation System **(SDPS)**.
➔ The fourth element is to design a liquid droplet radiator (LDR) for both models The PVPS and the SDPS.
➔ Results and discussion will be the fifth element.
➔ The sixth element in this report is to construct a Matlab code used for designing the LDRs for different units in both models according to the amount of waste heat generated by each unit of the PVPS and the SDPS.

Operation of LDR:

The operation of the LDR is schematically shown in figure 1. the LDR, which consists of a droplet generator, a circulating pump, and a heat exchanger, circulates working fluid as follows. The working fluid is heated through a heat exchanger by the waste heat generated in a large space structure. Then, the working fluid is subjected to a pressure disturbance generated by a piezoelectric vibrator in the droplet generator and is emitted into space through nozzles on the droplet generator toward droplet collector. At some distance from the droplet generator, the working fluid is atomized into multiple streams of liquid droplets by the growth of the radial disturbance amplitude caused by increasing the pressure disturbance, as shown in figure 2. During the transport in space from the droplet generator to the droplet collector, the droplets lose thermal energy via radiative heat transfer. After the cooled droplets are captured by the droplet collector, the working fluid is recycled to heat exchanger by the circulating pump.

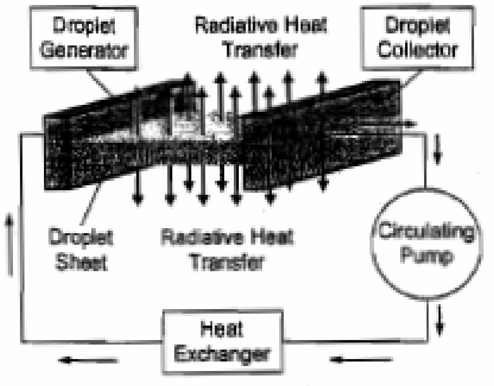

Fig. 1 Schematic diagram of liquid droplet radiator.

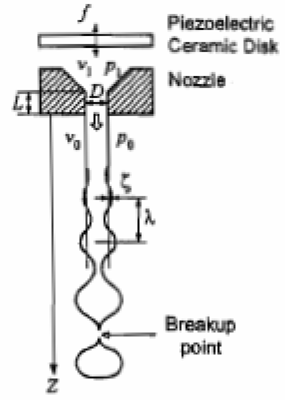

Fig. 2 Transformation process from a jet to droplets.

Liquids with low vapor pressure are nominated as candidates of working fluids in the LDR to minimize the evaporation loss.
Our working fluid that is going to be used in the LDR is silicon oils that could stand for the waste heat temperature range of 250-350 K.

Microgravity Experiment:

As we know that the designed LDR for the SPS is going to be at low earth orbit where gravity there is too less. And of course it is not reasonable to design the LDR here in our earth condition. The LDR supposed to be designed in a condition similar to the low earth orbit conditions. So to do so, the microgravity experiment is used to test the performance of different LDR elements satisfying similar conditions as low earth orbit conditions. Performance tests of LDR elements have been carried out under microgravity by using two dropshafts in Japan: Japan Microgravity Center CO., Ltd.

- **Droplet Generator:**
  Images of droplets under the microgravity condition are shown in figure 3. the pressure difference between the inside and outside of the droplet generator is 0.48 MPa, and the disturbance frequency is 20 KHz. These images clearly proved that a droplet stream is also produced under microgravity condition and the droplets diameter and spacing between droplets are uniform.

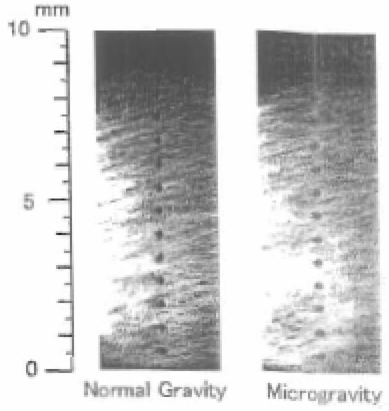

Fig. 3 Images of droplets under normal gravity and microgravity ($\Delta P = 0.48$ MPa, $f = 20$ kHz): black spherical shades are droplets.

To increase the efficiency of the LDR, the droplets diameter and the spacing diameter between droplets should be uniform as much as possible to avoid collision between droplets of the working fluid inside the LDR. To investigate that, we look to figure 4 that plots the non-dimensional wave number (k) VS the growth factor (β). Where $k = \pi Df/\upsilon_0$ and β is the growth factor in disturbance frequency applied by the piezoelectric vibrator across the nozzle of the droplet generator. In this figure, the experimental conditions of figure 3, figure 5a (uniform droplet stream), and figure 5b (non-uniform droplet stream) are all plotted.

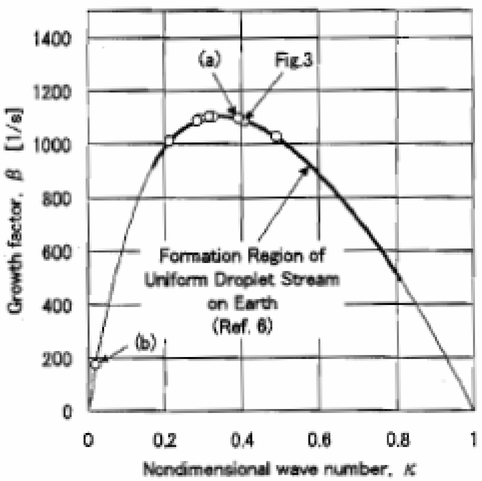

Fig. 4 Growth factor vs nondimensional wave number.

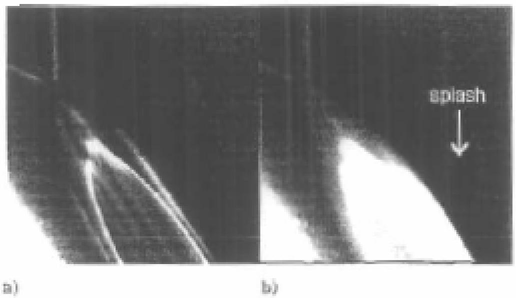

Fig. 5 Collisions of droplet stream: a) uniform droplet stream and b) nonuniform droplet stream.

A uniform stream of droplets of uniform diameter and spacing is generated in the range denoted by the bold section of the curve in figure 4. uniform droplet streams have been observed under the conditions marked by the open circles in microgravity environments. It has been clarified from the microgravity experiments on the droplet generator that the diameter of droplets and spacing between droplets generated under microgravity can be predicted by the following equations based on the low of conservations of mass.

$$d_d = (3\pi/2k)^{\frac{1}{3}} D \qquad (1)$$

$$s_d = (\pi/k)D - (3\pi/2k)^{\frac{1}{3}} D \qquad (2)$$

Where:
K is the non-dimensional number.
D is the diameter of the nozzle.
d_d is the diameter of the droplet.
s_d is the spacing between droplets.

- **Droplet Collector:**

Figure 5 shows images for a) a uniform droplet stream and b) a non-uniform droplet stream colliding against an aluminum board. As the images show, splashing of working fluid does not occur in figure 5a, whereas splashing of working fluid takes place in figure 5b. So it is clear from figure 4 that a non-uniform droplet stream is produced in case b. but for case a, the droplet stream is uniform and it is laying in the region for maximum values of the growth factor β. **So to guarantee a uniform droplet stream of the working fluid of the LDR, the nozzle should be designed to certain value of k that gives maximum value of β.**

Photovoltaic Power Generation System (PVPS)

The PVPS is a model of SPS. It consists from a solar cell of a single crystal cell as the generation unit and distribution and transmission units. The concept of the PVPS is schematically shown in figure 6.

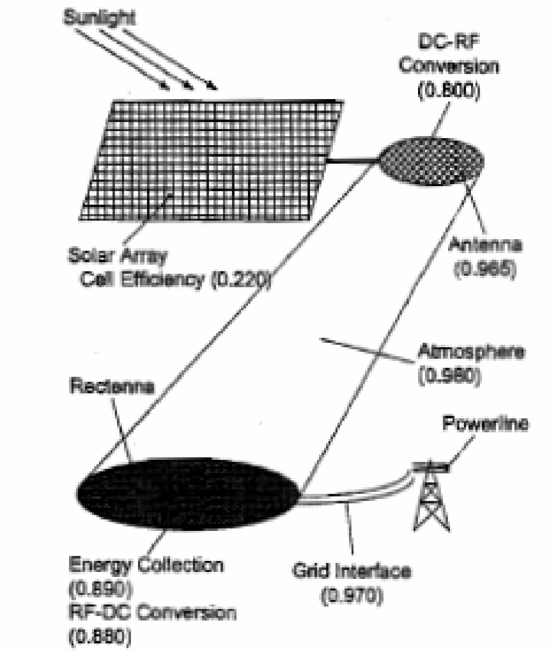

Fig. 6 Photovoltaic power generation system.

Table 1 shows the efficiency, the input energy and waste heat for each element in the PVPS.

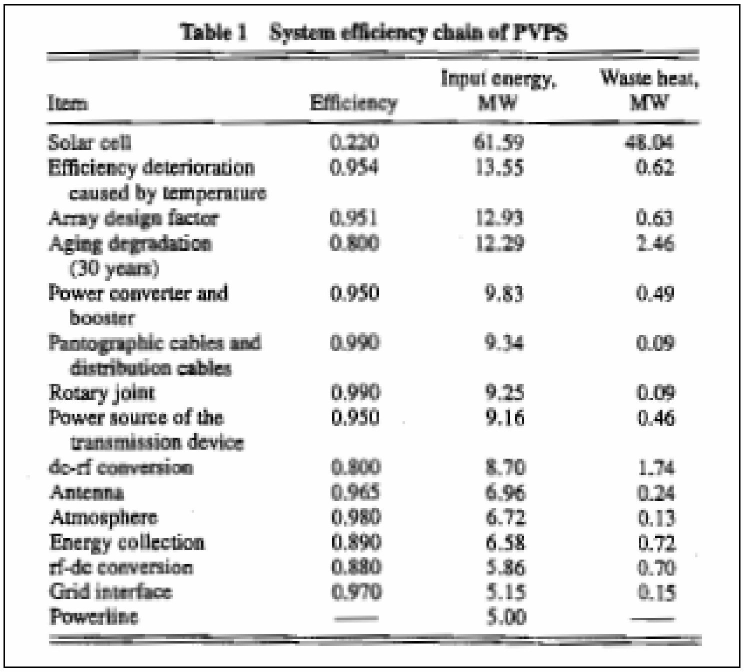

Table 1 System efficiency chain of PVPS

Item	Efficiency	Input energy, MW	Waste heat, MW
Solar cell	0.220	61.59	48.04
Efficiency deterioration caused by temperature	0.954	13.55	0.62
Array design factor	0.951	12.93	0.63
Aging degradation (30 years)	0.800	12.29	2.46
Power converter and booster	0.950	9.83	0.49
Pantographic cables and distribution cables	0.990	9.34	0.09
Rotary joint	0.990	9.25	0.09
Power source of the transmission device	0.950	9.16	0.46
dc-rf conversion	0.800	8.70	1.74
Antenna	0.965	6.96	0.24
Atmosphere	0.980	6.72	0.13
Energy collection	0.890	6.58	0.72
rf-dc conversion	0.880	5.86	0.70
Grid interface	0.970	5.15	0.15
Powerline	—	5.00	—

The required area of the solar array is obtained from the following equation:

$$A_{sa} = H_{1sa}/C_s = 45.0 \times 10^3 \text{ m}^2 \qquad (3)$$

Where:
H_{1sa} = 61.6 MW is the input energy received by the solar array.
C_S = 1.37 KW/m^2 is the solar constant in earth orbit.

From table 1, the antenna must transmit the energy per second E_{aPV} = 6.72 MW.
The required area of the antenna is obtained from the following equation:

$$A_{aPV} = E_{aPV}/\eta_a C_a = 3.03 \times 10^3 \text{ m}^2 \qquad (4)$$

Where:
η_a = 0.965 is the antenna efficiency from table.
C_a = 2.3 KW/m^2 is the amount of transmittable energy per unit area perpendicular to the transmission direction.
If the antenna is a circular, the diameter of the antenna is:

$$d_{aPV} = \sqrt{(4/\pi)A_{aPV}} = 62.1 \text{ m} \qquad (5)$$

As evidenced in table 1, the amount of waste heat per second of **51.8 MW** that is the sum from the cell efficiency to aging degradation must be discarded from the power generation unit in this model. And the amount of waste heat per second of **3.11 MW** must be disposed of at the power distribution unit and the power transmission unit.

Solar Dynamic Power Generation System (SDPS)

The concept of the SDPS is the same as the PVPS but the difference is that the generation unit in the SDPS is not a solar array like the PVPS. The SDPS employs the closed-Brayton-cycle **(CBC)** as the generation unit. The concept of the SDPS is schematically shown in figure7.

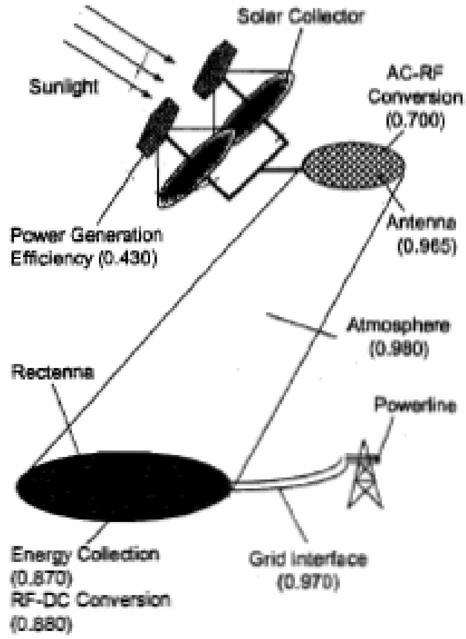

Fig. 7 Solar dynamic power generation system.

Table 2 shows the efficiency, the input energy and waste heat for each element in the SDPS.

The closed-Brayton-cycle system is shown in figure 8.

The working fluid used in the CBC is helium-xenon gas mixture. The properties of helium-xenon are shown in table 3.

The temperature at each point, the efficiencies and some other useful information of elements in the CBC are shown in table 4.

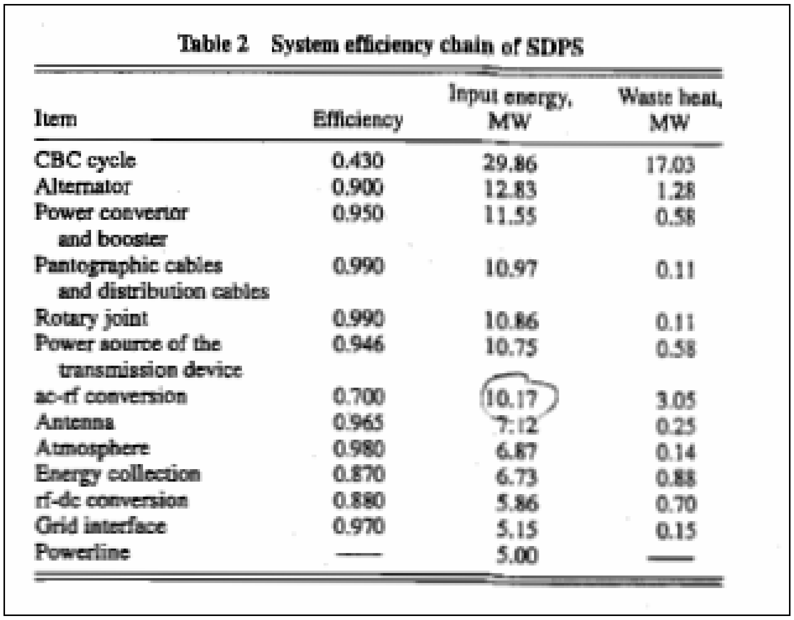

Table 2 System efficiency chain of SDPS

Item	Efficiency	Input energy, MW	Waste heat, MW
CBC cycle	0.430	29.86	17.03
Alternator	0.900	12.83	1.28
Power convertor and booster	0.950	11.55	0.58
Pantographic cables and distribution cables	0.990	10.97	0.11
Rotary joint	0.990	10.86	0.11
Power source of the transmission device	0.946	10.75	0.58
ac-rf conversion	0.700	10.17	3.05
Antenna	0.965	7.12	0.25
Atmosphere	0.980	6.87	0.14
Energy collection	0.870	6.73	0.88
rf-dc conversion	0.880	5.86	0.70
Grid interface	0.970	5.15	0.15
Powerline	——	5.00	——

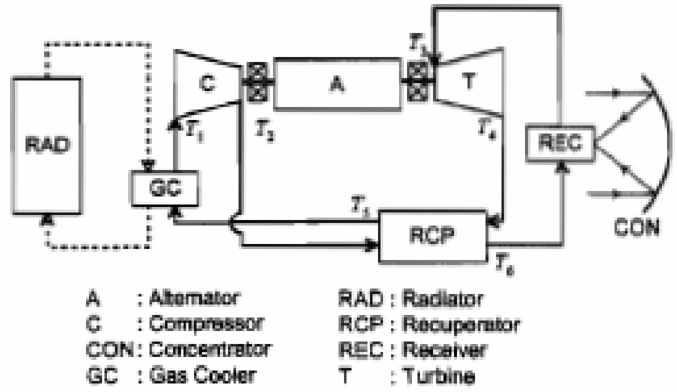

Fig. 8 Closed-Brayton-cycle system.

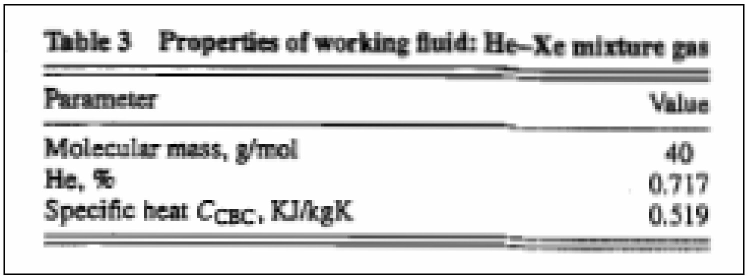

Table 3 Properties of working fluid: He–Xe mixture gas

Parameter	Value
Molecular mass, g/mol	40
He, %	0.717
Specific heat C_{CBC}, KJ/kgK	0.519

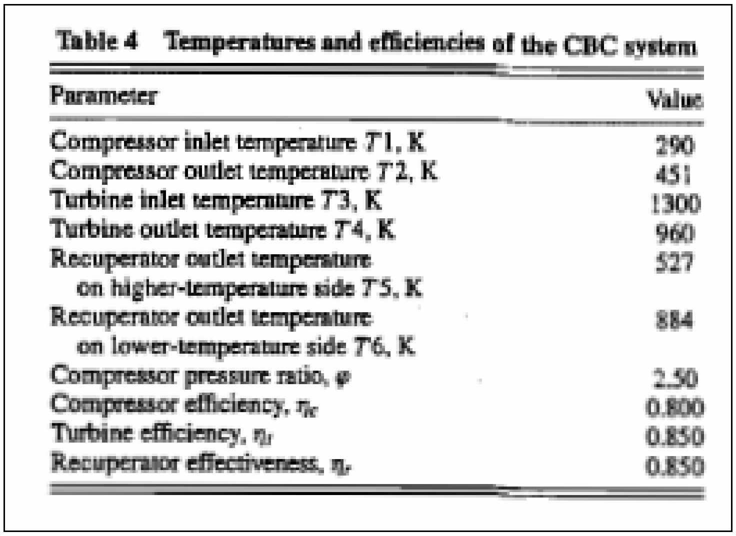

Table 4 Temperatures and efficiencies of the CBC system

Parameter	Value
Compressor inlet temperature $T1$, K	290
Compressor outlet temperature $T2$, K	451
Turbine inlet temperature $T3$, K	1300
Turbine outlet temperature $T4$, K	960
Recuperator outlet temperature on higher-temperature side $T5$, K	527
Recuperator outlet temperature on lower-temperature side $T6$, K	884
Compressor pressure ratio, φ	2.50
Compressor efficiency, η_c	0.800
Turbine efficiency, η_t	0.850
Recuperator effectiveness, η_r	0.850

The heat input to the generation unit (CBC) of SDPS is H_{1CBC} = 29.86 MW per second, and the heat output per second from the gas cooler in the CBC is H_{2CBC} are calculated by using the following equations:

$$H_{1CBC} = \dot{m}c_{CBC}(T_3 - T_6) \qquad (6)$$

$$H_{2CBC} = \dot{m}c_{CBC}(T_5 - T_1) \qquad (7)$$

The CBC efficiency is calculated as follows:

$$\eta_{CBC} = (H_{1CBC} - H_{2CBC})/H_{1CBC} = 1 - (T_5 - T_1)/(T_3 - T_6) \qquad (8)$$

The cycle efficiency in table 2 is calculated from equation 8.
The mass flow rate of the working fluid in the CBC is calculated by using equation 6.

$$\dot{m} = H_{1CBC}/c_{CBC}(T_3 - T_6) = 138 \text{ kg/s} \qquad (9)$$

Where c_{CBC} = 519 J/kg.K is the specific heat of the working fluid in the CBC.
The cross sectional area of the concentrator perpendicular to the rays of the sun is calculated by the following equation:

$$A_c = H_{1CBC}/C_s = 21.8 \times 10^3 \text{ m}^2 \qquad (10)$$

If the cross section perpendicular to the sun rays is circular, the diameter of the circle is:

$$d_c = \sqrt{(4/\pi)A_c} = 167 \text{ m} \qquad (11)$$

From table 2, the antenna must transmit the energy per second $E_{aSD} = 6.87$ MW.
The required area of the antenna is obtained from the following equation:

$$\boxed{A_{aSD} = E_{aSD}/\eta_a C_a = 3.10 \times 10^3 \text{ m}^2 \qquad (12)}$$

Where:
$\eta_a = 0.965$ is the antenna efficiency from table.
$C_a = 2.3$ KW/m^2 is the amount of transmittable energy per unit area perpendicular to the transmission direction.
If the antenna is a circular, the diameter of the antenna is:

$$\boxed{d_{aSD} = \sqrt{(4/\pi)A_{aSD}} = 62.8 \text{ m} \qquad (13)}$$

As evidenced in table 2, the amount of waste heat per second of **18.3 MW** generated at the generation unit (the cycle + the alternator) of SDPS. And the amount of waste heat per second of **4.68 MW** must be disposed of at the power distribution unit and the power transmission unit.

Design of Liquid Droplet Radiator

To design LDR, we need to find the three dimensions of LDR sheet, the length (l), the width (w) and the thickness (h).
We know the flow rate q = AV, where A stands for area and V stands for velocity. And the mass flow rate m = ρ A V. So from these two relations➔

$$\boxed{m = \rho\, q \ldots\ldots\ldots\ldots *}$$

Considering that the temperature of the working fluid of the LDR (silicon oil) decreases by ΔT during the flight in space from the droplet generator to the droplet collector, thermal energy lost per second of the working fluid is:

$$\boxed{\Delta H_{LDR} = m\, c_{LDR}\, \Delta T \ldots\ldots\ldots **}$$

Combining equations (*) and (**) to get:

$$\boxed{\Delta H_{LDR} = \rho_{LDR} c_{LDR} q \Delta T \qquad (14)}$$

Where:
$c_{LDR} = 1506$ J/kg.K is the specific heat of the working fluid of LDR.

$$\boxed{q = \frac{\Delta H_{LDR}}{\rho_{LDR} c_{LDR} \Delta T} \qquad (15)}$$

The temperature drop ΔT is determined with the Vapor pressure of the working fluid lower than 10^{-9} mm Hg to minimize the evaporation loss of the working fluid. ΔT ranges from **300 K to 285 K**.

➔ Thickness, Width and Length of the LDR sheet:

The concept of optical depth normal to the surface of the droplet sheet is used. Because the optical depth represents the number of droplets included in a cylinder whose diameter is equal to the droplet diameter, the optical depth is obtained by:

$$\boxed{\tau = n\left(\pi d_d^2/4\right)h \qquad (16)}$$

The number density of droplets (n) is represented as:

$$\boxed{n = \left(f/s_n^2 v_0\right) \qquad (17)}$$

Where:

f is the frequency.

$S_n = 5 \times 10^{-3}$ m is the pacing between nozzles in the droplet generator.

It is known that the increase of the emissivity of the droplet sheet becomes small with optical depth greater than two (Ref. 3).in this study, the optical depth is set at 2. So, the thickness of the droplet sheet is determined by:

$$\boxed{h = 8/n\pi d_d^2 \qquad (18)}$$

The flow rate of the working fluid is represented by:

$$\boxed{q = nwhv_0 \cdot \frac{1}{6}\pi d_d^3 \qquad (19)}$$

By substituting equation 18 into equation 19:

$$\boxed{w = \frac{3q}{2\tau d_d v_0} \qquad (20)}$$

Where:

$\tau = 2$ in our study to keep LDR droplet sheet emissivity large.

Considering the total volume $dV = w\,h\,v_0\,dt$ of the droplets with temperature T travel the distance dx during time dt and increase the temperature by dT via radiative heat transfer, the following equation is satisfied:

$$\boxed{-\rho_{LDR} c_{LDR}\, dV\, dT = 2\sigma\varepsilon_{sheet} T^4 w\, dx\, dt \qquad (21)}$$

Where:
$H_R = \sigma A_s T^4$ is the radiative heat transfer.
$\sigma = 5.67 \times 10^{-8}$ W/(m^2.K^4) is the Stefen-Boltzmann constant.
$\varepsilon = 0.8$ is the emissivity of the droplet sheet and for the antenna too.

We divide equation 21 by *dt* for both sides and integrate by separation of variables under the following initial condition, $T = T_0$ at $x = 0$the following equation is obtained:

$$\boxed{\frac{1}{T^3} = \frac{6\varepsilon_{\mathrm{sheet}}\sigma w}{\rho_{\mathrm{LDR}} c_{\mathrm{LDR}} q} x + \frac{1}{T_0^3} \qquad (22)}$$

Under the initial conditions, when the working fluid of the LDR is emitted from the droplet generator, the temperature of the working fluid is T_0. Considering that the working fluid temperature decreases by ΔT that ranges from **300 K to 285 K** during the flight of length *l* from the droplet generator to the droplet collector, $T = T_0 - \Delta T$ at $x = l$. and the length of the droplet sheet of the LDR is obtained by:

$$\boxed{l = \frac{\rho_{\mathrm{LDR}} c_{\mathrm{LDR}} q}{6\varepsilon_{\mathrm{sheet}}\sigma w}\left[\frac{1}{(T_0 - \Delta T)^3} - \frac{1}{T_0^3}\right] \qquad (23)}$$

For the nozzle used in our experiments, it has been clarified that the droplet velocity υ_0 is expressed by (Ref.10):

$$\boxed{\upsilon_0 = -\left[\left(\frac{64\nu_{\mathrm{LDR}} L}{D^2} + \frac{\xi \nu_{\mathrm{LDR}} L}{a D^2}\right) - \sqrt{\left(\frac{64\nu_{\mathrm{LDR}} L}{D^2} + \frac{\xi \nu_{\mathrm{LDR}} L}{a D^2}\right)^2 + \frac{8\Delta P}{\rho_{\mathrm{LDR}}}}\right] \Big/ 2 \qquad (24)}$$

Where:
υ_{LDR} is the kinematic viscosity of the working fluid ➔ $\upsilon_{LDR} = \mu_{LDR} / \rho_{LDR}$.
a = 0.065 m, is the entrance length of the nozzle.
L = 100 µm, is the length of the nozzle, it is almost equals to D.

Results and Discussion:

➔ LDR for the PVPS Model

➢ Power Generation Unit for PVPS

As shown in table 1, **51.8 MW** of waste heat per second must be disposed of the solar array (power generation unit) of the PVPS. Assuming that the total amount of waste heat is discarded by radiative heat transfer form both sides of the solar array, the following equation is satisfied:

$$\boxed{2\varepsilon_{sa}\sigma T_{sa}^4 A_{sa} = H_{sa} \qquad (25)}$$

Solving for T_{sa}:

$$\boxed{T_{sa} = 333\ \mathrm{K} \qquad (26)}$$

This equation means that the solar array attains equilibrium at this temperature T_{sa}=300 k. and if we assume that the upper allowable flight temperature limit of the solar cell is 353.15 K, it means that the generation unit of the PVPS doesn't require any active cooling system in the case of condensing sunlight with the reflector:

$$\boxed{2\varepsilon_{sa}\sigma T_{sa}^4 (A_{sa}/C_r) = H_{sa} \qquad (27)}$$

Assuming T_{sa}=353.15 K (upper allowable flight temperature limit of the solar cell):

$$\boxed{C_r = 1.34 \qquad (28)}$$

Therefore, a power generation unit with reflectors whose concentration ratio C_r is higher than 1.34 requires an active cooling system. But with reflectors whose concentration ratio C_r is less than or equal to1.34, it requires an active cooling system (LDR).

➢ Power Distribution Unit and Power Transmission Unit for PVPS

As shown in table 1, the total amount of waste heat per second $H_{LDR\ d\text{-}t}$ of **3.11 MW** must be discarded from the power distribution unit and the power transmission unit of the PVPS. Assuming a part of the waste heat is disposed by radiative heat transfer from both sides of the antenna and setting the surface temperature of both sides at T_a=333, the LDR for the power distribution unit and the power transmission unit must dispose of the following amount of waste heat per second:

$$\boxed{H_{LDR\,d-t} = H_{d-t\,PV} + \varepsilon_a C_s A_{aPV} - 2\varepsilon_a\sigma T_a^4 A_{aPV} = 3.05\ \mathrm{MW} \qquad (29)}$$

The characteristics of the LDR, with the working fluid of silicon oil, for the PVPS power distribution unit and the power transmission unit are summarized in table 7 using the equations above in finding all parameters.

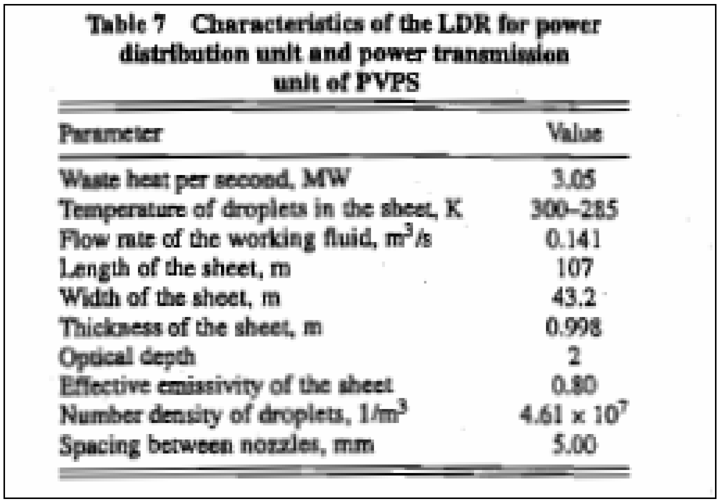

Table 7 Characteristics of the LDR for power distribution unit and power transmission unit of PVPS

Parameter	Value
Waste heat per second, MW	3.05
Temperature of droplets in the sheet, K	300–285
Flow rate of the working fluid, m³/s	0.141
Length of the sheet, m	107
Width of the sheet, m	43.2
Thickness of the sheet, m	0.998
Optical depth	2
Effective emissivity of the sheet	0.80
Number density of droplets, 1/m³	4.61 × 10⁷
Spacing between nozzles, mm	5.00

➔ LDR for the SDPS Model

➢ Power Generation Unit for SDPS

As shown in table 2, the amount of waste heat per second H_c of **18.3 MW** generated at the generation unit (CBC + alternator) of the SDPS. Assuming that the waste heat is disposed of by the radiative heat transfer from the back of the reflective surface of the concentrator in the CBC unit, the following equation is satisfied:

$$\varepsilon_c \sigma T_c^4 A_c = H_c \qquad (30)$$

Where the emissivity of the reflective surface is 0.8. Solving this equation for T_c gives:

$$T_c = 374\,\mathrm{K} = 101^\circ\mathrm{C} \qquad (31)$$

This equilibrium temperature is beyond the permissible temperature T_c = 333 K of the control unit of the concentrator. Assuming that part of the waste heat is disposed of by radiative heat transfer from the back of the reflective surface of the concentrator and setting the surface temperature of the back at T_c = 333 K, the LDR for the generation unit must dispose of the following amount of waste heat per second:

$$H_{\mathrm{LDR\,SD}} = H_c - \varepsilon_c \sigma T_c^4 A_c = 6.13\,\mathrm{MW} \qquad (32)$$

The characteristics of the LDR, with the working fluid of silicon oil, for the SDPS power generation unit and are summarized in table 8-C using the equations above in finding all parameters.

Table 8-C

The flow rate q = 0.2842 m^3/s.
The thickness of the sheet = 0.9990 m.
The width of the droplet sheet = 86.9403 m.
The length of the droplet sheet = 106.6398 m.

- **Power Distribution Unit and Power Transmission Unit for SDPS**

As shown in table 2, the total amount of waste heat per second $H_{LDR\ d\text{-}t}$ of **4.68 MW** must be discarded from the power distribution unit and the power transmission unit of the SDPS. Assuming a part of the waste heat is disposed by radiative heat transfer from both sides of the antenna and setting the surface temperature of both sides at T_a=333, the LDR for the power distribution unit and the power transmission unit must dispose of the following amount of waste heat per second:

$$H_{LDR\,d-t} = H_{d-t} + \varepsilon_a C_s A_a - 2\varepsilon_a \sigma T_a^4 A_s = 4.61\ \mathrm{MW} \qquad (33)$$

The characteristics of the LDR, with the working fluid of silicon oil, for the SDPS power distribution unit and the power transmission unit are summarized in table 9 using the equations above in finding all parameters.

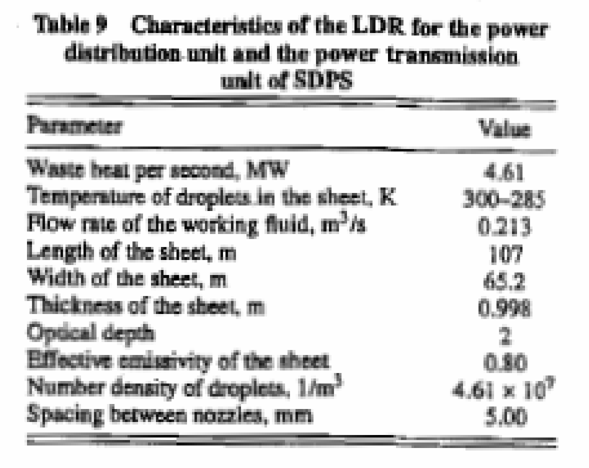

Table 9 Characteristics of the LDR for the power distribution unit and the power transmission unit of SDPS

Parameter	Value
Waste heat per second, MW	4.61
Temperature of droplets in the sheet, K	300–285
Flow rate of the working fluid, m^3/s	0.213
Length of the sheet, m	107
Width of the sheet, m	65.2
Thickness of the sheet, m	0.998
Optical depth	2
Effective emissivity of the sheet	0.80
Number density of droplets, $1/m^3$	4.61×10^7
Spacing between nozzles, mm	5.00

Conclusion

In the present work, the waste heat from a space solar-power system (SPS) and its removal by liquid droplet radiators have been considered. The quantitative study of liquid droplet radiators has been performed on the basis of the results of experiments carried out under microgravity. Two power generation systems, the photovoltaic power system (PVPS) and the solar dynamic power system (SDPS), have been considered as models of the SPS. Different LDRs are designed for both models according to the amount of waste heat emitted by their parts and all the results are in tables 7, 8 and 9. Some remarks about this paper are below.

➔**General Remarks:**

1- Generally speaking, the paper was very clear and easy to understand.

2- There are many typing mistakes in this paper for example:

Equation 24 that is used to find the droplet velocity is not correct. The wrong formula is

$$v_0 = -\left[\left(\frac{64\nu_{\mathrm{LDR}}L}{D^2} + \frac{\xi\nu_{\mathrm{LDR}}L}{aD^2}\right) + \sqrt{\left(\frac{64\nu_{\mathrm{LDR}}L}{D^2} + \frac{\xi\nu_{\mathrm{LDR}}L}{aD^2}\right)^2 + \frac{8\Delta P}{\rho_{\mathrm{LDR}}}}\right] \Big/ 2$$

While the correct formula is:

$$v_0 = -\left[\left(\frac{64\nu_{\mathrm{LDR}}L}{D^2} + \frac{\xi\nu_{\mathrm{LDR}}L}{aD^2}\right) - \sqrt{\left(\frac{64\nu_{\mathrm{LDR}}L}{D^2} + \frac{\xi\nu_{\mathrm{LDR}}L}{aD^2}\right)^2 + \frac{8\Delta P}{\rho_{\mathrm{LDR}}}}\right] \Big/ 2 \qquad (24)$$

And also there is a major mistake in calculations for the droplet sheet dimensions in the generation unit of the SDPS system as shown in table 8:

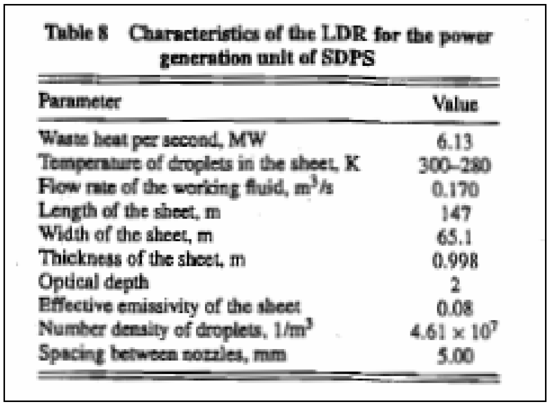

Table 8 Characteristics of the LDR for the power generation unit of SDPS

Parameter	Value
Waste heat per second, MW	6.13
Temperature of droplets in the sheet, K	300–280
Flow rate of the working fluid, m^3/s	0.170
Length of the sheet, m	147
Width of the sheet, m	65.1
Thickness of the sheet, m	0.998
Optical depth	2
Effective emissivity of the sheet	0.08
Number density of droplets, $1/m^3$	4.61×10^7
Spacing between nozzles, mm	5.00

While the correct values appear in table 8-C as follows:

Table 8-C

The flow rate q = 0.2842 m^3/s.
The thickness of the sheet = 0.9990 m.
The width of the droplet sheet = 86.9403 m.
The length of the droplet sheet = 106.6398 m.

3- Some important parameters do not exist in the paper; it was tough to find them in references like the specific heat of the working fluid for the LDR (silicon oil). And also like the length of the nozzle L used in this experiment.

4- some calculations are not accurate like the amount of waste heat per second disposed of the power distribution unit and the power transmission unit of the PVPS is calculated to be 3.12 MW by mistake, while if we add the waste heat per second for each element of the power distribution unit and the power transmission unit of the PVPS it gives 3.11 MW.

5- Many assumptions were made without mentioning the reasons of making these assumptions.

6- The construction of the LDR in real life is high in cost and advanced technologies such as inflatable deployment technology are needed.

7- The full texts of the references are difficult to find them in electronic files and hard files too. Most of these references are old and some of them are written in Japanese language only.