International Journal Of Science, Engineering, And Information Technology
Volume 03, Issue 01, December 2018
Journal homepage: https://journal.trunojoyo.ac.id/ijseit

The Calculation and Thermal Coating Selection of Nano Satellite Steady State Temperature

Ahmad Fauzi[a]

[a]Space Technology Center-National Institute of Aeronautics and Space (LAPAN), Indonesia

A B S T R A C T

At the beginning of the design phase of satellite, it is an important in order to consider the design of satellite's thermal control system by analyzing the temperature that occurs in the space environment. This paper presented the analysis of coating thermal steady-state temperature calculation that occurs in the structure and solar panels of the satellite. Temperature calculation analysis without internal power dissipation satellite is performed in three cases with different of thermal coating, to determine whether the temperature scale in accordance with the allowable temperature. The calculation results are shown that by using the materials of 61% solar cells, 39% aluminum and 100% black paint (Case C) is the best choice of thermal coating materials selection and it will take the operating temperature between -107.82°C and 26.46°C. It's still within the limits of allowable satellite's operations

Keywords: Satellite, Steady state temperature, Thermal control, Material.

Article History
Received 10 December 17 Received in revised form 25 January 18 Accepted 10 June 18

1. Introductions

The main purpose of the thermal control system is to maintain the temperature limits for all satellite components in accordance with the allowable operational limits (Gilmore, 1994). As for the thermal control system of the satellite is a satellite to trade off study which have an altitude orbit of 500 km which is designed in LEO (Low Earth Orbit) and cube shape. It has dimension 50 cm in length, 50 cm in width, and 50 cm in height. TCS (Thermal Control System) satellite can be passive or active's, depending on the design approach was used. In addition, thermal control is also the beginning of a key satellite design program in order to keep the satellite with respect to component temperature limits allowable operating temperature and minimize the power consumption requirements of the satellite (Bulut and Sozbir, 2008).

The analysis of satellite thermal control is using passive thermal control system because of the steady-state calculations performed can be seen that the limit distribution of temperature that occur in solar panels is still within the limits allowable operating temperatures. The satellite shape is cube (Cube-Sat) that controlled by the selection of optical surface property materials and insulation material.

The material selection of solar absorptive and emissivity are used in the structure and also determine the amount of solar panel temperature to remain between temperatures limits each satellite components. Thermal control performance and structural properties with optical properties chosen are important factors in selection of satellite structures. Thermal control is a process of energy management in which environmental heating plays a major role (Larson and Wertz, 1996). The extreme temperature range of the space environment is very critical aspect for satellite. Absolutely, the satellite's component was decided to use the exclusively devices by the industrial range temperature. It's namely based COTS standard (commercially of the shelf, -40°C to +85°C). Solar radiation is the biggest source of heat energy to affect the satellite in the orbit's, albedo (reflected sunlight to the earth) and earth infrared (Earth IR) is emitted by the Earth, All of them are the sources of thermal energy that affect the environmental performance of the satellite's orbit. The intensity of solar radiation in low earth orbit satellites can achieve ± 3.5% depending on the distance of the earth to the sun. The constant intensity value of solar radiation varies depending on the change in the distance the earth and the sun, in the winter and solstice summer, occurred solar radiation achieve the maximum and minimum temperatures are 1418 W/m2 and 1322 W/m2 and mean value is 1367 W/m2. Temperature that occurs on the satellite is the result of the energy balance between the absorbed and emitted energy from the three sources of energy. Solar radiation environments can cause extreme temperatures that occur in the outer surface of the satellites varies (especially structure and solar panels). Outer layer of degraded satellite extreme heat can reach temperatures of 110°C, when the satellite towards the sun directly and decreased at temperatures of -150°C, and when the satellite is in the shadow of the Earth or the so-called Eclipse. The temperature scale operational constraints of satellite sub-systems are shown in Table 1 (Larson and Wertz, 1996). This paper presents the thermal design and temperature analysis of nano-satellite which cover the material

* *Corresponding author.*
E-mail address: fauzi7557@gmail.com

E-ISSN 2548-4214

structure and solar panels by its surface properties, ε (IR emissivity) and α (solar absorptivity), to be able to predict to the temperature scale that occurred on a satellite.

Table 1. Operating temperature limits (Larson and Wertz, 1996)

Components	Operating temperature [°C]
Battery	0 s/d 15
Antenna	-100 s/d 100
Solar panels	-150 s/d 110

2. Materials and Methods

The methodology is used in the calculation of the satellite temperature, by using satellite design data, which are consists of the satellite material mechanical properties, satellite thermal environment, and the satellite energy balance data. The thermal control design of the nano-satellite has been started by calculating temperatures steady-state condition by using equation and refers to in (Czernik, 2004). The calculation is limited to the analysis without internal energy dissipation, and then finally as result, we get the maximum and minimum temperatures. The methodology of analysis is shown in Fig. 1.

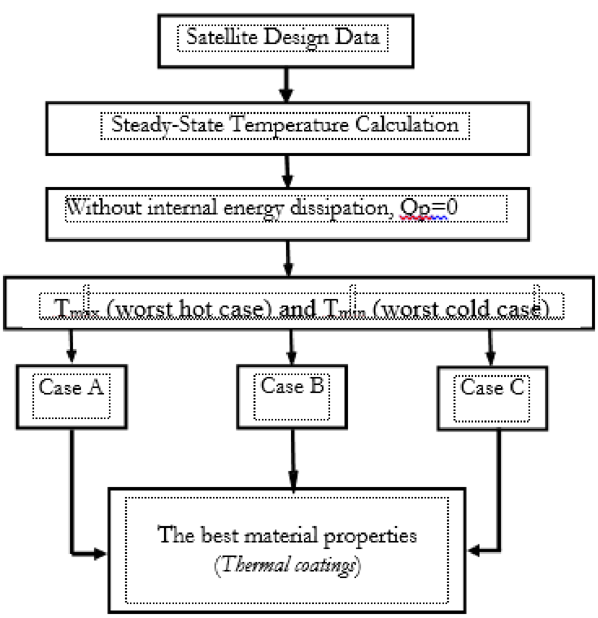

Figure 1. The calculation method

3. Results and Discussion

The nano-satellite model (Bulut et al., 2010) for trade study is Cube-Sat as shown in Fig. 2. The surface of the satellite structure are covered with solar cells and coating black paint material (Bulut and Sozbir, 2008) in three cases, which in this analysis, the use of material with four sides (1, 3, 5 and 6) are covered with 61% to 71% solar cells and anodized coatings (29% to 39% aluminum) while side 2 is covered with aluminum anodized and black paint coatings, because these sides will face towards to the sun which absorbs a lot of energy.

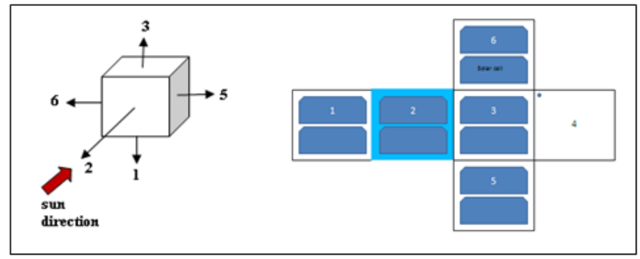

Figure 2. Structure and satellite model

Because the satellite surface made of a mixture material (with 71% and 61% solar cells; and 29% and 39% aluminum or the percentage of other mixed), so that it should be calculated the average of optical properties (emissivity ε, and absorptivity, α) that used by Equation 1.

$$Q_{Ap} = Q_{Sc} + Q_{Al} ----\rightarrow T_{Al} = T_{Sc}$$

$$\varepsilon_{Al-Sc}.A_p.\sigma.T^4 = \sigma.T^4(\varepsilon_{Sc}.\alpha_{Sc} + \varepsilon_{Al}.\alpha_{Al})$$

$$\varepsilon_{Al-Sc} = \varepsilon_{Sc}.\frac{\alpha_{Sc}}{A_p} + \varepsilon_{Al}.\frac{\alpha_{Al}}{A_p} \quad \text{.......... (1)}$$

Outer surface of the satellite experienced extreme temperatures obvious degradation because this part directly exposed to environmental sources of thermal energy such as solar radiation, albedo and Earth IR emission, thus the selection of material properties of the materials used must be taken to ensure that the energy balance is obtained in accordance with the satellite component temperature limits is used. For nano-satellites, cube-sat as a trade off study, the material properties are used in the analysis as shown in Table 2 (Abouel Fatouh et al., 2006; Sagsveen, 2003; Aluminum 7075-T651, 2019).

Table 2. CubeSat material properties

Parameters	Aluminum 7075-T651	Solar cells	Chemglaze Z304-Black Paint [9,10]	AZ-1000-ECB	TMJ-20-LSB
			Case A	Case B	Case C
Physical Properties-Density [kg/m^3]	2.810	2100	-	-	-
Thermal Conductivity [W/m°K]	130	200	-	-	-
Thermal Properties Specific Heat [J/kg°K]	960	1600	-	-	-

Emissivity, ε	0.87	0.85	0.9	0.89	0.91
Absorptivity, α	0.83	0.91	0.96	0.97	0.96

AZ-1000-ECB is a high absorptance electrically conductive inorganic black thermal control paint developed for used on spacecraft and satellite surfaces exposed to the deleterious effects of the space environment, and TMJ-20-LSB is an organic black paint developed for use on spacecraft and satellite hardware that has been coated with inorganic thermal control coatings (AZ-100-ECB, 2019).

The main purpose of the thermal control system is to maintain the balance of thermal energy to the internal components of the satellite according to the given temperature limits either both of worst case hot or worst case cold. The steady-state temperature calculation using the law of energy balance, where Qin = Qout. The calculations are consists of internal energy dissipation Qp, solar radiation QS, albedo Qa, earth radiation QE and an external radiation, generally as given in Equation 2.

$$Q_{in} = Q_{out}$$
$$Q_{sun} + Q_{earth} + Q_{albedo} + Q_p = Q_{sat\rightarrow earth} + Q_{earth\rightarrow sat}$$
$$Q_{sun} = Ap.\alpha_s.S = \frac{I_S}{\sigma}.\frac{Ap}{5Ap}.\frac{\alpha_{Ss}}{\varepsilon'_{IR}}$$
$$Q_{albedo} = (Ap.F_{sat\rightarrow earth}).\alpha_s.Fa.S.\cos\theta = \frac{0.34.I_S}{\sigma}.\frac{Ap}{5Ap}.\frac{\alpha_{SB}}{\varepsilon'_{IR}}$$
$$Q_{earthIR} = (Ap.F_{sat\rightarrow earth}).\varepsilon.I_S = \frac{I_E}{\sigma}.\frac{Ap}{5Ap}.\frac{\varepsilon_{IR}}{\varepsilon'_{IR}}$$

…………………………………………… (2)

In our design and analysis carried out by using a mixture consisting of a percentage of the material used can be unknown magnitude occurred in the satellite temperature. The temperature scales are consists of the maximum temperature and the minimum temperature, which is calculated by the energy balance of equation.2, and resulting in the formulation temperature. Orbiting satellites are degraded in the circulation of extreme temperature changes when the satellite face towards the sun, it was called worst hot case and degradation temperature decrease when the eclipse, was called worst cold case, both are the condition in which there is no solar radiation, albedo and no energy is generated by solar cells, so that the amount of temperature change can be calculated using Equation 3 and Equation 4 (Czernik, 2004).

$$T_{\max} = \left[T^4_{space} + \frac{I_S}{\sigma}.\frac{A_P}{5A_P}.\frac{\alpha_{S_S}}{\varepsilon'_{IR}} + \frac{I_E}{\sigma}.\frac{A_P}{5A_P}.\frac{\varepsilon_{IR}}{\varepsilon'_{IR}} + \frac{0.34.I_S}{\sigma}.\frac{A_P}{5A_P}.\frac{\alpha_{S_n}}{\varepsilon'_{IR}}\right]^{1/4}$$

……….. (3)

$$T_{\min} = \left[T^4_{space} + \frac{I_E}{\sigma}.\frac{A_P}{5A_P}.\frac{\varepsilon_{IR}}{\varepsilon'_{IR}}\right]^{1/4}$$

…………………………………………………………… (4)

A steady state analysis was performed and the temperature distribution results for worst hot case (WHC) and worst cold case (WCC) are occurs for various percentages of aluminum material circumstances. Firstly, solar cells and black paint coating material by using equation 3 and equation 4 are shown in Table. 3 and Table.4 (Case A), which shows that the maximum temperature between 26.68°C and 26.89°C on coverage area (sun radiated side) with 100% black paint, the satellite position facing the sun and while the minimum temperatures between -107.86°C and -107.91°C with 100% black paint coatings, the position of the satellite is in eclipse condition. Next in Table.5 and Table.6 (Case B) are shown that the maximum temperature between 27.33°C and 27.46°C on coverage area (sun radiated side) with 100% black paint, the satellite position facing the sun and while the minimum temperature between -108°C and -108.03°C with 100% black paint coatings, the position of the satellite is in eclipse condition, then in Table.7 and Table.8 (Case C) are shown that the maximum temperature between 26.46°C and 26.72°C on coverage area (sun radiated side) with 100% black paint, the satellite position facing the sun and while the minimum temperature between -107.82°C and -107.88°C with 100% black paint coatings, the position of the satellite too is in eclipse condition.

Table 3. Results of the steady-state temperatures for 71% solar cell and 29% aluminum without internal energy dissipation (Case A)

Coverage (sun radiated side)	Value (deg, C)	Stationary calculation	
		Bottom 71% solar cells, 29% aluminum	Bottom 71% solar cells, 29% black paint
71% solar cells 29% aluminum	T_{max}	24.31	25.10
	T_{min}	-107.15	-106.73
100% aluminum	T_{max}	21.12	21.94
	T_{min}	-107.15	-106.73
71% solar cells 29% black paint	T_{max}	15.48	25.01
	T_{min}	-108.33	-107.91
100% black paint	T_{max}	26.13	26.89
	T_{min}	-108.33	-107.91

Table 4. Results of the steady-state temperatures for 61% solar cell and 39% aluminum without internal energy dissipation (Case A)

Coverage (sun radiated side)	Value (deg, C)	Stationary calculation	
		Bottom 61% solar cells, 39% aluminum	Bottom 61% solar cells, 39% black paint
61% solar cells 39% aluminum	T_{max}	23.60	24.67
	T_{min}	-107.13	-106.56
100% aluminum	T_{max}	20.85	21.95
	T_{min}	-107.13	-106.56
61% solar cells 39% black	T_{max}	15.29	25.08
	T_{min}	-108.42	-107.86

paint			
100% black paint	T_{max}	25.67	26.68
	T_{min}	-108.42	-107.86

Table 5. Results of the steady-state temperatures for 71% solar cell and 29% aluminum without internal energy dissipation (Case B)

Coverage (sun radiated side)	Value (deg, C)	Stationary calculation	
		Bottom 71% solar cells, 29% aluminum	Bottom 71% solar cells, 29% black paint
71% solar cells 29% aluminum	T_{max}	24.31	25.13
	T_{min}	-107.15	-106.87
100% aluminum	T_{max}	21.12	21.96
	T_{min}	-107.15	-106.87
71% solar cells 29% black paint	T_{max}	15.68	25.22
	T_{min}	-108.32	-108.04
100% black paint	T_{max}	26.68	27.46
	T_{min}	-108.32	-108.03

Table 6. Results of the steady-state temperatures for 61% solar cell and 39% aluminum without internal energy dissipation (Case B)

Coverage (sun radiated side)	Value (deg, C)	Stationary calculation	
		Bottom 61% solar cells, 39% aluminum	Bottom 61% solar cells, 39% black paint
61% solar cells 39% aluminum	T_{max}	23.60	24.70
	T_{min}	-107.13	-106.75
100% aluminum	T_{max}	20.85	21.98
	T_{min}	-107.13	-106.75
61% solar cells 39% black paint	T_{max}	15.61	25.41
	T_{min}	-108.37	-108
100% black paint	T_{max}	26.29	27.33
	T_{min}	-108.37	-108

Table 7. Results of the steady-state temperatures for 71% solar cell and 29% aluminum without internal energy dissipation (Case C)

Coverage (sun radiated side)	Value (deg, C)	Stationary calculation	
		Bottom 71% solar cells, 29% aluminum	Bottom 71% solar cells, 29% black paint
71% solar cells 29% aluminum	T_{max}	24.31	25.13
	T_{min}	-107.15	-106.59
100% aluminum	T_{max}	21.12	21.97
	T_{min}	-107.15	-106.59
71% solar cells 29% black paint	T_{max}	15.29	24.84
	T_{min}	-108.44	-107.88
100% black paint	T_{max}	25.93	26.72
	T_{min}	-108.44	-107.88

Table 8. Results of the steady-state temperatures for 61% solar cell and 39% aluminum without internal energy dissipation (Case C)

Coverage (sun radiated side)	Value (deg, C)	Stationary calculation	
		Bottom 61% solar cells, 39% aluminum	Bottom 61% solar cells, 39% black paint
61solar cells 39% aluminum	T_{max}	23.60	24.71
	T_{min}	-107.13	-106.38
100% aluminum	T_{max}	20.85	21.99
	T_{min}	-107.13	-106.38
61% solar cells 39% black paint	T_{max}	15.03	24.85
	T_{min}	-108.57	-107.82
100% black paint	T_{max}	25.40	**26.46**
	T_{min}	-108.57	**-107.82**

4. Conclusion and Future works

The analysis and design of TCS satellite carried out by observing satellite component temperature limits specified. With the use of coating materials, it can be seen that by using materials 61% solar cells, 39% aluminum and 100% black paint on Case C, that was the best choice of materials selection, and under these conditions the battery is also able to withstand sun exposure due to the difference in battery temperature range (Table 1).

Based on this condition the passive control analysis was used on the satellite, and the main design feature was the selection of the external surface coating to manage the heat exchange between the satellite and the environment, and to get an appropriate temperature distribution for all components of the satellite. Whereas in order to prevent excess heat also need to be used heater to keep satellite warm in the cold case. Based on mathematical model, the steady state analyzed, was developed to predict the temperature distribution on surface coating properties of materials. For further thermal analysis, transient analysis needs to be done on a satellite using some commercial software's such as MatLab, Esatan/EsaRad, Sinda/G, Nastran, and Ansys, Femap or other software's.

REFERENCES

[1] Gilmore, D.G. 1994. Thermal Control Handbook. The Aerospace Corporation Press. El Segundo, California.

[2] Bulut, M., and Sozbir, N. 2008. Nano-Satellite Thermal Control, The International Conference on Thermal Engineering, TURKSAT A.S. R&D and Satellite Design. Mechanical Engineering Department. Sakarya University. Turkey.

[3] Larson, W. J., and Wertz, J. R.. 1996. Space Mission Analysis and Design. Kluwer Academic Publisher. Dordrecht. The Netherlands.

[4] Czernik, S. 2004. Design of the Thermal Control System for Compass-1. University of Applied Sciences Aachen Germany.

[5] Bulut, M., Kahriman, A., and Sozbir, N. 2010. Design and Analysis for Thermal Control System of Nanosatellite, Proceedings of the ASME 2010 International Mechanical Engineering Congress&Exposition IMECE, Canada, pp. 1-4.

[6] A.M., Abouel Fotouh., I. Shabaka, A. Elsharkawy and A. Elfar. 2006. Material Selection for Satellite Passive Thermal Control, Journal of Applied Sciences Research. INSInet Publication, Vol. 2, No. 12, pp. 1106-1111.

[7] SAGSVEEN Bendik Andreas. 2003. Thermal and Mechanical Analyses for The NSAT-1 Phase B Study. The Norwegian Defence Research Establishment FFI.

[8] 7075-T651 Aluminum. Thermal Properties. 2019. ASM Aerospace Specification Metals Inc. 800 398-4345.

[9] Diego A. Melani Barreiro. 2008. A Small Satellit Preliminary Thermal Control and Heat Shield Analysis. Bachelor of Science. Thesis. Department of Mechanical Engineering, Massachusetts Institute of Technology.

[10] Stephen M. Pompea, Robert P. Breault. Black Surfaces for Optical Properties Handbook Chapter 37 p: 37.1-37.70. [Online]. Available: http://photonics.intec.ugent.be/education/ivpv/res_handbook/v2ch37.pdf

[11] AZ-100-ECB Black Thermal Control, Electrically Conductive Paint/Coating and TJM-20-LSB Black Spacecraft Coating. 2019. [Online]. Available: http://www.aztechnology.com/materials-coatings-az-1000-ecb.html, http://www.aztechnology.com/materials-coatings-TMJ-20-LSB.html