Effect of Gravity on PCM –TA Performance

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Agenda

- Using Phase Change Material Thermal Accumulator (PCM-TA) for thermal control of cubesats
- Effect of natural convection on **PCM-TA** performance
- Testing of **PCM-TA** in terrestrial conditions
- Conclusion

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Introduction

- Traditionally, cubesats used to not to use much power, let's 3-5 w which does not require a thermal management.
- BUT, now the power of cubesats goes up to 100-200 watts. And as keynote speaker, Maj. Gen. Shiess implied, much more power will be required in future.
- In some applications, a large amount of waste heat is generated quickly; example, a payload of high power (~300 W) operating on a low-duty cycle. In these cases, it is advantageous to accumulate the waste heat rather than to install a large enough radiator to instantly dissipate the waste heat into space.

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Introduction- cont'd

- PCM based heat accumulator will store waste heat during high power load and release it during time of low thermal loads. Understanding PCM behavior at terrestrial vs. microgravity conditions is very important for correct design an PCM –TA for space applications.

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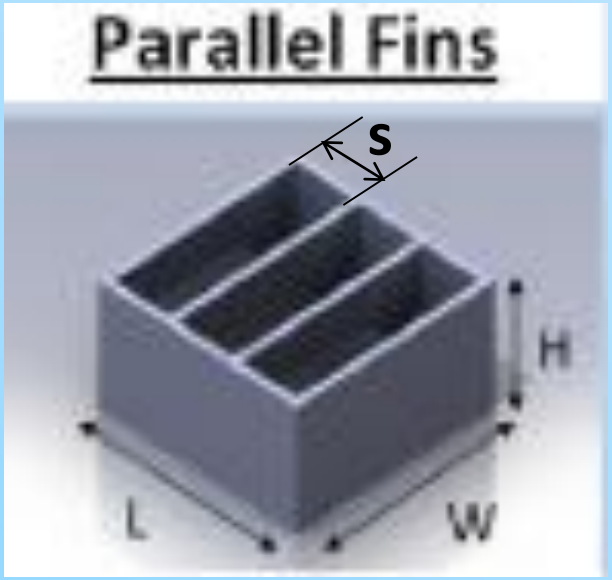
Introduction – cont'd

- Experimental data indicates that an efficiency of PCM -TA is strongly affected by gravity. Understanding of such dependency is important for proper PCM-TA testing in terrestrial conditions and correct use results (which terrestrially obtained) for microgravity applications. This presentation discusses the nature of such a difference and its implications.

PCM-TA design



Ref.1

- Common PCM candidates has low thermal conductivity
- Internal fins have been used to enhance heat transfer between walls and PCM
- Many studies have been conducted to find an optimal configuration for PCM-TA

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PCM-TA Testing

- The “mantra “ of testing- “Test as we fly”
- Two mechanisms of heat transfer from walls/fins to PCM in terrestrial conditions

1. Conduction
2. Natural convection – does not exist in microgravity

Natural Convection should be minimized during the test or included into model in order to estimate and remove the effect

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Natural Convection

Natural convection is defined by Grashof Number

$$Gr = \frac{g\,\beta(T_s - T_\infty)\,L^3}{\nu^2}\,cos\alpha$$

Where:

- g is the gravitational constant
- β and ν are the thermal expansion coefficient and kinematic viscosity, respectively
- T_s and T_∞ are the surface and bulk temperatures, respectively
- L is the characteristic length.
- α is the angle of inclination of the surface to the horizon

A characteristic length may be chosen as the height of the liquid phase along the direction of the heat flux.

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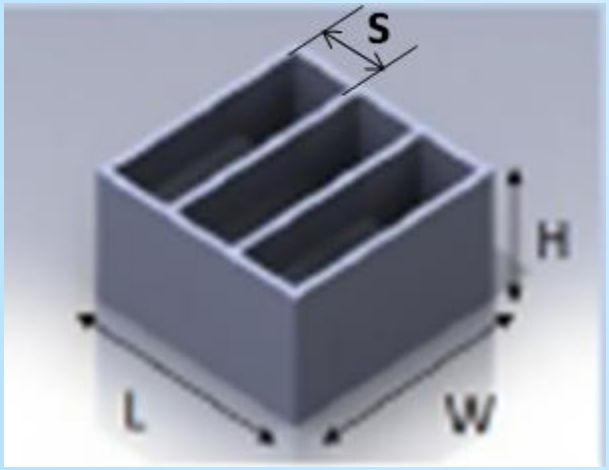
PCM-TA orientation

Orientation 1

S is the characteristic length



Orientation 2

H is the characteristic length

$$Gr_1/Gr_2 \sim S/H \ll 1$$

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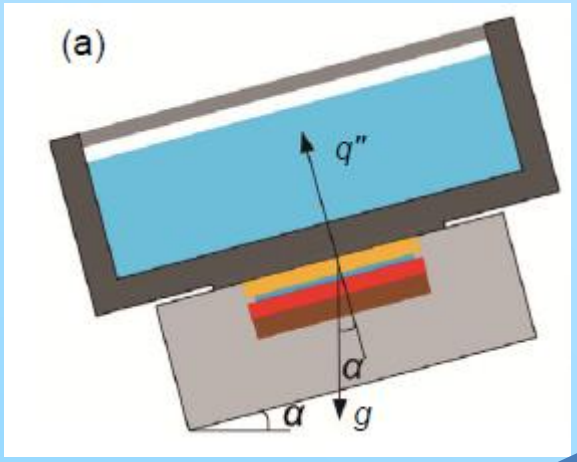
Effect of Gravity on PCM performance



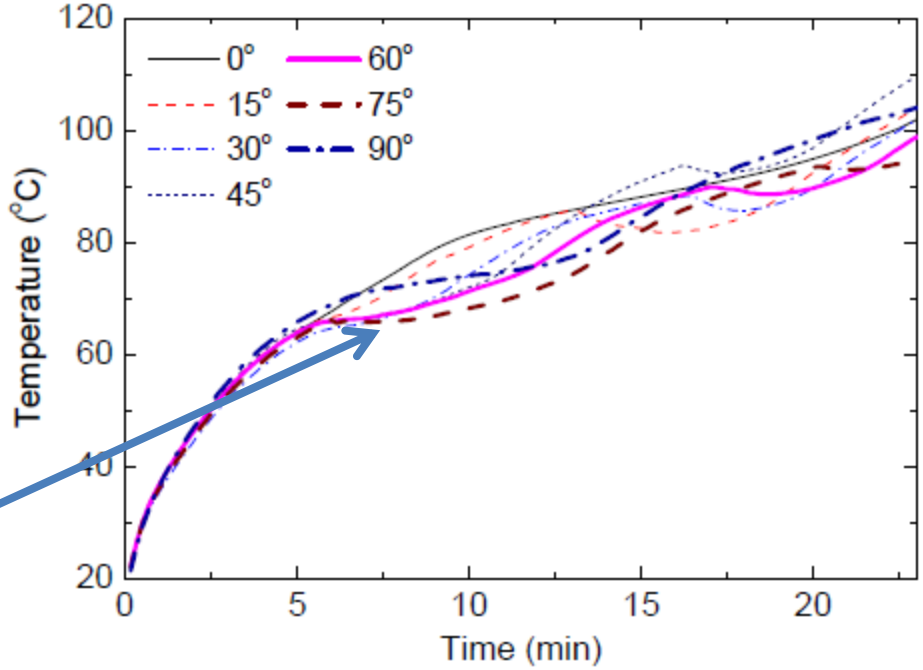


Fig. 4 Transient temperature rises at the center of the round copper plate for the heat sink operated at various inclination angles under the heat load of 40 W

Flat curve corresponds to PCM melting.

Ref.2

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Measurement of PCM-TA Performance

Parameter to measure PCM-TA performance is the Maximum Operational Time, that is, a time to maintain payload temperature below the maximum allowable temperature.

Per Ref. 2:

20W

natural convection	Heating time (sec)	Time extension
min	2420	
max	2550	5.4%

40W

natural convection	Heating time (sec)	Time extension
min	480	
max	800	66.7%

At high power levels, a contribution of natural convection into melting process is significant.

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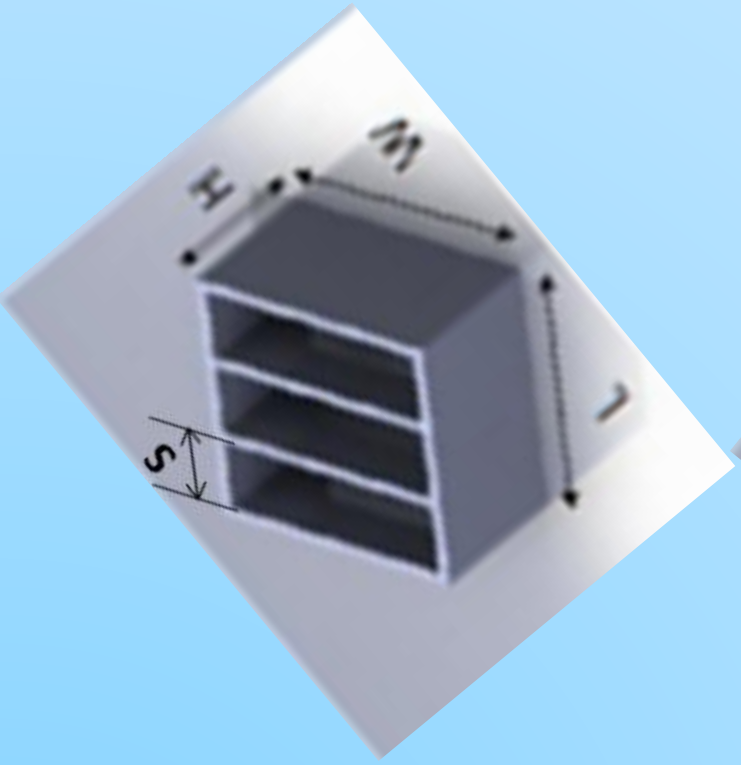
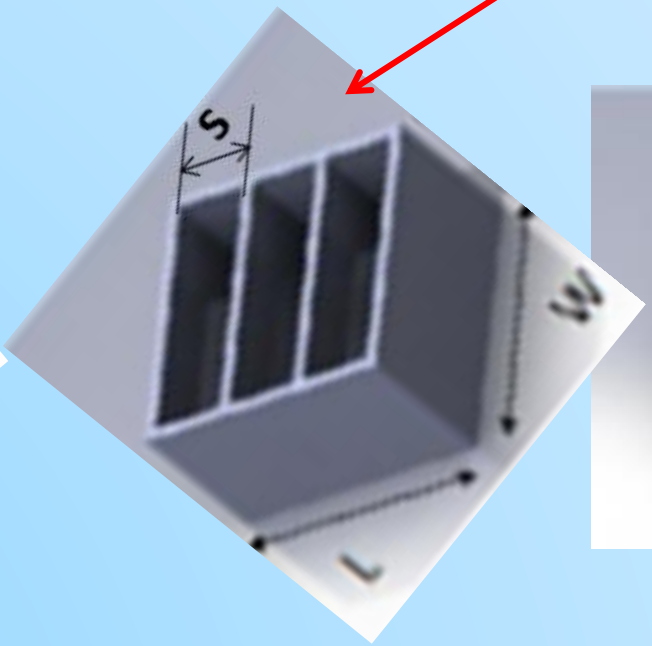
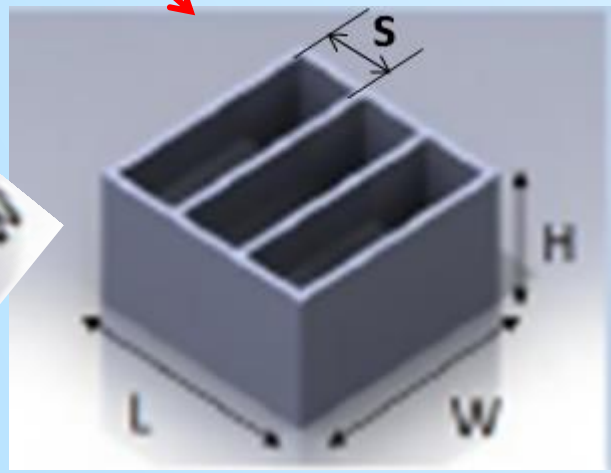
Conclusion - cont'd

DON'T







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Conclusion

- During PCM –TA test in terrestrial conditions, be aware that natural convection can significantly increase heat transfer between fins and PCM inside of a thermal accumulator
- Use this heating time duration obtained in terrestrial conditions for microgravity applications would be incorrect
- Test set up should reduce natural convection as much as possible

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References

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2. Lu, J. et al, “Effect of the inclination angle on the transient performance of a phase change material-based heat sink under pulsed heat loads”, Journal of Zhejiang University - Science A: Applied Physics & Engineering · October 2014
3. Kalbasi, R., et al, “Studies on optimum fins number in PCM-based heat sinks”, Energy 171 (2019) 1088e1099