TFAWS '02
Thermal Systems Session
August 2002

Modeling of Multi-Layer Insulation Layups with Transmissive Outer Layers

Eugene K. Ungar
Crew and Thermal Systems Division
NASA/Johnson Space Center
Houston, TX

Content

- Problem Statement
- Optics Measurements
- Inference of Emissivity, Absorptivity, and Transmissivity
- Simplified and Detailed Modeling
- Analysis Results
- Recommendations

Problem Statement

- Many of the insulation blankets on the International Space Station use an insulating layup consisting of
  - Chemglas 250 fabric outer layer
  - silver/Teflon film with Inconel backing
  - multiple layers of aluminized Mylar
- The silver/Teflon layer is designed to counteract the effect of the Chemglas transmissivity

Problem Statement

- Original concern arose from discovery of some ISS blankets with the silver/Teflon reversed
  - effect of reversal on blanket performance
- Larger question is how we measure optics and model performance of blankets with transmissive outer layers
  - can standard measurement techniques give useful results?
  - is simple single surface modeling accurate?

Measurements

- Standard optics measuring tools sense hemispherical reflectance and read out emissivity and absorptivity
  - transmissive surfaces are problematic
- Measurements for present work performed using various layups of
  - Chemglas 250 fabric
  - Ortho Fabric
  - double-sided aluminized Mylar
  - reinforced aluminized Mylar
  - white cardboard

Emissivity measured using AZTek 2000 - performs total hemispherical reflectance measurements from less than 3 to greater than 35 μm wavelength

Absorptivity measured using AZTek LPSR300 - makes measurements from 250-2800 nm, automatic integration of the reflectance data is performed to calculate and display solar absorption

Raw Data from Test

layup	cardboard	Chemglas 250 ↑	Chemglas 250 ↓	Chemglas 250 ↑	Chemglas 250 ↓	Chemglas 250 ↑	Chemglas 250 ↓
				cardboard	cardboard	Mylar ↑	Mylar ↑
						cardboard	cardboard
measured absorptivity	0.231	0.385, 0.378	0.348, 0.350	0.219, 0.220	0.220, 0.218		
measured emissivity	0.848	0.865	0.865	0.865	0.86	0.85	0.85
layup		Ortho Fabric ↑	Ortho Fabric ↓	Ortho Fabric ↑	Ortho Fabric ↓	Ortho Fabric ↑	Ortho Fabric ↓
				cardboard	cardboard	Mylar ↑	Mylar ↑
						cardboard	cardboard
measured absorptivity		0.274	0.353	0.187	0.249		
measured emissivity		0.84	0.84			0.83	0.838
layup		Mylar	Mylar	scrim Mylar, scrim ↓	scrim Mylar, scrim ↑	scrim Mylar, scrim ↓	scrim Mylar, scrim ↑
			cardboard			cardboard	cardboard
measured absorptivity		0.164	0.091	0.083	0.262	0.078	0.264
measured emissivity		0.03	0.03	0.022	0.54	0.03	0.52

All emissivity measurements are the average of two or more measurements at different positions on sample

Two absorptivity measurements at different positions were averaged to yield values for Ortho Fabric – all others were single measurements

Where multiple absorptivity measurements are reported, they are the results of testing on different days

Emissivity measurements are reported to two significant figures by instrument

Absorptivity measurements are reported to three significant figures by instrument

Chemglas sample was marked to differentiate sides, side toward instrument is represented by ↑ or ↓

No visible difference between sides of Chemglas

Ortho Fabric sample ↑ has outer layer towards instrument

Scrim Mylar sample ↑ has scrim towards instrument

Data Analysis

surface with same optics both sides

1 without backing

with opaque backing 2
emissivity ε_o

q" from instrument

$$\varepsilon_1 = \varepsilon + \tau$$

q"

$$\varepsilon_2 = 1 - \frac{q''_{out}}{q''}$$

$$\varepsilon_2 = 1 - [1 - (\tau + \varepsilon)] - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n [1 - (\tau + \varepsilon)]^{n-1}$$

$$\varepsilon_2 = \varepsilon_1 - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n (1 - \varepsilon_1)^{n-1}$$

$$\tau = \sqrt{\frac{\varepsilon_1 - \varepsilon_2}{\sum_{n=1}^{\infty} (1 - \varepsilon_o)^n (1 - \varepsilon_1)^{n-1}}}$$

ε_1 and ε_2 are the emissivities (or absorptivities) reported by the instrument

Last equation can be solved for τ

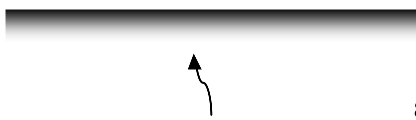
First equation can then be solved for ε

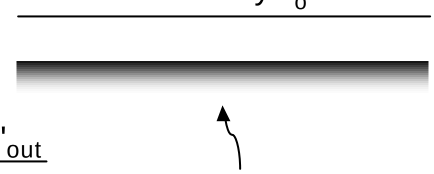
Data Analysis

surface with differing optics

1 without backing

with opaque backing 2
emissivity ε_o





q" from instrument

q"

$$\varepsilon_1 = \varepsilon_f + \tau$$

$$\varepsilon_2 = 1 - \frac{q''_{out}}{q''}$$

$$\varepsilon_2 = 1 - \left[1 - (\tau + \varepsilon_f)\right] - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n \left[1 - (\tau + \varepsilon_b)\right]^{n-1}$$

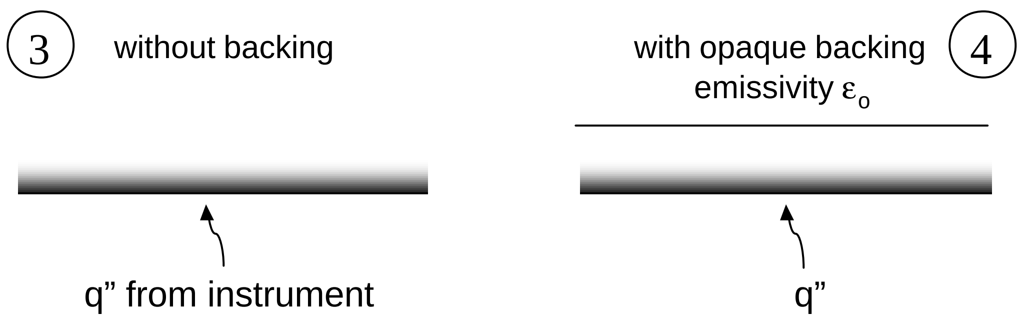
$$\varepsilon_2 = (\tau + \varepsilon_f) - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n \left[1 - (\tau + \varepsilon_b)\right]^{n-1}$$

$$\varepsilon_2 = \varepsilon_1 - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n \left[1 - (\tau + \varepsilon_b)\right]^{n-1}$$

ε_f and ε_b are the emissivities of the front and back of the sample, respectively

Data Analysis

surface with differing optics



$$\varepsilon_3 = \varepsilon_b + \tau$$

$$\varepsilon_4 = \varepsilon_3 - \tau^2 \sum_{n=1}^{\infty} (1-\varepsilon_o)^n [1-(\tau+\varepsilon_f)]^{n-1}$$

four equations, three unknowns: ε_f, ε_b and τ

two values of τ are calculated and averaged

ε_3 and ε_4 are the emissivities (and absorbtivities) reported by the instrument with front layer inverted

Calculated Diffuse Optical Properties

<table>
<tr><th></th><th>ε</th><th>τ_{IR}</th><th>α</th><th>τ_{sol}</th></tr>
<tr><td>Chemglas ↑</td><td>0.865</td><td>opaque</td><td>0.05</td><td rowspan="2">0.31</td></tr>
<tr><td>Chemglas ↓</td><td>0.865</td><td>opaque</td><td>0.06</td></tr>
<tr><td>Ortho Fabric (outside)</td><td>0.84</td><td rowspan="2">opaque</td><td>0.05</td><td rowspan="2">0.24</td></tr>
<tr><td>Ortho Fabric (inside)</td><td>0.84</td><td>0.09</td></tr>
<tr><td>double-sided Mylar</td><td>0.03</td><td>opaque</td><td>near zero</td><td>0.19</td></tr>
<tr><td>scrim Mylar (shiny side)</td><td>0.022</td><td rowspan="2">opaque</td><td>0.083</td><td rowspan="2">opaque</td></tr>
<tr><td>scrim Mylar (scrim side)</td><td>0.54</td><td>0.262</td></tr>
</table>

Opaque surfaces are identified by negligible difference between measurements with and without backing

Simplified and Detailed Modeling

- Simplified modeling
  - measure layup emissivity and absorptivity using instruments
  - model MLI outer layers as single surface
- Detailed modeling
  - determine emissivity, transmissivity in solar and IR ranges for relevant layers
  - calculate performance based on multiple-surface model

Simplified Modeling

- Emissivity and absorptivity that would be measured for layups can be calculated based on known parameters for each layer, ε, α, τ_{IR}, τ_{sol}
  - different optics on each side of top layer

$$\varepsilon_{meas} = (\tau + \varepsilon_f) - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n \left[1 - (\tau + \varepsilon_b)\right]^{n-1}$$

  - same optics on each side of top layer

$$\varepsilon_{meas} = (\tau + \varepsilon) - \tau^2 \sum_{n=1}^{\infty} (1 - \varepsilon_o)^n \left[1 - (\tau + \varepsilon)\right]^{n-1}$$

Simplified Modeling
– Chemglas-silver/Teflon

			ε	τ_{IR}	ε_{meas}	α	τ_{sol}	α_{meas}
correct layup	1st layer	Chemglas 250	0.865*	opaque*	0.865	0.055*	0.31*	0.16
	2nd layer	silver/ Teflon	0.75†			0.09†	opaque	
incorrect layup	1st layer	Chemglas 250	0.865*	opaque*	0.865	0.055*	0.31*	0.32
	2nd layer	Inconel	0.04‡			0.65‡	opaque	

* Present work

† Sheldahl Product Bulliten - 0.005 thick silver/Teflon, from Sheldahl Technical Materials, 1150 Sheldahl Rd., Northfield, MN

‡ The Red Book (RB1), from Sheldahl Technical Materials, 1150 Sheldahl Rd., Northfield, MN

Analysis Case – Simplified Model

- Cube with 1 sun (435 BTU/hr ft^2) on one side (background absolute zero) and 0°F blackbody on other 5 sides
- Cube internals will reach average sink temperature
- Correct layup, ε=0.865, α=0.16
  - T_∞=1°F
- Incorrect layup, ε=0.865, α=0.32
  - T_∞=20°F

Detailed Modeling

- Model internal MLI (cube with $\varepsilon^*=0.05$) and both sides of outer and inner layers
- Calculate solar energy absorbed on outer layer and inner layer
- Use radiation resistance modeling to calculate resulting internal temperature

Detailed Modeling

- Absorbed radiation
  - outer layer

$$q''_{absorbed} = q''\varepsilon_f + q''\tau_s \sum_{n=1}^{\infty} (1-\varepsilon_o)^n \left[1-(\tau_d+\varepsilon_b)\right]^{n-1} \varepsilon_b$$

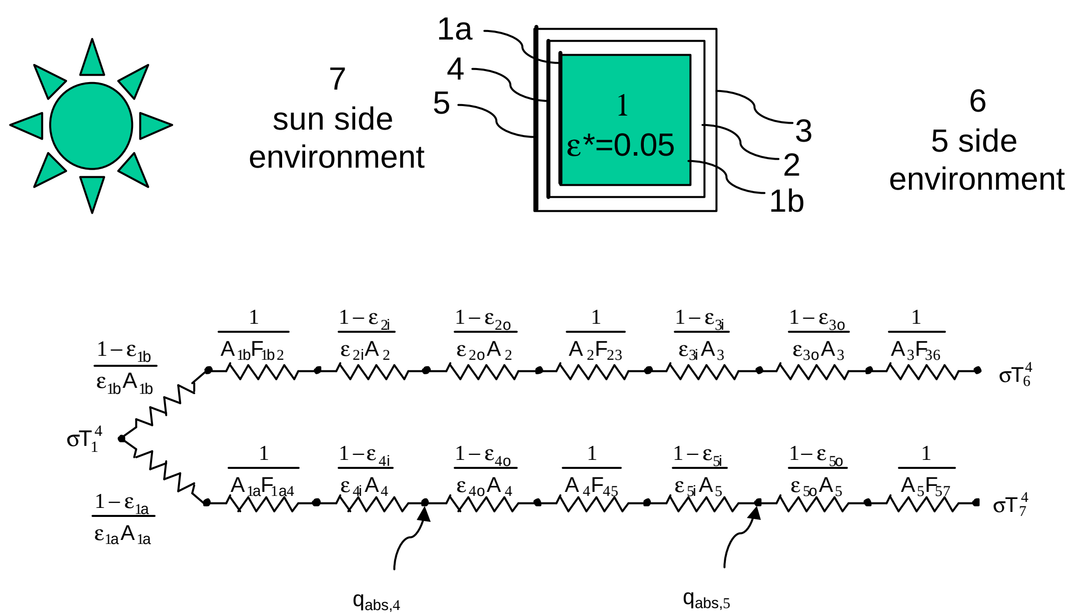
  - opaque inner layer

$$q''_{absorbed} = q''\tau_s\varepsilon_o + q''\tau_s \sum_{n=1}^{\infty} (1-\varepsilon_o)^n \left[1-(\tau_d+\varepsilon_b)\right]^{n-1} \varepsilon_o$$

Subscripts s and d refer to specular and diffuse values, respectively

For zero angle of incidence τ_s=1.5τ_d based on distance traveled through material

Detailed Modeling



All view factors are unity

A_{1a}, A_4, A_5 = 1 ft^2 for convenience

A_{1b}, A_2, A_3 = 5 ft^2

T_6=0°F

T_7=0°R

Analysis Case Results – Detailed Model - Chemglas-silver/Teflon

	Chemglas absorbed solar	inner layer absorbed solar	internal temperature
correct layup	49.7 BTU/hr ft^2	44.7 BTU/hr ft^2	23°F
incorrect layup	30.0 BTU/hr ft^2	175.3 BTU/hr ft^2	294°F

Model Comparison
Chemglas-silver/Teflon

	internal temperature (simplified model)	internal temperature (detailed model)
correct layup	1°F	23°F
incorrect layup	20°F	294°F

- Detailed model is required to capture physics

Recommendations

- MLI with transmissive outer layers must be modeled in detail to capture effect of reversed inner layers
- Significantly different results are obtained using detailed modeling for even correctly built blankets