

TEMP-COAT® Brand Products, LLC

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TEMP-COAT OVERALL THERMAL RESISTANCE RATIO

Regarding a request for test data pertinent to the ability of TEMP-COAT TO INSULATE

The attached study employed a guarded hot plate with TEMP-COAT applied at varying mil thicknesses employing more product as the test progressed. A companion guarded hot plate was fitted with 2 inches of industrial fiberglass insulated board rated at an "R-8". The object of the test was to check the Thermal Resistance of TEMP-COAT at varying thicknesses against the performance of the Fiberglass insulation in a comparative study. The OVERALL THERMAL RESISTANCE RATION GAUGE IS ON THE LEFT OF THE SHEET. The darker thick line represents the thermal resistance of fiberglass at varying temperatures. The thin line in the chart represents the effectiveness of TEMP-COAT at varying mil thicknesses and increasing temperatures.

Because this test is performed under controlled conditions it does not consider factors that occur in the field such as the absorption of moisture from rain, humidity, hygroscopic action or condensation which reduces the effectiveness of fiberglass (or other similar mass products) and causes corrosion problems. By comparison, TEMP-COAT adheres to the surface it insulates creating a steady state result and helps to prevent corrosion.

Please refer to the attached chart and notes comparing Overall Thermal Resistance.

Note 1: This point on the graph represents the lowest temperature setting of the four points of comparison (180 degrees F to 200 degrees F at 85 mils). TEMP-COAT performed between 98% and 104% as well as the fiberglass.

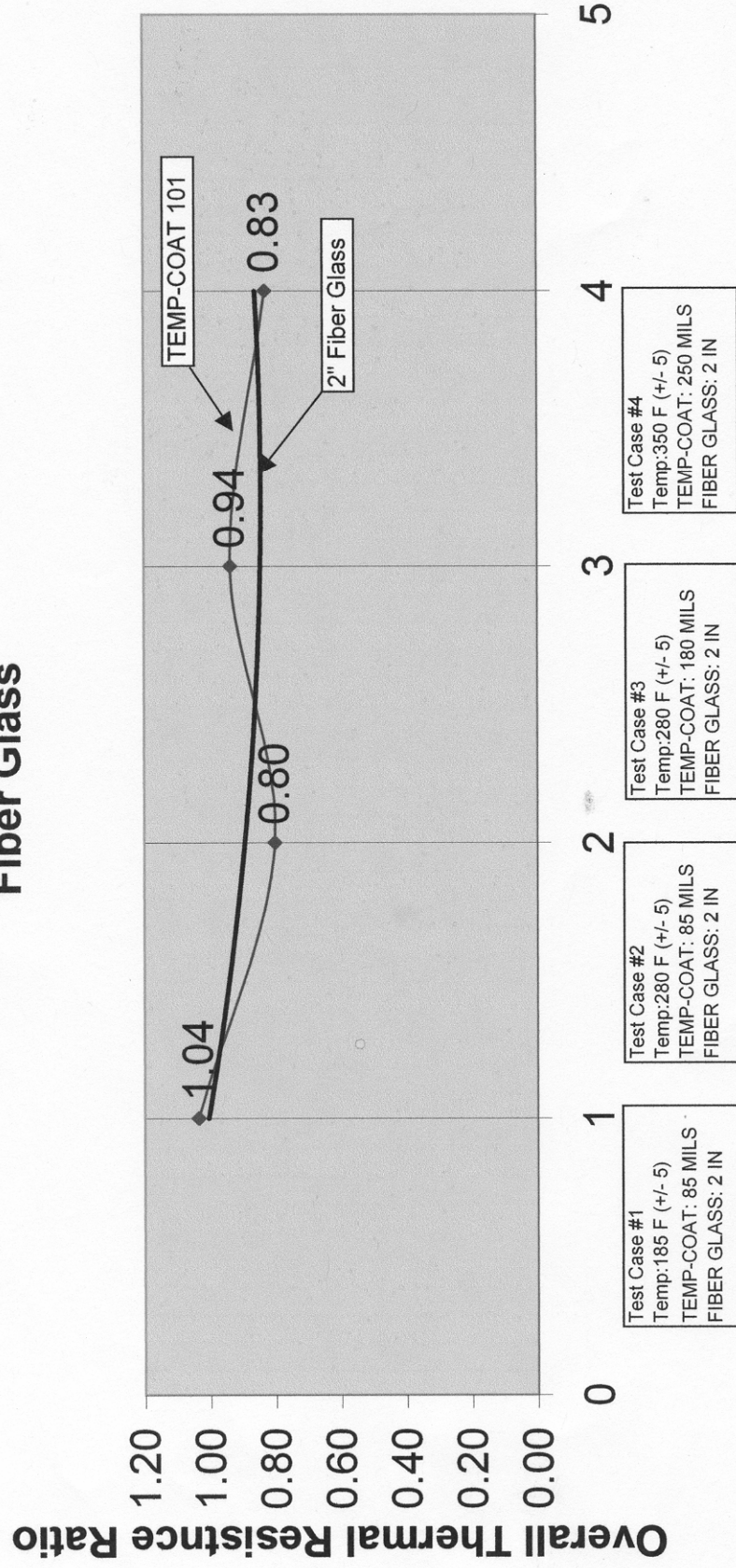
Note 2: This note represents an increase in temperature setting of 280 degrees F to 300 degrees F with the same 85 mil thickness of TEMP-COAT. This thickness is not sufficient for this temperature range but TEMP-COAT still performed within 80% of the thermal resistance needed to be comparable to fiberglass.

Note 3: This note represents the same temperature as note #2 at 280 degrees F. TEMP-COAT has been increased to 180 mils. At this thickness the chart shows that TEMP-COAT is rated at .94 vs. .84 for the fiberglass. At this temperature and thickness, TEMP-COAT out performed the fiberglass.

Note 4: TEMP-COAT thickness was increased to 250 mils and the temperature was increased to 350 degrees F. for both products. In this instance the fiberglass slightly out performed TEMP-COAT at .85 for fiberglass and .83 for TEMP-COAT.

TEMP-COAT is a barrier form of insulation/ the thermal resistance is created by air encapsulated in a proprietary mixture of ceramics held together by a high quality acrylic latex binder. The ceramic spheres provide the impetus for thermal resistance.

Overall Thermal Resistance Ratio of TEMP-COAT VS. Fiber Glass



**Fiber Glass Insulation: 2" Aluminum Backed R-8 (Owens Corning)

Heat Transfer Characteristics of Temp-Coat® Vs. Fiberglass as Insulating Material: A Comparative Approach

Project Report

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August, 2004**

Background:

In order to understand on a comparative basis, the insulating capacity of Temp-Coat® vis-à-vis Fiberglass, for different geometry and application as documented (report DDS3901-1) and furnished by George Nakamura of Northrop Grumman, the previous semi-quantitative analysis conducted and reported by Poddar & Associates for Southern Chemical Industries, Inc (SCI) of LaPlace, LA have been taken into account

This report summarizes the approach and findings of such an exercise.

The approach and methodology taken are to 1) review salient features of various modes of heat transfer in a situation similar to the experimental condition, 2) introduce the concept of the “overall heat transfer coefficient”, U (Thermal transmittance) and its interrelationship with “thermal conductivity” k , 3) utilize the ratio of U factors put forward previously for SCI, 4) develop a semi-quantitative model and 5) utilize such a model as a predictive tool for estimating equivalent Temp-Coat thickness in comparison with Fiberglass insulation..

Basic mode of Heat Transfer:

There are three basic modes of heat transfer under any situation and all three of them proceed simultaneously; although contributions made by each of these path ways could vary significantly depending on a given situation. These modes of heat transfer are:

- Conduction
- Convection and
- Radiation

In conduction, quantity of heat energy transferred per unit time can mathematically be expressed in terms of Fourier’s law. For a one-dimensional flow, the rate of heat transfer by conduction with respect to time can be expressed as:

$$dQ/dt = q_{\text{conduction}} = -kAdT/dx \quad (1)$$

(negative sign signifies that the heat always is transferred from higher temperature to lower temperature).

Here Q is the total heat energy transferred, k is the thermal conductivity, A is the heat transfer area perpendicular to the direction of flow, in this case in x direction.

Note that k is a thermo-physical property of any material and is not a function of the thickness of the conducting body and in thermodynamics sense it is an intensive property.

Equation (1) above can also be expressed as

$$q = \Delta T / [(\Delta x) / kA] \quad (1A)$$

Here $\Delta x / kA$ in equation (1A) can be viewed as the resistance to conduction flow and is usually expressed as $R_{\text{Conduction}}$

Conduction of heat occurs in all forms of matter without any physical movement of particles in molecular level.

In convection, heat transfer occurs due to random molecular motion (diffusion), known as free convection as well as by the bulk or macroscopic motion, known as forced convection. The phenomenon of convection is very complex.

For convective heat transfer, the heat transfer rate equation can be expressed as follows:

$$q_{\text{Convection}} = hA(T_{\text{Surface}} - T_{\text{Ambient}}) \quad (2)$$

Where, h is the convective heat transfer coefficient. h can be predicted by established empirical equation (s) and is dependent on many factors e.g., geometry of the surface, velocity, physical property of fluid and sometimes even ΔT .

Equation (2) can also be expressed as

$$q_{\text{Convection}} = (T_{\text{Surface}} - T_{\text{Ambient}}) / (1/hA) \quad (2A)$$

Here $(1/hA)$ can be viewed as a convective heat transfer resistance, $R_{\text{Convection}}$.

In Radiation, the rate of heat transfer can be expressed by the following equation:

$$q_{\text{Radiation}} = \sigma A (T_1^4 - T_2^4) \quad (3)$$

Where, σ is the Stefan-Boltzman constant

This equation is known as Stefan – Boltzman Law and is applicable for perfect black body. In practical cases they are more often gray in nature (from radiation point of view) and for gray body cases such equation can be expressed as

$$q_{\text{Radiation}} = \sigma A \epsilon (T_1^4 - T_2^4) \quad (3A)$$

Here ϵ is emissivity (or emittance) of the surface.

Note that Emissivity is any material's ability to absorb and re-radiate thermal energy. $\epsilon = 1.0$ for a perfect black body (absorbing and reradiating all radiant energy heating the surface)

Equation (3A) can also be expressed in terms of radiation resistance as

$$\begin{aligned} q_{\text{Radiation}} &= (T_1 - T_2) / [(T_1 - T_2) / \sigma A \epsilon (T_1^4 - T_2^4)] \\ &= (T_1 - T_2) / [1 / \sigma A \epsilon (T_1^2 + T_2^2) (T_1 + T_2)] \end{aligned} \quad (3B)$$

Here radiation resistance, $R_{\text{Radiation}}$ can be expressed as:

$$[1 / \sigma A \epsilon (T_1^2 + T_2^2) (T_1 + T_2)] \quad (3C)$$

Concept of Overall Heat Transfer Coefficient:

For a case where all three mode of heat transfer is in occurrence (which by the way is the most prevalent case, although all three mode of transfer may or may not have the same level of relative impact to the transfer of heat, q can be expressed in terms of an **overall heat transfer coefficient**, U . Here q can be expressed as

$$q = UA\Delta T = \Delta T / (1/UA) \quad (4)$$

Here by analogy, $(1/UA)$ can be viewed as the overall heat transfer resistance, $\sum R_i$.

$$\text{Where } \sum R_i = R_{\text{Conduction}} + R_{\text{Convection}} + R_{\text{Radiation}} \quad (5)$$

$$\text{Therefore, } UA = 1/\sum R_i. \quad (6)$$

Interrelationship of k and U:

$$\text{From equation (5), } \sum R_i \geq R_{\text{Conduction}} \quad (7)$$

Therefore, combining equations (1A) and (7)

$$\sum R_i \geq \Delta x/kA$$

$$\text{Or, } 1/UA \geq \Delta x/kA$$

$$\text{Therefore for all practical purposes, } 1/UA > (\Delta x/kA) \quad (8)$$

$$\text{Or, } 1/UA = \alpha (\Delta x/kA) \text{ where } \alpha \text{ is greater than 1} \quad (9)$$

Semi-Quantitative Approach relating Effective Thermal Conductivities of Tem-Coat® and Fiberglass:

Based on the previous finding as reported in SCI report, within the accuracy of experimental data and all other uncertainties associated with a set of rather crude experiments, an arithmetic mean value for the ratio of U_{FG} and U_{TC} , U_{ratio} can be taken into account for further analysis.

Please note that the subscripts FG and TC used in this section refer to the respective physical parameters for Fiberglass and Temp-Coat® insulation respectively.

$$U_{\text{ratio}} = U_{\text{FG}}/U_{\text{TC}} = (0.80+0.94 + 0.83) = 0.86 \quad (10)$$

Using equation (9) for U_{FG} and U_{TC}

$$U_{\text{ratio}} = (\alpha_{\text{TC}}/\alpha_{\text{FG}})(k_{\text{FG}}/k_{\text{TC}}) (\Delta x_{\text{TC}}/\Delta x_{\text{FG}}) \quad (11)$$

Defining the fraction, $(\alpha_{TC}/\alpha_{FG})$ as a factor β , equation (11) can be rearranged as

$$1/(k_{FG}/k_{TC}) = \beta(1/U_{ratio}) (\Delta x_{TC}/\Delta x_{FG})$$

$$\text{Or, } k_{TC} = \beta k_{FG} \{(1/U_{ratio}) (\Delta x_{TC}/\Delta x_{FG})\} \quad (12)$$

From previous SCI experiments, on the average, the factor under parenthesis,

$$(1/U_{ratio}) (\Delta x_{TC}/\Delta x_{FG}) = (1/0.86)(200)/\{(1000)(2)\} = 0.12$$

$$k_{TC} \leq 0.12 k_{FG} \quad (\text{ratio, } \beta \text{ being } \geq 1) \quad (13)$$

This suggests that for a given application, Temp-Coat® thickness of 240 mil shall be equal or better than 2" thickness of Fiber glass.

Conclusions:

Expected Results vs. Fiberglass (k= .23)

TEMP-COAT @

85 mils (2.16 mm) will perform as well as 2" of Industrial Fiberglass Board on a 185 F (85C) surface:

180 mils (4.57 mm) will perform as well as 2" of Industrial Fiberglass Board on a 280 F(137C) surface:

250 mils (6.35 mm) will perform as well as 2" of Industrial Fiberglass Board on a 350 F(177C) surface:

NOTE: This documentation presents a very conservative view.

Expected Results vs. Polyimide Foam (k =<0.29)

TEMP-COAT @ Surface Ambient

90 Degrees F vs. 65 Degrees F

45 mils (1.14 mm) will perform as well as 1" of Polyimide Foam

130 Degrees F vs. 65 Degrees F

85 mils (2.16 mm) will perform as well as 2" of Polyimide Foam

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Experimental Data

Experiments⁽¹⁾ at a Lower Temperature Setting:

Heat Transfer Experiment with Temp-Coat Insulation

Lower Temp Setting

Experiment T1A

Time in Sec	Temperature °F
0	84
35	196
400	127
410	156
667	125
674	145
880	125
886	140
1061	125
1071	144
1268	124
1272	140
1448	123
1460	151
1710	123
1721	150

Heat Transfer Experiment with Fiber Glass Insulation

Lower Temp Setting

Experiment F1A

Time in Sec	Temperature °F
0	86
45	165
560	129
575	162
871	128
883	167
1200	127
1215	165
1495	128
1503	150
1749	129
1764	173

Note: **(1) Please refer to report on Project 1**

Experiments⁽¹⁾ at a Higher Temperature Setting 1:

Heat Transfer Experiment with Temp-Coat Insulation Higher Temperature Setting 1 Experiment T1B

Time in Sec	Temperature °F
0	82
86	302
257	211
268	231
348	208
358	225
448	206
463	231
558	202
568	219
653	199
661	215
736	199
746	220
831	197
841	218

Higher Temperature Setting Experiment F1B Heat Transfer Experiment with Fiber Glass Insulation

Time in Sec	Temperature °F
0	86
80	329
315	212
325	230
435	210
450	247
592	206
602	233
719	205
729	233
844	204
857	239

Note: (1) Please refer to report on Project 1

Experiments⁽²⁾ at a Higher Temperature Setting 2:

Heat Transfer Experiment with Temp Coat Insulation Higher Temperature Setting 2 Experiment T2B

Time in Sec	Temperature °F
0	81
90	272
175	227
185	244
260	223
275	241
365	217
375	235
460	214
470	231
550	212
560	232
650	209
660	230
740	208
750	223
826	205
836	222

**Heat Transfer Experiment with Fiber
Glass Insulation
Higher Temperature Setting
Experiment F2B**

Time in Sec	Temperature °F
0	82
75	324
200	234
210	262
310	229
320	256
415	222
425	246
515	221
525	242
610	219
622	249
727	217
739	244
854	218
864	244

**Analysis of Experimental Data and a Semi-quantitative
Interpretation of Results:**

The experimental data for all three sets of experiments were analyzed in terms of Overall Heat Transfer Coefficient. Detailed methodology and computational model developed are summarized in Appendix A.

The calculated results in terms of Overall Heat Transfer Coefficient, U and the ratio of Overall Thermal Resistance, R for Temp-Coat with respect to that of Fiber Glass at various experimental conditions are tabulated on the next page. A plot of R -ratios for three cases is included on page 6.

These results are arrived at by a series of calculation done with the model developed with a series of assumptions.

Overall Heat Transfer Coefficient, U and Overall Thermal Resistance Ratio for Temp-Coat and Fiber Glass

Material	Condition	U Btu/(hr)(ft ²)(°F)	Overall Thermal Resistance Ratio $R_{Temp\ Coat}/R_{Fiberglass}$
Fiberglass	Lower temp & 2" thickness	3.16	1.036066
Temp-Coat	Lower Temp & 85 mil thickness	3.05	
Fiberglass	Higher temp & 2" thickness	3.19	0.801508
Temp-Coat	Higher temp & 85 mil thickness	3.98	
Fiberglass	Higher temp & 2" thickness	3.05	0.918675
Temp-Coat	Higher temp & 210 mil thickness	3.32	
	1 Lower Temp & 85 mil thickness		1.04
	2 Higher temp setting 1 & 85 mil thickness		0.80
	3 Higher temp setting & 210 mil thickness		0.92

Without any statistical variance analysis (because of the absence of any repeat experiments), no statistical confidence could be attached to any of these results. Therefore it is recommended that instead of the absolute numbers, the results should be looked at on a relative scale. The following semi-quantitative observations may be made:

With variability of data, particularly for experiments at lower temperature setting, the Overall Thermal Resistance ratio at may be inferred that for all practical purposes both insulating media behaved similar at their respective experimental conditions of the first set of experiments.

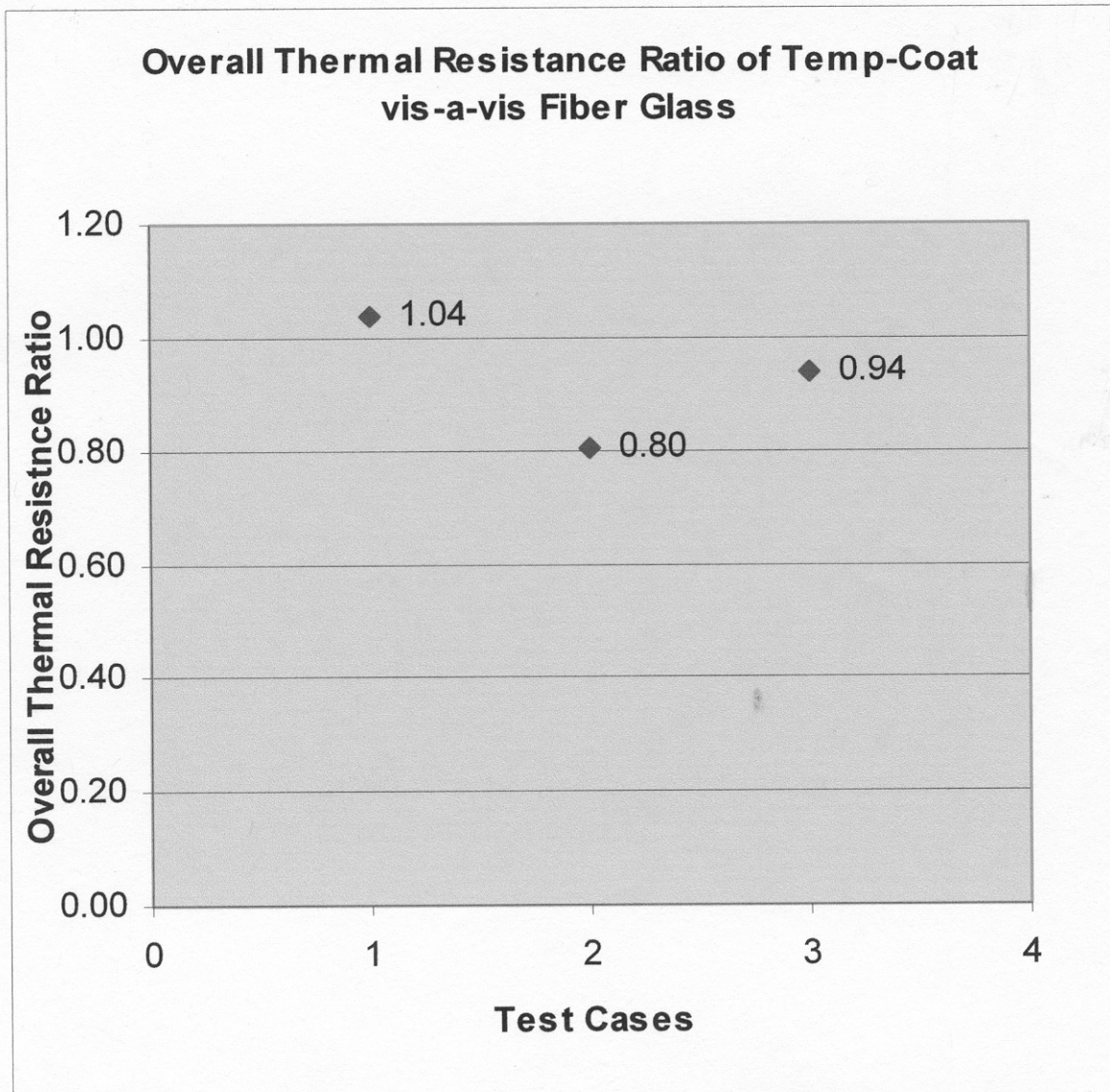
For the second set up experiments the ratio indicates that there is a significant difference between Fiberglass and Temp-Coat with reference to their overall thermal resistances at the respective experimental conditions; Overall Thermal Resistance of Temp-Coat is estimated to be about 80% of that of Fiberglass.

The results of the analysis of the third set of experiments suggest that at the experimental conditions, the Overall Thermal Resistance for Temp-Coat with 210 mil thickness is fairly close to that of Fiber Glass with 2" thickness.

In order to understand the directional effect of Temp-Coat thickness on the Overall heat Transfer coefficient as well as on the Overall Thermal Resistance, a set of experiments is recommended whereby similar experiments are done, one with maximum commercially applicable & viable

thickness of Temp-Coat and the other one (back-to-back) with Fiber Glass with 2" thickness. Both experiments are to be at the same higher temperature setting (similar to the earlier experiments).

Plot of Thermal Resistance Ratios for three sets of Experiments



Legend for X-Axis:

1. Lower Temperature Setting: Temp-Coat thickness 85 mil
Fiber Glass thickness 2"
2. Higher Temperature Setting 1: Temp-Coat thickness 85 mil
Fiber Glass thickness 2"
3. Higher Temperature Setting 2: Temp-Coat thickness 210 mil
Fiber Glass thickness 2"

TEMP-COAT Analysis
By Dr. Syamal Poddar

Conclusions:

Expected Results vs. Fiberglass (k= .23)

TEMP-COAT @ (k= 0.23)

85 mils (2.16 mm) will perform as well as 2” of Industrial Fiberglass on a 185 F (85C) surface:

180 mils (4.57 mm) will perform as well as 2” of Industrial Fiberglass on a 280 F(137C) surface:

250 mils (6.35 mm) will perform as well as 2” of Industrial Fiberglass on a 350 F(177C) surface:

Expected Results vs. Polyimide Foam (k =<0.29)

TEMP-COAT @ (k= 0.23)

45 mils (1.14 mm) will perform as well as 1” of Polyimide Foam

85 mils (2.16 mm) will perform as well as 2” of Polyimide Foam

Appendix A

During the heating cycle at a fixed temperature setting:

The actual time when the heat cut off was noted, however, the temperature at that instant was not noted.

In addition, at what time the temperature attended the pick is also not available
Duration of each heating cycle was noted

Temperature at which heat came on is known and the duration the heater was on is known.

Basic Heat Transfer Equation:

$$dQ/dt = UA \Delta T \text{ or } \int dQ = Q_{\text{Total}} = UA \int \Delta T dt, \text{ where, } \Delta T = T - T_{\text{ambient}}$$

Where, Q is the heat energy transferred at a given time t, T is the temperature in absolute scale at time t, U is the overall heat transfer coefficient and A is the heat transfer area normal to the direction of heat flow

In absence of any additional temperature data at intermediate points during heating and/or cooling cycles, for this analysis it is assumed that Temperature, T is a linear function of time, t during heating as well as during cooling part of the cycle.

Total heating part can be divided in to two parts: 1) initial heating, which is relatively of longer time duration plus 2) a series of heating cycle with an average cycle duration.

$$\text{Total } Q = Q_{\text{Total}} = Q_{\text{initial heating}} + Q_{\text{cycle heating}} + Q_{\text{initial cooling}} + Q_{\text{cycle cooling}}$$

$$Q_{\text{Total}} = \int dQ = UA \{ [\int (T - T_{\text{ambient}}) dt]_{\text{initial heating}} + [\int (T - T_{\text{ambient}}) dt]_{\text{cycle heating}} + [\int (T - T_{\text{ambient}}) dt]_{\text{initial cooling}} + [\int (T - T_{\text{ambient}}) dt]_{\text{cycle cooling}} \}$$

$$Q_{\text{Total}} = UA \{ \int (a_1 + b_1 t - 538) dt + \int (a_2 + b_2 t - 538) dt + \int (a_3 + b_3 t - 538) dt + \int (a_4 + b_4 t - 538) dt \}$$

$$Q_{\text{Total}} = UA \{ (a_1 t + b_1 t^2 / 2 - 538 t) + (a_2 t + b_2 t^2 / 2 - 538 t) + (a_3 t + b_3 t^2 / 2 - 538 t) + (a_4 t + b_4 t^2 / 2 - 538 t) \}$$

T_{ambient} is assumed to be 78 °F

Case 1a: Fiber Glass Insulation with Lower Temperature Setting

Total Heat Input, BTU

63.74667

For initial part of heating: $T = a_1 + b_1 t$

Therefore, $86+460 = a_1$ and $T = 86 + b_1 t$

a_1 546 Coeff. of t 8

$165+460=86+460+(45/3600)b_1 = 86 + 460 + .0125b_1$

b_1 6320.00 Coeff. of t^2 3160

$Q1/UA$ 0.346875

For Cycle Heating:

a_2 588.20 Coeff of t 50.20

Average

Cycle Time, hr 0.0031

Average

Peak Temp, R 623.40

Average

Floor Temp, R 588.20

b_2 11314.28571 Coeff of t^2 5657.143

$Q2/UA$ 0.917778

For Initial part of cooling:

a_3 589 coeff of t 51

Cycle Time, hr 0.143055556

Peak Temp, R 625

Floor Temp, R 589

b_3 251.6504854 Coeff of t^2 125.8252

$Q3/UA$ 8.583333

For Cycle Cooling:

a_4 588.20 Coeff of t 50.20

Average

Cycle Time, hr 0.0791

Average

Peak Temp, R 623.40

Average

Floor Temp, R 588.20

b_4 539.23 Coeff of t^2 269.617

$Q4/UA$ 19.25716

U for heating and cooling cycles 3.159695

Case 1b: Temp-Coat Insulation with Lower Temperature Setting

Total Heat Input, BTU

68.3

For initial part of heating:

$$T = a_1 + b_1 t$$

Therefore, $84+460 = a$ and $T = 84 + bt$

a_1	544	Coeff of t	6
$196+460=84+460+0.0097b_1$			
b_1	11546.39	Coeff of t^2	5773.196

$Q1/UA$ 0.331179

For Cycle Heating:

a_2	584.57	Coeff of t	46.57
Average			
Cycle Time, hr	0.0024		
Average			
Peak Temp, R	606.57		
Average			
Floor Temp, R	584.57		
b_2	9240	Coeff of t^2	4620

$Q2/UA$ 0.867857

For Initial part of cooling:

a_3	587	coeff of t	49
Cycle Time, hr	0.101389		
Peak Temp, R	656		
Floor Temp, R	587		
b_3	680.5479	Coeff of t^2	340.274

$Q3/UA$ 6.717014

For Cycle Cooling:

a_4	584.57	Coeff of t	46.57
Average			
Cycle Time, hr	0.0583		
Average			
Peak Temp, R	606.57		
Average			
Floor Temp, R	584.57		
b_4	413.73	Coeff of t^2	206.8657

$Q4/UA$ 21.4667

U for heating and cooling cycles 3.058042

Case 2a: Fiber Glass Insulation With Higher Temperature Setting 1

Total Heat Input, BTU 66.023

For initial part of heating: $T = a_1 + b_1 t$

Therefore, $86+460 = a_1$ and $T = 86+460 + b_1 t$

For Cycle Heating:

a_2	663.14	Coeff of t	125.14
Average			
Cycle Time, hr	0.002937		
Average			
Peak Temp, R	682.71		
Average			
Floor Temp, R	663.14		
b_2	6664.865	Coeff of t^2	3332.432

Q2/UA	2.672956
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For Initial Part of Cooling:

a_3	671	coeff of t	133
Time, hr	0.0475		
Peak Temp, R	762		
Floor Temp, R	671		
b_3	1915.789	Coeff of t^2	957.8947

Q3/UA	7.398125
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For Cycle Cooling:

a_4	663.14	Coeff of t	125.14
Average			
Cycle Time, hr	0.0236		
Average			
Peak Temp, R	682.71		
Average			
Floor Temp, R	663.14		
b_4	908.29	Coeff of t^2	454.1436

Q4/UA	18.47905
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U for heating & cooling Cycles	3.982444
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Case 3a: Fiber Glass Insulation With Higher Temperature Setting 2

Total Heat Input BTU	84.23667
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For initial part of heating: $T = a_1 + b_1 t$

Therefore, $82+460 = a_1$ and $T = 82+460 + b_1 t$

a_1	542	Coeff of t	4
$324+460=82+460+((1*60+15)/3600)*b_1$	$546 + .02083b_1$		
b_1	11617.86	Coeff of t^2	5808.929

Q1/UA	1.343952
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For Cycle Heating:

a_2	682.86	Coeff of t	144.86
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Average
 Cycle Time, hr 0.0029
 Average
 Peak Temp, R 709.00
 Average
 Floor Temp, R **682.86**
b₂ **8902.703** Coeff of t² 4451.351

Q2/UA 2.222832

For Initial part of cooling:

a₃ 694 coeff of t 156
 Cycle Time, hr 0.034722
 Peak Temp, R 784
 Floor Temp, R 694
b₃ 2592 Coeff of t² 1296

Q3/UA 6.197917

For Cycle Cooling:

a₄ **682.86** Coeff of t 144.86
 Average
 Cycle Time, hr 0.0248 0.0273
 Average
 Peak Temp, R 709.00
 Average
 Floor Temp, R **682.86**
b₄ **1052.40** Coeff of t² 526.1981

Q4/UA 24.90411

U for heating & cooling Cycles 3.105277

Case 3b: Temp-Coat Insulation With Higher Temperature Setting 2

Total Heat Input BTU 96.75833

For Initial Part of Heating: $T = a_1 + b_1 t$

Therefore, $81+460 = a_1$ and $T = 81+460+ b_1 t$

a₁ 541 Coeff of t 3
 $-.272+460=81+460+(1*60+30)/3600)b_1 = 541+ 0.025b_1$
b₁ 7640.00 Coeff of t² 3820

Q1/UA 1.26875

For Cycle Heating:

a₂ **674.38** Coeff of t 136.38
 Average
 Cycle Time, hr 0.002951
 Average
 Peak Temp, R 692.25
 Average

Floor Temp, R	674.38		
b_2	6056.471	Coeff of t^2	3028.235

Q2/UA	3.325477
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For Initial Part of Cooling:

a_3	687	coeff of t	149
Time, hr	0.023611		
Peak Temp, R	732		
Floor Temp, R	687		
b_3	1905.882	Coeff of t^2	952.9412

Q3/UA	3.783681
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For Cycle Cooling:

a_4	674.38	Coeff of t	136.38
Average			
Cycle Time, hr	0.0229		
Average			
Peak Temp, R	692.25		
Average			
Floor Temp, R	674.38		

b_4	804.38	Coeff of t^2	402.1875
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Q4/UA	25.82754
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U for cycle heating & cooling	3.318981
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Appendix B

During the heating cycle at a fixed temperature setting:

The actual time when the heat cut off was noted, however, the temperature at that instant was not noted.

In addition, at what time the temperature attended the pick is also not available
Duration of each heating cycle was noted

Temperature at which heat came on is known and the duration the heater was on is known.

Basic Heat Transfer Equation:

$$dQ/dt = UA \Delta T \text{ or } \int dQ = Q_{Total} = UA \int \Delta T dt, \text{ where, } \Delta T = T - T_{ambient}$$

Where, Q is the heat energy transferred at a given time t, T is the temperature in absolute scale at time t, U is the overall heat transfer coefficient and A is the heat transfer area normal to the direction of heat flow

In absence of any additional temperature data at intermediate points during heating and/or cooling cycles, for this analysis it is assumed that Temperature, T is a linear function of time, t during heating as well as during cooling part of the cycle.

Total heating part can be divided in to two parts: 1) initial heating, which is relatively of longer time duration plus 2) a series of heating cycle with an average cycle duration.

$$\text{Total } Q = Q_{Total} = Q_{\text{initial heating}} + Q_{\text{cycle heating}} + Q_{\text{initial cooling}} + Q_{\text{cycle cooling}}$$

$$Q_{Total} = \int dQ = UA \{ \int (T - T_{ambient}) dt \}_{\text{initial heating}} + \int (T - T_{ambient}) dt \}_{\text{cycle heating}} \\ + \int (T - T_{ambient}) dt \}_{\text{initial cooling}} + \int (T - T_{ambient}) dt \}_{\text{cycle cooling}} \}$$

$$Q_{Total} = UA \{ \int (a_1 + b_1 t - 538) dt + \int (a_2 + b_2 t - 538) dt + \int (a_3 + b_3 t - 538) dt + \int (a_4 + b_4 t - 538) dt \}$$

$$Q_{Total} = UA \{ (a_1 t + b_1 t^2 / 2 - 538 t) + (a_2 t + b_2 t^2 / 2 - 538 t) + (a_3 t + b_3 t^2 / 2 - 538 t) + (a_4 t + b_4 t^2 / 2 - 538 t) \}$$

$T_{ambient}$ is assumed to be 78 °F

Case 1: Temp-Coat Insulation with Lower Temperature Setting

For Initial Part of Heating:

$$T = a_1 + b_1 t$$

$$\text{Therefore, } 84 + 460 = a \text{ and } T = 84 + bt$$

$$a_1 \quad 357 \quad \text{Coeff. of } t \quad 6$$

$$196 + 460 = 84 + 460 + 0.0097b$$

$$b_1 \quad 11546.39 \quad \text{Coeff. of } t^2 \quad 5773.20$$

$$Q_1/UA \quad 0.33$$

For Cycle Heating:

$$a_2 \quad 397.57 \quad \text{Coeff. of } t \quad 46.57$$

$$\text{Average Cycle Time, hr} \quad 0.0024$$

$$\text{Average Peak Temp, } ^\circ\text{R} \quad 606.57$$

$$\text{Average Floor Temp, } ^\circ\text{R} \quad 584.57$$

$$b_2 \quad 9240 \quad \text{Coeff. of } t^2 \quad 4620$$

$$Q_2/UA \quad 0.87$$

For Initial part of cooling:

$$a_3 \quad 400 \quad \text{Coeff. of } t \quad 49$$

$$\text{Cycle Time, hr} \quad 0.101389$$

$$\text{Peak Temp, } ^\circ\text{R} \quad 656$$

$$\text{Floor Temp, } ^\circ\text{R} \quad 587$$

$$b_3 \quad 680.5479 \quad \text{Coeff. of } t^2 \quad 340.27$$

$$Q_3/UA \quad 6.72$$

For Cycle Cooling:

a₄	397.57	Coeff. of t	46.57143
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Average Cycle Time, hr	0.0532
Average Peak Temp, °R	606.57
Average Floor Temp, °R	584.57

b₄	413.73	Coeff. of t²	206.87
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Q₄/UA	19.38
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ΣQ/UA	27.30
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U	3.96
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Case 2: Temp-Coat Insulation With Higher Temperature Setting**For Initial Part of Heating:**

$$T = a_1 + b_1 t$$

$$\text{Therefore, } 82+460 = a_1 \text{ and } T = 82+460+ b_1 t$$

a₁	355	Coeff. of t	4
$302+460=82+460+(1*60+26)/3600)b_1 = 542+ 0.0239b_1$			

b₁	9205.02	Coeff. of t²	4602.51
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Q₁/UA	1.41
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For Cycle Heating:

a₂	476.14	Coeff. of t	125.14
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Average Cycle Time, hr	0.002937
Average Peak Temp, °R	682.71
Average Floor Temp, °R	663.14

b_2	6664.865	Coeff. of t^2	3332.43
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Q_2/UA			2.67
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For Initial Part of Cooling:

a_3	484	Coeff. of t	133
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Time, hr	0.0475
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Peak Temp, $^{\circ}R$	762
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Floor Temp, $^{\circ}R$	671
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b_3	1915.789	Coeff. of t^2	957.8947
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Q_3/UA			7.40
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For Cycle Cooling:

a_4	476.14	Coeff. of t	125.14
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Average	
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Cycle Time, hr	0.0215
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Average	
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Peak Temp, $^{\circ}R$	682.71
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Average	
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Floor Temp, $^{\circ}R$	663.14
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b_4	908.29	Coeff. of t^2	454.14
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Q_4/UA			19.61
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$\Sigma(Q/UA)$			31.09
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$U = \Sigma Q/A$			5.86
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Case 3: Fiberglass Insulation with Lower Temperature Setting

For initial part of heating: $T = a_1 + b_1t$

Therefore, $86+460 = a_1$ and $T = 86 + b_1t$

a_1	359	Coeff. of t	8
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1

$65+273=86+460+(45/3600)b_1 = 86 + 460 + .0125b_1$

b_1	6320.00	Coeff. of t^2	3160
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Q_1/UA 0.35

For Cycle Heating:

a_2 401.20 Coeff. of t 50.2

Average
Cycle Time, hr 0.0031

Average
Peak Temp, $^{\circ}R$ 623.40

Average
Floor Temp, $^{\circ}R$ 588.20

b_2 11314.28571 Coeff. of t^2 5657.143

Q_2/UA 0.92

For Initial part of cooling:

a_3 402 Coeff. of t 51

Cycle Time, hr 0.143055556

Peak Temp, $^{\circ}R$ 625

Floor Temp, $^{\circ}R$ 589

b_3 251.651 Coeff. of t^2 125.83

Q_3/UA 8.58

For Cycle Cooling:

a_4 401.20 Coeff. of t 50.2

Average
Cycle Time, hr 0.0653

Average
Peak Temp, $^{\circ}R$ 623.40

Average
Floor Temp, $^{\circ}R$ 588.20

b_4 539.23 Coeff. of t^2 269.62

Q_4/UA 27

$\Sigma(Q/UA)$ 36.81

$$U = \sum Q/A$$

3.42

Case 4: Fiberglass Insulation with Higher Temperature Setting

For initial part of heating:

$$T = a_1 + b_1 t$$

$$\text{Therefore, } 86+460 = a_1 \text{ and } T = 86+460 + b_1 t$$

$$a_1 \quad 359 \quad \text{Coeff. of } t \quad 8$$

$$329+460=86+460+((1*60+20)/3600)*b_1 = 546 + .0222b_1$$

$$b_1 \quad 10945.95 \quad \text{Coeff. of } t^2 \quad 5472.973$$

$$Q_1/UA \quad 1.53$$

For Cycle Heating:

$$a_2 \quad 480.40 \quad \text{Coeff. of } t \quad 129.4$$

$$\begin{array}{ll} \text{Average} & \\ \text{Cycle Time, hr} & 0.0032 \end{array}$$

$$\begin{array}{ll} \text{Average} & \\ \text{Peak Temp, } ^\circ\text{R} & 696.40 \end{array}$$

$$\begin{array}{ll} \text{Average} & \\ \text{Floor Temp, } ^\circ\text{R} & 667.40 \end{array}$$

$$b_2 \quad 9000 \quad \text{Coeff. of } t^2 \quad 4500$$

$$Q_2/UA \quad 2.20$$

For Initial part of cooling:

$$a_3 \quad 485 \quad \text{Coeff. of } t \quad 134$$

$$\text{Cycle Time, hr } 0.065278$$

$$\text{Peak Temp, } ^\circ\text{R} \quad 789$$

$$\text{Floor Temp, } ^\circ\text{R} \quad 672$$

$$b_3 \quad 1792.34 \quad \text{Coeff. of } t^2 \quad 896.1702$$

$$Q_3/UA \quad 10.66$$

a₄ **480.40** **Coeff. of t 129.4**

Average Peak Temp, °R	696.40
Average Floor Temp, °R	667.40

Q₄/UA	20.00
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U 4.57