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Thermal Analysis Supporting the Design of the Avery Island Field Experiments

R. A. Just

OPERATED BY
UNION CARBIDE CORPORATION
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UCC-ND Engineering

THERMAL ANALYSIS SUPPORTING THE DESIGN OF THE
AVERY ISLAND FIELD EXPERIMENTS

R. A. Just

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Oak Ridge, Tennessee 37830
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In 1978 W. A. Burnett assumed responsibility for coordinating the thermal analysis effort of the Avery Island experiments for the Office of Waste Isolation until this responsibility was assumed by the Office of Nuclear Waste Isolation of the Battelle Memorial Institute.

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ABSTRACT

This report documents the thermal analysis that was performed in support of the design effort of the three Avery Island field tests. The Avery Island experiments use simulated waste canisters to generate quantitative data to validate analytical predictions that use laboratory-measured properties and numerical models to simulate effects in the field. Results from the field tests will include the determination of the thermal conductivity of a field salt formation, temperatures and temperature gradients in the adjacent salt formation, and room and canister-hole deformations. This report furnishes the necessary documentation to compare these *a priori* calculations with experimental results from the Avery Island field tests, as well as time-temperature histories at selected points of interest.

1. INTRODUCTION

A primary objective of the Avery Island field tests, using simulated waste canisters, is the generation of quantitative data to validate analytical predictions that use laboratory-measured properties and numerical models to simulate effects in the field. Results from the field tests will include the determination of the thermal conductivity of an in-situ salt formation, temperatures and temperature gradients in the adjacent salt formation, and room and canister-hole deformations. The purpose of this report is to document the thermal analysis of the three field experiments at Avery Island. Calculations were completed before the experiments began, but they were only reported in internal correspondence, which is not usable for reference. This report furnishes the necessary documentation to compare *a priori* calculations with experimental results from the Avery Island field tests.¹⁻⁴

2. AVERY ISLAND TEST SITE

The Avery Island Salt Dome is located 10 miles south-southwest of New Iberia, Louisiana. Avery Island is the second of the "Five Islands" that form a chain across the southern part of Louisiana. The salt dome is predominantly composed of rock salt; the rock salt is mainly composed of halite with some impurities of anhydrite, dolomite, calcite, pyrite, quartz, limonite, hauerite, sulfur, hematite, and kaolinite. The location (with respect to the supporting pillars) of the three test sites on the 550-ft level at the Avery Island Mine is shown schematically in Fig. 1. The three test sites are labeled A, B, and C.

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Fig. 1. Avery Island field salt mine experiment plot plan at 550-ft mine level.

3. EXPERIMENTAL CONFIGURATION

A typical schematic representation of a field test installation is shown in Fig. 2. The basic specifications for the three Avery Island installations include a central electric heater assembly 8 ft long and surrounded by a steel pipe (sleeve). The sleeve extends from the mine floor to a depth of approximately 18 ft. The annulus between the wall of the hole and the sleeve is either backfilled with crushed salt or

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Fig. 2. Schematic of field test installation at site A.

left open (filled with air). The collection drum assumed in the thermal analysis, as shown in Fig. 2, was replaced by a gasket in the actual experiments.

The three field tests, one of which is a unit-cell experiment, differed in the type of backfill used, the power supplied to the peripheral heaters (for the case including heaters), the power supplied to the calrod heaters inside the aluminum cylinder, and the size of the carbon steel sleeve. The central electric heaters will be operated at constant power levels of 6 kW at site A, 3 kW at site B, and 4 kW at site C. The peripheral heaters for the unit-cell experiment are to be operated in a manner that will simulate the adiabatic boundary of a "unit cell."

4. THERMAL MODEL

A large system of nonlinear partial-differential equations must be solved in order to calculate the transient-temperature distributions resulting from the placement of a heat source in a medium in which the thermal diffusivity is temperature dependent. HEATING5, a general-purpose, finite-difference, heat transfer code,⁵ was chosen to perform the thermal calculations.

HEATING5 is designed to solve steady-state and transient heat conduction problems with temperature- and spatially-dependent thermal properties as well as time-dependent heat-generation rates. Boundary conditions may be specified as adiabatic, forced convection, natural convection, radiation, isothermal, or constant heat flux. Various explicit and implicit techniques are available for solving transient heat conduction problems. HEATING5 is designed to solve a transient problem by numerical schemes that include the Classical Explicit Procedure, Levy's modification to the Classical Explicit Procedure, the Crank-Nicholson technique, and the Classical Implicit Procedure. Economic considerations led to the choice of the Classical Implicit Procedure to perform the thermal analysis.

HEATING5 was chosen for calculating temperature distributions for the three experiments because of its flexibility, wide use and acceptance for thermal analysis, and the author's extensive experience using the code.

The thermal models used in the analysis of the field experiments are shown in Figs. 3-5. Each thermal model was divided into regions that had the thermal properties of the various materials. The finite-difference nodal mesh formed within the HEATING5 code resulted in a total of approximately 750 nodes for each of the three models. The initial temperature of the system is the ambient temperature 70°F. An effective heat transfer coefficient (which includes radiation, free, and forced convection), $H_{eff} = 1.0 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$, was used to model the heat transferred from the floor of the salt mine to the ambient environment. The thermal properties used in the analysis are tabulated in Table 1.

Fig. 3. Crushed-salt backfill with 4-kW source.

It should be noted that in the analysis, the thermal conductivities of salt, stainless steel, carbon steel, and air are temperature dependent. The calrod heaters implanted inside the aluminum cylinder, region 6 (see Figs. 3-5), are modeled as a uniform aluminum body, with the simulated decay heat evenly distributed throughout. The surface enclosed by the bellows assembly was modeled as adiabatic. This will cause the calculated temperatures on the interior of this surface to be somewhat higher

Fig. 4. Air backfill with 6-kW source.

than actual. The temperature of the section of the assembly above ground level will be between the maximum sleeve temperature at ground level, 108°F, and the atmospheric temperature, 70°F. A surface emissivity of 0.6 was used for all radiating surfaces.

In modeling the unit-cell experiment at site C (see Fig. 3), with a salt backfill, an adiabatic boundary was imposed at a radius of

Fig. 5. Air backfill with 3-kW source.

10.8 ft. The 4 kW generated by the calrod heaters was modeled as a uniformly distributed volumetric heat source. An adiabatic surface at 200 ft below grade was used to model the infinite depth of the salt.

The second and third experiments at sites A and B, with air as the backfill material (as shown in Figs. 4 and 5), will not be unit-cell experiments; that is, there will be no peripheral heaters activated.

Table 1. Material properties used in thermal analysis

Material	Temperature (°F)	Thermal conductivity (Btu hr-ft ⁻² -°F)	Density (lb ft ⁻³)	Heat capacity (Btu lb ⁻¹ -°F)
Salt*	32	2.53	135	0.22
	122	2.90		
	212	2.43		
	302	2.08		
	392	1.80		
	482	1.60		
	572	1.44		
	662	1.23		
	752	1.20		
Crushed salt*		0.20	98	0.21
Sand*		0.19	99.9	0.18
304L stainless steel	32	8.49	494	0.120
	80.3	8.78		
	170.3	9.36		
	260.3	9.82		
	350.3	10.2		
	440.3	10.6		
	620.3	11.4		
	800.3	12.2		
	980.3	13.0		
A106 carbon steel	0	30.56	490	0.120
	1000	21.01		
Aluminum		97	168	0.23
Air	100	0.0153	0.071	0.240
	200	0.0174		
	300	0.0193		
	400	0.0212		
	500	0.0231		
	600	0.0250		
	700	0.0268		
	800	0.0286		
	900	0.0303		
	1000	0.0319		
	1500	0.0400		

The thermal properties of salt were obtained from R. D. Cheverton and W. D. Turner, *Thermal Analysis of the National Radioactive Waste Repository: Progress through March 1972*, Oak Ridge National Laboratory, ORNL-4789, September 1972.

The density and specific heat of crushed salt were obtained from ORNL-4789. A thermal conductivity of 0.20 Btu hr-ft⁻²-°F was assumed for the crushed salt.

The thermal properties of sand were obtained from A. E. Edwards, *A Compilation of Thermal Property Data for Computer Heat-Conduction Calculations*, UCRL-50589, Lawrence Radiation Laboratory, Livermore, Calif., 1969. The thermal properties are based on the average properties of dry sand with the specific gravity ranging from 1.36 to 1.84.

The density and specific heat of 304L stainless steel were obtained from Y. S. Touloukian, *Thermophysical Properties of Matter*, III Plenum, 1970.

The thermal conductivity of A106 carbon steel was calculated empirically from a correlation in S. S. Kutateladze et al., *A Concise Encyclopedia of Heat Transfer*, Pergamon Press, 1966.

The properties of the A356.2 cast aluminum are assumed values. In *Standards for Aluminum, Sand, and Permanent Mold Castings*, (Aluminum Association, 1980), the density for A356 is given as 167 lb ft⁻³ and the thermal conductivity is given as varying from 87 to 97 Btu hr-ft⁻²-°F, depending on the temper.

The thermal properties of air were obtained from F. Kreith, *Principles of Heat Transfer*, International Textbook Company, 1965.

The thermal models will simulate an infinite body of salt by using a model extending 200 ft in both the axial and radial directions. The heat sources provided by the calrod heaters were also modeled as uniformly distributed heat sources.

The results of the thermal analysis at all three sites indicate that the calculated temperatures at a point 200 ft from the source remain essentially constant over the two years of simulation. Therefore, an adiabatic surface at 200 ft is a satisfactory approximation of a semi-infinite media.

5. RESULTS

Calculated temperatures at selected points are presented in Tables 2, 3, and 4. It should be noted that these calculated temperature distributions may have an error of $\pm 15-20\%$ (estimated) because of uncertainties in the physical properties, primarily the thermal conductivity of the salt, and uncertainty in the value of the effective heat transfer coefficient that is applied at the floor of the salt mine.

In the analysis described above, an effective heat-transfer coefficient of $1 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ was assumed between the floor of the salt mine and the ambient environment. This overall heat transfer coefficient includes the effects of radiation as well as forced and natural convection. Because of the complex heat transfer phenomena involved, there is a significant level of uncertainty in the estimated overall coefficient. To assess the sensitivity of the heat transfer coefficient on the temperature profile, the thermal analysis at site A was repeated twice, using heat transfer coefficients of $H = 2$ and $4 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$. The calculated temperatures at selected points are shown in Tables 5 and 6.

Table 2. Temperature rise calculated for a 3-kW source with an air backfill (see Fig. 6 for location)

T199 (°F)	T1 (°F)	T2 (°F)	T3 (°F)	T4 (°F)	T5 (°F)	T6 (°F)	T7 (°F)	T8 (°F)	T9 (°F)	T10 (°F)	T11 (°F)	T12 (°F)	T13 (°F)	T14 (°F)	T15 (°F)	T16 (°F)
1	223.	223.	63.	63.	38.	19.1	15.4	10.1	3.7	3.05	0.01	0.01	0.00	0.00	0.00	0.00
2	211.	237.	63.	62.	56.	34.1	29.4	22.1	11.6	3.14	0.05	0.35	0.36	0.33	0.03	0.02
3	216.	244.	93.	72.	66.	42.7	37.6	29.6	17.5	0.30	0.15	0.15	0.13	0.12	0.11	0.09
4	214.	248.	102.	78.	72.	48.4	43.1	34.7	21.9	0.50	0.31	0.31	0.28	0.27	0.25	0.20
5	221.	252.	105.	83.	77.	52.5	47.1	38.5	25.1	0.81	0.52	0.51	0.46	0.45	0.42	0.36
6	222.	254.	109.	87.	80.	55.7	50.2	41.4	27.6	1.11	0.75	0.74	0.69	0.66	0.63	0.54
7	224.	256.	111.	89.	83.	58.2	52.7	43.8	29.8	1.41	0.99	0.97	0.90	0.88	0.84	0.74
8	225.	257.	114.	92.	85.	60.3	54.8	45.8	31.5	1.71	1.23	1.21	1.11	1.11	1.06	0.95
9	225.	259.	116.	94.	87.	62.1	56.5	47.4	33.0	2.00	1.46	1.44	1.36	1.33	1.29	1.15
10	226.	259.	118.	95.	88.	63.6	57.9	48.8	34.3	2.28	1.69	1.67	1.57	1.54	1.49	1.35
11	227.	261.	119.	97.	90.	64.9	59.2	50.6	35.4	2.54	1.91	1.88	1.78	1.75	1.69	1.54
12	227.	262.	120.	98.	91.	66.0	60.3	51.1	36.4	2.79	2.11	2.09	1.97	1.94	1.87	1.72
13	228.	262.	122.	99.	92.	67.0	61.3	52.1	37.3	3.02	2.30	2.29	2.16	2.12	2.05	1.89
14	228.	263.	123.	100.	93.	67.9	62.2	52.9	38.1	3.24	2.48	2.46	2.33	2.29	2.22	2.05
15	229.	264.	124.	101.	94.	68.7	63.0	53.7	38.8	3.44	2.65	2.62	2.49	2.45	2.38	2.20
16	229.	264.	124.	101.	95.	69.4	63.6	54.3	39.4	3.63	2.81	2.78	2.64	2.60	2.52	2.34
17	229.	265.	125.	102.	95.	70.0	64.3	55.0	39.9	3.81	2.95	2.92	2.78	2.74	2.66	2.47
18	229.	265.	126.	103.	96.	70.6	64.8	55.5	40.5	3.97	3.09	3.06	2.91	2.87	2.79	2.59
19	230.	266.	126.	103.	97.	71.1	65.4	56.0	40.9	4.12	3.22	3.18	3.03	2.99	2.91	2.71
20	230.	266.	127.	104.	97.	71.6	65.9	56.5	41.4	4.27	3.34	3.30	3.15	3.11	3.02	2.82
21	231.	266.	127.	104.	98.	72.1	66.3	56.9	41.8	4.40	3.45	3.41	3.26	3.21	3.12	2.92
22	231.	267.	128.	105.	98.	72.5	66.7	57.3	42.2	4.53	3.56	3.52	3.36	3.31	3.22	3.01
23	231.	267.	129.	105.	98.	72.9	67.1	57.7	42.5	4.64	3.65	3.62	3.45	3.41	3.32	3.11
24	231.	267.	129.	106.	99.	73.3	67.4	58.0	42.9	4.75	3.75	3.71	3.54	3.50	3.41	3.19
25	231.	268.	129.	106.	99.	73.6	67.8	58.4	43.2	4.86	3.83	3.79	3.63	3.58	3.49	3.27
26	232.	268.	130.	106.	100.	73.9	68.1	58.6	43.4	4.96	3.92	3.88	3.71	3.66	3.57	3.35
27	232.	268.	130.	107.	100.	74.2	68.4	58.9	43.7	5.05	4.00	3.95	3.78	3.73	3.64	3.42
28	232.	268.	130.	107.	100.	74.5	68.7	59.2	44.0	5.14	4.07	4.03	3.85	3.80	3.71	3.49
29	232.	269.	131.	107.	100.	74.8	68.9	59.5	44.2	5.22	4.14	4.10	3.92	3.87	3.78	3.55
30	232.	269.	131.	108.	101.	75.0	69.2	59.7	44.5	5.30	4.21	4.16	3.99	3.94	3.84	3.62
31	233.	269.	132.	108.	102.	75.1	69.3	60.0	44.6	5.37	4.28	4.23	4.05	4.00	3.91	3.69
32	233.	270.	132.	108.	103.	75.2	69.4	60.1	44.7	5.44	4.34	4.29	4.11	4.06	3.97	3.75
33	233.	270.	133.	109.	103.	75.3	69.5	60.2	44.8	5.50	4.40	4.35	4.17	4.12	4.03	3.81
34	233.	271.	133.	109.	104.	75.4	69.6	60.3	44.9	5.56	4.46	4.41	4.23	4.18	4.09	3.87
35	233.	271.	134.	110.	104.	75.5	69.7	60.4	45.0	5.62	4.52	4.47	4.29	4.24	4.15	3.93
36	233.	272.	135.	110.	105.	75.6	69.8	60.5	45.1	5.68	4.58	4.53	4.35	4.30	4.21	3.99
37	233.	272.	136.	111.	105.	75.7	69.9	60.6	45.2	5.73	4.64	4.59	4.41	4.36	4.27	4.05
38	233.	273.	137.	111.	106.	75.8	70.0	60.7	45.3	5.79	4.70	4.65	4.47	4.42	4.33	4.11
39	233.	273.	137.	111.	107.	75.9	70.1	60.8	45.4	5.84	4.76	4.71	4.53	4.48	4.39	4.17
40	233.	273.	138.	112.	107.	76.0	70.2	60.9	45.5	5.89	4.82	4.77	4.59	4.54	4.45	4.23
41	233.	273.	138.	112.	108.	76.1	70.3	61.0	45.6	5.94	4.88	4.83	4.65	4.60	4.51	4.29
42	233.	274.	139.	113.	108.	76.2	70.4	61.1	45.7	5.99	4.94	4.89	4.71	4.66	4.57	4.35
43	233.	274.	139.	113.	109.	76.3	70.5	61.2	45.8	6.04	5.00	4.95	4.77	4.72	4.63	4.41
44	233.	274.	140.	114.	109.	76.4	70.6	61.3	45.9	6.09	5.06	5.01	4.83	4.78	4.69	4.47
45	233.	275.	140.	114.	110.	76.5	70.7	61.4	46.0	6.14	5.12	5.07	4.89	4.84	4.75	4.53
46	233.	275.	141.	115.	110.	76.6	70.8	61.5	46.1	6.19	5.18	5.13	4.95	4.90	4.81	4.59
47	233.	275.	141.	115.	111.	76.7	70.9	61.6	46.2	6.24	5.24	5.19	4.97	4.92	4.83	4.61
48	233.	276.	142.	116.	111.	76.8	71.0	61.7	46.3	6.29	5.30	5.25	5.01	4.96	4.87	4.65
49	233.	276.	142.	116.	112.	76.9	71.1	61.8	46.4	6.34	5.36	5.31	5.07	5.02	4.93	4.71
50	233.	276.	142.	116.	113.	77.0	71.2	61.9	46.5	6.39	5.42	5.37	5.13	5.08	4.99	4.77
51	233.	277.	143.	117.	113.	77.1	71.3	62.0	46.6	6.44	5.48	5.43	5.19	5.14	5.05	4.83
52	233.	277.	143.	117.	114.	77.2	71.4	62.1	46.7	6.49	5.54	5.49	5.25	5.20	5.11	4.89
53	233.	277.	144.	118.	114.	77.3	71.5	62.2	46.8	6.54	5.60	5.55	5.31	5.26	5.17	4.95
54	233.	278.	144.	118.	115.	77.4	71.6	62.3	46.9	6.59	5.66	5.61	5.37	5.32	5.23	5.01
55	233.	278.	145.	119.	115.	77.5	71.7	62.4	47.0	6.64	5.72	5.67	5.43	5.38	5.29	5.07
56	233.	278.	145.	119.	116.	77.6	71.8	62.5	47.1	6.69	5.78	5.73	5.49	5.44	5.35	5.13
57	233.	279.	146.	120.	116.	77.7	71.9	62.6	47.2	6.74	5.84	5.79	5.55	5.50	5.41	5.19
58	233.	279.	146.	120.	117.	77.8	72.0	62.7	47.3	6.79	5.90	5.85	5.61	5.56	5.47	5.25
59	233.	279.	147.	121.	117.	77.9	72.1	62.8	47.4	6.84	5.96	5.91	5.67	5.62	5.53	5.31
60	233.	280.	147.	121.	118.	78.0	72.2	62.9	47.5	6.89	6.02	5.97	5.73	5.68	5.59	5.37
61	233.	280.	148.	122.	118.	78.1	72.3	63.0	47.6	6.94	6.08	6.03	5.79	5.74	5.65	5.43
62	233.	281.	148.	122.	119.	78.2	72.4	63.1	47.7	6.99	6.14	6.09	5.85	5.80	5.71	5.49
63	233.	281.	149.	123.	119.	78.3	72.5	63.2	47.8	7.04	6.20	6.15	5.91	5.86	5.77	5.55
64	233.	282.	149.	123.	120.	78.4	72.6	63.3	47.9	7.09	6.26	6.21	5.97	5.92	5.83	5.61
65	233.	282.	150.	124.	120.	78.5	72.7	63.4	48.0	7.14	6.32	6.27	6.03	5.98	5.89	5.67
66	233.	283.	150.	124.	121.	78.6	72.8	63.5	48.1	7.19	6.38	6.33	6.09	6.04	5.95	5.73
67	233.	283.	151.	125.	121.	78.7	72.9	63.6	48.2	7.24	6.44	6.39	6.15	6.10	6.01	5.79
68	233.	284.	151.	125.	122.	78.8	73.0	63.7	48.3	7.29	6.50	6.45	6.21	6.16	6.07	5.85
69	233.	284.	152.	126.	122.	78.9	73.1	63.8	48.4	7.34	6.56	6.51	6.27	6.22	6.13	5.91
70	233.	285.	152.	126.	123.	79.0	73.2	63.9	48.5	7.39	6.62	6.57	6.33	6.28	6.19	5.97
71	233.	285.	153.	127.	123.	79.1	73.3	64.0	48.6	7.44	6.68	6.63	6.39	6.34	6.25	6.03
72	233.	286.	153.	127.	124.	79.2	73.4	64.1	48.7	7.49	6.74	6.69	6.45	6.40	6.31	6.09
73	233.	286.	154.	128.	124.	79.3	73.5	64.2	48.8	7.54	6.80	6.75	6.51	6.46	6.37	6.15
74	233.	287.	154.	128.	125.	79.4	73.6	64.3	48.9	7.59	6.86	6.81	6.57	6.52	6.43	6.21
75	233.	287.	155.	129.	125.	79.5	73.7	64.4	49.0	7.64	6.92	6.87	6.63	6.58	6.49	6.27
76	233.	288.	155.	129.	126.	79.6	73.8	64.5	49.1	7.69	6.98	6.93	6.69	6.64	6.55	6.33
77	233.	288.	156.	130.	126.	79.7	73.9	64.6	49.2	7.74	7.04	6.99	6.75	6.70	6.61	6.39
78	233.	289.	156.	130.	127.	79.8	74.0	64.7	49.3	7.79	7.10	7.05	6.81	6.76	6.67	6.45
79	233.	289.	157.	131.	127.	79.9	74.1	64.8	49.4	7.84	7.16	7.11	6.87	6.82	6.73	6.51
80	233.	290.	157.	131.	128.	80.0	74.2	64.9	49.5	7.89	7.22	7.17	6.93	6.88	6.79	6.57
81	233.	290.														

Table 3. Temperature rise calculated for a 4-kW source with a crushed-salt backfill (see Fig. 7 for location)

TIME (HRS)	T1 (°F)	T2 (°F)	T3 (°F)	T4 (°F)	T5 (°F)	T6 (°F)	T7 (°F)	T8 (°F)	T9 (°F)	T10 (°F)	T11 (°F)	T12 (°F)	T13 (°F)	T14 (°F)	T15 (°F)	T16 (°F)
1	448.	353.	95.	64.	56.	27.	22.	16.	5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	478.	395.	129.	95.	85.	51.	44.	32.	17.	8.1	8.0	8.0	8.0	8.0	8.0	8.0
3	505.	412.	166.	111.	101.	66.	56.	44.	25.	12.1	12.1	12.1	12.1	12.1	12.1	12.1
4	522.	423.	157.	121.	111.	73.	64.	51.	32.	15.5	15.5	15.5	15.5	15.5	15.5	15.5
5	549.	431.	165.	129.	119.	79.	70.	57.	36.	18.0	18.0	18.0	18.0	18.0	18.0	18.0
6	600.	437.	171.	136.	123.	86.	75.	61.	42.	1.2	1.2	1.2	1.2	1.2	1.2	1.2
7	603.	441.	176.	138.	127.	87.	75.	65.	43.	1.6	1.3	1.3	1.2	1.2	1.1	1.6
8	636.	445.	179.	142.	131.	91.	82.	68.	46.	2.0	1.6	1.6	1.5	1.5	1.4	1.3
9	638.	448.	183.	145.	136.	93.	84.	70.	48.	2.5	2.0	2.0	1.9	1.8	1.8	1.6
10	640.	451.	186.	148.	136.	96.	87.	73.	50.	2.9	2.4	2.3	2.2	2.2	2.1	1.9
11	611.	454.	188.	150.	139.	98.	89.	75.	52.	3.3	2.7	2.7	2.6	2.5	2.4	2.3
12	613.	456.	191.	152.	141.	100.	91.	77.	54.	3.7	3.1	3.1	2.9	2.9	2.9	2.6
13	616.	459.	193.	154.	143.	102.	92.	78.	56.	4.1	3.4	3.4	3.3	3.2	3.1	2.9
14	616.	460.	195.	156.	145.	104.	94.	80.	57.	4.5	3.8	3.8	3.6	3.6	3.5	3.3
15	617.	462.	197.	158.	147.	105.	96.	81.	59.	4.9	4.2	4.1	3.9	3.9	3.9	3.6
16	618.	464.	199.	160.	148.	107.	98.	83.	60.	5.3	4.5	4.5	4.3	4.2	4.1	3.4
17	619.	465.	200.	161.	150.	108.	99.	84.	61.	5.7	4.9	4.8	4.6	4.6	4.5	4.3
18	620.	467.	202.	163.	151.	110.	100.	86.	63.	6.1	5.2	5.1	4.9	4.9	4.8	4.6
19	621.	468.	204.	164.	153.	111.	102.	87.	64.	6.5	5.5	5.5	5.3	5.2	5.1	4.9
20	622.	470.	205.	166.	154.	112.	103.	88.	65.	6.9	5.8	5.8	5.6	5.5	5.4	5.2
21	623.	471.	207.	167.	156.	114.	104.	89.	66.	7.2	6.2	6.1	5.9	5.8	5.7	5.5
22	626.	473.	208.	169.	157.	115.	106.	91.	67.	7.6	6.5	6.4	6.2	6.1	6.0	5.8
23	625.	474.	209.	170.	158.	116.	107.	92.	68.	7.9	6.8	6.7	6.5	6.4	6.3	6.1
24	626.	476.	211.	171.	160.	117.	109.	93.	70.	8.3	7.1	7.0	6.8	6.7	6.6	6.4
25	627.	477.	212.	173.	161.	118.	110.	94.	71.	8.6	7.4	7.3	7.1	7.0	6.9	6.6
26	628.	478.	214.	174.	162.	119.	111.	95.	72.	9.0	7.7	7.6	7.3	7.3	7.2	6.9
27	628.	479.	215.	175.	163.	121.	111.	96.	73.	9.3	7.9	7.9	7.6	7.5	7.4	7.1
28	629.	481.	216.	176.	164.	122.	112.	97.	74.	9.6	8.2	8.1	7.9	7.8	7.7	7.4
29	630.	482.	217.	177.	166.	123.	113.	98.	75.	9.9	8.5	8.4	8.1	8.1	7.9	7.6
30	631.	483.	219.	178.	167.	124.	114.	99.	76.	10.2	8.8	8.7	8.4	8.3	8.2	7.9
31	635.	489.	224.	184.	172.	129.	119.	104.	80.	11.6	10.0	9.9	9.6	9.5	9.4	9.1
32	640.	496.	231.	191.	179.	135.	125.	110.	86.	13.3	11.5	11.4	11.0	10.9	10.4	10.5
33	644.	502.	238.	197.	185.	140.	131.	115.	91.	14.9	12.8	12.6	12.3	12.2	12.0	11.8
34	648.	508.	244.	202.	190.	144.	136.	120.	95.	16.1	13.9	13.8	13.3	13.3	13.1	12.4
35	652.	513.	250.	208.	195.	149.	140.	124.	100.	17.2	14.9	14.7	14.2	14.2	14.0	13.8
36	656.	519.	255.	212.	200.	155.	145.	129.	104.	18.2	15.8	15.6	15.1	15.1	14.9	14.4
37	659.	521.	263.	217.	204.	159.	149.	133.	107.	19.1	16.6	16.4	15.9	15.8	15.7	15.4
38	662.	528.	268.	221.	208.	163.	152.	136.	111.	20.0	17.3	17.1	16.6	16.5	16.4	16.1
39	665.	532.	268.	225.	212.	166.	156.	140.	114.	20.4	17.8	17.4	17.3	17.2	17.0	16.7
40	668.	536.	272.	229.	216.	170.	159.	143.	117.	21.5	18.6	18.4	17.9	17.8	17.6	17.3
41	671.	543.	276.	233.	220.	173.	163.	146.	120.	22.2	19.2	19.0	18.5	18.4	18.2	17.9
42	673.	543.	280.	236.	221.	176.	166.	149.	123.	22.8	19.8	19.6	19.0	18.9	18.7	18.4
43	676.	547.	283.	239.	224.	179.	169.	152.	126.	23.4	20.3	20.1	19.5	19.4	19.2	18.9
44	678.	550.	287.	242.	229.	182.	172.	155.	128.	24.0	20.8	20.6	20.0	19.9	19.7	19.4
45	680.	553.	290.	245.	232.	184.	175.	157.	131.	24.5	21.2	21.1	20.4	20.3	20.1	19.6
46	682.	556.	293.	248.	235.	187.	178.	160.	133.	25.0	21.7	21.5	20.9	20.8	20.6	20.2
47	684.	559.	296.	251.	238.	189.	179.	162.	135.	25.5	22.1	21.9	21.3	21.1	20.9	20.4
48	686.	561.	299.	253.	240.	192.	181.	164.	138.	26.0	22.5	22.3	21.7	21.5	21.3	21.0
49	688.	564.	301.	255.	243.	194.	183.	166.	140.	26.4	22.9	22.7	22.0	21.9	21.7	21.3
50	690.	567.	304.	258.	245.	196.	185.	168.	142.	26.8	23.2	23.0	22.4	22.2	22.0	21.7
51	692.	569.	306.	261.	247.	198.	187.	170.	143.	27.2	23.6	23.4	22.7	22.6	22.4	22.0
52	694.	571.	309.	263.	249.	200.	190.	172.	145.	27.6	23.9	23.7	23.1	22.9	22.7	22.3
53	696.	574.	310.	271.	254.	203.	197.	185.	147.	28.1	24.3	24.0	23.3	23.1	22.9	22.5
54	698.	576.	312.	274.	257.	205.	200.	188.	149.	28.5	24.7	24.4	23.7	23.5	23.3	22.9
55	700.	578.	314.	277.	259.	207.	202.	190.	151.	28.9	25.1	24.8	24.1	23.9	23.7	23.3
56	702.	580.	316.	279.	261.	209.	204.	192.	153.	29.3	25.5	25.2	24.5	24.3	24.1	23.7
57	704.	582.	318.	281.	263.	211.	206.	194.	155.	29.7	25.9	25.6	24.9	24.7	24.5	24.1
58	706.	584.	320.	283.	265.	213.	208.	196.	157.	30.1	26.3	26.0	25.3	25.1	24.9	24.5
59	708.	586.	322.	285.	267.	215.	210.	198.	159.	30.5	26.7	26.4	25.7	25.5	25.3	24.9
60	710.	588.	324.	287.	269.	217.	212.	200.	161.	30.9	27.1	26.8	26.1	25.9	25.7	25.3
61	712.	590.	326.	289.	271.	219.	214.	202.	163.	31.3	27.5	27.2	26.5	26.3	26.1	25.7
62	714.	592.	328.	291.	273.	221.	216.	204.	165.	31.7	27.9	27.6	26.9	26.7	26.5	26.1
63	716.	594.	330.	293.	275.	223.	218.	206.	167.	32.1	28.3	28.0	27.3	27.1	26.9	26.5
64	718.	596.	332.	295.	277.	225.	220.	208.	169.	32.5	28.7	28.4	27.7	27.5	27.3	26.9
65	720.	598.	334.	297.	279.	227.	222.	210.	171.	32.9	29.1	28.8	28.1	27.9	27.7	27.3
66	722.	600.	336.	299.	281.	229.	224.	212.	173.	33.3	29.5	29.2	28.5	28.3	28.1	27.7
67	724.	602.	338.	301.	283.	231.	226.	214.	175.	33.7	29.9	29.6	28.9	28.7	28.5	28.1
68	726.	604.	340.	303.	285.	233.	228.	216.	177.	34.1	30.3	30.0	29.3	29.1	28.9	28.5
69	728.	606.	342.	305.	287.	235.	230.	218.	179.	34.5	30.7	30.4	29.7	29.5	29.3	28.9
70	730.	608.	344.	307.	289.	237.	232.	220.	181.	34.9	31.1	30.8	30.1	29.9	29.7	29.3
71	732.	610.	346.	309.	291.	239.	234.	222.	183.	35.3	31.5	31.2	30.5	30.3	30.1	29.7
72	734.	612.	348.	311.	293.	241.	236.	224.	185.	35.7	31.9	31.6	30.9	30.7	30.5	29.9
73	736.	614.	350.	313.	295.	243.	238.	226.	187.	36.1	32.3	32.0	31.3	31.1	30.9	30.5
74	738.	616.	352.	315.	297.	245.	240.	228.	189.	36.5	32.7	32.4	31.7	31.5	31.3	30.9
75	740.	618.	354.	317.	299.	247.	242.	230.	191.	36.9	33.1	32.8	32.1	31.9	31.7	31.3
76	742.	620.	356.	319.	301.	249.	244.	232.	193.	37.3	33.5	33.2	32.5	32.3	32.1	31.7
77	744.	622.	358.	321.	303.	251.	246.	234.	195.	37.7	33.9	33.6	32.9	32.7	32.5	32.1
78	746.	624.	360.	323.	305.	253.	248.	236.	197.	38.1	34.3	34.0	33.3	33.1	32.9	32.5
79	748.	626.	362.	325.	307.	255.	250.	238.	199.	38.5	34.7	34.4	33.7	33.5	33.3	32.9
80	750.	628.	364.	327.	309.	257.	252.	240.	201.	38.9	35.1	34.8	34.1	33.9	33.7	33.3
81	752.	630.	366.	329.	311.	259.	254.	242.	203.	39.3	35.5	35.2	34.5	34.3	34.1	33.7
82	754.	632.	368.	331.	313.	261.	256.	244.	205.	39.7	35.9	35.6	34.9	34.7	34.5	34.1
83	756.	634.	370.	333.	315.	263.	258.	246.	207.	40.1	36.3	36.0	35.3	35.1	34.9	34.5
84	758.	636.	372.	335.	317.	265.	260.	248.	209.	40.5	36.7	36.4	35.7	35.5	35.3	34.9
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Table 4. Temperature rise calculated for a 6-kW source with an air backfill with $H = 1 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ (see Fig. 8 for location)

Time (days)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
1	653.	612.	557.	511.	481.	452.	428.	408.	392.	379.	369.	361.	354.	348.	343.	338.	334.	330.	327.	325.
2	464.	436.	397.	356.	328.	303.	282.	264.	249.	236.	226.	218.	211.	205.	200.	195.	191.	187.	184.	182.
3	473.	445.	406.	365.	337.	312.	290.	271.	255.	242.	231.	222.	214.	207.	201.	196.	192.	188.	185.	183.
4	474.	446.	407.	366.	338.	313.	291.	272.	256.	243.	232.	223.	215.	208.	202.	197.	193.	189.	186.	184.
5	482.	454.	415.	374.	346.	321.	299.	280.	264.	251.	240.	231.	223.	216.	210.	205.	201.	197.	194.	192.
6	485.	457.	418.	377.	349.	324.	302.	283.	267.	254.	243.	234.	226.	219.	213.	208.	204.	200.	197.	195.
7	488.	460.	421.	380.	352.	327.	305.	286.	270.	257.	246.	237.	229.	222.	216.	211.	207.	203.	199.	197.
8	493.	465.	426.	385.	357.	332.	310.	291.	275.	262.	251.	242.	234.	227.	221.	216.	212.	208.	205.	203.
9	495.	467.	428.	387.	359.	334.	312.	293.	277.	264.	253.	244.	236.	229.	223.	218.	214.	210.	207.	205.
10	497.	469.	430.	389.	361.	336.	314.	295.	279.	266.	255.	246.	238.	231.	225.	220.	216.	212.	209.	207.
11	499.	471.	432.	391.	363.	338.	316.	297.	281.	268.	257.	248.	240.	233.	227.	222.	218.	214.	211.	209.
12	500.	472.	433.	392.	364.	339.	317.	298.	282.	269.	258.	249.	241.	234.	228.	223.	219.	215.	212.	210.
13	501.	473.	434.	393.	365.	340.	318.	300.	284.	271.	260.	251.	243.	236.	230.	225.	221.	217.	214.	212.
14	502.	474.	435.	394.	366.	341.	319.	301.	285.	272.	261.	252.	244.	237.	231.	226.	222.	218.	215.	213.
15	503.	475.	436.	395.	367.	342.	320.	302.	286.	273.	262.	253.	245.	238.	232.	227.	223.	219.	216.	214.
16	504.	476.	437.	396.	368.	343.	321.	303.	287.	274.	263.	254.	246.	239.	233.	228.	224.	220.	217.	215.
17	505.	477.	438.	397.	369.	344.	322.	304.	288.	275.	264.	255.	247.	240.	234.	229.	225.	221.	218.	216.
18	506.	478.	439.	398.	370.	345.	323.	305.	289.	276.	265.	256.	248.	241.	235.	230.	226.	222.	219.	217.
19	507.	479.	440.	399.	371.	346.	324.	306.	290.	277.	266.	257.	249.	242.	236.	231.	227.	223.	220.	218.
20	508.	480.	441.	400.	372.	347.	325.	307.	291.	278.	267.	258.	250.	243.	237.	232.	228.	224.	221.	219.
21	509.	481.	442.	401.	373.	348.	326.	308.	292.	279.	268.	259.	251.	244.	238.	233.	229.	225.	222.	220.
22	510.	482.	443.	402.	374.	349.	327.	309.	293.	280.	269.	260.	252.	245.	239.	234.	230.	226.	223.	221.
23	511.	483.	444.	403.	375.	350.	328.	310.	294.	281.	270.	261.	253.	246.	240.	235.	231.	227.	224.	222.
24	512.	484.	445.	404.	376.	351.	329.	311.	295.	282.	271.	262.	254.	247.	241.	236.	232.	228.	225.	223.
25	513.	485.	446.	405.	377.	352.	330.	312.	296.	283.	272.	263.	255.	248.	242.	237.	233.	229.	226.	224.
26	514.	486.	447.	406.	378.	353.	331.	313.	297.	284.	273.	264.	256.	249.	243.	238.	234.	230.	227.	225.
27	515.	487.	448.	407.	379.	354.	332.	314.	298.	285.	274.	265.	257.	250.	244.	239.	235.	231.	228.	226.
28	516.	488.	449.	408.	380.	355.	333.	315.	299.	286.	275.	266.	258.	251.	245.	240.	236.	232.	229.	227.
29	517.	489.	450.	409.	381.	356.	334.	316.	300.	287.	276.	267.	259.	252.	246.	241.	237.	233.	230.	228.
30	518.	490.	451.	410.	382.	357.	335.	317.	301.	288.	277.	268.	260.	253.	247.	242.	238.	234.	231.	229.
31	519.	491.	452.	411.	383.	358.	336.	318.	302.	289.	278.	269.	261.	254.	248.	243.	239.	235.	232.	230.
32	520.	492.	453.	412.	384.	359.	337.	319.	303.	290.	279.	270.	262.	255.	249.	244.	240.	236.	233.	231.
33	521.	493.	454.	413.	385.	360.	338.	320.	304.	291.	280.	271.	263.	256.	250.	245.	241.	237.	234.	232.
34	522.	494.	455.	414.	386.	361.	339.	321.	305.	292.	281.	272.	264.	257.	251.	246.	242.	238.	235.	233.
35	523.	495.	456.	415.	387.	362.	340.	322.	306.	293.	282.	273.	265.	258.	252.	247.	243.	239.	236.	234.
36	524.	496.	457.	416.	388.	363.	341.	323.	307.	294.	283.	274.	266.	259.	253.	248.	244.	240.	237.	235.
37	525.	497.	458.	417.	389.	364.	342.	324.	308.	295.	284.	275.	267.	260.	254.	249.	245.	241.	238.	236.
38	526.	498.	459.	418.	390.	365.	343.	325.	309.	296.	285.	276.	268.	261.	255.	250.	246.	242.	239.	237.
39	527.	499.	460.	419.	391.	366.	344.	326.	310.	297.	286.	277.	269.	262.	256.	251.	247.	243.	240.	238.
40	528.	500.	461.	420.	392.	367.	345.	327.	311.	298.	287.	278.	270.	263.	257.	252.	248.	244.	241.	239.
41	529.	501.	462.	421.	393.	368.	346.	328.	312.	299.	288.	279.	271.	264.	258.	253.	249.	245.	242.	240.
42	530.	502.	463.	422.	394.	369.	347.	329.	313.	300.	289.	280.	272.	265.	259.	254.	250.	246.	243.	241.
43	531.	503.	464.	423.	395.	370.	348.	330.	314.	301.	290.	281.	273.	266.	260.	255.	251.	247.	244.	242.
44	532.	504.	465.	424.	396.	371.	349.	331.	315.	302.	291.	282.	274.	267.	261.	256.	252.	248.	245.	243.
45	533.	505.	466.	425.	397.	372.	350.	332.	316.	303.	292.	283.	275.	268.	262.	257.	253.	249.	246.	244.
46	534.	506.	467.	426.	398.	373.	351.	333.	317.	304.	293.	284.	276.	269.	263.	258.	254.	250.	247.	245.
47	535.	507.	468.	427.	399.	374.	352.	334.	318.	305.	294.	285.	277.	270.	264.	259.	255.	251.	248.	246.
48	536.	508.	469.	428.	400.	375.	353.	335.	319.	306.	295.	286.	278.	271.	265.	260.	256.	252.	249.	247.
49	537.	509.	470.	429.	401.	376.	354.	336.	320.	307.	296.	287.	279.	272.	266.	261.	257.	253.	250.	248.
50	538.	510.	471.	430.	402.	377.	355.	337.	321.	308.	297.	288.	280.	273.	267.	262.	258.	254.	251.	249.
51	539.	511.	472.	431.	403.	378.	356.	338.	322.	309.	298.	289.	281.	274.	268.	263.	259.	255.	252.	250.
52	540.	512.	473.	432.	404.	379.	357.	339.	323.	310.	299.	290.	282.	275.	269.	264.	260.	256.	253.	251.
53	541.	513.	474.	433.	405.	380.	358.	340.	324.	311.	300.	291.	283.	276.	270.	265.	261.	257.	254.	252.
54	542.	514.	475.	434.	406.	381.	359.	341.	325.	312.	301.	292.	284.	277.	271.	266.	262.	258.	255.	253.
55	543.	515.	476.	435.	407.	382.	360.	342.	326.	313.	302.	293.	285.	278.	272.	267.	263.	259.	256.	254.
56	544.	516.	477.	436.	408.	383.	361.	343.	327.	314.	303.	294.	286.	279.	273.	268.	264.	260.	257.	255.
57	545.	517.	478.	437.	409.	384.	362.	344.	328.	315.	304.	295.	287.	280.	274.	269.	265.	261.	258.	256.
58	546.	518.	479.	438.	410.	385.	363.	345.	329.	316.	305.	296.	288.	281.	275.	270.	266.	262.	259.	257.
59	547.	519.	480.	439.	411.	386.	364.	346.	330.	317.	306.	297.	289.	282.	276.	271.	267.	263.	260.	258.
60	548.	520.	481.	440.	412.	387.	365.	347.	331.	318.	307.	298.	290.	283.	277.	272.	268.	264.	261.	259.
61	549.	521.	482.	441.	413.	388.	366.	348.	332.	319.	308.	299.	291.	284.	278.	273.	269.	265.	262.	260.
62	550.	522.	483.	442.	414.	389.	367.	349.	333.	320.	309.	300.	292.	285.	279.	274.	270.	266.	263.	261.
63	551.	523.	484.	443.	415.	390.	368.	350.	334.	321.	310.	301.	293.	286.	280.	275.	271.	267.	264.	262.
64	552.	524.	485.	444.	416.	391.	369.	351.	335.	322.	311.	302.	294.	287.	281.	276.	272.	268.	265.	263.
65	553.	525.	486.	445.	417.	392.	370.	352.	336.	323.	312.	303.	295.	288.	282.	277.	273.	269.	266.	264.
66	554.	526.	487.	446.	418.	393.	371.	353.	337.	324.	313.	304.	296.	289.	283.	278.	274.	270.	267.	265.
67	555.	527.	488.	447.	419.	394.	372.	354.	338.	325.	314.	305.	297.	290.	284.	279.	275.	271.	268.	266.
68	556.	528.	489.	448.	420.	395.	373.	355.	339.	326.	315.	306.	298.	291.	285.	280.	276.	272.	269.	267.
69	557.	529.	490.	449.	421.	396.	374.	356.	340.	327.	316.	307.	299.	292.	286.	281.	277.	273.	270.	268.
70	558.	530.	491.	450.	422.	397.	375.	357.	341.	328.	317.	308.	300.	293.	287.	282.	278.	274.	271.	269.

Table 5. Temperature rise calculated for a 6-kW source with an air backfill with $H = 2 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ (see Fig. 8 for location)

TIME (HRS)	T1 (OF)	T2 (OF)	T3 (OF)	T4 (OF)	T5 (OF)	T6 (OF)	T7 (OF)	T8 (OF)	T9 (OF)	T10 (OF)	T11 (OF)	T12 (OF)	T13 (OF)	T14 (OF)	T15 (OF)	T16 (OF)	T17 (OF)	T18 (OF)	T19 (OF)	T20 (OF)
1	652.	652.	157.	111.	83.	62.	38.	25.	9.	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	666.	656.	207.	156.	124.	99.	76.	52.	26.	6.9	0.0	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0
3	673.	659.	230.	181.	147.	120.	101.	89.	39.	13.6	0.1	1.9	0.4	0.3	0.3	0.3	0.2	0.2	0.1	0.0
4	678.	659.	232.	187.	152.	135.	101.	90.	49.	19.3	0.3	2.9	0.6	0.6	0.5	0.5	0.4	0.3	0.2	0.0
5	682.	664.	245.	209.	173.	145.	110.	99.	55.	26.1	0.5	2.5	1.0	0.8	0.8	0.8	0.7	0.6	0.5	0.0
6	685.	671.	275.	210.	181.	153.	123.	107.	61.	28.1	0.8	3.1	1.3	1.2	1.2	1.1	1.0	0.9	0.8	0.0
7	697.	675.	283.	225.	189.	159.	129.	106.	66.	31.6	1.2	3.7	1.7	1.6	1.5	1.4	1.3	1.1	1.0	0.0
8	698.	679.	289.	231.	193.	164.	129.	106.	70.	34.6	1.6	4.2	2.0	1.9	1.8	1.7	1.6	1.4	1.1	0.0
9	691.	682.	295.	236.	198.	169.	132.	109.	73.	37.1	2.1	4.8	2.3	2.2	2.1	2.0	1.9	1.7	1.3	0.0
10	693.	685.	299.	240.	202.	173.	136.	113.	76.	39.4	2.5	5.3	2.7	2.6	2.5	2.3	2.2	2.0	1.5	0.0
11	694.	687.	303.	244.	206.	176.	139.	115.	78.	41.5	3.0	5.8	3.0	2.9	2.8	2.7	2.5	2.2	1.7	0.0
12	695.	689.	307.	247.	209.	179.	142.	118.	80.	43.3	3.5	6.3	3.3	3.1	3.0	2.9	2.7	2.5	1.9	0.0
13	697.	691.	310.	250.	211.	181.	144.	120.	83.	44.9	4.0	6.7	3.5	3.4	3.3	3.1	3.0	2.7	2.1	0.0
14	698.	693.	313.	253.	214.	184.	146.	122.	86.	46.4	4.5	7.0	3.8	3.6	3.5	3.3	3.2	2.9	2.3	0.0
15	699.	694.	316.	255.	216.	186.	148.	124.	88.	47.7	4.9	7.4	4.0	3.8	3.7	3.5	3.4	3.1	2.5	0.0
16	699.	695.	319.	257.	218.	188.	150.	126.	87.	48.9	5.4	7.7	4.2	4.0	3.9	3.7	3.6	3.3	2.7	0.0
17	700.	697.	320.	259.	220.	189.	151.	127.	89.	50.0	5.9	8.0	4.4	4.2	4.1	3.9	3.8	3.4	2.8	0.0
18	701.	698.	322.	261.	222.	191.	153.	129.	90.	51.0	6.3	8.3	4.6	4.4	4.3	4.1	3.9	3.6	3.0	0.0
19	701.	699.	324.	262.	223.	192.	154.	130.	91.	52.0	6.8	8.6	4.7	4.6	4.4	4.2	4.1	3.7	3.1	0.0
20	702.	700.	325.	264.	224.	194.	155.	131.	92.	52.9	7.2	8.8	4.9	4.7	4.6	4.4	4.2	3.9	3.2	0.0
21	702.	701.	327.	265.	226.	195.	156.	132.	93.	53.7	7.6	9.0	5.0	4.9	4.7	4.5	4.4	4.0	3.4	0.0
22	703.	701.	328.	266.	227.	196.	157.	133.	94.	54.5	8.0	9.2	5.2	5.0	4.8	4.6	4.5	4.1	3.5	1.0
23	703.	702.	329.	269.	228.	197.	158.	134.	95.	55.2	8.4	9.4	5.3	5.1	5.0	4.8	4.6	4.2	3.6	1.0
24	704.	703.	331.	269.	229.	198.	159.	135.	95.	55.8	8.8	9.6	5.4	5.2	5.1	4.9	4.7	4.3	3.7	1.5
25	704.	704.	332.	270.	230.	199.	160.	136.	96.	56.5	9.2	9.8	5.5	5.3	5.2	5.0	4.8	4.4	3.8	1.2
26	705.	704.	333.	271.	231.	200.	161.	136.	97.	57.1	9.5	9.9	5.6	5.4	5.3	5.1	4.9	4.5	3.9	1.2
27	705.	705.	334.	272.	232.	200.	162.	137.	98.	57.6	9.9	10.1	5.7	5.5	5.4	5.1	5.0	4.6	3.9	1.3
28	705.	705.	335.	272.	233.	201.	162.	138.	98.	58.2	10.2	10.2	5.8	5.6	5.5	5.2	5.1	4.7	4.0	1.3
29	705.	706.	336.	273.	233.	202.	163.	138.	99.	58.7	10.5	10.4	5.9	5.7	5.5	5.3	5.2	4.8	4.1	1.4
30	706.	706.	336.	274.	234.	203.	164.	139.	99.	59.2	10.8	10.5	6.0	5.8	5.6	5.4	5.2	4.9	4.2	1.5
31	707.	707.	340.	277.	237.	206.	166.	142.	102.	61.3	12.3	11.0	6.4	6.1	6.0	5.7	5.6	5.2	4.5	1.7
32	709.	711.	340.	281.	240.	209.	169.	144.	109.	63.6	13.9	11.6	6.7	6.5	6.3	6.1	5.9	5.5	4.8	1.9
33	710.	713.	347.	284.	243.	211.	172.	147.	106.	65.3	15.2	12.0	7.0	6.8	6.6	6.4	6.2	5.8	5.1	2.2
34	711.	718.	349.	285.	245.	213.	173.	148.	108.	66.7	16.2	12.4	7.2	7.0	6.8	6.6	6.4	6.0	5.2	2.6
35	711.	715.	351.	287.	247.	215.	175.	150.	109.	67.9	17.1	12.6	7.4	7.2	7.0	6.7	6.5	6.1	5.4	2.8
36	712.	716.	353.	288.	248.	216.	176.	151.	110.	68.4	17.8	12.8	7.5	7.3	7.1	6.9	6.7	6.3	5.5	2.9
37	712.	717.	354.	289.	249.	217.	177.	152.	111.	69.6	18.4	13.0	7.6	7.4	7.2	6.9	6.7	6.4	5.6	2.6
38	713.	718.	355.	291.	250.	218.	178.	153.	112.	70.2	18.9	13.1	7.8	7.5	7.3	7.0	6.9	6.4	5.7	2.7
39	713.	719.	356.	292.	251.	219.	179.	153.	112.	70.8	19.4	13.3	7.8	7.6	7.4	7.1	6.9	6.5	5.8	2.8
40	714.	719.	357.	293.	252.	219.	179.	154.	113.	71.3	19.8	13.4	7.9	7.6	7.4	7.2	7.0	6.6	5.8	2.8
41	714.	719.	357.	293.	252.	220.	180.	154.	113.	71.7	20.1	13.4	7.9	7.7	7.5	7.2	7.0	6.6	5.9	2.9
42	714.	720.	359.	294.	253.	220.	180.	155.	114.	72.1	20.4	13.5	8.0	7.7	7.5	7.3	7.1	6.7	5.9	2.9
43	714.	720.	359.	294.	253.	221.	181.	155.	114.	72.4	20.7	13.6	8.0	7.6	7.4	7.3	7.1	6.7	5.9	2.9
44	715.	720.	359.	295.	253.	221.	181.	155.	114.	72.7	20.9	13.6	8.1	7.8	7.6	7.3	7.1	6.7	6.0	3.0
45	715.	721.	359.	295.	254.	221.	181.	156.	115.	72.9	21.1	13.7	8.1	7.8	7.6	7.4	7.2	6.8	6.0	3.0
46	715.	721.	360.	295.	254.	222.	182.	156.	115.	73.2	21.3	13.7	8.1	7.9	7.7	7.4	7.2	6.8	6.0	3.0
47	715.	721.	360.	296.	254.	222.	182.	156.	115.	73.4	21.5	13.8	8.2	7.9	7.7	7.4	7.2	6.8	6.1	3.0
48	715.	721.	360.	296.	255.	222.	182.	157.	115.	73.6	21.6	13.8	8.2	7.9	7.7	7.4	7.3	6.8	6.1	3.0
49	715.	721.	361.	296.	255.	223.	182.	157.	116.	73.7	21.8	13.9	8.2	7.9	7.7	7.5	7.3	6.9	6.1	3.1
50	715.	722.	361.	296.	255.	223.	182.	157.	116.	73.9	21.9	13.9	8.2	8.0	7.8	7.5	7.3	6.9	6.1	3.1
51	715.	722.	361.	297.	255.	223.	183.	157.	116.	74.0	22.0	13.9	8.2	8.0	7.8	7.5	7.3	6.9	6.1	3.1
52	715.	722.	361.	297.	256.	223.	183.	157.	116.	74.2	22.1	13.9	8.3	8.0	7.9	7.5	7.3	6.9	6.1	3.1
53	716.	722.	362.	298.	256.	224.	183.	158.	116.	74.4	22.5	14.0	8.3	8.1	7.8	7.6	7.4	7.0	6.2	3.2
54	716.	723.	363.	299.	257.	224.	184.	158.	117.	74.9	22.8	14.1	8.4	8.1	7.9	7.6	7.4	7.0	6.2	3.2
55	716.	723.	363.	299.	257.	225.	184.	159.	117.	75.2	23.0	14.1	8.4	8.1	7.9	7.6	7.4	7.0	6.3	3.2
56	716.	723.	363.	299.	257.	225.	184.	159.	117.	75.4	23.1	14.1	8.4	8.1	7.9	7.6	7.5	7.0	6.3	3.2
57	716.	723.	364.	299.	257.	225.	184.	159.	117.	75.5	23.2	14.2	8.4	8.1	7.9	7.7	7.5	7.1	6.3	3.2
58	716.	723.	364.	299.	258.	225.	185.	159.	118.	75.6	23.4	14.2	8.4	8.2	7.9	7.7	7.5	7.1	6.3	3.3
59	716.	723.	364.	299.	258.	225.	185.	159.	118.	75.7	23.5	14.2	8.4	8.2	8.0	7.7	7.5	7.1	6.3	3.3
60	717.	724.	364.	299.	258.	225.	185.	159.	118.	75.8	23.5	14.2	8.4	8.2	8.0	7.7	7.5	7.1	6.3	3.3
61	717.	724.	364.	299.	258.	225.	185.	159.	118.	75.9	23.6	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
62	717.	724.	364.	300.	258.	225.	185.	159.	118.	76.0	23.7	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
63	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.0	23.7	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
64	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.1	23.8	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
65	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.1	23.8	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
66	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.1	23.8	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
67	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.1	23.8	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
68	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.1	23.8	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
69	717.	724.	364.	300.	258.	226.	185.	159.	118.	76.1	23.8	14.3	8.5	8.2	8.0	7.7	7.5	7.1	6.3	3.3
70	717.	724.																		

Table 6. Temperature rise calculated for a 6-kW source with an air backfill with $H = 4 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ (see Fig. 8 for location)

TIME (HRS)	T1 (°F)	T2 (°F)	T3 (°F)	T4 (°F)	T5 (°F)	T6 (°F)	T7 (°F)	T8 (°F)	T9 (°F)	T10 (°F)	T11 (°F)	T12 (°F)	T13 (°F)	T14 (°F)	T15 (°F)	T16 (°F)	T17 (°F)	T18 (°F)	T19 (°F)	T20 (°F)
1	653.	652.	157.	111.	83.	62.	38.	25.	9.	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	666.	636.	207.	156.	126.	99.	70.	52.	26.	6.9	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3	673.	653.	236.	181.	147.	120.	89.	69.	39.	13.6	3.1	1.3	3.3	3.3	3.2	3.2	3.2	3.1	3.1	3.0
4	678.	659.	252.	197.	162.	135.	101.	80.	49.	19.3	8.3	1.8	5.5	5.4	5.4	5.4	5.3	5.3	5.1	5.0
5	682.	666.	267.	209.	173.	145.	110.	89.	59.	24.1	10.5	2.4	6.7	6.7	6.6	6.5	6.5	6.4	6.3	6.2
6	685.	671.	275.	218.	181.	151.	118.	96.	67.	28.1	12.0	2.9	7.9	7.9	7.8	7.7	7.7	7.6	7.4	7.3
7	687.	675.	283.	225.	189.	159.	123.	101.	76.	31.6	12.2	3.4	9.2	9.2	9.1	9.0	8.9	8.8	8.6	8.5
8	689.	679.	289.	231.	193.	166.	128.	106.	70.	34.6	12.6	3.9	10.4	10.4	10.3	10.2	10.1	10.0	9.7	9.6
9	691.	682.	295.	236.	198.	169.	132.	109.	73.	37.1	12.1	4.3	11.7	11.6	11.5	11.4	11.3	11.1	10.9	10.8
10	693.	685.	299.	240.	200.	173.	136.	113.	76.	39.6	12.5	4.8	12.9	12.9	12.8	12.7	12.6	12.4	12.2	12.1
11	694.	687.	301.	244.	206.	176.	139.	115.	78.	41.5	12.8	5.1	14.1	14.1	14.0	13.9	13.8	13.6	13.4	13.3
12	695.	689.	307.	247.	209.	179.	142.	118.	81.	43.3	13.5	5.5	15.3	15.3	15.2	15.1	15.0	14.8	14.6	14.5
13	697.	691.	310.	250.	211.	181.	144.	120.	83.	44.9	14.0	5.9	16.5	16.5	16.4	16.3	16.2	16.0	15.8	15.7
14	698.	693.	313.	253.	214.	184.	146.	122.	84.	46.8	14.6	6.1	17.6	17.6	17.5	17.4	17.3	17.1	16.9	16.8
15	698.	694.	316.	255.	216.	186.	148.	124.	86.	47.7	14.9	6.4	18.7	18.7	18.6	18.5	18.4	18.2	18.0	17.9
16	699.	695.	319.	257.	218.	188.	150.	126.	87.	49.5	15.4	6.7	19.8	19.8	19.7	19.6	19.5	19.3	19.1	19.0
17	700.	697.	320.	259.	220.	189.	151.	127.	89.	50.0	15.9	6.9	20.9	20.9	20.8	20.7	20.6	20.4	20.2	20.1
18	701.	698.	322.	261.	222.	191.	153.	129.	90.	51.0	16.3	7.1	21.9	21.9	21.8	21.7	21.6	21.4	21.2	21.1
19	701.	699.	324.	262.	223.	192.	154.	130.	91.	52.0	16.8	7.3	22.9	22.9	22.8	22.7	22.6	22.4	22.2	22.1
20	702.	700.	325.	264.	224.	193.	155.	131.	92.	52.0	17.2	7.5	23.9	23.9	23.8	23.7	23.6	23.4	23.2	23.1
21	702.	701.	327.	265.	226.	195.	156.	132.	93.	53.6	17.6	7.7	24.9	24.9	24.8	24.7	24.6	24.4	24.2	24.1
22	703.	701.	329.	266.	227.	196.	157.	133.	94.	54.0	18.0	7.9	25.9	25.9	25.8	25.7	25.6	25.4	25.2	25.1
23	703.	702.	329.	267.	228.	197.	158.	134.	95.	55.1	18.4	8.0	26.9	26.9	26.8	26.7	26.6	26.4	26.2	26.1
24	704.	703.	331.	269.	229.	199.	159.	135.	95.	55.8	18.8	8.1	27.9	27.9	27.8	27.7	27.6	27.4	27.2	27.1
25	704.	704.	332.	270.	230.	199.	160.	136.	96.	56.0	19.1	8.2	28.9	28.9	28.8	28.7	28.6	28.4	28.2	28.1
26	705.	704.	333.	271.	231.	200.	161.	136.	97.	57.0	19.5	8.4	29.9	29.9	29.8	29.7	29.6	29.4	29.2	29.1
27	705.	705.	334.	272.	232.	201.	162.	137.	97.	57.5	19.8	8.5	30.9	30.9	30.8	30.7	30.6	30.4	30.2	30.1
28	705.	705.	335.	272.	232.	201.	162.	137.	98.	59.1	20.2	8.6	31.9	31.9	31.8	31.7	31.6	31.4	31.2	31.1
29	705.	706.	335.	273.	233.	202.	163.	138.	99.	59.6	20.5	8.7	32.9	32.9	32.8	32.7	32.6	32.4	32.2	32.1
30	706.	706.	336.	274.	234.	202.	164.	139.	99.	59.0	20.8	8.8	33.9	33.9	33.8	33.7	33.6	33.4	33.2	33.1
35	707.	708.	340.	277.	237.	205.	166.	141.	101.	61.1	22.2	9.2	34.9	34.9	34.8	34.7	34.6	34.4	34.2	34.1
42	708.	711.	344.	281.	241.	209.	169.	144.	104.	63.3	23.8	9.6	35.9	35.9	35.8	35.7	35.6	35.4	35.2	35.1
49	710.	713.	346.	283.	243.	211.	171.	146.	106.	65.0	25.0	9.9	36.9	36.9	36.8	36.7	36.6	36.4	36.2	36.1
56	710.	714.	349.	285.	245.	213.	173.	148.	107.	66.8	26.0	10.2	37.9	37.9	37.8	37.7	37.6	37.4	37.2	37.1
63	711.	715.	352.	287.	246.	214.	174.	149.	109.	67.5	26.8	10.4	38.9	38.9	38.8	38.7	38.6	38.4	38.2	38.1
70	712.	716.	352.	288.	247.	215.	175.	150.	110.	68.0	27.5	10.5	39.9	39.9	39.8	39.7	39.6	39.4	39.2	39.1
77	712.	717.	353.	289.	248.	216.	176.	151.	110.	69.1	28.1	10.6	40.9	40.9	40.8	40.7	40.6	40.4	40.2	40.1
84	713.	717.	354.	290.	249.	217.	177.	152.	111.	69.7	28.4	10.7	41.9	41.9	41.8	41.7	41.6	41.4	41.2	41.1
91	713.	718.	355.	291.	250.	218.	178.	153.	112.	70.3	29.0	10.9	42.9	42.9	42.8	42.7	42.6	42.4	42.2	42.1
98	713.	719.	356.	292.	251.	219.	179.	154.	113.	71.1	29.7	11.0	43.9	43.9	43.8	43.7	43.6	43.4	43.2	43.1
105	713.	719.	356.	292.	251.	219.	179.	154.	113.	71.5	29.9	11.1	44.9	44.9	44.8	44.7	44.6	44.4	44.2	44.1
112	713.	719.	357.	293.	252.	219.	179.	154.	113.	71.8	30.2	11.2	45.9	45.9	45.8	45.7	45.6	45.4	45.2	45.1
119	714.	720.	357.	293.	252.	220.	180.	154.	113.	72.0	30.4	11.3	46.9	46.9	46.8	46.7	46.6	46.4	46.2	46.1
126	714.	720.	358.	294.	253.	220.	180.	155.	114.	72.0	30.6	11.3	47.9	47.9	47.8	47.7	47.6	47.4	47.2	47.1
133	714.	720.	358.	294.	253.	221.	180.	155.	114.	72.3	30.6	11.3	48.9	48.9	48.8	48.7	48.6	48.4	48.2	48.1
140	714.	720.	359.	294.	253.	221.	181.	155.	114.	72.5	30.6	11.3	49.9	49.9	49.8	49.7	49.6	49.4	49.2	49.1
147	715.	720.	359.	295.	253.	221.	181.	155.	114.	72.7	30.9	11.3	50.9	50.9	50.8	50.7	50.6	50.4	50.2	50.1
154	715.	720.	359.	295.	254.	221.	181.	156.	115.	72.9	31.1	11.3	51.9	51.9	51.8	51.7	51.6	51.4	51.2	51.1
161	715.	721.	359.	295.	254.	222.	181.	156.	115.	73.0	31.2	11.3	52.9	52.9	52.8	52.7	52.6	52.4	52.2	52.1
168	715.	721.	360.	295.	254.	222.	181.	156.	115.	73.1	31.3	11.3	53.9	53.9	53.8	53.7	53.6	53.4	53.2	53.1
175	715.	721.	360.	296.	254.	222.	182.	156.	115.	73.3	31.4	11.3	54.9	54.9	54.8	54.7	54.6	54.4	54.2	54.1
182	715.	721.	360.	296.	254.	223.	182.	156.	115.	73.4	31.4	11.3	55.9	55.9	55.8	55.7	55.6	55.4	55.2	55.1
189	715.	721.	361.	296.	255.	223.	182.	157.	116.	73.8	31.9	11.4	56.9	56.9	56.8	56.7	56.6	56.4	56.2	56.1
196	715.	722.	361.	297.	255.	223.	183.	157.	116.	74.1	32.2	11.4	57.9	57.9	57.8	57.7	57.6	57.4	57.2	57.1
203	716.	722.	362.	297.	256.	224.	183.	157.	116.	74.5	32.5	11.4	58.9	58.9	58.8	58.7	58.6	58.4	58.2	58.1
210	716.	722.	362.	297.	256.	224.	183.	158.	117.	74.6	32.6	11.5	59.9	59.9	59.8	59.7	59.6	59.4	59.2	59.1
217	716.	722.	362.	298.	256.	224.	183.	158.	117.	74.8	32.7	11.5	60.9	60.9	60.8	60.7	60.6	60.4	60.2	60.1
224	716.	722.	362.	298.	256.	224.	184.	158.	117.	74.8	32.8	11.5	61.9	61.9	61.8	61.7	61.6	61.4	61.2	61.1
231	716.	723.	363.	299.	257.	224.	184.	158.	117.	74.9	32.9	11.5	62.9	62.9	62.8	62.7	62.6	62.4	62.2	62.1
238	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.0	32.9	11.5	63.9	63.9	63.8	63.7	63.6	63.4	63.2	63.1
245	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.0	32.9	11.5	64.9	64.9	64.8	64.7	64.6	64.4	64.2	64.1
252	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.1	33.0	11.5	65.9	65.9	65.8	65.7	65.6	65.4	65.2	65.1
259	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.1	33.0	11.5	66.9	66.9	66.8	66.7	66.6	66.4	66.2	66.1
266	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.1	33.0	11.5	67.9	67.9	67.8	67.7	67.6	67.4	67.2	67.1
273	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.1	33.0	11.5	68.9	68.9	68.8	68.7	68.6	68.4	68.2	68.1
280	716.	723.	363.	299.	257.	224.	184.	158.	117.	75.1	33.0	11.5	69.9	69.9	69.8	69.7	69.6	69.4	69.2	69.1
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