Title: Report on the First ASTM Interlaboratory Comparison of Vacuum Panels

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ABSTRACT

A interlaboratory comparison was initiated in February of 2000 to compare different methods of determining the effective thermal resistance of vacuum panels. The outcome of this interlaboratory comparison will provide support for the ASTM material specification and the development of a future ASTM test method. Four issues were identified and addressed: (1) calorimetric vs. center-of-panel/barrier conductivity approaches, (2) comparison of available finite difference/element models, (3) appropriate boundary conditions for all measurements/models,and (4) comparison of center-of-panel measurements. Six conventional vacuum panels were constructed. All six shared the same dimensional configuration, the same core material, the same getter insert, and the same manufacturing techniques and equipment. Two different barrier materials (three panels from each) were used because barrier thermal conductivity is recognized as a key factor in the determination of effective thermal resistance for vacuum panels, and because the different methods used in this interlaboratory comparison should be sensitive to the barrier thermal properties. The getters were included in these panels to help them remain stable throughout the duration of the interlaboratory comparison.

Each of the eight participating laboratories measured the center-of-panel resistance of each of the six panels as described in the ASTM standard C1484-00 and reported those results along with pertinent information about the transducer(s) size and location. Several laboratories also calculated the whole-panel effective thermal resistance, using two assumed sets of boundary conditions.

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INTRODUCTION

Vacuum insulation systems have long been used for cryogenic applications. These systems have historically consisted of multi-layer evacuated jackets with active vacuum systems. In the early 1990s, sealed evacuated panels became commercially available. These panels were filled with either fiberglass or silica and had either metal or plastic barriers. The continuing design evolution includes open-celled foam and advanced powdered fillers, specialty multi-layer films, and the inclusion of new adsorbent systems. In order to help potential users understand the performance of these panels, a task group was formed in 1995 to create an ASTM material specification [1]. Due to the complexity of this non-homogenous insulation form, several evaluation methods were developed by researchers and panel manufacturers. The task group initiated efforts to systematically compare the results of these differing approaches.

The resulting interlaboratory comparison was initiated in February of 2000, with the goal of comparing different methods of determining the effective thermal resistance of vacuum panels. The outcome of this interlaboratory comparison will provide support for the ASTM material specification and the development of a future ASTM test method. Four issues were identified and addressed: (1) calorimetric vs. center-of-panel/barrier conductivity approaches, (2) comparison of available finite difference/element models, (3) appropriate boundary conditions for all measurements/models, and (4) comparison of center-of-panel measurements.

DESIGN of INTERLABORATORY COMPARISON

Six conventional vacuum panels were constructed by Dow Chemical Co. in January, 2000. All six shared the same dimensional configuration, the same core material, the same getter insert, and the same manufacturing techniques and equipment. The specimens were each 30 x 30 x 2.5 cm (12 x 12 x 1 in.), and each was clearly marked and evacuated to the same pressure. Two different barrier materials (three panels from each) were used, both multi-layer construction, one with a higher thermal conductivity than the other. Barrier thermal conductivity is recognized as a key factor in the determination of effective thermal resistance for vacuum panels and the different methods used in this interlaboratory comparison should be sensitive to the barrier thermal properties. Aggressive getters were included in these panels to help them remain stable throughout the duration of the interlaboratory comparison.

The eight participating laboratories were Advantek, Dow Chemical, Dupont, Holometrix, LaserComp, National Research Council Canada, Oak Ridge National Laboratory, and the Product Design Center. Each laboratory measured the center-of-panel thermal resistance of each of the six panels as described in [1] and reported those results. Several of the laboratories made multiple measurements using different types of apparatus. Pertinent information about the test equipment used to date in this

TABLE I. HEAT FLOW METER PARAMETERS TO TEST 30 X 30 X 2.5 cm SPECIMEN

Plate size		Central transducer size	
(cm)	(in.)	(cm)	(in.)
61 x 61	24 x 24	8 x 8	3 x 3
61 x 61	24 x 24	10 x 10	4 x 4
61 x 61	24 x 24	10 x 20	4 x 8
61 x 61	24 x 24	25 x 25	10 x 10
30 x 30	12 x 12	10 x 10	4 x 4
30 x 30	12 x 12	8 x 8	3 x 3
30 x 30	12 x 12	8(diameter)	3 (diameter)

interlaboratory comparison is shown in Table I. Several laboratories also calculated the whole-panel effective thermal resistance, using two assumed sets of boundary conditions.

An examination of Table I shows that some of the test devices were the same size as the vacuum panels, 30 x 30 cm (12 x 12 in.). In these devices, the entire surface of the vacuum panel was in direct contact with the controlled temperature plate. This configuration therefore represents a constant temperature boundary condition, where the temperature gradient from the center of the panel to the edge of the panel is minimized and the lateral heat transfer from the center of the panel to the outer edge through the boundary material is reduced. Other test devices were twice as wide as the vacuum insulation panels. For these tests, a high-density fiberglass blanket was sculpted to fit tightly around the vacuum panels and to match the area of the test apparatus plate size. For some of these large plate tests, the vacuum panel was still in direct contact with the constant temperature plate. For others, an arrangement where the fiberglass blanket also covers the bottom and top of the vacuum panel was used. When the fiberglass blanket was inserted between the constant temperature plates and the vacuum panel, thermocouples were attached directly to the center of the vacuum panel to record the temperature at that location. This last arrangement was typically used with an array of heat flux transducers and was directed more toward measurement of whole panel performance, because it allows a temperature gradient to develop along the face of the barrier material. Despite this limitation, center-of-panel resistivity measurements were also made using this arrangement.

RESULTS

The measured thermal resistivity values are summarized in Table II. For the panels with a more conductive barrier (1a,b,c), and excluding the measurement made with the 25 x 25 cm(10 x 10 in.) transducer, the resistivities are all between 177 and 225 m·K/W (25.6 and 32.5 h·ft^2·°F/Btu·in., hereinafter designated R/in.) or between 89 to 113% of the average value of 199 m·K/W (28.7 R/in.). The standard deviation for

TABLE II. MEASURED CENTER OF PANEL THERMAL RESISTIVITY

Lab	Transducer Size		Panel a		Panel b		Panel c		Average	
	cm	in.	m·K/W	R/in.	m·K/W	R/in.	m·K/W	R/in.	m·K/W	R/in.
			Panels With a More Conductive Barrier (1a, 1b, 1c)							
A	10 x 10	4 x 4	211	30.5	193	27.8	215	31.0	207	29.8
B	8(diam)	3 (diam)	177	25.6	177	25.6	193	27.8	183	26.4
C	10 x 10	4 x 4	210	30.3	217	31.3	225	32.5	218	31.4
D	10 x 20	4 x 8	178	25.7	181	26.1	198	28.5	186	26.8
D	8 x 8	3 x 3	201	29.0						
D	8 x 8	3 x 3	191	27.6	191	27.6	220	31.7	201	29.0
E	10 x 10	4 x 4	189	27.3	187	27.0	204	29.4	193	27.9
E	10 x 10	4 x 4	191	27.5	189	27.2	202	29.2	194	28.0
E	25 x 25	10 x 10							97	14.0
F	10 x 10	4 x 4	205	29.5	187	27.0	214	30.8	202	29.1
G	10 x 10	4 x 4	184	26.6	190	27.4	207	29.8	193	27.9
H	10 x 10	4 x 4	200	28.8	200	28.8	218	31.4	206	29.7
			Panels With a Less Conductive Barrier (2a, 2b, 2c)							
A	10 x 10	4 x 4	198	28.5	196	28.3	207	29.8	200	28.9
B	8(diam)	3 (diam)	224	32.3	231	33.3	224	32.3	226	32.6
C	10 x 10	4 x 4	209	30.2	216	31.1	210	30.3	211	30.5
D	10 x 20	4 x 8	211	30.5	211	30.5	200	28.9	208	30.0
D	8 x 8	3 x 3	216	31.2						
D	8 x 8	3 x 3	210	30.3	207	29.8	200	28.8	205	29.6
E	10 x 10	4 x 4	192	27.7	194	28.0	194	28.0	193	27.9
E	10 x 10	4 x 4	191	27.6	193	27.8	194	28.0	193	27.8
E	25 x 25	10 x 10								
F	10 x 10	4 x 4	193	27.9	192	27.7	206	29.7	197	28.4
G	10 x 10	4 x 4	190	27.4	193	27.8	191	27.6	191	27.6
H	10 x 10	4 x 4	190	27.4	193	27.8	191	27.6	192	27.7

these 11 measurements is 4.7%. For the panels with the less conductive barrier, the resistivities are all between 190 and 230 m·K/W (27.4 and 33.3 R/in.), for a range of 94 to 115% of the average value of 201 m·K/W (29.0 R/in..). The standard deviation for the ten measurements on the less conductive barrier panels is 5.4%.

TABLE III. COMPARISON OF
MEASURED CENTER-OF-PANEL THERMAL RESISTANCE TO
CALCULATED EFFECTIVE WHOLE PANEL RESISTANCE FOR PANEL 1

Transducer size (in.)	Number of measurements	Average		Standard Deviation	
		m·K/W	R/in.	m·K/W	R/in.
3 x 3	4	201	29.0	12	1.7
4 x 4	21	203	29.3	12	1.7
4 x 8	3	186	26.8	8	1.2
10 x 10	3	97	14.0	Not available	
Calculated effective whole panel		76	11		

Previous modeling work on vacuum panels has shown that the center-of-panel measurement will be more accurate for smaller transducer sizes [1]. This is most important if the barrier is more conductive, and the results for this interlaboratory comparison show that effect, as seen in Table III. The effect of lateral heat transfer through the panel barrier becomes more important as the transducer size approaches the panel size. As this lateral heat flow is captured by the center heat flux transducer, the perceived center-of-panel thermal resistance is reduced. Indeed, the value measured by a 25 x 25 cm (10 x 10 in.) transducer is almost the same as the calculated whole panel effective thermal resistance (as defined in [1] and described later in this paper).

The center-of-panel thermal resistivity measurements are also highly dependent on the measured thickness of the panel. When the vacuum panel is in direct contact with the heat flow meter's plate, the thickness is automatically measured by the test apparatus. For other test configurations, especially those that employ a fiberglass blanket above and below the panel, independent measurements are required. When such measurements were made, they were the average of eight locations over the surface of each panel. A summary of the measured panel thicknesses show a variation from -7 to +11% relative to the nominal value of one inch. The average of the 36 reported measurements is 2.51 cm (0.99 in.), with a standard deviation of 0.13 cm (0.05 in.). Considering the direct relationship between measured thermal resistance and measured thickness, this variation explains much of the variation in the resistance data discussed above, and therefore provides useful guidance for future efforts to improve the procedures.

Because vacuum insulation panels are non-homogenous, various approaches have been developed to determine their overall thermal effectiveness. One method employs an overall hot box technique where mathematical models are used to correct for the effects of materials used to surround the test panel. That method has not yet been tested with the interlaboratory comparison specimens.

The other method in common use employs a finite difference model of the panel, and requires a priori knowledge of the barrier thermal conductivity, the apparent thermal conductivity of the evacuated region within the panel, and a definition of the thermal boundary conditions for the analysis. That latter method was used by three of the participating laboratories and the results are shown in Table IV.

TABLE IV. FINITE DIFFERENCE /ELEMENT MODEL RESULTS FOR WHOLE PANEL

Lab	Boundary conditions	Whole panel thermal resistance			
		Barrier: more conductive		Barrier: less conductive	
		m²·K/W	h·ft²·°F/Btu	m²·K/W	h·ft²·°F/Btu
B	Refrigerator door	1.8	10	4.6	26
D	Refrigerator door	1.8	10	4.1	23
B	Building Wall	2.1	12	5.6	32
D	Building Wall	1.8	10	4.8	27
D	Test apparatus	1.9	11	4.8	27
C	Not available	2.3	13	4.8	27

Four sets of boundary conditions were considered. The first represents the typical door of a refrigerator. For this configuration, one side of the panel would face a thin sheet of steel (0.0006 m thick, 69. W/m-K) which is in turn exposed to indoor convective transfer to an environment at 21°C. The other side of the panel would be surrounded by 2.5 cm of foam (0.024 W/m-K) and a thin sheet of ABS (0.003 m thick, 0.26 W/m-K) exposed to an air temperature of 4°C. The second set of boundary conditions represents a wall section of a building. In that wall, one side of the panel would face 1.3 cm gypsum board (0.16 W/m-K) exposed to indoor convective conditions (21°C). The other side would face 1.3 cm of foam (0.03 W/m-K), followed by a thin cladding (wood, 2.5 cm thick, 0.19 W/m-K) exposed to external convection at -7°C. The third set of boundary conditions is a bit simpler, because it represents a heat flow meter apparatus with standard high-density fiberglass surrounding the panel which is in turn encased within two constant temperature plates. The fourth set of boundary conditions was not reported by the laboratory.

Considering the different mathematical models, the different values used for the element conductivities, and the different boundary condition implementations, there is a surprising degree of agreement. The average effective whole panel thermal resistance for the more conductive barrier was 1.97 m^2·K/W (11.2 h·ft^2·°F/Btu) with a standard deviation of 11%, giving a 95% confidence that the effective thermal resistance is between 1.53 and 2.41 m^2·K/W (8.7 and 13.7 h·ft^2·°F/Btu). The average whole panel thermal resistance for the less conductive barrier was 26.9 h·ft^2·°F/Btu with a standard deviation of 12%, giving a 95% confidence that the effective thermal resistance is between 3.5 and 5.8 m^2·K/W (20 and 33 h·ft^2·°F/Btu).

FUTURE PLANS

Considering the exploratory nature of this interlaboratory comparison, and the complexity of the measurements, the results showed better agreement than expected. However, there is still much to learn. Future plans to expand the interlaboratory comparison include the addition of more measurements and more laboratories. Specifically, a standard foam board has been added to the interlaboratory comparison to allow us to compare the baseline performance of all the included test apparatus devices. This board will be circulated to all the participating laboratories. There are also several other laboratories that have asked to be included in the program and measurements will be completed using their apparatus and methodologies as soon as possible.

One of the most important future efforts will be the addition of calorimetric measurements at a facility dedicated to such work. This will provide a valuable benchmark for the finite element modeling efforts.

Another important issue to be addressed is that of the low heat flux calibration. Many of these test devices are typically used to measure insulation with lower resistivity, so the heat flux is usually much greater than that measured during these tests. Special calibration procedures have been developed and reported by some participants, and efforts will be made to determine procedures used by others.

The ultimate goal of the interlaboratory comparison is to determine which test methods give the most useful results, and to provide a definition of the expected accuracy. The information gathered during this effort will lead us to improved industry consensus standard test methods for vacuum insulation panels.

REFERENCES

1. ASTM C1484-00, Standard Specification for Vacuum Insulation Panels, 2000 Annual book of ASTM Standards, Vol. 04.06, West Conshohocken, PA.

BIOGRAPHIES

Andrzej Brzezinski

Andrzej Brzezinski, LaserComp's President and Product Development Director, has been in the thermal conductivity business in a variety of capacities for more than 20 years. After graduating from the University of Illinois in 1977 with a degree in Material Science, he worked at Foxborough Corporation before taking a position at Dynatech as Manager in their Testing Laboratory. He then ventured into Sales, Research and Development (he developed a LaserFlash System still being sold) and Management at the highest levels. When Mr. Brzezinski created LaserComp he utilized his experience in running both a testing lab and a sales department to pinpoint the needs of the marketplace. Years in design and development provided the technical background needed to create the precise, compact, and easy to use line of Fox instruments.

Therese K. Stovall

Therese K. Stovall has worked at Oak Ridge National Laboratory since 1978. She is currently supporting the distributed generation and building materials programs. She updated the DOE Insulation Fact Sheet, the second most requested document published by DOE, and has contributed to laboratory evaluations of a variety of insulation materials, focusing her efforts on evacuated insulation panels. Previously, Therese managed the Ice Storage Test Facility, a commercial ice storage testing program sponsored by the Electric Power Research Institute. She received a patent for a load management method using wallboard containing a phase change material.

Therese Stovall received her B.S.M.E. with distinction from Purdue University in 1977, her M.S.M.E. from the University of Tennessee in 1988 and is a Licensed Professional Engineer in the state of Tennessee. She is also a member of the American Society of Mechanical Engineers, the American Society for Testing and Materials, and the American Society of Heating Refrigerating and Air Conditioning Engineers.