Thermal Performance of Pipe Insulation: A Performance Degradation Comparison Study

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The Importance of Pipe Insulation: Four Primary Benefits

Pipe insulation plays a crucial role in various aspects of industrial and commercial operations with four major benefits.

1. Thermal Performance & Reduced Utility Costs: Proper insulation helps maintain consistent temperatures within pipes, whether they're carrying hot or cold fluids. This consistency is essential for efficient operation and can significantly reduce energy loss, leading to lower utility costs over time. Lower energy usage has sustainability benefits, including direct reductions in emissions and significant CO^2 reductions.

2. Condensation Control: When piping and equipment operate at temperatures lower than ambient air, moisture in the air can condense on the cold surface, or when insulated incorrectly, on or within the insulation system. The piping system can be protected by an insulation system with sufficient thickness and an adequate vapor retarder. Condensation can lead to corrosion and other forms of damage, so controlling it is vital for the longevity of the piping system.

3. Sound Control: Pipes in operation can generate vibrations and noise, which can be disruptive and even damaging in certain environments. Insulating pipes helps dampen these sounds, creating a quieter and more comfortable environment.

4. Safety: Insulation acts as a protective barrier, especially for pipes carrying high-temperature fluids. It reduces the risk of accidental burns or injuries by minimizing heat transfer from the pipe surface. Additionally, certain types of insulation provide fire protection, limiting the spread of flames in case of a fire incident.

Overall, investing in proper pipe insulation not only improves the efficiency and reliability of industrial and commercial processes but also contributes to safety and cost-effectiveness in the long run.

Standard Test for Pipe Insulation Performance: ASTM C335

To ensure that pipe insulation performs as advertised, ASTM C335 was developed and is maintained by ASTM. The formal name for ASTM C335 is the Standard Test Method for Steady-State Heat Transfer Properties of Pipe Insulation.

Performance Testing Approach: Thermal Conductivity Test Plan

In 2021 the North American Insulation Manufacturers Association (NAIMA) contracted R&D Services to conduct ASTM C335 testing on its members' products, along with samples of two different aerogel blanket products. R&D Services conducted three test iterations on samples of these products and repeated these tests for two rounds. In the process of the second round of testing, a third aerogel product was added to the test plan.

Test 1: An initial thermal conductivity measurement of all product specimens.

Test 2: A thermal conductivity measurement according to ASTM C335 up to a maximum pipe surface temperature of 1200ºF (650ºC). All product specimens were allowed to cool down.

Test 3: A repeat thermal conductivity measurement according to ASTM C335 up to a maximum pipe surface temperature of 1200ºF (650ºC) of all product specimens.

All thermal conductivity data was calculated using ASTM C1045 and compared to the appropriate product standard specification. If three specimens were tested, all thermal data was grouped together by test sequence (i.e., test 1, test 2, and test 3) and analyzed together to provide the overall average performance for each sequence.

Diameter and length were measured prior to each test sequence to ensure the proper area basis was used for each test sequence. Measurements were conducted with the material installed on the pipe apparatus. Thermal conductivity tests on aerogel products were conducted with six layers of nominal 10mm thick material installed on the pipe apparatus.

Performance Testing Results

Temperature Cycling Effects on Aerogel Products

Organic components, including hydrophobic agents, undergo oxidation within the temperature range of 300°F (149°C) to 600°F (316°C). This oxidation process can affect the structural integrity and properties of aerogel. At elevated temperatures, aerogels become more friable (easily crumbled or broken) and may experience a reduction in closed-cell structures. This can result in a decrease in thermal performance.

Once the aerogel material has been compromised due to oxidation or other factors, the thermal performance will be permanently reduced. However, once cycled, the material will not continue to lose thermal performance beyond the initial compromise. Overall, this information highlights the sensitivity of aerogels to temperature exposure and the resulting impact on their thermal properties.

Aerogel Results

The aerogel specimens performed considerably worse after being subjected to thermal testing, with thermal performance reductions as high as 20%. The first heat up caused degradation in the aerogels and the specimens then stabilized at that worse performance. Additionally, another aerogel specimen was subjected to only one round of testing and saw similar results.

Fiberglass and Mineral Wool Results

The fiberglass and mineral wool specimens performed significantly better than the aerogel specimens. All fiberglass and mineral wool specimens experienced less than 2% thermal performance degradation after the first heat up and then stabilized for the second and third tests.

Conclusion

Designers, engineers, and end users should be aware that aerogel's thermal performance degrades more than fiberglass and mineral wool pipe insulation when used with high process temperatures. Designers and engineers should reach out to manufacturers if they have questions about a product's performance.

NAIMA Thermal Shift Testing Summary

Result Summary from Two Rounds of Testing

Thermal Conductivity Btu·in / h·ft^2·°F

Mean Temperature ºF	Aerogel A						Aerogel B					
	Round 1			Round 2			Round 1			Round 2		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
75	0.171	0.194	0.196	0.177	0.196	0.196	0.169	0.172	0.171	0.182	0.187	0.187
100	0.176	0.201	0.202	0.181	0.204	0.203	0.170	0.176	0.175	0.185	0.191	0.191
150	0.185	0.215	0.216	0.189	0.219	0.219	0.176	0.185	0.185	0.192	0.200	0.200
200	0.196	0.229	0.230	0.198	0.235	0.235	0.183	0.193	0.193	0.199	0.209	0.209
250	0.208	0.244	0.245	0.209	0.252	0.252	0.190	0.202	0.203	0.206	0.219	0.219
300	0.221	0.260	0.260	0.221	0.269	0.269	0.197	0.212	0.212	0.214	0.229	0.228
350	0.236	0.277	0.277	0.235	0.288	0.288	0.205	0.221	0.222	0.223	0.239	0.239
400	0.253	0.295	0.295	0.252	0.307	0.307	0.214	0.231	0.232	0.233	0.250	0.249
450	0.273	0.317	0.314	0.271	0.328	0.328	0.224	0.342	0.243	0.243	0.261	0.261
500	0.295	0.335	0.334	0.293	0.350	0.350	0.234	0.253	0.254	0.255	0.273	0.272
550	0.319	0.357	0.356	0.319	0.374	0.374	0.246	0.264	0.265	0.268	0.286	0.285
600	0.347	0.381	0.380	0.348	0.400	0.400	0.258	0.276	0.277	0.282	0.300	0.298
650	0.379	0.407	0.406	0.381	0.428	0.428	0.272	0.289	0.290	0.297	0.314	0.313
700	0.414	0.434	0.433	0.419	0.458	0.457	0.287	0.303	0.304	0.314	0.329	0.328
Average % Degradation	-	13.7%	13.9%	-	17.1%	17.0%	-	6.4%	6.5%	-	5.8%	5.6%

Mean Temperature ºF	Aerogel C*.**		
	Round 1		
	Test 1	Test 2	Test 3
75	0.147	0.226	0.228
144	0.176	0.248	0.249
214	0.204	0.270	0.271
283	0.234	0.292	0.294
353	0.265	0.315	0.317
422	0.298	0.340	0.342
492	0.233	0.365	0.367
561	0.370	0.392	0.394
631	0.410	0.421	0.423
700	0.453	0.451	0.453
Average % Degradation	-	20.1%	20.8%

*Aerogel C experienced a large change in efficiency between set points 3 and 4, leading to an unwieldy fit for smoothed C335 results.

**Aerogel C testing consisted of one round of tests performed in 2021.

NAIMA Thermal Shift Testing Summary

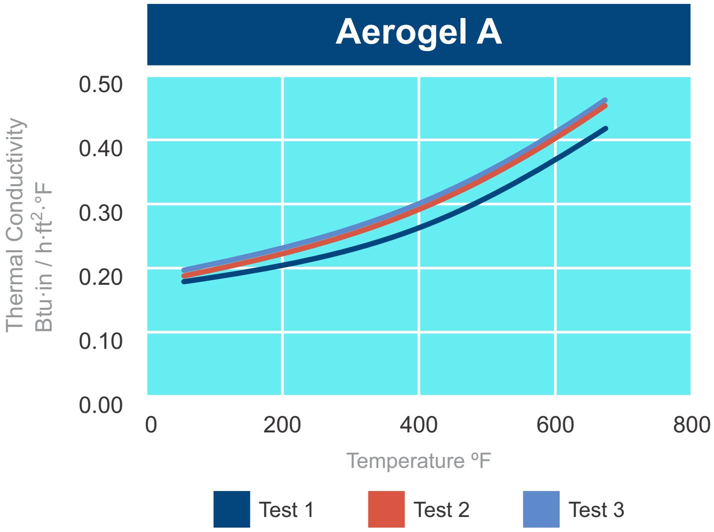
Result Summary from Two Rounds of Testing

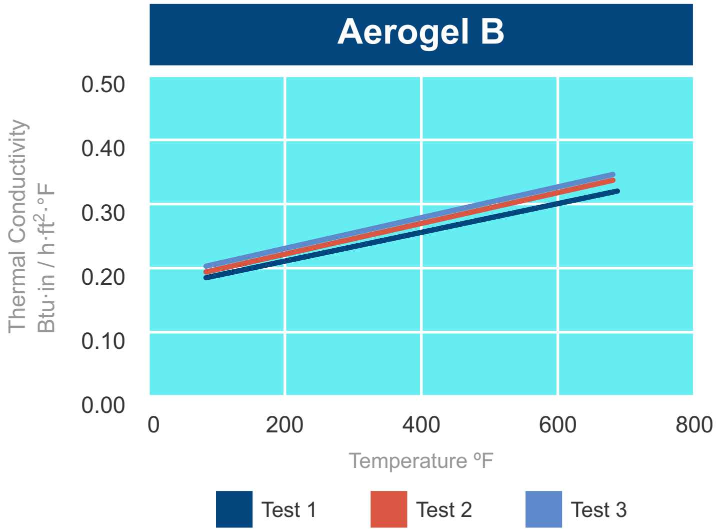
Thermal Conductivity Btu·in / h·ft^2·°F

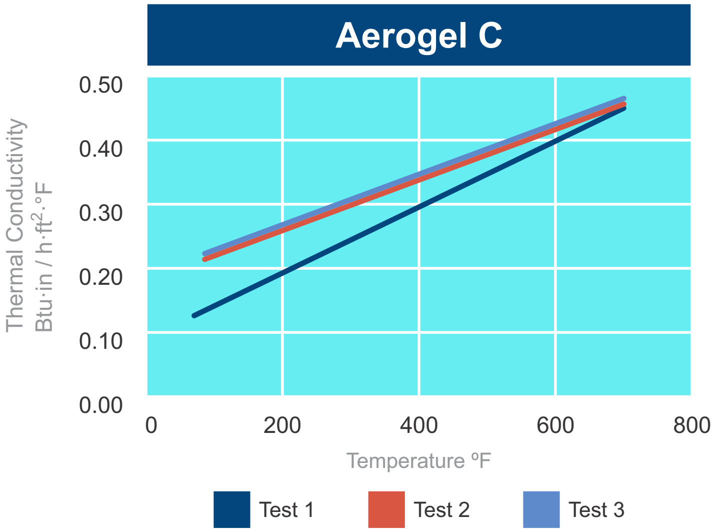
Mean Temperature ºF	Mineral Wool					
	Round 1			Round 2		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
75	0.239	0.239	0.239	0.230	0.232	0.234
100	0.253	0.253	0.253	0.242	0.244	0.246
150	0.282	0.282	0.283	0.266	0.269	0.271
200	0.311	0.312	0.312	0.291	0.294	0.296
250	0.341	0.342	0.343	0.316	0.320	0.322
300	0.372	0.374	0.375	0.342	0.346	0.349
350	0.405	0.408	0.409	0.370	0.374	0.376
400	0.440	0.442	0.444	0.398	0.403	0.406
450	0.476	0.479	0.480	0.429	0.434	0.436
500	0.516	0.518	0.519	0.460	0.466	0.468
550	0.557	0.559	0.560	0.494	0.499	0.502
600	0.601	0.603	0.604	0.530	0.535	0.538
650	0.649	0.650	0.651	0.568	0.573	0.576
700	0.700	0.699	0.700	0.608	0.613	0.616
Average % Degradation	-	0.3%	0.5%	-	1.1%	1.7%

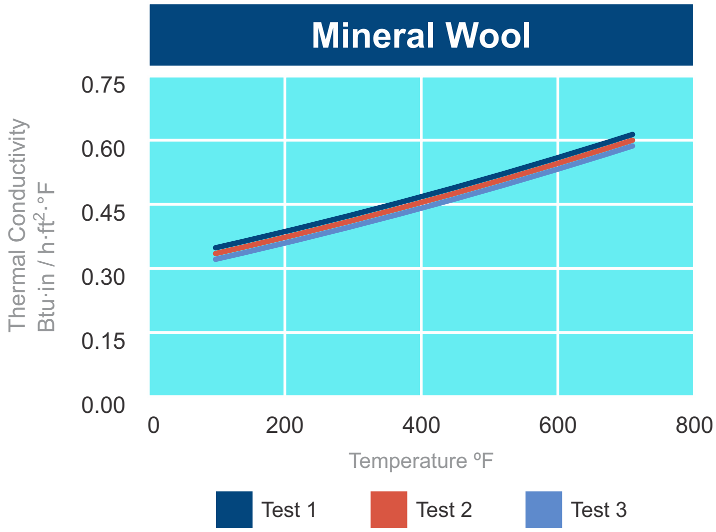
Mean Temperature ºF	Fiberglass					
	Round 1			Round 2		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
75	0.228	0.230	0.230	0.220	0.221	0.221
100	0.243	0.246	0.246	0.232	0.234	0.234
150	0.273	0.279	0.279	0.257	0.261	0.261
200	0.306	0.315	0.315	0.283	0.289	0.289
250	0.341	0.352	0.353	0.312	0.319	0.319
300	0.381	0.394	0.394	0.343	0.351	0.352
350	0.425	0.439	0.439	0.377	0.386	0.387
400	0.474	0.488	0.489	0.415	0.425	0.426
450	0.529	0.543	0.544	0.457	0.468	0.469
500	0.591	0.604	0.604	0.504	0.514	0.516
550	0.661	0.671	0.671	0.556	0.566	0.567
600	0.739	0.745	0.745	0.613	0.623	0.624
650	0.826	0.828	0.826	0.677	0.685	0.687
700	0.923	0.918	0.916	0.748	0.754	0.756
Average % Degradation	-	1.9%	1.9%	-	1.7%	1.9%

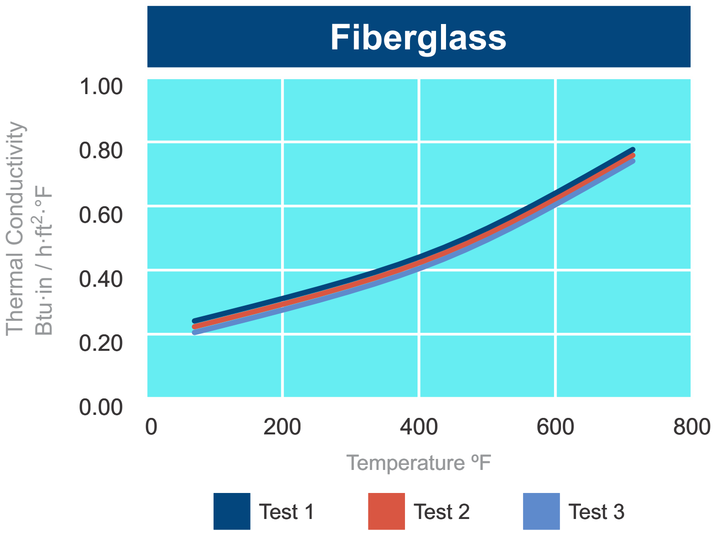
Results


Aerogel A
Thermal Conductivity
Btu·in / h·ft²·°F
0.50
0.40
0.30
0.20
0.10
0.00
0
200
400
600
800
Temperature ºF
Test 1
Test 2
Test 3


Aerogel B
Thermal Conductivity
Btu·in / h·ft²·°F
0.50
0.40
0.30
0.20
0.10
0.00
0
200
400
600
800
Temperature ºF
Test 1
Test 2
Test 3


Aerogel C
Thermal Conductivity
Btu·in / h·ft²·°F
0.50
0.40
0.30
0.20
0.10
0.00
0
200
400
600
800
Temperature ºF
Test 1
Test 2
Test 3


Mineral Wool
Thermal Conductivity
Btu·in / h·ft²·°F
0.75
0.60
0.45
0.30
0.15
0.00
0
200
400
600
800
Temperature ºF
Test 1
Test 2
Test 3


Fiberglass
Thermal Conductivity
Btu·in / h·ft²·°F
1.00
0.80
0.60
0.40
0.20
0.00
0
200
400
600
800
Temperature ºF
Test 1
Test 2
Test 3

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NAIMA is the association for North American manufacturers of fiber glass, rock wool, and slag wool insulation products. Its role is to promote energy efficiency and environmental preservation through the use of fiber glass, rock wool, and slag wool insulation, and to encourage the safe production and use of these materials. Through the Insulation Institute™, we leverage the collective insulation expertise of our organization and our members to empower homeowners and professionals to make informed insulation choices. Our mission is to enable a more comfortable, energy-efficient and sustainable future through insulation — and we are constantly working with building professionals, homeowners, government agencies, and public interest, energy and environmental groups to realize that vision.

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