Title: Apparent Thermal Conductivity Data and Related Information for Rice Hulls and Crushed Pecan Shells

Authors: David W. Yarbrough
Kenneth E. Wilkes
Paul A. Olivier
Ronald S. Graves
Arun Vohra

ABSTRACT

Rice hulls and crushed pecan shells are two solid waste materials with potential for use as thermal insulation. The apparent thermal conductivity, k_a, of parboiled rice hulls and crushed pecan shells has been measured in two laboratories over the temperature range 4 to 41 ºC using heat-flow meter apparatuses.

Thermal data were obtained for dried material and as-received material in order to provide information about the variation of k_a with water content. In the case of rice hulls, results have been obtained for properties such as resistance to smoldering combustion, critical radiant flux, flame spread index, smoke development index, water sorption, corrosion, odor emission and resistance to fungal growth in order to determine the suitability of this material for use as a building insulation. The measured k_a of rice hulls and crushed pecan shells are compared with data for other solid waste materials such as coconut fiber, sugarcane fiber, and cellulose insulation made from newsprint.

INTRODUCTION

Parboiled rice hulls and crushed pecan shells are two solid waste materials with potential for use as building thermal insulation. The annual U.S. supply of rice hulls exceeds one million metric tons, and the world supply is 100 times this quantity [1]. Rice hulls could be used to supplement existing supplies of waste stream materials currently used to manufacture building thermal insulation. Recycled newsprint and cardboard, for example, are widely used as starting materials for building thermal insulation [2]. Sugarcane and coconut fibers have also been explored as possible thermal insulations for buildings in some regions of the world [3, 4]. The apparent thermal conductivity and the associated thermal resistance of candidate materials for building thermal insulations are of primary interest. A successful insulation product, however, must satisfy requirements such as fire resistance, fungal growth resistance, corrosion resistance, and water sorption limits in addition to having a favorable thermal resistivity.

David W. Yarbrough, R&D Services, Inc., Cookeville, Tennessee, USA
Kenneth E. Wilkes, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
Paul A. Olivier, Engineering, Separation, and Recycling, LLC, Washington, Louisiana, USA
Ronald S. Graves, R&D Services, Inc., Cookeville, Tennessee, USA
Arun Vohra, U.S. Department of Energy, Washington, D.C., USA

MATERIALS TESTED

The rice hulls examined in this study were received from a processing plant. The rice hulls tested by R&D Services, Inc. (RDS) were parboiled while the rice hulls tested at the Oak Ridge National Laboratory (ORNL) were not parboiled. The crushed pecan shells were obtained from a pecan shelling operation.

Thermal measurements ORNL were made on “as-received” material and “oven-dried” material. The drying process consisted of six days at 70 ºC, one day at 103 ºC, and one day at 104 ºC. The density of the oven-dried specimens was determined to be 599.1 kg/m^3 while the as-received material was 680.8 kg/m^3. The pecan shells, therefore, contained about 13.6 wt. % water (dry basis) in the as-received condition. The drying process for the rice hulls consisted of six days at 70 ºC and two days at 103 ºC. The density of the oven-dried rice hulls was 153.8 kg/m^3 while the density of the as-received material was 168.2 kg/m^3. The rice hulls contained about 9.4 wt.% water (dry basis). Thermal measurements at RDS were made only on rice hulls and they were conditioned to constant weight in a temperature and humidity-controlled laboratory space at 21 +/- 3 ºC and 50 +/- 5% relative humidity. The densities for the RDS thermal test specimens were 144.3, 139.4, 155.4, and 147.5 kg/m^3 for an average of 146.7 kg/m^3.

Apparent thermal conductivity values have been measured for the two waste materials in this study using equipment built and operated in accordance with ASTM C 518. [5] Thermal specimens were prepared by pouring the rice hulls or crushed pecan shells into 305x305x51 mm test frames. Figure 1 contains a photograph of a test specimen consisting of poured rice hulls. Figure 2 contains a photograph of the crushed pecan shells in a thermal test frame. The k_a data, therefore, were obtained at “poured” density.

Resistance to smoldering combustion [6] and critical radiant flux [7] were measured by RDS for both materials using test methods developed primarily for cellulosic insulation. The rice hulls were tested by RDS for moisture vapor sorption [8], corrosiveness [9], odor emission [10], and resistance to fungal growth [11]. A vibration test was performed by RDS to determine a candidate settled density for the rice hulls. Two specimens of poured rice hulls were subjected to 24 hours of vertical vibration at 15 Hertz and 2.5 mm vertical amplitude. The average density of the rice hulls after the vibration test was 158.5 kg/m^3.

Table I contains a list of tests that were completed for the two materials. The tests completed for pecan shells were limited since the density for this material is greater than normally accepted for building insulation.

Table I. List of Measured Properties

	Pecan Shells	Rice Hulls	ASTM Test Method
Thermal conductivity	X	X	C 518
Settled density		X	none
Smolder combustion	X	X	C 739 (sect. 14)
Moisture vapor sorption		X	C 739 (sect. 12)
Corrosiveness		X	C 739 (sect. 9)
Odor emission		X	C 739 (sect. 13)
Resistance to fungal growth		X	C 1338
Critical radiant flux	X	X	E 970
Flame spread index		X	E 84

Figure 1. Photograph of Rice Hull Thermal Test Specimen

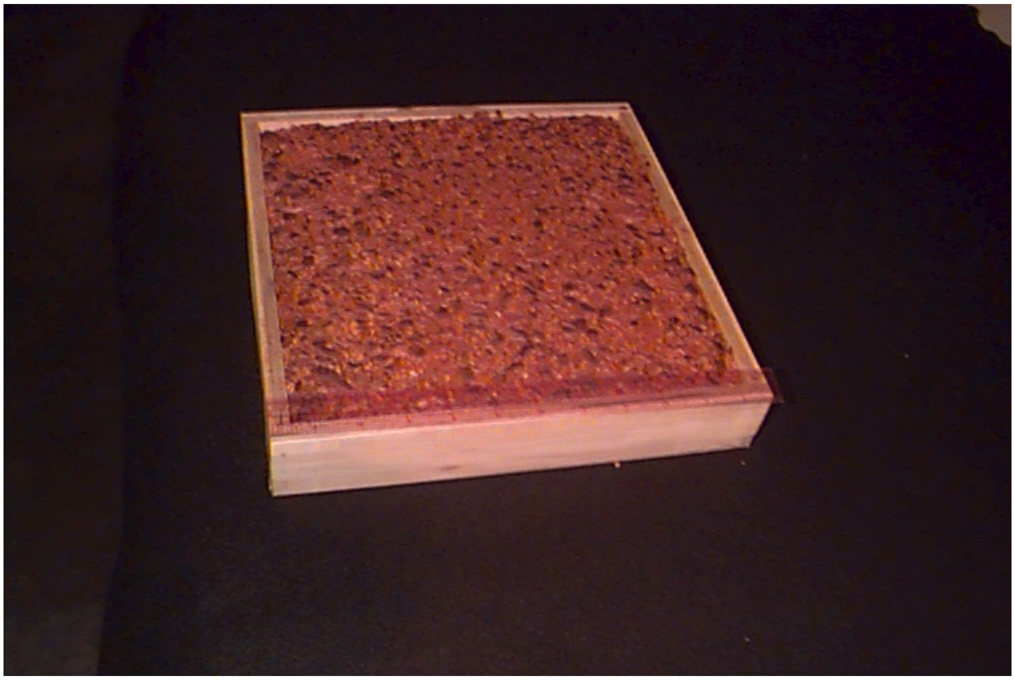

Figure 2. Photograph of Crushed Pecan Shell Thermal Test Specimen

THERMAL TEST RESULTS

Table II contains k_a for crushed pecan shells from the measurements at ORNL. The apparent thermal conductivity on the as-received pecan shells at 680.8 kg/m^3 and 23.9 ºC indicates that some drying likely occurred between the measurements. The repeatability of the k_a measurements for crushed pecan shells at 599.1 kg/m^3 (dry material) and 23.9 ºC is excellent. Repeated measurements yielded the same result.

Table III contains k_a data for rice hulls from measurements at both laboratories. There was also indication of drying during the k_a measurement of as-received rice hulls at 23.9 ºC. The repeatability of the rice hull measurements on dry material was excellent as demonstrated by two k_a measurements at 153.8 kg/m^3 and 23.9 °C that differed by about 0.4%.

Table II Apparent Thermal Conductivity for Crushed Pecan Shells from ORNL

Temperature (ºC)	k_a@ 680.8 kg/m^3 (W/m·K)	k_a@ 599.1 kg/m^3 (W/m·K)
7.2	0.0964	0.0849
15.5	0.0996	0.0866
23.9	0.1030	0.0884
32.2	0.1073	0.0900
40.5	0.1124	0.0917
23.9	0.1016	0.0884

Table III Apparent Thermal Conductivity Data for Rice Hulls from Two Laboratories

Temperature (º C)	Density (kg/m^3)	k_a (W/m·K)	Laboratory
7.4	153.8	0.0441	ORNL
15.5	153.8	0.0452	ORNL
23.9	153.8	0.0464	ORNL
32.2	153.8	0.0476	ORNL
40.6	153.8	0.0484	ORNL
23.9	153.8	0.0462	ORNL
7.3	168.2	0.0488	ORNL
15.6	168.2	0.0510	ORNL
23.9	168.2	0.0532	ORNL
32.2	168.2	0.0552	ORNL
40.6	168.2	0.0561	ORNL
23.9	168.2	0.0496	ORNL
23.9	144.3	0.0566	RDS
23.9	139.4	0.0477	RDS
23.9	155.4	0.0493	RDS
23.9	147.5	0.0490	RDS

Figure 3 contains a comparison of k_a for "conditioned" rice hulls at 24 ºC as a function of density. Data from both laboratories are included in the figure. Figure 4 shows the variation of k_a with temperature for oven-dry rice hulls and crushed pecan shells. As expected, the k_a increases with increasing temperature for both materials. The slope based on the ORNL data is observed to be 1.3x10^{-4} W/m·K per °C for rice hulls and

2x10^{-4} W/m·K per °C for crushed pecan shells. The average density for the specimens tested at RDS at a mean temperature of 24 ºC was 146.6 kg/m^3. If the differences in density are ignored, then the difference in k_a from the two laboratories is about 6%.

The rice hulls are a better candidate for building thermal insulation than crushed pecan shells because of the lower k_a and lower density. As a result, the k_a data for rice hulls are compared with k_a data for coconut fiber [12], sugar cane fiber [13], and spray-applied cellulose insulation [14] in Figure 5. The three agricultural fibers have k_a between 0.045 and 0.060 W/m·K while the k_a for cellulose is significantly lower. The six k_a values for rice hulls at 23.9 ºC for dry or conditioned material average 0.049 W/m·K at an average density of 149 kg/m^3.

ADDITIONAL TEST RESULTS FOR RICE HULLS AND PECAN SHELLS

The crushed pecan shells passed the test for resistance to smoldering combustion. They did not ignite during the critical radiant flux test or the smoldering combustion test. This material, therefore, was judged to pass both tests. No other tests were done because of limited interest in this material due to high k_a and density.

The k_a data for parboiled rice hulls suggest the possibility of using this material for building thermal insulation applications. Because of this, several commonly applied tests for cellulose insulation were completed for the rice hulls. The results of these tests are listed in Table IV. These tests were done with the same lot of material used by RDS for thermal measurements. The results in Table IV indicate that rice hulls satisfy important requirements for use of the material as a building thermal insulation.

.

Table IV. Test Results for Rice Hulls

Test	Result	Conclusion
Critical radiant flux	0.29 W/cm^2	Pass
Smoldering combustion	0.04 wt % loss	Pass
Moisture vapor sorption	3.23 wt % gain	Pass
Corrosiveness	no holes	Pass
Odor	no perceptible odor	Pass
Flame Spread	10	Class A
Smoke developed	50	Class A

CONCLUSIONS

Crushed pecan shells were found to have k_a at 24 °C in the range 0.088 to 0.103 W/m·K. The higher k_a is for the "as-received" material while the lower k_a is for the dry material. The range is too high for much interest in this material for building thermal insulation applications.

Measurements from two laboratories showed that dry rice hulls at 24°C to have k_a in the range 0.046 to 0.057 W/m·K. The k_a for rice hulls is comparable in magnitude with k_a for coconut fiber or sugarcane fibers, but higher than that of cellulosic insulation. The average k_a for dry rice hulls at 24 ºC was found to be 0.049 W/m·K at an average density of 149 kg/m^3.

The rice hulls performed satisfactorily in seven tests commonly required of building thermal insulations. These results combined with good thermal performance suggest that rice hulls can be considered for building thermal insulation applications.

ACKNOWLEDGEMENTS

This project was funded by Riceland Foods, Inc. located in Stuttgart, AR, Engineering, Separation, & Recycling Company located in Washington, LA and the U.S. Department of Energy Office of Building Technology, State, and Community Programs under contract number DE-AC05-000R22725 with the Oak Ridge National Laboratory, managed by UT-Battelle, LLC. The authors acknowledge and appreciate the constructive reviews by Therese K. Stovall and Thomas W. Petrie of ORNL.

REFERENCES

1. Olivier, Paul A. , "The Rice Hull House", Engineering, Separation, & Recycling, Washington, LA (2003).
2. Yarbrough, D.W., and K.E. Wilkes, "Thermal Properties and Use of Cellulose Insulation Produced from Recycled Paper", Proceedings Number 7286, Forest Products Society (1996) pp. 108-114.
3. Manohar, K., D.W. Yarbrough, and G.S. Kochhar, "Building Thermal Insulation-Biodegradable Sugarcane and Coconut Fiber," *J. of Thermal Envelope and Building Science* 23 (3) 263-276 (2000).
4. Manohar, Krishpersad and David W. Yarbrough, "A Comparison of Biodegradable Fiber Insulation with Conventional Insulation", *Proc.of the International Conference on Thermal Insulation* 18 133-140 (2003).
5. ASTM C 518, "Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus" , 2002 Annual Book of ASTM Standards, Vol. 04.06 (2002) pp. 156-167.
6. ASTM C 739-00, "Standard Specification for Cellulosic Fiber (Wood-Base) Loose-Fill Thermal Insulation", 2002 Annual Book of ASTM Standards, Vol. 04.06 (2002) Section 14.
7. ASTM E 970-00, "Standard Test Method for Critical Radiant Flux of Exposed Attic Floor Insulation Using a Radiant heat Energy Source", 2002 Annual Book of ASTM Standards, Vol. 04.07 (2002)
8. loc. cit. 6. Section 12
9. loc. cit. 6. Section 9
10. loc. cit 6. Section 13
11. ASTM 1338, "Standard Test Method for Determining Fungi Resistance of Insulation Materials and Facings", 2002 Annual Book of ASTM Standards, Vol. 04.06 (2002) pp 221-223.
12. Manohar, Krishpersad and David W. Yarbrough, "A Comparison of Biodegradable Fiber Insulation with Conventional Insulation", *Proc. of the International Conference on Thermal Insulation* 18 133-140 (2003)
13. Yarbrough, David W., K.E. Depew, and S. Rashid, "The Thermal Resistance of Spray-Applied Cellulosic Insulation as a Function of Density and temperature", *Proc. of the International Conference on Thermal Insulation* 6 22-34 (1990).

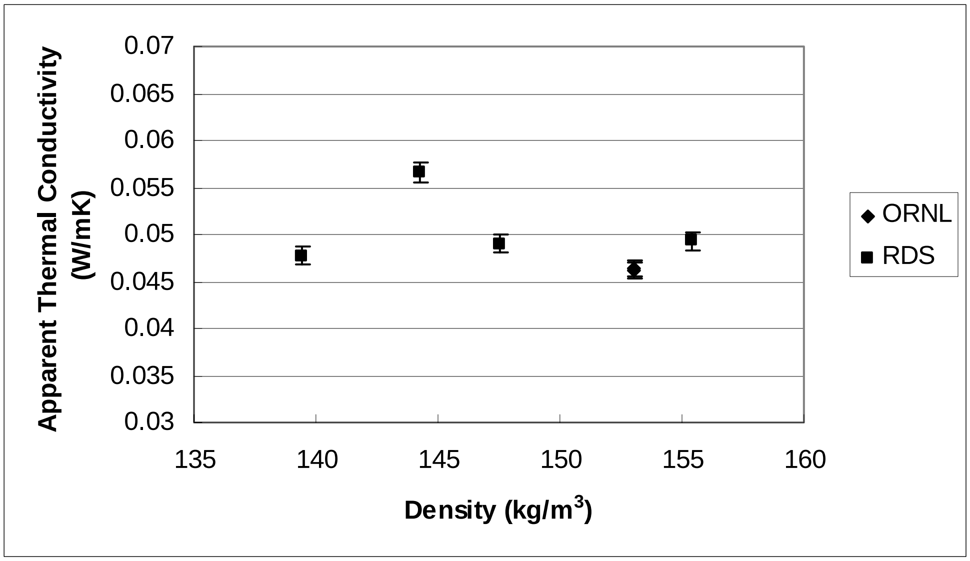

Figure 3. Apparent Thermal Conductivity at 24 °C for Rice Hulls

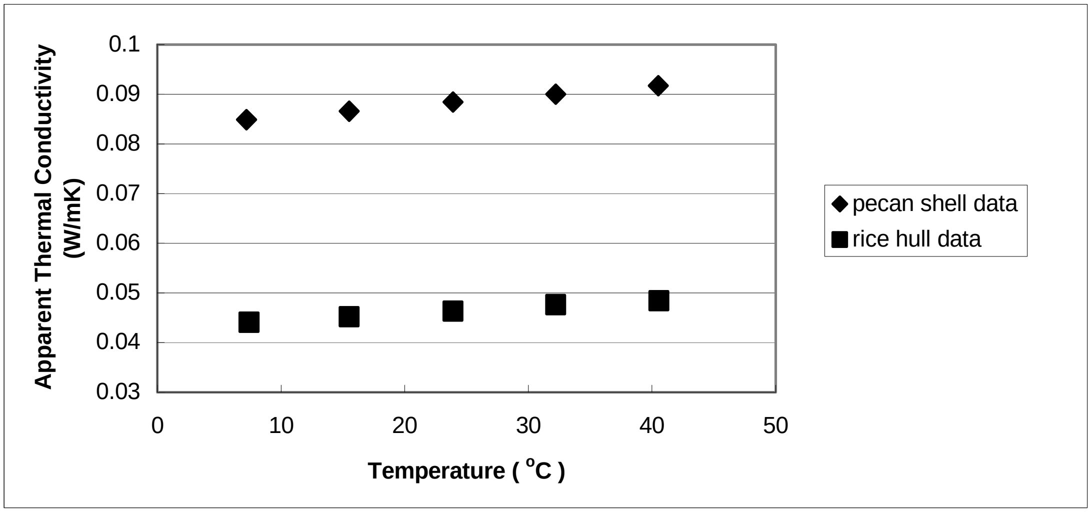

Figure 4. Apparent Thermal Conductivity of Dry Material

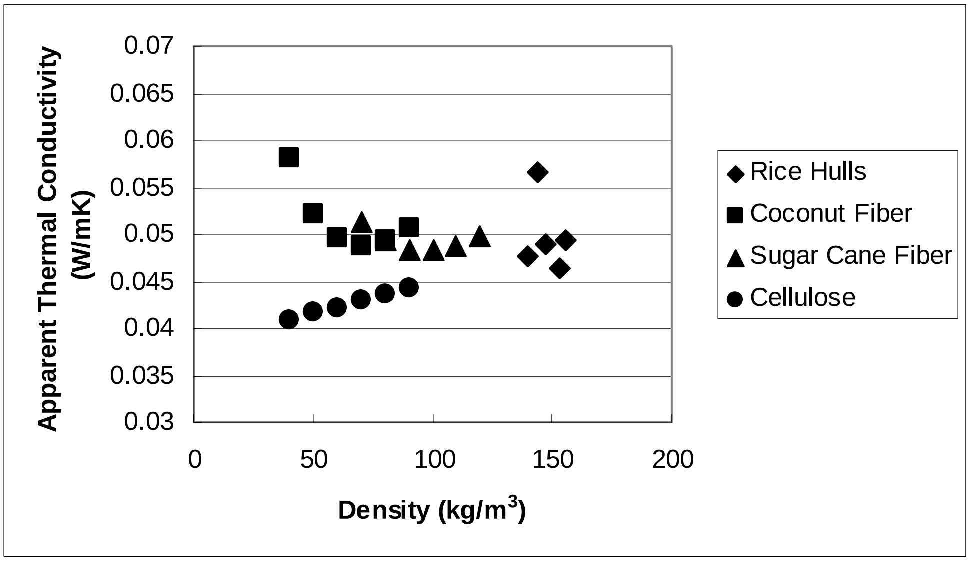

Figure 5. Apparent Thermal Conductivity at 24 °C for Four Materials