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# Effects of Water to Rice Ratio and Bulk Density on the Thermal Conductivity of Cooked Rice

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**Abstract**

To investigate the effect of bulk density on the thermal conductivity of cooked rice, short grain rice (Japonica) was cooked with various water to rice ratios (WR; 1.4, 1.5 and 1.6) using an electric rice cooker. The bulk densities ($\rho$, kg/m$^3$) of cooked rice were adjusted to 800, 900 and 1000 kg/m$^3$, for three types of cooked rice; *Deunbob* (WR=1.4, moisture content M=60.4%), *Bob* (WR=1.5, M=62.5%) and *Jinbob* (WR=1.6, M=65%), respectively. The thermal conductivities (k, W/mK) of the cooked rice samples were measured at various temperatures (t, °C). The thermal conductivities of *Deunbob, Bob* and *JinBob* were in the range of 0.167~0.306, 0.170~0.331, and 0.244~0.383 W/mK for bulk density of 800, 900 and 1000 kg/m$^3$, respectively. The thermal conductivities were linearly proportional to the bulk density of cooked rice for given water ratios and temperatures; the empirical equation was found to be $k= 0.016834\ M+0.000481\ \rho+0.001254\ t-1.28872$ ($r^2$=0.935). The correlation could yield closer estimation of thermal conductivity for *Bob,* compared to other types of cooked rice, due to the irregular porous structure of *Jinbob* and *Deunbob.*

Key words: cooked rice, thermal conductivity, density, water to rice ratio

## Introduction

Rice cooking method at kitchen in the Far East is well established and its commercial products are expanding in food market. Cooked rice is classified into 3 groups depending on its moisture content (M); *Jinbob* with high M, *Bob* with moderate M and *Deanbob* with low M. The moisture content of cooked rice is generally determined by the ratio of water to rice (WR) in cooking process. The textural properties of cooked rice such as stickiness, adhesivness and hardness are influenced by water ratio employed (Lee *et al.*, 1995). After cooking, cooked rice mass is rearranged to a loose packing to serve as meal or for a lunch box. It is often pressed to form rice roll along with laver sheet to make *Gimbob*, which is one of the popular prepared lunch in the Far East. Thermal property of cooked rice is an important factor to solve the problems faced at the distribution and storage of the products.

Several researchers (Chang and Chun, 1982; Biliaderis *et al.*, 1986; Yoon, 1994) reported thermal properties of rice grain and rice starch. Moisture content, density and temperature of cooked rice are the factors affecting thermal properties, and moisture content is known as the major process variable in the rice cooking process (Wallapapan *et al.*, 1984; Choi, 1986; Drouzas and Saravacos, 1988). In general, the thermal conductivity of foods appeared to increase linearly as bulk density increased, and interrelated moisture content with bulk density of foods (Sweat, 1986; Farrall *et al.*, 1970; Chang, 1986). Uniform thermal property of cooked rice, therefore, is not applicable to rice products with different bulk texture at various moisture contents and temperatures. This study is aimed to find out the effects of the bulk density and storage temperatures of cooked rice on their thermal conductivities.

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## Materials and Methods

### Rice cooking

Rice (Japonica) was cooked with an electrical rice cooker (NDA-187A, Samsung, Korea) at three levels of water addition ratios (WR); 1.4, 1.5 and 1.6. After cooking, the massive cooked rice was loosened by turning up and cured for 10 min prior to the measurement of thermal properties. On the basis of water ratio, three types of cooked rice were defined as *Deunbob* (WR=1.4), *Bob* (WR=1.5), and *Jinbob* (WR=1.6). The moisture content of *Deunbob*, *Bob* and *Jinbob* were 60.4, 62.5, and 65%, respectively.

### Measurement of thermal conductivity

The thermal conductivity of cooked rice was determined by the probe method (Biliaderis *et al.*, 1986). The stainless steel pipe (OD: 60.5 mm, ID: 57.3 mm, 2500 mm long) with Teflon screwed caps was used for the sample container. The heating source probe was fabricated with a stainless steel tubing (OD: 2.3 mm, ID: 1.7 mm, 214 mm long) using Ni-Cr wire (12.876 Ω/m, OD: 0.3 mm) with Teflon tube insulation (OD: 0.5 mm). The calibration constant and time correction factor were determined with glycerol (0.284 W/mK at 20°C) by method of Rizvi and Mittal Time correction factor was obtained to be 1.68 (±0.20) from a linear regression line with correlation coefficients 0.996. Calibration constant was calculated to be 0.922 (Rizvi and Mittal, 1992).

The sample container was loaded with cooked rice to have three levels of bulk density; 800, 900 and 1000 $kg/m^3$, and then the heat source probe was inserted into the center of sample. The measurements of thermal conductivity were conducted at 30, 40, 50, 60 and 70°C (Chang and Chun, 1982.). Temperature was measured with T-type thermocouple (0.5 mm diameter) with hybrid recorder (HR-2300, Yokogawa, Japan). Moisture measurement of cooked rice was carried out by conventional oven method at 105°C.

## Results and Discussion

### Effect of bulk density on the thermal conductivity of cooked rice

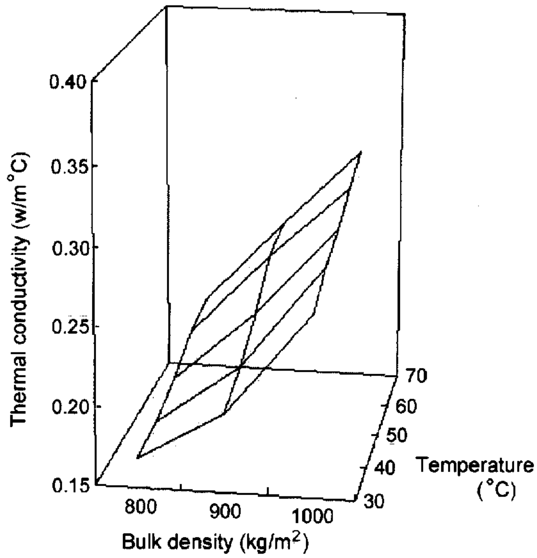


**Fig. 1. Effects of density and temperature on the thermal conductivity of Deunbob.**

As shown in Figure 1, the thermal conductivity of *Deunbob* increased from 0.167 to 0.306 W/mK as increasing temperature and bulk density. As increasing density of cooked rice from 800 to 1000 $kg/m^3$, its thermal conductivity is increased to 1.5 times higher than that of low bulk density. Thermal conductivities at 70°C, the highest storage temperature of the cooked rice in a electrical rice cooker, was 1.3 times higher than that at a low temperature, 30°C.

The thermal conductivities of *Bob*, most common type of cooked rice, ranged from 0.170 to 0.331W/mK as temperature and bulk density increased. For *Jinbob*, high moistured sample showed increase from 0.244 to 0.383 W/mK, in the same condition of *Bob* as shown in Figure 2.

Based on these results, the density is proved to be the most predominant factor among process variables tested. Comparing data with in literature, our data is lower, and it is probably caused by the differences in bulk density of samples employed (Chang and Chun. 1982).

### Estimation of thermal conductivity of cooked rice

From the relationship among thermal conductivity (k, w/m°C), moisture content (M, %DB) and bulk density(, $kg/m^3$) and temperatures (t, °C), a correlation equation could be established as described in Equation (1).

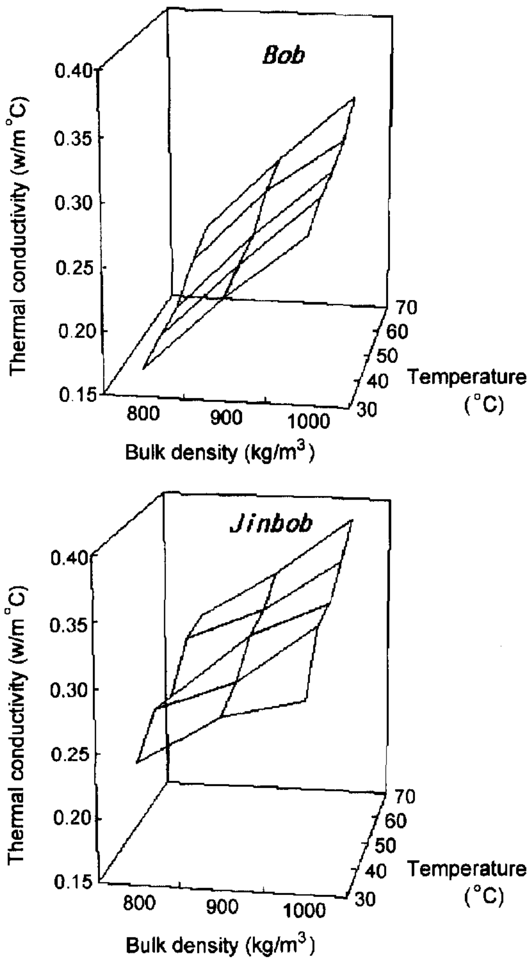


**Fig. 2. Effects of density and temperature on the thermal conductivity of *Bob* and *Jnbob*.**

$$k=0.016834M+0.000481+0.001254t-1.28872 \qquad (1)$$

The higher determination coefficient (0.935) was obtained with higher bulk density above 900 kg/m$^3$ due to the relatively homogeneous porous structure of *Bob*.


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## References


Lee, Y.J., S.W. Hwang, Y.S. Park, W.J. Yoon and J.K. Chun. 1995. Measurement of hardness and adhesiveness of cooked-rice. *J. Korean Agr. Chem. Soc,* **38**(5): 398-402

Chang, K. S. and J. K. Chun. 1982. Studies on the Thermal Properties of Foods. I. Thermal properties of some korean foods. *Korean J. Food Sci. Technol.,* **14**(2):112-121

Biliaderis, C. G., Page, C. M., Maurice, T. J. and B. O. Juliano. 1986. Thermal Characterization of rice starches; a polymeri approach to phase transitions of granular starch. *J. Agric. Food Chem.* 34(1): 6-11

Yoon, J. 1994. Effective thermal conductivity of rice starch. *Korean J. Food Sci. Technol.,* **26**(1): 1-5

Wallapapan, K., V. E. Sweat, J. A. Arce and P. F. Darm. 1984. Thermal diffusivity and conductivity of defatted soy flour. *Trans. of the ASAE.* **29**(5): 1610-1613

Choi, Y. H. 1986. Effects of temperature and composition on the thermal conductivity and thermal diffusivity of some food components. *Korean J. Food Sci. Technol.,* **18**(5): 357-363

Drouzas, A. E. and G. D. Saravacos. 1988. Effective thermal conductivity of granular starch materials. *J. of Food Science.* **53**(6): 1795-1799

Sweat, V. E. 1986. Thermal properties of foods in *Engineering Properties of Foods.* M. A. Rao and S. S. H. Rizvi.. Marcel Dekker, Inc., New York, NY., p49-87

Farrall, A. W., A. C. Chen, P. Y. Wang, A. M. Dhanak, T. I. Hedrick, and Heldman, D. R. 1970. Thermal conductivity of dry milk in a packed bed. *Trans. of the ASAE.* **13**(3): 391-394

Chang, C. S. 1986. Thermal conductivity of wheat, corn and grain sorghum as affected by bulk density and moisture content. *Trans. of the ASAE.* **29**(5): 1447-1450

Rizvi, S. S. and G. S. Mittal. 1992. Experimental methods in food engineering. *Van Nostrand Reinhold Inc,* New York., pp129-140