J. Agr. Sci. Tech. (2012) Vol. 14: 975-984

Thermal Conductivity of Feed Pellets

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ABSTRACT

Application of feed pellets in animal and aquatic farming industries has grown because of both the physical and the nutritional benefits it provides. Development of feed pellets manufacturing industry is also considerable. Steam conditioning process, which plays an important role in pelleting production, includes heating feed particles, adding moisture, and mixing the mash. Pellets cooling and drying processes are also involved in heat transfer phenomena. In this study, thermal conductivity of feed pellets was determined at different temperatures ranging from 25 to 85°C and moisture contents of 11.8 to 18.2% wb. It was measured by the transient technique using the line heat source method assembled in a thermal conductivity probe. It turned out that decreasing moisture contents from 18.2 to 11.8% (wb) produced non-linear reduction in thermal conductivity. The average values of thermal conductivity changed from 0.1509 to 0.2143 W m^{-1} °C^{-1} at different moisture contents. Tests conducted on two pellet size categories (based on nominal diameter) revealed a significant difference in thermal conductivity between these categories. The thermal conductivities of the first category (minor than nominal dia.) appeared to be 8.5% higher than those of the second category (superior to nominal dia.). Average values of thermal conductivity changed from 0.1538 to 0.2333 W m^{-1} °C^{-1} for the first category and from 0.1235 to 0.2456 W m^{-1} °C^{-1} for the second category (in 25°C). In addition, some empirical models were developed to express thermal properties as a function of moisture content and temperature.

Keywords: Feed pellets, Line heat source method, Thermal conductivity.

INTRODUCTION

Feeding pelleted diet has grown in animal husbandry as well as aquaculture industries. Feed pellets manufacturing factories are developed in Iran. Today, pelleting is widely used because of both the physical and the nutritional benefits it provides. The physical benefits include improved ease of handling, reduced ingredient segregation, increased bulk density, and less feed wastage. Moreover, feeding pelleted diet improves animal performance and feed conversion compared with feeding a meal form diet (Behnke, 1996). Pelleted diets can affect animal performance in a variety of ways such as reducing selective feeding, lowering time and energy for prehension, thermal modification of starch and protein, etc. Many factors such as diet formulation, particle size, conditioning, die specification, and cooling and drying affect pellet quality. Steam conditioning plays an important role in pelleting process (Gilpin *et al.,* 2002). In general, the main objective of conditioning process includes heating feed particles, adding moisture, and mixing. In a conditioner, temperature is relatively easy to control with steam typically added. Conditioner discharge temperatures between 76 to 85°C are common. Temperatures have to be controlled carefully to prevent harm to heat-sensitive vitamins and amino acids (Kannadhason *et al.,* 2008). The temperature must be quickly reduced to ambient temperature or less and the moisture level reduced to 10-12% or less for proper storage

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and handling. Pellets must therefore be cooled and dried. Thermal conductivity of pellets is an important property that must be taken into consideration in calculations relating to the rate of heat transfer throughout conditioning, drying, and cooling (Bhadra *et al.,* 2010).

In mathematical terms, thermal conductivity, denoted by *k*, is the proportional factor in Fourier's law describing steady-state conduction of heat (Mohsenin, 1980):

$$q = kA\frac{dT}{dx} \qquad (1$$

Where, q is the thermal energy flow per unit time, A is the cross-sectional area, T is temperature and x is the distance in the direction of heat flow.

Methods of measurement of k can be divided into two broad categories: those using the steady-state condition of heat transfer and those using the unsteady state. The latter have been found more suitable for biological materials, which are generally heterogeneous and have high moisture content, whereas, the steady-state method requires a long time to reach a steady state and moisture migration may introduce significant measurement errors. The unsteady-state methods of thermal conductivity measurements make use of either a line source of heat or one or more plane sources of heat. In both categories, the procedure is to apply a steady heat flux to the medium that must be in thermal equilibrium initially, and to measure the temperature rise resulting from the applied flux at a certain point in the medium. The line heat source method is one of the most commonly used unsteady-state methods, particularly with granular materials (Yang *et al.*, 2003).

The line heat source method uses either a bare-wire type apparatus or a thermal conductivity probe (Van Gelder, 1998). A line heat source (no mass and no volume) is placed in an infinite conduction heating, homogeneous medium having a uniform initial temperature distribution with constant thermal conductivity. Heat is generated along the line source at a constant rate (Wang and Hayakawa, 1993). This method estimates the thermal conductivity based on the relationship between the sample core temperature and the heating time. In principle, the heat is generated in a hot wire at a rate q in W:

$$q = I^2R \qquad (2$$

Where, I is the electric current in A and R is the electric resistance in Ω m^{-1}. For a long cylindrical sample, where the end effects and the mass of the hot wire can be neglected, when the sample is homogeneous and isotropic, heat conduction in the sample is governed by the following equation (in cylindrical coordinates), assuming that k remains constant (Incropera and DeWitt, 2006):

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{\partial T}{r\partial r}\right) \qquad (3$$

Where, T is the sample temperature anywhere in the cylinder in °C, t is the time in s, r is the radial axis in *m*, and α is the thermal diffusivity in m^2 s^{-1}. The solution to Equation (3) is (Suter *et al.,* 1975):

$$T = \frac{Q}{2\pi k}\int_{\beta}^{\infty}\frac{\exp(-x^2)dx}{x} \qquad (4$$

Where, β is a dimensionless parameter equals to $r/(2\sqrt{\alpha t}$ and x is the variable. The solution to Equation (4), which is a definite integral, is (Yang *et al.,* 2002):

$$T - T_0 = \frac{q}{2\pi k}F(rn) \qquad (5$$

Where, T_0 is the initial sample temperature, n is an intermediate variable and

$$F(rn) = A - \ln(rn) + \frac{(rn)^2}{2} + \frac{(rn)^4}{4} + ... \quad (6$$

$$n = \frac{1}{2}(\alpha t)^{-1/2} \qquad (7$$

Where, A is a constant. If the product of r and n is very small, namely, *a* negligibly small value for r and a large value for t, Equation (6) can be approximated by the first two terms:

$$T - T_0 = \frac{q}{2\pi k}[A - \ln(rn)] \quad (8$$

$$T - T_0 = \frac{qA}{2\pi k} - \frac{q}{2\pi k}\ln(\frac{1}{2}r\alpha^{-1/2}) + \frac{q}{4\pi k}\ln(t) \quad (9$$

Equation (9) shows a linear relationship between *$(T$-$T_0)$* and *ln(t)* with the slope *S= q/(4πk).* The slope S can be obtained from the experimental data of *$(T$-$T_0)$* versus *ln(t)* by linear regression, and the thermal conductivity can then be calculated from the linear slope *S* (substituting $q= I^2R$):

$$k = \frac{I^2 R}{4\pi S} \quad (10$$

Due to non-ideal conditions during the experimental trials, such as non-zero mass and volume of the hot wire, heterogeneous and anisotropic properties of biological materials, finite sample size, and axial heat flow (Mohsenin, 1980; Suter *et al*., 1975; Wang and Hayakawa, 1993), temperature rise *$(T$-$T_0)$* versus *ln(t)* does not always follow a linear regression relationship. This calls for correction during data analysis. The most commonly used method for data correction is the time-correction factor method, which minimizes the non-linearity of the *$(T$-$T_0)$* versus *ln(t)* curve by subtracting a factor from the time elapsed. Considering the time correction factor (t_0) in Equation (9):

$$K = \frac{q}{4\pi}\left[\ln\left(\frac{t_2 - t_0}{t_1 - t_0}\right) / (T_2 - T_1)\right] \quad (11$$

Where, t_0 is the time correction factor. Thermal conductivity of many foods and agricultural products such as pistachios (Hsu *et al.,* 1991), peanuts (Suter *et al*., 1975), rough rice (Morita and Singh, 1979), rapeseeds (Moysey *et al.,* 1977), cumin seed (Singh and Goswami, 2000), corn grain(Kustermann *et al.,* 1981), chickpea (Sabapathy and Tabil, 2004), borage seeds (Yang *et al.,* 2002), frozen meats (Kumcuglu *et al.,* 2010) was studied using line heat source method. The results have shown that the thermal conductivities determined by this method are more accurate than the steady-state condition methods.

The objective of this study was to determine the thermal conductivity of feed pellets as a function of pellet moisture content and temperature. The study consisted of two parts. The first part was conducted to investigate the effect of temperature and moisture content of pellets on thermal conductivity. The other part aimed to measure the thermal conductivity and its variations with moisture content in two categories of feed pellets selected based on nominal diameter.

MATERIALS AND METHODS

Sample Preparation

The feed pellets with 18.2% initial moisture content (wb) were obtained from Pars Animal Feed Co. in two nominal diameters: 4 and 8 mm. The specification of utilized die in pelleting process i.e., holes diameter, overall die thickness and depth of relief, determine the final pellet size and characteristics. The crude fat/oil, protein, and starch contents were 1.53, 8.55, and 65.63%, respectively. The pellets had an initial bulk density of 644 kg m^{-3} and an average pellet length of 10.5 mm (Standard deviation= 1.2 mm). The samples were prepared by drying pellets in a laboratory scale hot-air dryer of the "static-tray type" at 40ºC (Tahmasebi *et al.,* 2011). The pellets were conditioned to four different moisture contents, namely, 11.8%, 13.5%, 15.1%, and 16.4%. Moisture content was determined for randomly selected pellets according to S269.4 method (ASAE, 2002). The samples were then stored at 4ºC before testing.

Probe Design and Construction

One of the key parameters for proper probe design is its dimensions. Despite the practical limitations in this case, it is important to know what should be the minimum ratio of length to diameter, L/d, in order for the conditions of radial heat flow and negligible axial heat flow to be valid. Considering the heater wire, temperature sensor and connection wires diameters, a steel hollow cylinder (outer diameter 8 mm and thickness of 1 mm) was used for probe assembly. Assuming a probe length of 56 cm, the ratio of length to diameter would be 70, which is acceptable according to recommendations of some researchers such as Christoffel and Calhaem (1979). In order to calculate the maximum error due to axial heat flow, the following expression can be used (Mohsenin, 1980):

$$(\Delta R)_{max} = \left[\frac{5.64}{\lambda} + 6.8\times10^{-3}\sigma\lambda(\varepsilon-\eta)\right]e^{-0.01\lambda^2} \quad (12$$

Where, $(\Delta R)_{max}$ is maximum relative error, λ is length to outside diameter ratio (L/d), σ is four times the proper wall thickness divided by the outside diameter (for hollow probes), ε is ratio of thermal conductivity of probe to thermal conductivity of external medium (K_1/K_2), and η is ratio of conductivity to diffusivity of probe (k_1/α_1) to conductivity to diffusivity of external medium (k_2/α_2). Substituting L/d= 70, σ= 0.5, ε= 70, and η= 5.25; the maximum percent error is found to be $(\Delta R)_{max} < 1\times10^{-18}$ that is very small and insignificant. Bare constantan wire (diameter 0.7 mm and resistance of 26.67 Ω m^{-1}) with insulation stripped at both ends was utilized as the heater wire. A temperature sensor (RTD) was inserted into the probe to half its length. Then, the tube was filled with high thermal conductivity paste material. The heater wire and the sensor were insulated from each other. The heater wire was fed through the steel tubing until it emerged from the paste at the opposite end. One end of the heater wire that emerged from the tubing was crimped and soldered to the tip of the tubing. The other end of the heater wire was attached to the power supply. A piece of heat shrink was attached to the end of the tubing to hold the heater and the sensor in place. A diagram of the assembled probe is shown in Figure 1.

The wires connecting the heater in the probe were plugged into a power supply set with a constant current supply of 0.575 A. Temperature data was recorded at every 0.25 second interval by data logger device (Kasra Electronics, Inc.). A schematic diagram of the instrumentation for measuring thermal conductivity is shown in Figure 2.

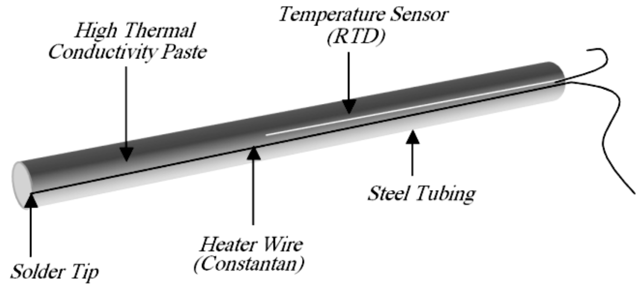

Figure 1. Assembled probe for thermal conductivity measurement.

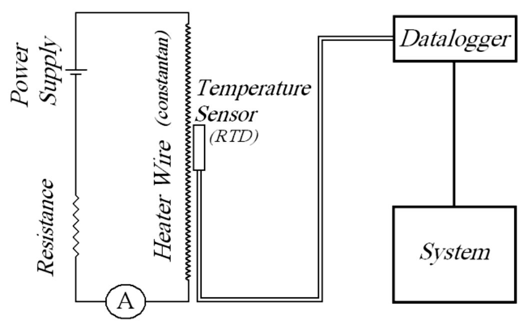

Figure 2. Schematic diagram of the thermal conductivity measurement.

The components of the system for thermal conductivity measurement consisted of the power supply, thermal conductivity probe and the data logger. The heater wire of the probe was connected to the power supply and the temperature sensor was connected to the data logger. The time-temperature data was monitored using the data logger.

Determination of Time Correction Factor

As mentioned before, a time correction coefficient is required in order to get compensation for non-ideal conditions during the experimental trials, such as non-zero mass and volume of the hot wire, heterogeneous and anisotropic properties of biological materials, and finite sample size. To determine the time correction factor**,** the temperature rise (T) versus time (t) was plotted on arithmetic scales. Next, the instantaneous slope, *dt/dT*, was taken at several different times from this plot. Then, the *dt/dT* values against time were plotted on arithmetic scales. Finally, the intercept of the best straight fit line was read as time correction factor (Figure 3).

Thermal Conductivity Measurement of Feed Pellets

Thermal conductivity measurements were conducted in triplicate at some stage in two factorial experiments based on completely randomized design (CRD). In the first experiment, thermal conductivity was measured within the temperature range of 25°C to 85 at 15°C intervals for 11.8, 13.5, 15.1, 16.4%, and 18.2% wb moisture contents. The pellets tested for thermal conductivity at different temperature ranges were allowed to equilibrate in the respective chamber before the experiments were conducted. A two-way ANOVA test was performed to analyze the thermal conductivity dependence on temperature and moisture content (temperature, 5 levels fixed; moisture content, 5 levels fixed). In the second experiment, thermal conductivity of the two feed pellet categories for different moisture contents was studied. Another two-way ANOVA test was also performed to analyze the thermal conductivity dependence on pellet size (nominal diameter) and moisture content (pellet size, 2 levels fixed; moisture content, 5 levels fixed). Before performing the analysis, the variance homogeneity was assessed by Cochran's test. All statistical tests and correlation analysis were made using the MSTAT-C statistics toolbox. In all cases, the significance level was fixed at $P< 0.01$.

RESULTS AND DISCUSSION

Figure 4 shows a typical temperature history curve for the feed pellets at 25ºC. It was observed that there was a rapid rise in temperature at the beginning and the curve

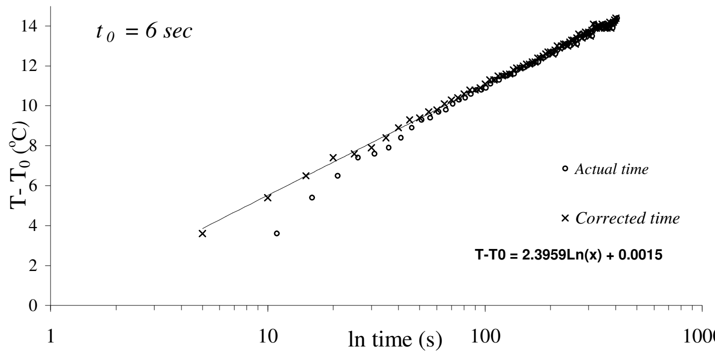

Figure 3. Temperature rise of heating element before and after correction.

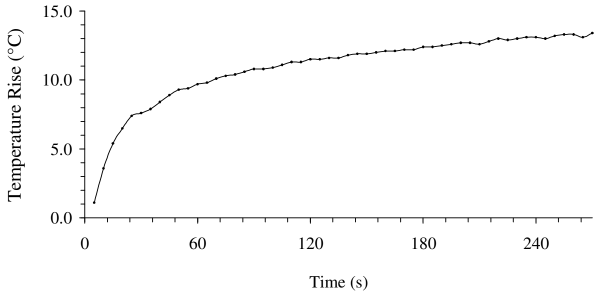

Figure 4. Typical temperature history curves during measurement of thermal conductivity.

leveled off to a plateau after a certain period of time. Data for thermal conductivity measurement of the feed pellets was collected at 1 second intervals for over 400 seconds. Heating was rapid for the first 200 seconds as shown in Figure 4. The rate of rise in temperature became constant.

The analysis of variance for thermal conductivity data (Table 1) showed that temperature and moisture content both significantly affected the thermal conductivity at 1% level. The interaction terms of temperature and moisture content (T×M) also significantly affected the thermal conductivity at 1% level. Table 2 shows the thermal conductivity mean values of feed pellets at moisture content of 11.8 to 18.2% wb, and temperature of 25 to 85°C.

The thermal conductivity of the feed pellets increased with increasing moisture content because of high thermal conductivity of water, ≈ 0.60 W m^{-1} $°C^{-1}$. The values of thermal conductivity for feed pellets ranged from 0.1235 to 0.2557 W m^{-1} $°C^{-1}$. The thermal conductivity of Kabuli chickpea for moisture content ranging from 7 to 25% wb, were reported to be 0.1535 to 0.3257 W m^{-1} $°C^{-1}$ by Sabapathy and Tabil (2004). The *k* values of Kabuli chickpea were slightly greater than that of the thermal conductivity values of the feed pellets. The thermal conductivity of the feed pellets was comparable with that of borage seeds (0.11 to 0.28 W m^{-1} $°C^{-1}$) at moisture contents from 1.2 to 30.3% wb, and

Table 1. Analysis of variance of thermal conductivity data.

Source	Degrees of freedom	Mean Square (10^{-4})	F	Probability
Temperature	4	95.462	3481.5	< 0.001
Moisture Content	4	110.67	4036.2	< 0.001
T × M.C.	16	0.903	32.9	< 0.001
Error	50	0.027		

Coefficient of Variation: 0.89%.

Table 2. Means comparison of the thermal conductivity (W m^{-1} $°C^{-1}$).

Moisture Content	Temperature (°C)					Average
(%wb)	25	40	55	70	85	
11.8	0.1235^{r}	0.1395^{q}	0.1495^{o}	0.1586^{n}	0.1836^{j}	0.1509^{E}
13.5	0.1449^{p}	0.1566^{n}	0.1629^{m}	0.1732^{l}	0.1943^{h}	0.1664^{D}
15.1	0.1663^{m}	0.1794^{k}	0.1893^{i}	0.2029^{g}	0.2342^{c}	0.1944^{C}
16.4	0.1765^{kl}	0.1891^{i}	0.2032^{g}	0.2204^{e}	0.2491^{b}	0.2077^{B}
18.2	0.1756^{l}	0.1937^{h}	0.2163^{f}	0.2301^{d}	0.2557^{a}	0.2143^{A}
Average	0.1574^{E}	0.1717^{D}	0.1842^{C}	0.1970^{B}	0.2234^{A}	0.1867

Values with the same superscript letter within rows and columns are not significantly different using least significant.

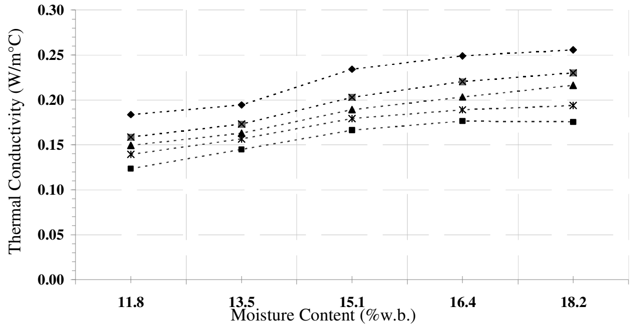

Figure 5. Thermal conductivity of pellets as a function of moisture content and temperature.

temperatures from 6 to 20°C (Yang *et al.,* 2002).

As shown in Figure 5, it was observed that the thermal conductivity increased with increase in moisture content and temperature. The magnitude and trend of the thermal conductivity of feed pellets versus increasing moisture content were in agreement with those from previous studies.

Deshpande and co-workers (1996) observed a linear increase in bulk thermal conductivity of soybean from 0.1157 to 0.1756 W m^{-1} $°C^{-1}$ at 27°C in the moisture content range between 8 and 25% w.b. Shepherd and Bhardwaj (1986) reported that the bulk thermal conductivity of pigeon pea linearly increased from 0.1358 to 0.1862 W m^{-1} $°C^{-1}$ in the moisture content range of 8 to 26% wb and temperature range of 10 to 40°C. The thermal conductivity of the feed pellets was comparable with that of whole rapeseed (0.108 to 0.155 W m^{-1} $°C^{-1}$) at moisture contents from 6.1 to 12.8% wb and temperatures in the range of 4.4 to 31.7°C (Moysey *et al.,* 1977). The thermal conductivity values of alfalfa cubes is higher than feed pellets and ranges from 0.31 to 0.48 W m^{-1} $°C^{-1}$ at 4.8 to 57°C (Khoshtaghaza *et al.,* 1995).

The variation of thermal conductivity with temperature and moisture contents is shown in Figure 6. It can be observed that the thermal conductivity increased with temperature at given moisture content and with moisture at a given temperature and followed second order polynomial relationship at all the moisture contents under study.

Empirical equations were developed to describe the combined effect of temperature and moisture content on thermal conductivity of the feed pellets. Equation (13) gives the linear relationship of temperature and moisture content with thermal conductivity (r^2= 0.95).

$K=0.03-(5.83\times10^{-5})T+(6.591\times10^{-3})$

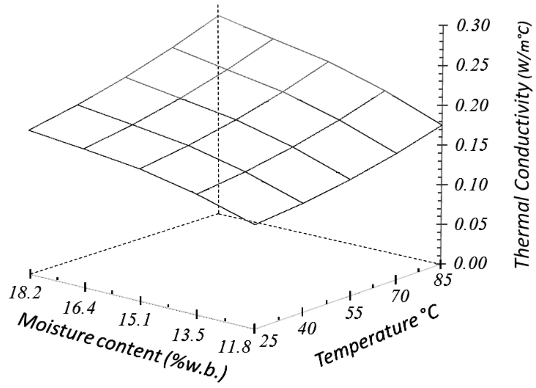

Figure 6. Variations in thermal conductivity of feed pellets with temperature and moisture content.

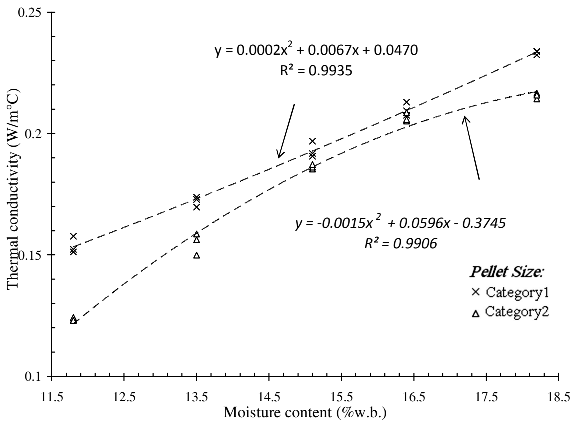

Figure 7. Thermal conductivity of feed pellets as a function of moisture content for two pellet size categories.

$M+(7.39\times10^{-5})TM$ (13

However, a small improvement in the coefficient of determination (R^2= 0.97) was obtained in the case of polynomial Equation (14).

$$K=-0.1374-(9.09\times10^{-4})T+(7.74\times10^{-6})T^2 (3.21\times10^{-2})M-(8.53\times10^{-4}T)M^2+(7.38\times10^{-5})TM \quad (14$$

The variation of thermal conductivity with size and moisture contents is shown in Figure 7. It can be observed that the thermal conductivity increased with moisture at a given size and followed second order polynomial relationship.

Table 3 shows the thermal conductivity mean values of feed pellets at moisture content ranging from 11.8 to 18.2% wb, for two size categories (based on nominal diameter). The thermal conductivity of the first category (minor than nominal dia.) was 8.5% higher than those of the second category (superior to nominal dia.). This difference may be attributed to the difference in total contact area between the pellets and the porosity of sample bulk.

Several empirical equations (linear and polynomial) were proposed to explain the effect of moisture content on thermal conductivity for both size categories. The regression equations are listed in Table 4.

Table 3. Means comparison of the thermal conductivity among the two size categories (W m^{-1} °C^{-1}).

Size	Moisture Content (%w.b.)					Average
	11.8	13.5	15.1	16.4	18.2	
Category1 (minor)	0.1538[g]	0.1721[f]	0.1931[d]	0.2099[c]	0.2333[a]	0.1925[A]
Category2 (superior)	0.1235[h]	0.1549[g]	0.1863[e]	0.2065[c]	0.2156[b]	0.1774[B]
Average	0.1386[E]	0.1635[D]	0.1897[C]	0.2082[B]	0.2244[A]	

Values with the same superscript letter within rows and columns are not significantly different using least significant difference test (LSD 0.05= 0.4241).

Table 4. The regression equations on the effect of moisture content on thermal conductivity.

Size	Relationship[a]	R^2	Eq. No.
Category1 (minor)	$K= 0.0044+0.0125M$	0.98	15
Category1 (minor)	$K = 0.0002M^2+0.0067M+0.0470$	0.99	16
Category2 (superior)	$K= -0.0473+0.0150M$	0.95	17
Category2 (superior)	$K = -0.0015M^2+0.0596M-0.3745$	0.99	18

[a] Where *k* is thermal conductivity (W m^{-1} °C^{-1}), and *M* is moisture content (%wb).

CONCLUSIONS

Thermal conductivity increased from 0.1509 to 0.2143 W m^{-1} °C^{-1} with increase in moisture content from 11.8 to 18.2% wet basis. It also showed a growth from 0.1574 to 0.2234 W m^{-1} °C^{-1} with increase in temperature from 25°C to 85°C. Its variation with temperature and moisture content was best represented by second order polynomials.

Thermal conductivity of feed pellets with minor nominal dia. appeared to be 8.5% higher than those of pellets with superior nominal dia. Average values of thermal conductivity changed from 0.1538 to 0.2333 W m^{-1} °C^{-1} for the first category and from 0.1235 to 0.2456 W m^{-1} °C^{-1} for the second category (in 25°C). Construction of thermal conductivity probe temperature sensors with higher accuracy (up to 0.01°C) is suggested. Another suggestion is to use longer time intervals.

ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of the Institute of Technical and Vocational Higher Education (ITVHE) of the Ministry of Jihad Agriculture**.** The Pars Animal Feed Co. technical assistance in this research is also acknowledged.

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ضریب رسانش گرمای قرص خوراک دام

ا. صادقی

چکیده

امروزه استفاده از خوراک دام بصورت قرص (پلت) در صنعت دام و آبزی‌پروری بدلیل مزایای فیزیکی و تغذیه‌ای آن افزایش یافته و صنعت تولید خوراک دام نیز رشد قابل ملاحظه‌ای داشته است. فرآیند پخت با بخار نقش مهمی در تولید خوراک دارد و شامل حرارت‌دهی، اضافه کردن رطوبت به مواد خام و مخلوط کردن آن است. همچنین فرآیندهای خشک و خنک کردن قرص‌های تولید شده نیز متضمن پدیده‌ی انتقال حرارت می‌باشد. در این پژوهش ضریب رسانش گرمای قرص‌های خوراک دام به عنوان تابعی از دما و رطوبت تعیین شد. بازهٔ رطوبتی قرص‌ها از ۱۱/۸٪ بر پایهٔ وزن تر تا ۱۸/۲٪ (رطوبت هنگام خروج از دستگاه قرص‌ساز) و بازهٔ دمایی از ۲۵ تا ۸۵ درجه سلسیوس متغیر بود. اندازه‌گیری ضریب رسانش گرما از تکنیک حالت گذرا و با استفاده از روش منبع خط گرما که درون کاوشگر ضریب رسانش گرما تعبیه شده بود انجام گردید. در این تحقیق معلوم گردید که کاهش رطوبت از ۱۸/۲٪ بر پایهٔ وزن تر به ۱۱/۸٪، منجر به کاهش غیر خطی در ضریب رسانش گرما می‌شود. این ضریب به طور متوسط از ۰/۱۵۰۹ تا ۰/۲۱۴۳ W/m°C برای بازه‌ی رطوبتی فوق تغییر نمود. آزمایش‌های انجام شده روی دو گروه از قرص‌هایی که بر اساس قطر نامی طبقه‌بندی شده بودند، حکایت از تفاوت معنی‌داری بین ضریب رسانش گرمایی این دو گروه داشت. آزمایش‌ها نشان داد که متوسط ضریب رسانش گرمایی گروهی از قرص‌ها که قطر نامی آنها کمتر است، ۸/۵٪ بیشتر از گروه دیگر (با قطر نامی بزرگتر) می‌باشد. ضریب رسانش گرما در دمای ۲۵°C برای گروه اول (با قطر نامی کمتر) به طور میانگین بین ۰/۱۵۳۸ تا ۰/۲۳۳۳ W/m°C و برای گروه دوم (با قطر نامی بزرگتر) بین ۰/۱۲۳۵ تا ۰/۲۴۵۶ W/m°C بدست آمد. همچنین چندین مدل تجربی از ضریب رسانش گرمای قرص خوراک دام به عنوان توابعی از دما و محتوای رطوبتی ارائه گردید.

[DOR: 20.1001.1.16807073.2012.14.5.14.2]