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Classification Index and Grade Levels for Energy Efficiency Classification of Agricultural Dryers in Korea

Chang Seop Shin[1], Jin Geun Park[2], Kyeong Uk Kim[1,3]*

[1]*Department of Biosystems and Biomaterial Science and Engineering, Seoul National University, Seoul, Korea*
[2]*Foundation of Agricultural Technology Commercialization & Transfer, Suwon, Korea*
[3]*Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, Korea*

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Abstract

Purpose: The objective of this study was to develop a classification index and the grade levels for a five-grade energy efficiency classification of agricultural dryers in Korea. **Methods:** The classification index and the grade levels were determined by using the performance test data published by the FACT over the last eight years to reflect a state of the art technology for agricultural dryers in Korea. The five grades were designed to have the classified dryers distributed normally over the grades with 15% for the 1st grade, 20% for the 2nd grade, 30% for the 3rd grade, 20% for the 4th grade and 15% for the 5th grade. **Results:** The classification index was defined as the total amount of fuel and electrical energy consumed per 1% of the wet basis moisture content evaporated from a unit mass of grain or agricultural crops during the drying process: 1 MT of paddy rice for grain dryers and 1 kg of red pepper for agricultural crop dryers as the standard mass. **Conclusions:** The grade levels for the five-grade energy efficiency classification of grain dryers, kerosene dryers, and electric dryers were proposed in terms of the classification index value.

Keywords: Agricultural dryers, Energy efficiency classification, Classification index, Grade levels

Introduction

In response to the rising cost of energy and demand for greenhouse gas reduction, energy efficiency classification of agricultural machines has received increased attention recently in Korea. Agricultural tractors and heaters were considered for the first time as the subject of the energy efficiency classification (Shin et al., 2012 and 2013).

Agricultural dryers have been the third largest consumer of tax-free fuel for agricultural use in Korea following the agricultural heaters and tractors. A total amount of 170,619 kL of kerosene was allocated for agricultural dryers in 2010, which constituted 8.8% of the total tax-free fuel for agricultural use (NACF, 2010). Two types of dryers are most commonly used for agriculture in Korea: dryer for paddy rice and dryer for agricultural crops such as pepper, tobacco etc. These dryers used kerosene as their fuels. Since 2006, many of kerosene dryers have been replaced by electric dryers because of reduced rate of electricity for agricultural use. As the end of 2012, population of agricultural dryers was estimated to be 77,136 for grain dryers, 207,808 for electric dryers and 92,000 for kerosene dryers, respectively (KSAM, 2013).

None of agricultural machines have been designated as the efficiency-controlled product by the government's energy program (MOTIE, 2012). However, some of agricultural machines are very likely to be designated as the efficient-controlled product in the near future. In response to such a foreseeable direction of government's energy policy, preparation for energy efficiency classification of agricultural dryers is needed in advance as those for tractors and agricultural heaters.

***Corresponding author:** Kyeong Uk Kim
Tel: +82-2-880-4602; **Fax:** +82-2-873-2049
E-mail: kukim@snu.ac.kr

The objective of this study was to develop a classification index and the grade levels required for energy efficiency classification of agricultural dryers. This is to reduce consumption of energy for agricultural use and encourage manufacturers to produce more energy-efficient agricultural dryers.

Materials and Methods

Classification index

Agricultural dryers use fossil fuel to heat air for drying and electricity to operate fans for air flow through the crops being dried. Their energy efficiency, therefore, can be generally expressed as the amount of energy required to evaporate a unit mass of water from the agricultural crops during the drying process. It depends on the dryer's performance, the weather conditions, the amount of agricultural crops dried, and the amount of energy consumed. In this study, specific energy consumption was proposed as the classification index, which can be defined as the total amount of fuel and electrical energy to evaporate 1% of the wet basis moisture content from a unit mass of grain or agricultural crops during the drying process; 1 MT of paddy rice for grain dryer and 1 kg of red pepper for kerosene and electric dryers as the standard mass. This can be expressed as

$$\text{EEI}=\frac{FtH_g+860E}{m(W_i-W_f)} \text{ for kerosene dryer and grain dryer} \quad (1)$$

$$\text{EEI}=\frac{860E}{m(W_i-W_f)} \text{ for electric dryer} \quad (2)$$

where, EEI = energy efficiency index, kcal/%kg
F = fuel consumption, L/h
t = drying duration, h
H_g = heating value of fuel, kcal/L
E = consumption of electrical energy, kWh
m = mass of crop to dry, kg or MT
W_i = initial moisture content in wet basis, %
W_f = final moisture content in wet basis, %

1 kWh of electrical energy equals to 860 kcal in equations (1) and (2). The classification index was then determined by using equations (1) for the grain and kerosene dryers and (2) for the electric dryers.

Classification and grade levels

A five-grade system was applied to the energy efficiency classification of agricultural dryers as did for the tractors and agricultural heaters. The five-grade system is also compatible with the grading system for the energy-related products of which efficiency is controlled by the Korean government. The classification was designed to have the classified dryers distributed normally over the five grades, resulting in 15% for the 1st grade, 20% for the 2nd grade, 30% for the 3rd grade, 20% for the 4th grade and 15% for the 5th grade in the order of efficiency. The normal distribution could be made by using the statistical method developed in the previous paper (Shin et al., 2012). Let $\triangle_i$ be a deviation of the index value of the ith dryer from the mean of the index distribution corresponding to the dryer having the same drying capacity defined here as a one-time drying mass. Let $\triangle_{avg}$ and $\sigma_\triangle$ be the mean and standard deviation of these deviations respectively. Then, the lower and upper limits for the five grade levels can be expressed as equation (3).

$$\begin{aligned}
&\triangle_i < \triangle_{avg}-1.0364\sigma_\triangle && \text{for the 1}^{st}\text{ grade}\\
\triangle_{avg}-1.0364\sigma_\triangle \le\ &\triangle_i < \triangle_{avg}-0.3853\sigma_\triangle && \text{for the 2}^{nd}\text{ grade}\\
\triangle_{avg}-0.3853\sigma_\triangle \le\ &\triangle_i < \triangle_{avg}+1.3853\sigma_\triangle && \text{for the 3}^{rd}\text{ grade}\\
\triangle_{avg}+0.3853\sigma_\triangle \le\ &\triangle_i < \triangle_{avg}+1.0364\sigma_\triangle && \text{for the 4}^{th}\text{ grade}\\
\triangle_{avg}+1.0364\sigma_\triangle \le\ &\triangle_i && \text{for the 5}^{th}\text{ grade}
\end{aligned} \quad (3)$$

Performance data of dryers

The grade levels must reflect a state of the art technology of agricultural dryers and be upgraded periodically as the technology advances. FACT (Foundation of Agricultural Technique Commercialization and Transfer) has tested performance of agricultural dryers in Korea. Until 2005 grain dryers were subjected to the performance testing and since then the safety inspection only. Performance of kerosene dryers were also tested until 2006. As electric dryers replaced most of kerosene dryers, performance testing has been conducted mainly on the electric dryers. The performance data of the agricultural dryers tested at the FACT included drying capacity, amount of agricultural crops dried, drying duration, fuel consumption, consumption of electrical energy, initial and final moisture contents measured by the official test code (FACT, 2012). These are considered as the most reliable data available in Korea. Table 1 shows number of dryer models of which performance data were used for the determination of the grade levels.

Results and Discussion

Classification index value

Using the performance data taken from the dryers given in Table 1, classification index values were calculated from equations (1) and (2) where 8200 kcal/L was used as a heating value H_g of kerosene (KIER, 2006).

Determination of grade levels

The scatter diagrams of the classification index values were obtained by plotting them as a function of drying capacity as shown in Figures 1, 2, and 3. The linear regression equations can be derived from each diagram and expressed as follows;

$$CI_m = -170.68C_a + 12854 \text{ kcal/\%MT for grain dryers}$$
$$CI_m = -0.0129C_a + 25.491 \text{ kcal/\%kg for kerosene dryers}$$
$$CI_m = 0.001C_a + 13.315 \text{ kcal/\%kg for electrical dryers} \quad (4)$$

where, CI_m = mean index value,
C_a = drying capacity, MT, kg

The regression equations give the mean classification index, CI_m of the dryers having a drying capacity of C_a. Let $\triangle_i$ be the deviation of the classification index CI of a dryer from the mean index CI_m of the same drying capacity, that is,

$$\triangle_i = CI - CI_m \quad (5)$$

Then, average $\triangle_{acg}$ and standard deviation $\sigma_{\triangle}$ of $\triangle_i$ can be calculated for each dryers as shown in Table 2.

Substituting the values of average and standard deviation given in Table 2 into equation (3) yields the upper and lower index values for the five grades of each dryer. In equation form, the grade boundaries can be expressed as follows:

Table 1. Number of tested agricultural dryer models used for determination of grade levels

Agricultural dryers	Number of models	Test year
Grain dryer	51	1997-2006
Kerosene dryer	49	1996-2005
Electric dryer	213	2008-2012

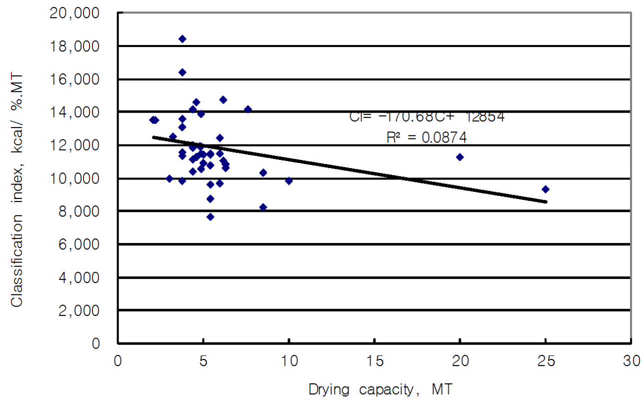

Figure 1. Scatter diagram of classification index for grain dryers.

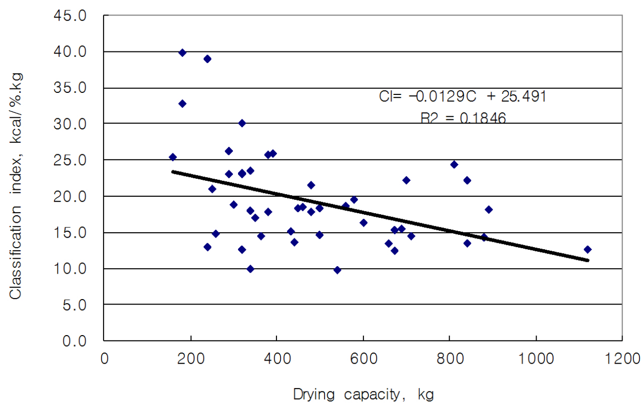

Figure 2. Scatter diagram of classification index for kerosene dryers.

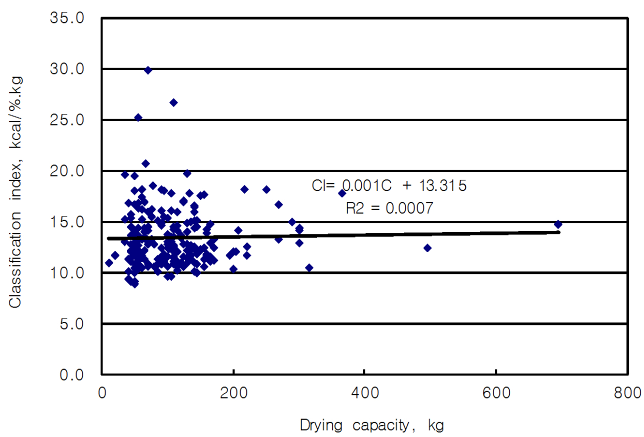

Figure 3. Scatter diagram of classification index for electrical dryers.

Table 2. The average $\triangle_{avg}$ and standard deviation $\sigma_{\triangle}$ for agricultural dryer models used for the determination of grade levels

Agricultural dryers	Average, $\triangle_{avg}$	Standard deviation, $\sigma_{\triangle}$
Grain dryer	-0.09406	2089.331
Kerosene dryer	0.02	5.89
Electrical dryer	-0.000775	2.902

Grain dryers

$$CI \le -170.68C_a + 10689 \text{ kcal/\%MT for the 1}^{st}\text{ grade}$$

$$-170.68C_a + 10689 < CI \le -170.68C_a + 12049 \text{ kcal/\%MT for the 2}^{nd}\text{ grade}$$

$$-170.69C_a + 12049 < CI \le -170.68C_a + 13659 \text{ kcal/\%MT for the 3}^{rd}\text{ grade}$$

$$-170.68C_a + 13659 < CI \le -170.68C_a + 15019 \text{ kcal/\%MT for the 4}^{th}\text{ grade}$$

$$-170.68C_a + 15019 < CI \text{ kcal/\%MT for the 5}^{th}\text{ grade}$$

Kerosene dryers

$$CI \le -0.0129C_a + 19.401 \text{ kcal/\%kg for the 1}^{st}\text{ grade}$$

$$-0.0129C_a + 19.401 < CI \le -0.0129C_a + 23.238 \text{ kcal/\%kg for the 2}^{nd}\text{ grade}$$

$$-0.0129C_a + 23.238 < CI \le -0.0129C_a + 27.78 \text{ kcal/\%kg for the 3}^{rd}\text{ grade}$$

$$-0.0129C_a + 27.78 < CI \le -0.0129C_a + 31.618 \text{ kcal/\%kg for the 4}^{th}\text{ grade}$$

$$-0.0129C_a + 31.618 < CI \text{ kcal/\%kg for the 5}^{th}\text{ grade}$$

Electric dryers

$$CI \le 0.001C_a + 10.307 \text{ kcal/\%kg for the 1}^{st}\text{ grade}$$

$$0.001C_a + 10.307 < CI \le 0.001C_a + 12.196 \text{ kcal/\%kg for the 2}^{nd}\text{ grade}$$

$$0.001C_a + 12.196 < CI \le 0.001C_a + 14.432 \text{ kcal/\%kg for the 3}^{rd}\text{ grade}$$

$$0.001C_a + 14.432 < CI \le 0.001C_a + 16.322 \text{ kcal/\%kg for the 4}^{th}\text{ grade}$$

$$0.001C_a + 16.322 < CI \text{ kcal/\%kg for the 5}^{th}\text{ grade}$$

where, CI = index value of a dryer, kcal/%MT or kcal/%kg
C_a = drying capacity of a dryer, MT or kg

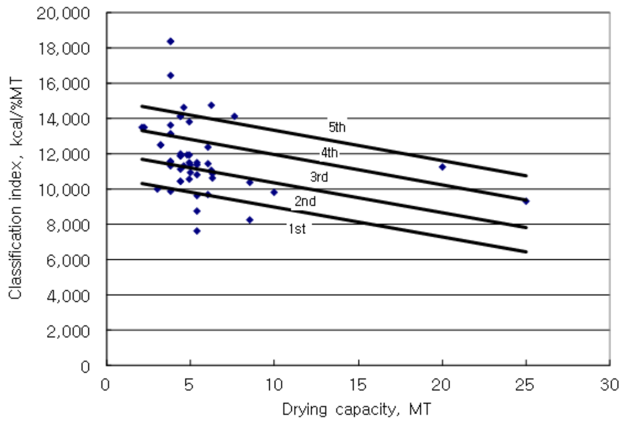

Figure 4. Upper and lower limits of the five grades for grain dryers.

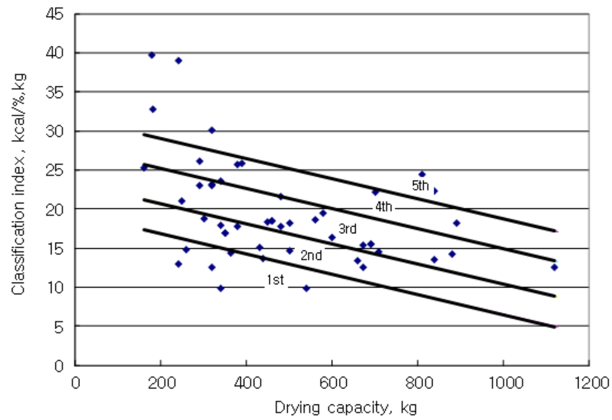

Figure 5. Upper and lower limits of the five grades for kerosene dryers.

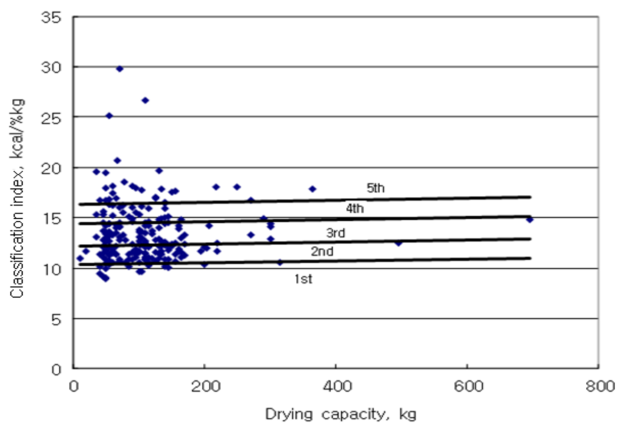

Figure 6. Upper and lower limits of the five grades for electrical dryers.

The upper and lower boundaries of the index values for the five grades are also depicted in Figures 4, 5, and 6. It was noted that the energy efficiency of the grain and kerosene dryers increases with drying capacity. However, the drying capacity of the electric dryers has little effect on the energy efficiency.

The above grade levels reflected the most recent performance data of agricultural dryers and can be used for the time being until they need to be upgraded. In other words, the grade levels should be upgraded periodically as the technology advances.

Summary and Conclusions

Agricultural dryers are the third largest consumer of tax-free fuels for agricultural use in Korea. Although none of agricultural machines have been designated as an efficiency-controlled product by the government, it is very likely that some of agricultural machines will be done so in the near future. In response to such an expansion of government's energy policy, energy efficiency classification of some agricultural machines needs to be prepared in advance.

This paper proposes a method of five-grade energy efficiency classification of agricultural dryers. The following are the results of this study.

(1) The classification index for agricultural dryers can be defined as the total amount of fuel and electrical energies to evaporate 1% of the wet basis moisture content from a unit mass of grain or agricultural crops during the drying process; 1 MT of paddy rice for grain dryer and 1 kg of red pepper for kerosene and electric dryers as the standard mass.

(2) A five-grade system can be applied to the energy efficiency classification of agricultural dryers where the classified dryers are distributed normally over the grades with 15% for the 1st grade, 20% for the 2nd grade, 30% for the 3rd grade, 20% for the 4th grade and 15% for the 5th grade in the order of efficiency.

(3) The performance data of agricultural dryers tested and published by the FACT are the most reliable data available in Korea that can be used to determine the grade levels for the classification.

(4) Using the most recent performance test data published by the FACT, the upper and lower boundary values of the five grades were calculated and proposed.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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