Kinetic Friction Coefficient and Factors Affecting Paddy Hulling

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Abstract

Paddy hulling is operated by Thai farmers in a manner that the rotating machine is dependent on the principle of transferring potential energy to kinetic energy. The original machine was constructed, and particularly required to husk paddy and importantly developed to determine the kinetic friction coefficient of a new machine. Three types of surface materials (phenolic discs, polyamide discs and hardwood discs) were designed, tested and then compared to paddy hulling while the moisture contents were adjusted and maintained to constant points. This investigation was plenned for the designed machine to measure forces, determine kinetic friction coefficients and factors affecting paddy hulling while the machine was operated. The experimental results of three moisture contents were about 11, 16 and 23 %w.b. of paddy types. The forces were measured to increase both the torques and the kinetic friction coefficient, but decreasing the percentage hulling as moisture contents were increased. The data comparisons of paddy hulling found that the kinetic friction coefficient of three types of surface materials averaged at 0.155-0.221, 0.214-0.288 and 0.189-0.246 for 11 to 23 %w.b. The results were used to find the important factors. Different results were due to the moisture contents of paddy grains and the contact between surface discs and paddy grains. The grains were hulled better within the ranges from 11 to 16 %w.b. than the 23 %w.b. of paddy types. The statistical values of the phenolic discs and the hardwood discs were 0.7 to 1.0 of the significance range with good relative data, except some of the percentage hulling data. However, results were observed that as the moisture contents increased, there was no effect on the friction coefficient for some paddy types. This was opposite to the percentage of hulling.

Keywords: phenolic discs, polyamide discs, hardwood discs, kinetic friction coefficient, paddies hulling.

1. Introduction

At present, Thai farmers are professing to do paddy farming. Its agricultural productions have been harvested (called paddy) and then hulled (called rice). The standard of rice, brown rice (cargo rice), means rice obtained from non-glutinous paddy or glutinous paddy of which only the husk has been removed. This includes its whole grain, head, big broken pieces, and small broken pieces [12]. For inspection, grading factors of paddy and rice were separated to determine qualities depending on moisture; impurities and foreign matter; seeds and foreign matter; red grains and streaks, chalky and immature grains, damaged grains, foreign grains, total and head rice milling yield in test milled rice [2]. The hulling was divided according to family and commercial machines were made up of rubber rolls to perform shearing, which differed in space rolls, diameters and speeds [4, 5, 8, 9, 13, 14].

Figure 1 shows background hulling with a family machine used by Thai farmers which was a rotating machine, which relied on the principle of transferring potential energy to kinetic energy for fixed rotation axis hulling [8]. The original machine that was used to husk paddy was newly designed and used by investigators to determine the kinetic friction coefficient of agricultural production. The usable testing consists of tilting of various angle planes for the static friction test or moving for the kinetic friction test.

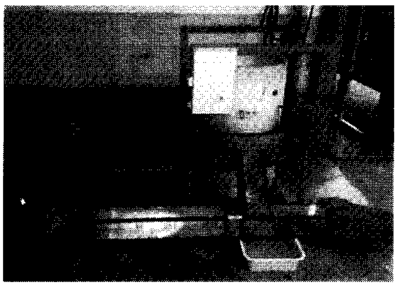
Figure 1. Original machine of Thai farmers

The research of various investigators employed facility with a transmission system to drive a table which moved linearly and horizontally at constant speed. The force requirement was measured by a transducer and connected to the cylinder stationary on moving surface. The results found that when moisture contents were increased the static friction coefficient decreased for soybeans on sheet metals. On the other hand, for both soybeans on sheet plywood and shelled corn on sheet metal, the results found that when the moisture content of grains increased the static friction coefficient also increased. Increasing the moisture content of grains, such as shelled corn, tended to lead to higher kinetic friction coefficient than soybeans [3].

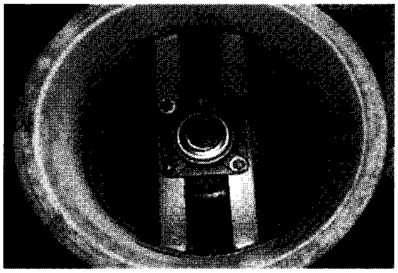
For investigated wheat on metal surfaces, it was found that both normal pressure and velocity have little affect on coefficients of kinetic friction. An increase of both relative humidity and moisture content of grains affected an increase of coefficient of kinetic friction [11]. To determine the friction coefficient, the static force was first measured with forces on the container transversely applied, and then the kinetic forces were also measured as read on a scale when its force was connected with rotating disc. It had been used to chop straw and hay under dry conditions, while it had also been used to chop grass and silage with high moisture contents. The results found that normal pressure had little affect on the static friction coefficient in dry conditions and there was no significant change in the kinetic friction coefficient for moisture conditions as well as dry conditions for chopped straw on steel at speeds to 30.5 m/s [10].

Investigation of the friction coefficients for paddy hulling was conducted for what was considered working forces for essential paddy hulling. Past research was involved in an improved machine for Thai farmers to decrease forces in paddy hulling. The experimental results showed that decreasing complete grain hulling caused moisture content of grains to decrease by favorable rotation of surface discs with moving air-velocities of 30 rpm and 9 m/s [5]. The investigation of surface materials involved effectiveness of paddy hulling. The additionally selected surface materials were phenolic (bakelite) and polyamide (nylon). The experimental results revealed that paddy hulling of coarse phenolic was close to wood. Polyamide was lower than wood and phenolic. It was believed that the friction coefficient affected paddy hulling as there were no different moisture contents [6]. Therefore, the purpose of this investigation was to plan on the designed machine to measure forces, determine the kinetic friction coefficients and factors affecting paddy hulling while the machine was operated.

2. Materials and Methods



(a) Main components of machine



(b) Top cylinder container

Figure 2. The experimental machine

Figure 2 shows the experimental machine which was designed to investigate and determine the kinetic friction coefficients and factors affecting paddy hulling. Figure 2 (a) shows the three main components of the machine and a top container as shown in Figure 2 (b). The working machine was driven with a transmission system of 0.5 hp and a rotation blower of 0.25 hp. The speeds of the motors were adjusted by an inverter for paddy hulling, brown rice and then husks were also separated.

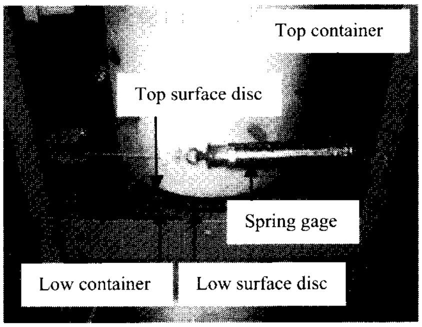
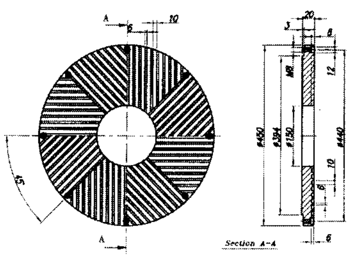
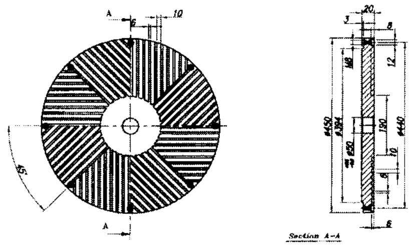


Figure 3. Setting and measuring friction forces

Figure 3 shows the experimental machine, in which each weight of paddy was replaced in the top container, and then rotation of a low container started. It was supported by a thrust ball bearing. The low surface disc was connected to a container. A top container was pulled by a wire which was connected with SYG 78095 force gage 20 kg (spring gage) to measure forces. The two rings of the container were dimensional specified by outside diameter and thickness of 450 mm and 40 mm, respectively. Three types of surface discs were used and made with phenolic (bakelite), polyamide (nylon) and hardwood which were dimensional specified as shown in Figure 4 (a and b).



(a) Drawing of top surface disc



(b) Drawing of low surface disc

Figure 4. Specification of surface disc

The frame of the experimental machine was designed with the transmission system to rotate the disc with two parts of a variable speed motor separated from the main frame of the machine. This determining speed was controlled at 30 rpm for the rotating low surface disc and moving air-velocities of 9 m/s in a square pipe of 120 x 120 mm and 1,200 mm in length. At the balance center, the main shaft was connected with the low surface disc. The side walls of the top container were essentially supported by the flanged bearing housings and the main shaft of 38 mm. It was machined to 25 mm in diameter to the balance center for paddy hulling.

The torque requirement can be calculated by a fundamental equation of friction forces, an observed on a scale of a force gage, multiplied by the 0.225 m moment arm. This coefficient of friction was calculated by a ratio of the friction forces to normal forces. A general equation can be written as [7]:

$$CF = \frac{T}{W R} = \frac{F}{W} \qquad (1)$$

where CF = friction coefficient
T = torque, kg-m
F = friction force, kg
W = normal force, kg
R = moment arm, m

The scale weight of paddy grains with top cylinder container was determined as normal forces. This required a scale weight equal to the original machine, which was operated by Thai farmers. The testing method was repeated with three replications per treatment of each paddy type: Phitsanulok 2, Pathum Thani 1 and Suphan

Buri 1. The moisture contents were tested by the air-oven method [2].

Powdered paddy samples (about 5 g with container) were placed in an electrical oven for 5 hours at 130 °c temperatures and removed into a desiccator immediately. The container plus dried samples were weighed and recorded [1, 2]. The percentage moisture contents were calculated on a wet basis (%w.b.) and algebraically, the equation can be written as [2]:

$$\%MC_{wb} = \frac{W_m}{W_t} \times 100$$

$$= \frac{W_m}{W_m - W_{dm}} \times 100 \qquad (2)$$

where $\%MC_{wb}$ = percentage moisture content on a wet basis

W_m = weight of moisture (H_2O) in the grain, g

W_t = total weight of the grain, g

W_{dm} = weight of dry matter in the grain, g

Three different moisture contents for each paddy type were used to investigate the kinetic friction coefficient. The moisture contents were later changed, by injecting with water to increase moisture contents and stored in a container. The moisture contents were maintained at constant points for about 2 to 3 days, and then the percentage moisture contents were calculated by Equation (2) on a wet basis with the air-oven method to determine percentage moisture contents. These percentage of moisture contents on a wet basis were 11.58, 16.67 and 22.93; 11.45, 16.80 and 22.84; 11.61, 16.60 and 23.00 for Phitsanulok 2, Pathum Thani 1 and Suphan Buri 1, respectively.

The data of each paddy type was tested and evaluated from 2 to 4 kg with a setting clearance of between 1.5 mm for the surface discs, uniformly calibrated 25.3, 26.3 and 27.3 kg. The top weight and measured force deflection from paddy hulling with previously specified speeds and air-velocities [5] were used to determine the torque and the kinetic friction coefficient by Equation (1). These results were then analyzed statistically.

3. Results and Discussions

The original results of the experimental machine as shown in Tables 1 to 3 were analyzed to find statistical correlations between moisture contents affecting the torque, the friction coefficient and percentage hulling. The results also showed the trend lines while using three types of surface discs, such as the phenolic (bakelite), the polyamide (nylon) and wood (hardwood), which were designed and made for essential testing.

Table 1. Torque, friction coefficient and hulling of the experimental machine with phenolic discs (density = 1,270 kg/m^3) by moisture content.

Paddy grains	MC (%w.b.)	T (kg-m)	CF (Kinetic)	Hulling (%)
Phitsanulok 2	11.58	0.765	0.134	38.00
		0.810	0.136	37.66
		0.868	0.141	33.00
	16.67	0.884	0.155	33.00
		0.990	0.167	39.00
		1.093	0.178	38.00
	22.93	1.221	0.214	25.50
		1.305	0.220	28.66
		1.440	0.234	22.50
Pathum Thani 1	11.45	0.823	0.144	32.00
		0.900	0.152	32.33
		1.003	0.163	27.50
	16.80	0.974	0.171	32.00
		1.019	0.172	40.00
		1.082	0.176	40.00
	22.84	1.183	0.207	20.00
		1.260	0.212	15.66
		1.390	0.227	17.75
Suphan Buri 1	11.61	0.992	0.174	42.50
		1.035	0.175	28.33
		1.125	0.183	39.00
	16.60	0.990	0.173	37.00
		1.048	0.177	35.00
		1.109	0.180	37.50
	23.00	1.318	0.231	29.00
		1.289	0.217	20.66
		1.395	0.227	19.00

Remark: Phitsanulok 2 : $T = 0.7381-0.0127MC+0.0017MC^2$, $R^2 = 0.8855$, SE = 0.0927 (Significance = 0.9569); $CF = 0.1225-0.0019MC+0.0003MC^2$, $R^2 = 0.9577$, SE = 0.0091 (Significance = 0.9786); $H = 3.5175+4.7249MC-0.1641MC^2$, $R^2 = 0.8113$, SE = 3.0346 (Significance = 0.5640)

Pathum Thani 1 : T = 0.9989-0.0281MC+0.0018MC^2, R^2 = 0.8289, SE = 0.0857 (Significance = 0.8255); CF = 0.1654-0.0044MC+0.0003MC^2, R^2 = 0.9364, SE = 0.0083 (Significance = 0.7098); H = -59.6199+12.3934MC-0.3942MC^2, R^2 = 0.8986, SE = 3.3329 (Significance = 0.6117)
Suphan Buri 1 : T = 1.8137-0.1115MC+0.0039MC^2, R^2 = 0.8787, SE = 0.0610 (Significance = 0.7942); CF = 0.3089-0.0192MC+0.0007MC^2, R^2 = 0.9629, SE = 0.0054 (Significance = 0.9938); H = 1.2473+5.1916MC-0.1848MC^2, R^2 = 0.6874, SE = 5.3213 (Significance = 0.9985)

Table 2. Torque, friction coefficient and percentage hulling of the experimental machine with nylon discs (density = 1,140 kg/m^3) by moisture content.

Paddy grains	MC (%w.b.)	T (kg-m)	CF (Kinetic)	Hulling (%)
Phitsanulok 2	11.58	1.237	0.217	15.50
		1.260	0.212	17.66
		1.305	0.212	20.00
	16.67	1.282	0.225	15.00
		1.363	0.230	17.33
		1.440	0.234	21.25
	22.93	1.543	0.271	9.00
		1.588	0.268	9.66
		1.768	0.287	9.50
Pathum Thani 1	11.45	1.215	0.213	13.00
		1.282	0.216	19.58
		1.395	0.227	28.75
	16.80	1.228	0.216	10.50
		1.289	0.217	20.66
		1.350	0.219	18.44
	22.84	1.543	0.271	6.50
		1.649	0.278	11.66
		1.780	0.290	7.00
Suphan Buri 1	11.61	1.154	0.202	23.00
		1.215	0.205	20.66
		1.372	0.223	19.25
	16.60	1.408	0.247	16.50
		1.469	0.248	24.66
		1.559	0.254	22.00
	23.00	1.768	0.310	8.00
		1.829	0.309	12.00
		1.923	0.313	9.00

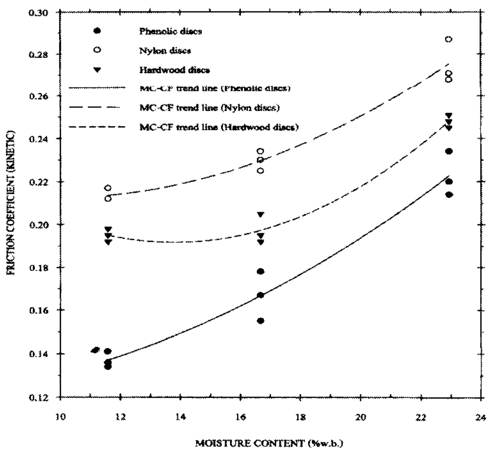
Remark: Phitsanulok 2 : T = 1.4747-0.0432MC+0.0022MC^2, R^2 = 0.8334, SE = 0.0849 (Significance = 0.9618); CF = 0.2479-0.0072MC+0.0004MC^2, R^2 = 0.9585, SE = 0.0067 (Significance = 0.9377); H = -6.0875+3.4650MC-0.1217MC^2, R^2 = 0.8233, SE = 2.2480 (Significance = 0.7102)
Pathum Thani 1 : T = 2.3714-0.1567MC+0.0055MC^2, R^2 = 0.8357, SE = 0.0933 (Significance = 0.9448); CF = 0.4000-0.0265MC+0.0009MC^2, R^2 = 0.9623, SE = 0.0070 (Significance = 0.8710); H = 18.3753+0.8018MC-0.0543MC^2, R^2 = 0.5336, SE = 5.7505 (Significance = 0.9959)
Suphan Buri 1 : T = 0.8777+0.0216MC+0.0009MC^2, R^2 = 0.9162, SE = 0.0904 (Significance = 0.7422); CF = 0.1445+0.0040MC+0.0001MC^2, R^2 = 0.9812, SE = 0.0070 (Significance = 0.7700); H = -9.6111+4.4646MC-0.1577MC^2, R^2 = 0.8361, SE = 2.9005 (Significance = 0.9930)

Table 3. Torque, friction coefficient and percentage hulling of the experimental machine with hardwood discs (density = 800 kg/m^3) by moisture content.

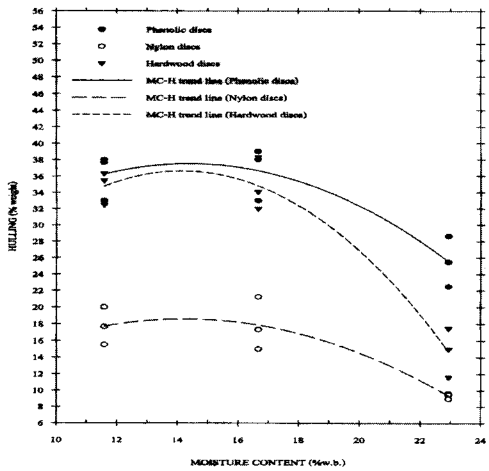
Paddy grains	MC (%w.b.)	T (kg-m)	CF (Kinetic)	Hulling (%)
Phitsanulok 2	11.58	1.093	0.192	35.50
		1.154	0.195	36.33
		1.215	0.198	32.50
	16.67	1.093	0.192	32.00
		1.154	0.195	38.33
		1.260	0.205	34.09
	22.93	1.395	0.245	11.66
		1.469	0.248	15.00
		1.543	0.251	17.50
Pathum Thani 1	11.45	1.093	0.192	34.50
		1.138	0.192	32.66
		1.244	0.202	30.00
	16.80	1.199	0.210	17.50
		1.260	0.213	29.66
		1.318	0.214	24.75
	22.84	1.350	0.237	11.00
		1.440	0.243	9.66
		1.543	0.251	12.75
Suphan Buri 1	11.61	0.913	0.160	42.50
		1.064	0.179	42.00
		1.221	0.198	42.00
	16.60	1.363	0.239	21.00
		1.424	0.240	27.33
		1.469	0.239	32.50
	23.00	1.395	0.245	13.50
		1.469	0.248	19.00
		1.543	0.251	14.50

Remark: Phitsanulok 2 : T = 1.8848-0.1090MC+0.0040MC^2, R^2 = 0.8529, SE = 0.0738 (Significance = 0.9448); CF = 0.3196-0.0185MC+0.0007MC^2, R^2 = 0.9766, SE = 0.0046 (Significance = 0.9448); H = -19.9653+8.0071MC-0.2832MC^2, R^2 = 0.9459, SE = 2.7717 (Significance = 0.9565)
Pathum Thani 1: T = 1.1433-0.0106MC+0.0010MC^2, R^2 = 0.7698, SE = 0.0793 (Significance = 0.9587); CF = 0.1929-0.0018MC+0.0002MC^2, R^2 = 0.9540, SE = 0.0054 (Significance = 0.9839); H = 41.0856-0.2053MC-0.0484MC^2, R^2 = 0.8843,

SE = 3.8705 (Significance = 0.9737)
Suphan Buri 1 : $T = -0.8173+0.2262MC-0.0055MC^2$, $R^2 = 0.8187$, SE = 0.1033 (Significance = 0.9652);
$CF = -0.1430+0.0387MC-0.0009MC^2$, $R^2 = 0.9196$, SE = 0.0111 (Significance = 0.4787);
$H = 99.3932-6.2428MC+0.1132MC^2$, $R^2 = 0.9269$, SE = 3.7346 (Significance = 0.6665)



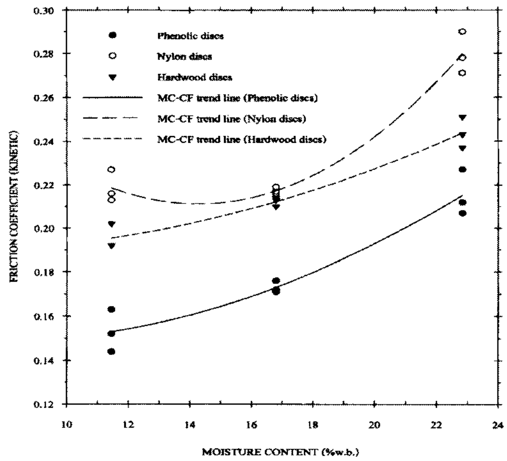
(a) Friction coefficient



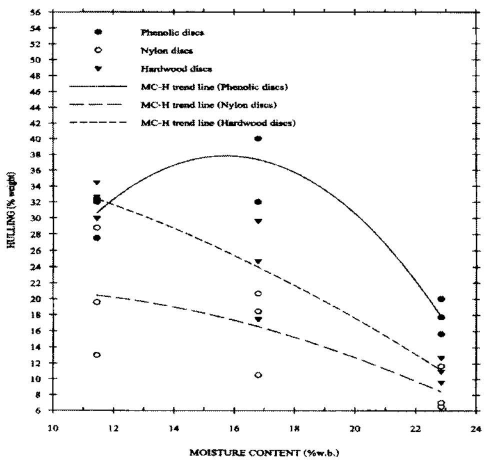
(b) Hulling

Figure 5. Relationship of moisture content to friction coefficient and hulling

The experimental results exhibited in Tables 1 to 3 of the Phitsanulok 2 type revealed that varied moisture contents and surface discs directly affected the friction coefficient, while friction forces caused an appreciable increase of the torques. It was possible that the moisture contents were highly increased with the adhesion of the paddy grains to the surface discs. The percentage hulling decreased due to higher cohesion of the bark to the brown rice. The percentage hulling exhibited with moisture contents about 11 to 16 %w.b. had a better percentage hulling than the 23 %w.b., which was close to the phenolic discs and the hardwood discs. The moisture contents were varied up to 23 %w.b. and the friction coefficient increased with increasing of the moisture contents, as shown in Figure 5. The friction coefficient of the phenolic discs exhibited good paddy hulling. The power of machine decreased for higher driving energy economization, when compared to the nylon discs or the hardwood discs.



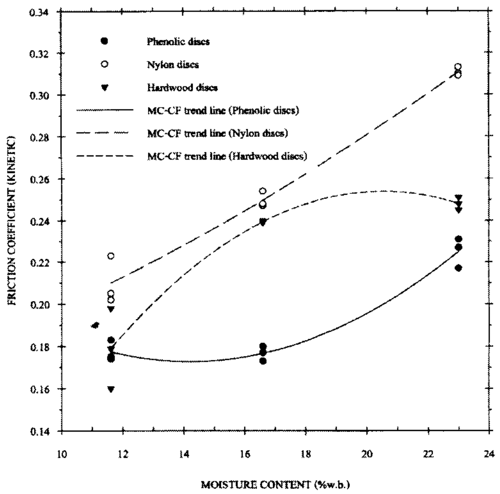
(a) Friction coefficient



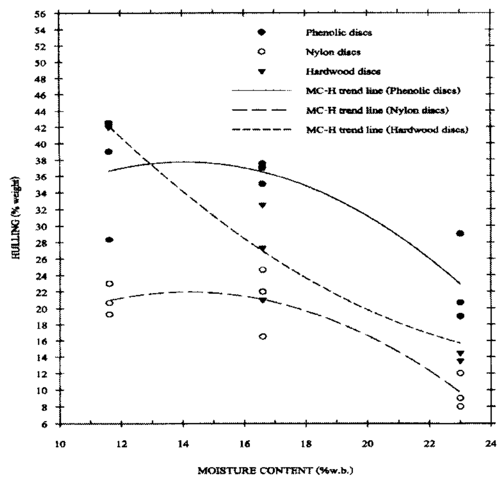
(b) Hulling

Figure 6. Relationship of moisture content to friction coefficient and hulling

The experimental results exhibited in Tables 1 to 3 of the Pathum Thani 1 type showed that Figure 6 was similar to figure 5 of the Phitsanulok 2 type. However, percentage hulling increased to about 16 %w.b. with the phenolic discs while normal decrease occurred in the hardwood discs and the nylon discs.



(a) Friction coefficient



(b) Hulling

Figure 7. Relationship of moisture content to friction coefficient and hulling

Figure 7 shows the experimental results exhibited in Tables 1 to 3 of the Suphan Buri 1 type. The phenolic discs had constant friction coefficients for moisture contents of 11 to 16 %w.b. The friction coefficient increased when the moisture contents were about 23 %w.b. The friction coefficients of the hardwood discs rose and then were constant. The nylon discs as shown in Figures 5, 6 and 7 exhibited high friction coefficients, but low percentage hulling. Nylon discs may not be appropriate for hulling.

The experimental results were used to find statistical correlations and plotted trend lines from average representation values of the three data points of dark circles, bright circles and dark triangles. The friction coefficient and the percentage hulling due to various moisture contents and materials are shown in Figures 5, 6 and 7. The phenolic discs and the hardwood discs have good relative data (R^2) within significance ranges of 0.7 to 1.0. The data comparison of three values revealed that differences in experimental results were due to physical properties of each paddy grains and characteristic contact between surface discs and paddy grains.

4. Conclusions

The designed machine was used to measure forces, determine kinetic friction coefficients and factors affecting paddy hulling while the machine was operated. Three types of surface materials (phenolic discs, polyamide discs and hardwood discs) were designed, tested and then compared for paddy hulling, while the moisture contents were adjusted. The experimental results were shown for three moisture contents (about 11, 16 and 23 %w.b. of paddy types). The forces were measured to increase both the torques and the kinetic friction coefficient. The percentage hulling decreased as moisture content increased. The friction coefficient values of the nylon discs (polyamide discs), the hardwood discs and the phenolic discs were directly opposite to the percentage hulling. The data comparisons of three values were determined to find important factors. Different results were due to the moisture contents of paddy grains and the contact between surface discs and paddy grains. The grains were hulled better within the ranges from 11 to 16 %w.b. of the percentage hulling than with 23 %w.b. paddy. The statistical values of the phenolic discs and the hardwood discs were 0.7 to 1.0 of the significance range and were good relative data, except some of the percentage hulling data.

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