次元解析方法에 의한 Thrower의 揚穀特性에 關한 硏究

Similitude Study on Grain Thrower

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要 約

本 論文은 Thrower의 揚穀性能에 關한 豫測 方程式을 次元解析法을 適用하여 誘導하는데 있다.

Thrower의 能率에 큰 영향을 미친다고 생각되는 因子들間의 關係式들을 Buckingham의 π理論에 依하여 求하여 졌으며 本硏究에 使用한 Thrower는 現在 農村에서 使用되고 있는 自動脫穀機의 Thrower와 類似한 型으로 製作된 것이며 實驗에 사용된 試料는 벼의 境遇는 통일벼와 미네히까리 品種이고 보리 品種으로서는 裸麥이며, Thrower의 Impeller 直徑, 速度 및 投入量을 變化시켜 가면서 各 試料에 對하여 揚穀높이를 測定하여 그 豫測方程式을 誘導하였다.

本 論文에서 얻은 結果는 다음과 같다.

1. Thrower의 揚穀性能에 至大한 영향을 미친다고 생각되는 主要 因子들을 Thrower의 揚程, impeller의 直徑과 速度, 投入量, 穀粒의 密度, 重力加速度等이라 看做하여 Buckingham의 π理論을 適用하여 이들에 關한 π項들을 決定하였으며 그 結果는 다음과 같다.

$$\pi_1=\frac{D}{H},\quad \pi_2=\frac{DN^{\frac{1}{2}}}{g^{\frac{1}{2}}},\quad \pi_3=\frac{Q}{g^{\frac{1}{2}}\rho D^{5/2}}$$

2. 實驗에 依하여 求해진 π項間의 關係式을 合成하여 Thrower의 揚穀性能에 關한 試料別 豫測方程式을 求하였으며 이 式들은 아래와 같다.

통 일 : $\pi_1=0.1223(\pi_2)^{-1.1813}\times(\pi_3)^{-0.1864}$

미네히까리 : $\pi_1=0.1185(\pi_2)^{-0.9663}(\pi_3)^{-0.1575}$

裸 麥 : $\pi_1=0.1599(\pi_2)^{-1.2350}\times(\pi_3)^{-0.1382}$

3. 現在 農村에서 使用되고 있는 自動脫穀機에 附着된 Thrower의 回轉數, Impeller의 直徑 및 投入量은 各各 1,100rpm, 30 cm 및 150gr/sec 程度로서 이와같은 水準의 變量들을 基礎로 하여 本 論文에서 誘導한 豫測方程式을 適用하여 Thrower의 揚程을 算出한 結果, 統一벼의 경우는 2.6m程度였고 미네

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히까리 品種과 裸麥의 揚程은 各各 2.4m, 2.9m 程度였다.

이와같은 事實로 부터 1m 內外의 揚程만으로 되어있는 自動脫穀機 Thrower 의 境遇 製作費절감, 所要動力 감소를 期하고 아울러 穀粒의 損傷을 줄이기 위해서는 設計 또는 作動條件의 變更을 通해 Thrower 의 回轉數를 現在 水準 以下로 줄일 必要가 있다고 判斷되었다.

I. Introduction

As the degree of mechanization in harvesting and processing of agricultural products advances, the importance of handling equipment increases accordingly. Handling equipment in common use may be classified as follows: belt conveyors, chain conveyors, screw conveyors, bucket elevaors, pneumatic conveyors, and throwers. Among these, thrower may be one of the conveyors extensively used on farm equipments because of its simple mechanism, relatively low cost, and low power requirement. The automatic thresher is an example of farm machinery equipped with thrower. It is used mostly for vertical movement of grains but can be used on any inclines except for the case to horizontal movement.

Thrower consists of feed hopper, impeller, casing, outlet pipe, and prime mover used for its operation. The performance of grain thrower may depend upon the factors, such as the size and speed of impeller, feed rate and material to be conveyed, and systematic combinations of these factors. Impeller speed is generally limited to reduce grain damage. Conveying rate of thrower should be adequate to handle the feeding rate of grains from the machine that functions as a system in connection with the thrower.

The design and operation of the thrower have been much depended upon the experience rather than science. The size and lifting height of throwers must be predicted within an allowable impeller speed and given feed rate for a rational design and selection of proper operational conditions. However, no work on the study of general functional relationships among these factors as a whole has been done so far, although there are a few papers that deals partially with these problems.

The dimensional analysis has been used as one of the powerful method of developing the general prediction equation. In this study, it will be demonstrated to develop the functional equation of thrower performance by use of the dimensional analysis.

(The objectives of this study were as follows)

1) to develop a general prediction equation among the major factors which affect the performance of grain thrower,
2) to determine the range of lifting height of the thrower used on automatic thresher within low rate of grain damage by applying the general prediction equation,

II. Review of Literature

The performance of handling equipments is measurably affected by the efficiency of the movement of grains from one unit operation to another. The importance of this movement of grains has been imposed on a function of its quality than a function of magnitude. Grains handling as recognized in general implies the movement of grains in any direction and elevation. In grain thrower, physical perperties of grain and aerodynamic characteristics of grain are considered important factors to affect on the lifting characteristics. Wratten[7] concluded that specific gravity for rough rice of medium and long grains was found to vary linearly with moisture content over the range of 12 to 18 per cent, wet basis. However, according to the relation developed by him, it is shown that the effect of moisture on the specific gravity within the range of moisture generally encountered in grain handling may be neglected for engineering purpose.

Investigating the particle separation within a pneumatic conveying system, Whitney[13] indicated that if physical properties of grains are such that the drag force is insufficient to overcome the gravitational forces, they drop to the hopper below.

Studying aerodynamic properties of Alfalfa Particles, Menzies[6] indicated that the suspension velocities of the stem could be expressed as a function of the weight of the particles, and be developed the differential equation of motion of a particle in an air-stream with the drag force in only the vertical direction.

Form this and other references[2,3,4] it can be understood that larger the projected area is, smaller the suspension velocity is. This means that the particle which has larger projected area could be lifted higher than one that has smaller projected area at the same weight of the particle.

Hawk[2] reported from the results of his study on the aerodynamic characteristics of selected farm grain that the air velocity is equal to the terminal velocity for the particle, since the forces acting on the body are in equlibrium when a kernel of grain is placed in a vertical airstream and the air velocity is adjusted until the kernel is suspended with no vertical movement. At terminal velocity, the drag force is numberically equal to the weight of the kernel in pounds. Terminal velocity increases as the weight of the particle increases, even if the particle volume remains constant.

Terminal velocity and the drag coefficient, are both functions of particle shape, and the Reynolds number. Drag coefficient decreases as the terminal velocity increases. Wheat and soybean kernels, for the most part, assumed a position with longest dimension of the kernels perpendicular to the air-stream, the kernels rotated about their long axis and would occasionally rotate about the two smaller axes.

Chancellor[16] indicated that, as the feed rate is increased, the pressure at the blower outlet decreases and the air velocity in the pipe increases.

Kiler[2] and others[3,8] concluded that the friction force between granular particles and ductwall could be neglected because the particles have much chances to move within the region with the high air velocity and made only occasional contact with the wall each other.

Henderson[14] explained that the relative size of particle to the solids-carrying-pipe diameter had very little effect on the flow rate. If the diameter of the granular particles is 0.04 times greater than the diameter of the orifice, a flow rate reduction may be experienced.

Chancellor[16] indicated that the air movement generated by an impeller blower, has been thought to influence the movement of solid materials, but it has been difficult to measure air movement under operating conditions because the solid interferes with the measuring instruments. Therefore, he derived three equations which depend upon the relative magnitudes of relative velocity between grains and air-stream, terminal velocity of grain, and grain velocity generated by impeller blower. He also concluded that when the particle moves through the pipe, particle velocity is influenced by two factors: the product of the acceleration of gravity and the time during which it acts and the force exerted between the air column and the particle.

It can be understood that lifting height of a certain particle is markedly affected by the terminal velocity of its particle. This reached almost the same conclusion as indicated above.

Nakagawa[23] developed the equation to calculate grain speed developed when leave at the impeller blade, which he referred to as the primary speed. Nakagawa compared the theoretical lifting height $Hs=V^2/2g$ with his experimental values, and stated that there were much differences between these two values.

The conveyance efficiency[20,24] in throwers was expressed by the percentage of energy required for grain conveyance to energy input to operate the impeller shaft. The conveyance efficiency increased as the carrying amount, and increased as the impeller speed up to about 800 Rpm above which the efficiency decreased gradually[20]. Nakagawa[20,24]reported that conveyance efficiency extremely low compared with that of other handling equipment, because of little difference of power input between on-load and no-load.

Irie Michio[18] indicated that the rate of damages of grain rose with increase of impeller speed, and decreased withi ncrease of moisture content of grains. Severe breakage grains occurred when impeller speed is over 1,100 Rpm by which dried rough rice at the moisture content of 13.9% were conveyed. In observing the relation between impeller-casing clearance and grain damages, the rate of damage was the lowest at the clearance about 3 mm. The number of impeller blade also affected the damage, four being more desirable than six. Irie Michio[21] concluded that the lifting height of 2 to 3 meters could be expected as the extent of the practical usage of the grain thrower with the proper impeller speed of about 700 Rpm. The air velocity in the outlet pipe of 12 to 13m/sec was the iowest value of the total pressure loss in the pipe.

Pickett[11] investigated that beans received less damage at higher cylinder speeds with the higher feed rates. He concluded that feed rate did affect the amount of mechanical damage to beans and the additional material provided either a cushion for the beans or more effective conveying through the combine. The critical impeller speed being used for lower moisture grains was found to be a little lower than one being used for higher moisture grains[20]

Ⅲ. Dimensional Analysis

1. The selection of the pertinent quantities to the grain thrower.

The selection of pertinent quantities is usually based on information in the literature of the related fields,and acknowledge of the fundamental equations which govern the phenomena. The common errors encountered at this stage are the inclusion of non-independent variables, and the omission of certain important quantities. With consideration of these points, the quantities pertained to the thrower performance are listed in the Table 1. However, the quantities which may be thought to have minor importance on this problem, such as friction between wall and material, shape factor of the material, size of pipe, and moisture content of materials, are excluded in this study.

Although the factors such as air velocity in the pipe, bulk density of material may be important on the thrower performance[18], those factors were also excluded because they are not independent quantities which could be expressed as the function of other quantities.

Table 1. Pertinent quantities to the grain thrower.

Number	Definition	Symbol	Unit	Dimension
1	Thrower hiead	H	cm	L
2	Impeller speed	N	Rpm	T^{-1}
3	Acceleraton of the gravity	g	cm/sec^2	LT^{-2}
4	Ture density of material	ρ	g/cm^3	LT^{-3}
5	Diameter of the impeller	D	cm	L
6	Feeding rate	Q	g/sec	MT^{-1}

2. Determination of Pi terms

The functional relationship between the thrower head H which was taken as primary quantity and the others given in Table 1, can be expressed as

$$H=f(N,g,\rho,D,Q) \qquad (1)$$

It should be formed in to three dimensionless and independent Pi terms, because,according to the Buckingham's π-theorem, there are six total quantities with three basic dimensions involved. Equation (1) may be written as

$$C\alpha(H)^{C_1}\cdot(N)^{C_2}\cdot(g)^{C_3}\cdot(\rho)^{C_4}\cdot(D)^{C_5}\cdot(Q)^{C_6}=1 \qquad (2)$$

where C_1, C_2, C_3, C_4, C_5 and C_6 are coefficients which make Equation (1) dimensional equality: The corresponding dimensional equation is

$$(L)^{C_1}(T^{-1})^{C_2}(LT^{-2})^{C_3}(ML^{-3})^{C_4}(L)^{C_5}(MT^{-1})^{C_6}=1 \quad (3)$$

from which three auxiliary equations may be written by matrix form as:

$$\begin{pmatrix} 1 & 0 & 1 & -3 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & -1 & -2 & 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

Since three equations are available for solving six unknowns, arbitrary values must be assigned to three of the unknowns. If C_1, C_2, and C_6 are to be fixed, then the determinant formed by remaining coefficients C_3, C_4 and C_5 is

$$\begin{vmatrix} 1 & -3 & 1 \\ 0 & 1 & 0 \\ -2 & 0 & 0 \end{vmatrix} = 2$$

Since this is not zero, the resulting equations are independent and the selection is valid. Assigning the appropriate values to C_1, C_2 and C_6, and using the Equation (3), the values of remaining coefficients C_3, C_4 and C_5 can be determined. The π terms can be formed by substituting the values of coefficient so determined to the Equation (2). The results of the dimensional analysis are summarized in Table 2.

Table 2. The determination of π-terms

assigned			determined			π-term
C_1	C_2	C_6	C_3	C_4	C_5	
1	0	0	0	0	-1	$\pi_1=\frac{D}{H}$
0	1	0	-1/2	0	1/2	$\pi_2=\frac{ND^{1/2}}{g^{1/2}}$
0	0	1	-1/2	-1	-5/2	$\pi_3=\frac{Q}{g^{1/2}\rho D^{5/2}}$

A gengeral solution may therefore be written as

$$\pi_1=F(\pi_2,\pi_3)$$

$$\text{or } \frac{D}{H}=F\left(\frac{ND^{1/2}}{g^{1/2}},\ \frac{Q}{g^{1/2}\rho D^{5/2}}\right) \quad (4)$$

Experimental Work

1. Equipment and material

The throwers used in this study were the similar to that which were attached to the automatic thresher manufactured by Hae-Ryuk Farm Machinery Manufacturing Company. The dimensions of the thrower are summarized in Table 3

Table 3. Dimensions of the thrower used in the study

Items \ Level		1	2	3	4
Inside diameter of the casing (cm)		30.9	35.4	39.4	44.4
Impeller diameter (cm)		30.3	34.8	38.8	43.8
Impeller speed (rpm)	When used in Rough Rice	900	750	659	550
	When used in Naked Barley	750	650	550	450
Impeller blade (cm)	Length	7			
	Width	5			
	Thickness	0.15			
	Material	Sheet metal			
Outlet pipe (cm)	Head	290			
	Size	10×7			
Impeller casing clearance (cm)		0.3			

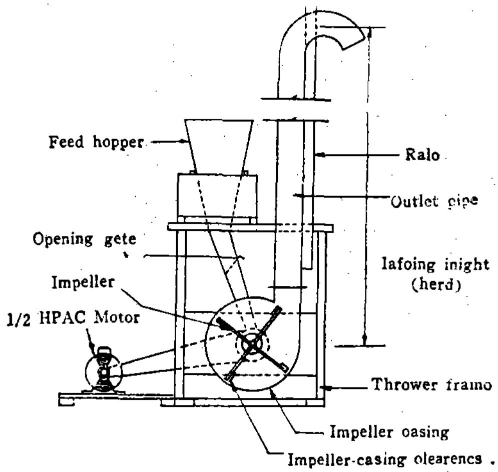

Fig 1. Schematic diagram of the thrower used in this study.

The cover of the casing and the outlet pipe were made of transparent plastic plate so as to be observed the motion of grain while testing and to measure the lifting height of grain in the pipe by the rule which attached to the pipe. The thrower was connected to electric motor (1/2 HP single phase, 1,725Rpm).

Three different grains were tested, and the properties of these materials are summarized in Table 4.

Table 4. Materials used in this study

Items	Rice		Barley (Naked)
Variety	Tong-il	Minehikari	Kwang Sung
Moisture content % 'w.b)	21.0	16.8	13.6
True density (g/cm³)	1.00	1.06	1.25

Rice and barley were selected to test in this study. Tong-il and minehikari were selected from rice and naked barley from barley. True density of Tong-il was the smallest but its projected area was larger than other variety of rice. True density and projected area of Minehikari were almost the same as other rice variety of short grain. Naked barley had the greatest true density but smaller projected area than other variety of rice and barley. Hewever, these grains may represent the various kinds of grains handled in Korean farm.

2. Experimental Plan and Procedure

Experimental plan to determine the functional relationship between π_1 and π_2 or π_1 and π_3 are summarized in Table 5.

Table 5. Experimental Plan

π_1	π_2	π_3
Measure π_1 for different level of π_2 while π_3 unvaried to obtain $\pi_1=f(\pi_2, \bar{\pi}_3)$	A_1, A_2, A_3, A_4	B_2
Measure π_1 for different level of π_3 while π_2 unvaried to obtain $\pi_1=f(\bar{\pi}_2, \bar{\pi}_3)$	A_2	B_1, B_2, B_3, B_4
Measure π_1 for different level of π_2 while π_3 held to another constant to obtain $\pi_1=f(\pi_2, \bar{\pi}_3)$	A_1, A_2, A_3	B_1

Four levels were given in each π_2 and π_3 as the independent variable in the functional relational relationship defined in Equation. (4). The levels of π_2-andπ_3-terms were determined in such a way that the quantites which involved in each term had the values within the range of practical application.

Feeding rates to the thrower were regulated by the degree of opening of gate in the feed hopper. For the same opening of the gate, the flow rate was different according to the materials used. Experimental results of feeding rates, taken the average of five replications, for different gate-opening and materials are given in Table 6.

Table 6. Feeding rate of materials regulated for testing thrower performance (Unit: g/sec)

Sample / Level	Rice: Tong-il	Rice: Minehikari	Barley
1	112.5	195.0	867.0
2	220.0	868.8	777.2
8	498.8	680.0	1,187.0
4	787.0	961.7	1,282.0

Different levels of impeller speed were attained by the exchange of pulleys to which thrower shaft and motor were connected. Impeller speeds actually used for testing different materials and levels are summarized in Table 3.

The π_1-term as the dependent variable was obtained by observing the lifting height of grains for each combinations of experimental treatments as given in experimental plan. Three replications were taken for each treatments.

V. Development of the General Prediction Equation

1. Development of component equations

Before proceed further, let us review again the

π-terms which were formed for the performance of grain thrower.

$$\pi_1=\frac{D}{H},\ \pi_2=\frac{ND^{1/2}}{g^{1/2}},\ \pi_3=\frac{Q}{g^{1/2}\rho D^{5/2}}$$

Observing each π-term, it can be seen that all the π-terms involve variable D, but that for a specific D π_1 is characterized by the lifting height H, π_2 by the impeller speed N and π_3 by the feeding rate Q and material factor ρ. Therefore, all the π-terms can be easily determined by the values of quantities for each specific treatments of variables and the measured ones. The determined values of π-terms and the associated quantities are summarized in Table .7 through to Table 9.

The relationship between π_1 and π_2 for two different rice varieties were plotted in Figure 2, being indicated that the natures of the functions were definately non-linear. The π_1 versus π_3 curve, as shown in Figure 3, also indicates a non-linear relationship.

Table 7. The values of π_1, π_2 and π_3 for Tong-il rice variety for different treatments

(a) π_1 vs. π_2 by holding π_3 at a given value

Kind	H	N	π_1	π_2
held π_3	260	900	0.134	2.826
at $\bar{\pi}_3=0.000984$	215	750	0.162	2.354
Q=220g/sec D=34.8cm	180	650	0.193	2.041
ρ=1.00g/cm³	145	550	0.240	1.728
held π_3	200	900	0.152	2.638
at $\bar{\bar{\pi}}_3=0.000711$	165	750	0.184	2.197
Q=112.5g/sec D=30.3cm	145	650	0.209	1.905
ρ=1.00g/cm³	120	550	0.253	1.613

(b) π_1 vs. π_3 by holding π_2 at a given value

Kind	H	Q	π_1	π_3
held π_2	190	112.5	0.183	0.000503
at $\bar{\pi}_2=2.354$	215	220.0	0.162	0.000984
D=348cm	250	498.0	0.139	0.002230
N=750Rpm	270	737.0	0.129	0.003290

Table 8. The values of π_1, π_2 and π_3 for Minehikari rice variety for different treatments

(a) π_1 vs. π_2 by holding π_3 at a given value

Kind	H	N	π_1	π_2
held π_3	290	900	0,120	2,826
at $\bar{\pi}_3=0.001550$	240	750	0.145	2.854
Q=368.8g/sec D=34.8cm	210	650	0.166	2.041
ρ=1.06g/cm³	180	550	0.198	1,728
held π_3	250	900	0.121	2.688
at $\bar{\bar{\pi}}_3=0.001160$	210	750	0.144	2.197
Q=195.0g/sec D=30.3cm	180	650	0.168	1,905
ρ=1.06g/cm³	150	550	0.202	1.618

(b) $\pi_1$vs·π_3 by holding 2 at a given value

Kind	H	Q	π_1	π_3
held π_2	220	195.0	0.158	0.000822
at $\bar{\pi}_2=2.354$	240	868.8	0.145	0.001550
D=34.8cm	270	680.0	0.129	0.002870
N=750Rpm	280	961.7	0.124	0.004060

Table 9. The values of π_1, π_2 and π_3 for naked barley for different treatments

(a) π_1 vs·π_2 by holding π_3 at a given value

Kind	H	N	π_1	π_2
held π_3 at	280	750	0.124	2.854
$\bar{\pi}_3=0.00278$	280	650	0.151	2.041
Q=777.2g/sec D=34.8cm	190	550	0.183	1,728
ρ=1.25g/cm³	150	450	0.232	1.416
held π_3 at	210	750	0.144	2.197
$\bar{\bar{\pi}}_3=0.00186$	170	650	0.178	1.905
Q=367.0g/sec D=30.3cm	140	550	0.216	1.613
ρ=1.25g/cm³	110	450	0.275	1.321

(b) π_1 vs· π_3 by holding π_2 at a given value

Kind	H	Q	π_1	π_3
held π_2 at	210	367.0	0.166	0.00131
$\bar{\pi}_2=2.04$	235	777.2	0.148	0.00278
D=34.8cm	245	1187.0	0.142	0.00425
N=650Rpm	250	1282.0	0.139	0.00458

Those two functional relationships examined for barley have almost the same natures as ones which showed in rice varieties, as shown in Figure 4 to Figure 5.

Therefore, any kind of transformation may be necessary to relate π_1 to π_2 or π_3 for each of

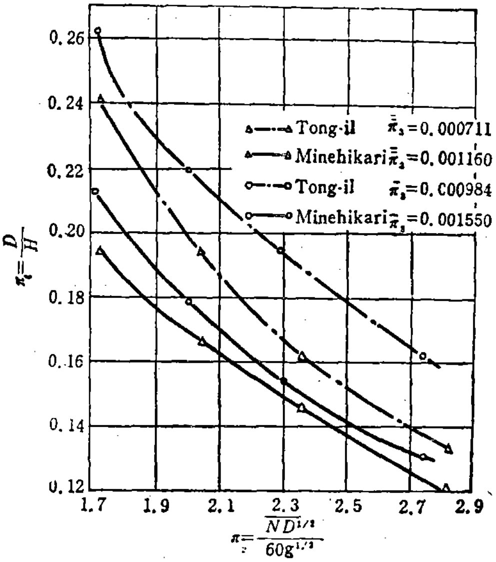

Fig 2. Relationship between π_1 and π_2 for rice varieties

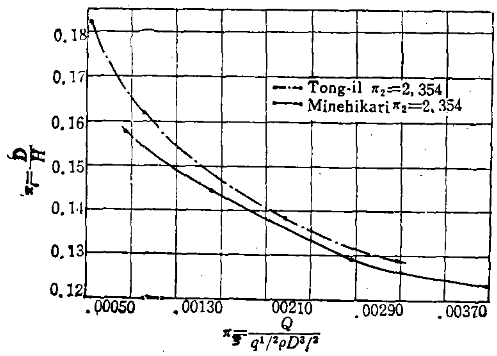

Fig 3. Relationship between π_1 and π_3 for rice verieties

these different materials in such a way that these relationships could be appeared as a linear form. Considering the basic characteristics of these curves, it was attempted to plot the data in the log-log grid paper, resulting natures of functions being indicated a linear trend as shown

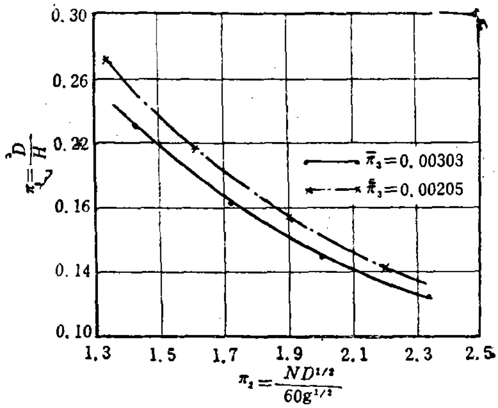

Fig 4. Relationship between π_1 and π_2 for bariey

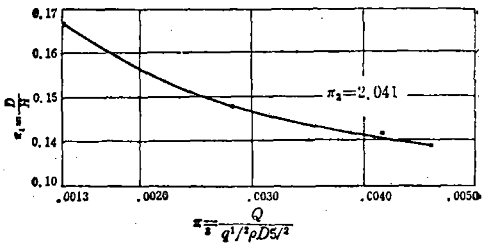

Fig 5. Relationship between π_1 and π_3 for barley

in Figure 6 though Figure 9.

It is now necessary to develop the component equations, that is, the functional equations between π_1 and π_2 or π_1 and π_3 for three cases with different materials. Since these relations have been proved to be linear in the log-log grid paper, the general component equation could be written as

$$(\pi_1)_1=A\pi_2^B \text{ when } \pi_3=\bar{\pi}_3 \quad (4)$$

$$(\pi_1)_2=C\pi_3^D \text{ when } \pi_2=\bar{\pi}_2 \quad (5)$$

$$(\pi_1)_3=E\pi_2^F \text{ when } \pi_3=\bar{\bar{\pi}}_3 \quad (6)$$

where A,B,………, E,F are parameters to be evaluated.

The regression analysis to determine the component equation defined above was performed by using the least-square method. The resulting equations are as follows.

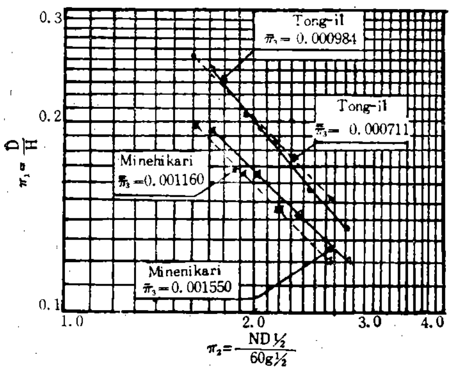

Fig 6. Relationship between π_1 and π_2 for rice varieties

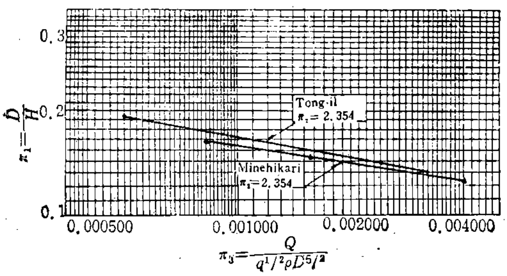

Fig 7. Relationship between π_1 and π_3 for rice varieties

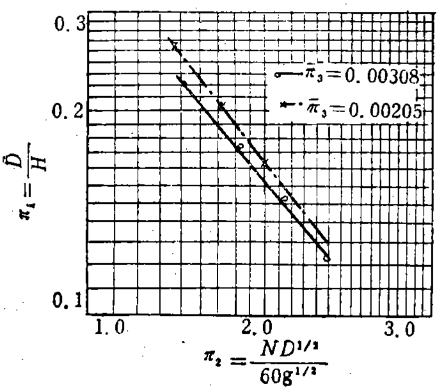

Fig 8. Relationship between π_1 and π_3 for barley

Tong-il

$(\pi_1)_{\bar{3}} = 0.4522(\pi_2)^{-1.1818}$ when $\bar{\pi}_3 = 0.000984$

$(\pi_1)_{\bar{2}} = 0.0445(\pi_3)^{-0.1884}$ when $\bar{\pi}_2 = 2.354$

$(\pi_1)_{\bar{3}} = 0.4213(\pi_2)^{-1.0709}$ when $\bar{\pi}_3 = 0.000711$

Minehikari

$(\pi_1)_{\bar{3}} = 0.3293(\pi_2)^{-0.9663}$ when $\bar{\pi}_3 = 0.001550$

$(\pi_1)_{\bar{2}} = 0.0518(\pi_3)^{-0.1575}$ when $\bar{\pi}_2 = 2.354$

$(\pi_1)_{\bar{3}} = 0.3401(\pi_2)^{-1.9917}$ when $\bar{\pi}_3 = 0.001160$

Naked Barley

$(\pi_1)_{\bar{3}} = 0.3597\ (\pi_2)^{-1.2850}$ when $\bar{\pi}_3 = 0.00278$

$(\pi_1)_{\bar{2}} = 0.0662\ (\pi_3)^{-0.1392}$ when $\bar{\pi}_2 = 2.041$

$(\pi_1)_{\bar{3}} = 0.3906\ (\pi_2)^{-1.2457}$ when $\bar{\pi}_3 = 0.00186$

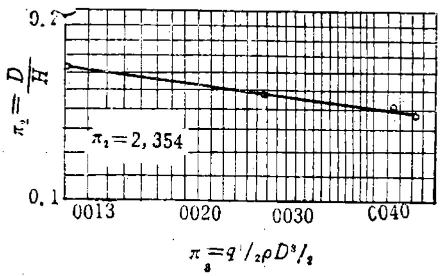

Fig 9. Relationship between π_1 and π_3 for barley

2. Development of general prediction equations

Since there were three π-terms involoved in this study, the prediction equation must form the surface whose three coordinate axes correspond to each π-term. Graphical representation of the surface is shown in Figure 10 Therefore, the general prediction equation corresponds to one for describing the surface.

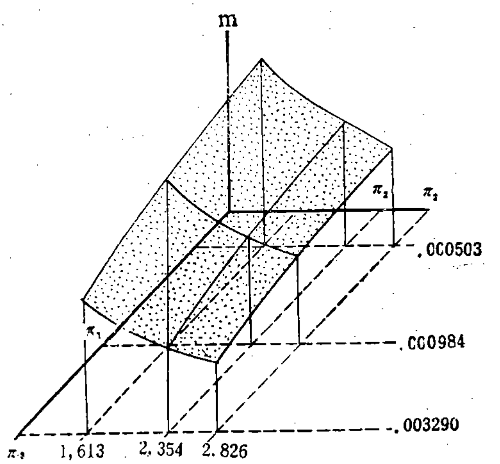

Fig 10. Graphical representation of $\pi_1 = F(\pi_2, \pi_3)$ surface for Tong-il rice variety

The theory for establishing a prediction equation is explained in detail in the reference (9). By following the general theory, the prediction equations for different materials were determined as

Tong-il rice variety:

$$\pi_1=0.1223\pi_2^{-1.1818}\times\pi_3^{-0.1864} \quad (7)$$

Minehikari:

$$\pi_1=0.1185\pi_3^{-0.9663}\times\pi_3^{-0.1576} \quad (8)$$

Naked Barley:

$$\pi_1=0.1599\pi_2^{-1.2860}\times\pi_3^{-0.1882} \quad (9)$$

The prediction equations developed should be tested for validity, the method and theory of which could also be referred to the reference (9). It can be thus written the testing equation

Table 10. Determination of the constants $F(\bar{\pi}_2,\bar{\pi}_3)$, $F(\bar{\pi}_2,\bar{\bar{\pi}}_3)$ and testing equation for validity

Constant / Materia	$F(\pi_2,\pi_3)$	$F(\pi_2,\pi_3)$	Testing equation for validity
Tong-il	0.165	0.169	$\frac{\pi_2^{-1.0709}}{\pi_2^{-1.1818}}=1.099$
Minehikari	0.156	0.133	$\frac{\pi_2^{-0.9663}}{\pi_2^{-1.0917}}=1.112$
Naked barley	0.149	0.161	$\frac{\pi_2^{-1.2860}}{\pi_2^{-1.2457}}=1.007$

for validity as

$$\frac{F(\pi_2,\bar{\pi}_3)}{F(\bar{\pi}_2,\bar{\pi}_3)}=\frac{F(\pi_2,\bar{\bar{\pi}}_3)}{F(\pi_2,\bar{\bar{\pi}}_3)} \quad (10)$$

where $F(\bar{\pi}_2,\bar{\pi}_3)$ and $F(\bar{\pi}_2,\bar{\bar{\pi}}_3)$ are constants to be evaluated.

The values of these constants and the testing equations for validity which were evaluated for different materials are summarized in Table 10.

The smaller the differences between the value for a gievn π_2 in left hand of the testing equation for validity and the constantvalue in its right hand, the more the generality of the prediction equation developed. As illustrated in Figure 11, the difference between these values was found to be nearly negligible for practical range of π_2. From the result, the prediction equation developed could be used satisfactorily for relating all those variables partained to thrower performance.

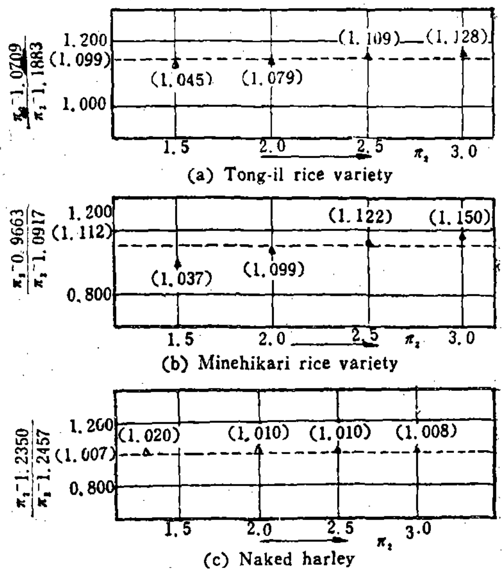

Fig 11. Graphical representation for testing equation validity

3. Applicatin of the general prediction equation.

Application 1

To demonstrate the application of the prediction equation developed, the lifting height of thrower that attached to automatic thresher will be estimated by use of its design and appropriate operational conditions.

Given quantities: D=30cm, N=1100Rpm, Q=150gr/sec.

By use of the prediction equation, the lifting height is expected to be 2.62 m for Tong-il, 2.48 m for Minehikari, and 2.91 m for naked qarley.

From the analysis, it can be seen that the lowest lifting height among the materials, 2.48m, may be unnecessarily high lift as compared to the required height of approximately 1.0 mater for the thrower attached to the automatic thresher. A new design of thrower with a smaller impeller diameter and a lower speed may be recommended to reduce the manufacturing cost, the power requirement and the grain damage.

Applieation 2

The prediction equation developed can be used to understand the relation between the lifting heihgt and the feed rate for the moderate impeller speed of 700 Rpm and its diameter of 30 cm. The relation for three grains are plotted in Figure 12.

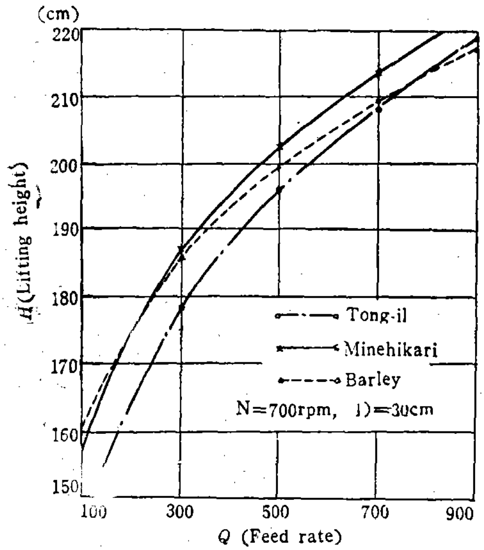

Fig 12. Effect of feed rate on the lifting height

It may be seen from Figure 12 that lifting heights of grains are increased with feed rate regardless of what kinds of grains are used. It is also observed that heavy grain moves up relatively higher at lower feed rate, but when the feed rate increases the light grains are lifted higher then heavy ones.

Naked barley having the greatest true density among three grains tested can be lifted to the highest of 160 cm at the same feed rate of 100 g/sec, however, barley could be lifted the lowest height with 217 cm, if impeller speed was maintained at 700 Rpm.

Application 3

To understand the relation between the lifting height and impeiler diameter for the moderate feed rat of 600g/sec and the impeiler speed of 700 Rpm, the relations for three grains are plotted in Figure 13.

As impeller diameter is increased, lifting heights of three grains tested are increased linearly but the slope of naked barley is a little steeper than rice varieties. Figure 13 also indicate that Minehikari, which has slightly greater density than Tong-il, can be lifted higher than Tong-il. The differences of lifting heights among the materials are getting greater as the impeller diameter increases, the naked barley having the highest lift. It seems to be the fact that air velocity in the pipe remains nearly constant when the impeller speed and feed rate were fixed, but that higher primary speed generated by impeller blade having greater diameter may influence dominantly to make the lifting height greater.

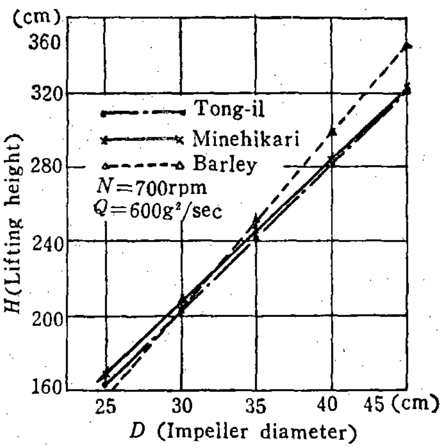

Fig 13. Effect of impeller diameter on the lifting height

Application 4

To understand the relationship between the lifting height and the impeller speed for the moderate impeller diameter (30cm) and feed rate (600g/sec), the relationship between them for three grains is plotted in Fig 14.

The increase of lifting height and the impeller speed is almost in linear relationship within the experimental range. Regardless of materials used, the lifting height is increased as the impeller speed increases. However, the differences of lifting height among the materials are varied for different level of the impeller speed, giving the narrowest range at the impeller speed of approximately 750 Rpm.

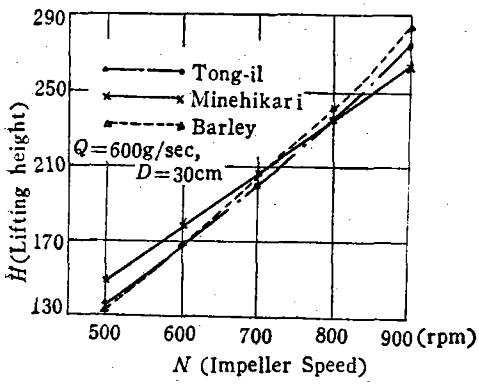

Fig 14. Effect of impeller speed on tqe libtihng height.

Summary and Conclusion

Similitude study on the grain thrower was carried out to develop the general prediction equation and to demonstrate the application of the equation developed.

The dimensional analysis for the quantities pertained to thrower performed by use of Buckingl am's π-theorem. Experimental work was conducted by constructing the thrower similar to one that has been used for the automatic thresher. Three grains, Ton-il and Minehikari rice variety and a naked barley, were tested by varying the feed rate of grain toward the thrower, the impeller size and its speed.

The results of this study are summarized as follows:

1. Pi terms determined by dimensional analysis for the selected quantities of the lifting heigt of the grain thrower (H), impeller speed (N), impeller diameter (D), feed rate (Q), true density (ρ) and the acceleration of gravity (g), are as follows:

$$\pi_1=\frac{D}{H},\quad \pi_2=\frac{ND^{1/2}}{g^{1/2}},\ \pi_3=\frac{Q}{g^{1/2}\rho D^{5/2}}$$

2. The component equations for each of three materials were analyzed based on experimental results. From these component equations, the general prediction equations were determined as

Tong-il

$$\pi_1=F(\pi_2,\pi_3)=0.1223(\pi_2)^{-0.1864}\times(\pi_3)^{-0.1864}$$

Minehikari

$$\pi_1=F(\pi_2,\pi_3)=0.1185(\pi_2)^{-0.9638}\times(\pi_3)^{-0.1575}$$

Naked barley

$$\pi_1=F(\pi_2,\pi_3)=0.1599(\pi_2)^{-1.2350}\times(\pi_3)^{-0.1382}$$

3. From the general prediction equation developed in this study, it may be possible to determine the alternative design and operational conditions of thrower in the automatic thresher used in Korean farm. For the design and operation conditions of thrower attached to the automatic thresher (impeller speed=1,100 Rpm, impeller diameter=30cm, and feed rate 150 gr/sec), the estimated lifting height by the prediction equation is 2.62 m for Tong-il, 2.48 m for Minehikari, and 2.91 m for naked barley. This suggeste that a new design having a smaller thrower with lower impeller speed may still work for lifting all the threshed grains to the desired height of about 1.0 meter.

References

1. Stepanoff. A. J. 1948. Centrifugal and Axial Flow Pumps. John Wiley and Sons Co. N.Y. 2 : 76—80.
2. Hawk, A.L. D.B. Brook, J.J. Cassidy. 1966. Aerodynamic Characteristics of Selected Farm Grains. Trans. of the A.S.A.E. Vol. 9, No.1. 48-51.
3. Kiler, C.F. I.J. Ross. 1966. An Equation of Motion for Mutipule Granular Particles in Free Fall in enclosed Vartical ducts. Trans. of the A.S.A.E. Vol. 9, No.4. 468-479.
4. Fiscus, D.E. G.H. Foster. 1971. Grain-stream Velocity Measurements. Trans. of the A. S. A.E. Vol. 14, No.4. 590-166.

5. Young. D.F. 1968. Simulation and Modeling Teichnques, Trans. of the A.S.A.E. Vol. 11, No.4. 590-594.
6. Menzies, D. W.K. Bilanski. 1968. Aerodynamic Properties of Alfalfa Particles. Trans. of the A.S.A.E. Vol. 11, No.6. 829-831.
7. Wratten, F.T. W.D. Poole. 1969. Physical and Thermal Propertles of Rough Rice Trans. of the A.S.A.E. Vol. 12, No.6. 801-803.
8. Cornish, G.K. L.F. Charity. 1966. Pressure Drop in Elbows of a Pneumatic Conveying System. Trans. of the A.S.A.E. Vol. 9, No. 1. 29-31.
9. Murphy. G. 1950. Similtude in Engineering. The Lonald Press Co. N.Y. 3-46.
10. Macaulay, J.T. J.H. Alee. 1969. Grain Separation on Oscillating Combine Sieves as Affected by Material Entrance Conditions. Trans. of the A.S.A.E. Vol. 12, No.5. 648-652
11. Pickett. L.K. 1973. Mechanical Damage an6 Processing Loss. Trans. of the A.S.A.E. Vol. 16, No.6. 1047-1050.
12. Garrett. R.E. D.B. Brooker. 1965. Aerodynamics Drag of Farm Grains. Trans. of the. A. S.A.E 49.
13. Whitney, R.W.J.G. Porterfield. 1948. Particle Separation in a Pneumatic Conveying System. Trans. of the A.S.A.E. Vol. 11, No.4, 477-479.
14. Henderson, S.M. R.L. Perry 1966. Agricultural Process Engineering 2-7 : 9-228.
15. ickert, W.G. F.H. Buelow 1966. Kinetici Friction of Grains on Surfaces. Trans. of the A.S.A.E. Vol. 9, No.1. 129-134.
16. hanceller. W.J. 1960. Relations between Air and Solid Particles Moving Upward in a Vartical Pipe. The Journal of A.S.A.E. Vol. 41, No.3 168-176.
17 Chanceller, W.J. G.E. Laduke. 1960. Analysis of Frage Flow in a Deflector Elbow The Journal of A.S,A.E. Vol. 41, No.4. 234-240.
18. 農業機械化研究所. 1971. スロワの構造および運轉條件と 籾の損傷增加の 關係
19. 入江道男 1969. 高性能する 農用搬送機と 使い方 機械化農業 六月 34-38
20. 農業機械化研究所. 1965. 各種搬送装置における 穀粒の 搬送及び 揚穀特性に 關する研究. 昭和39年度研究成績 241-264.
21. 入江道男外 2人1971. 高揚程スロワに 關する研究 農機研. 昭和45年度研究成績 47-52.
22. 中川健治外 2人 1970. 自走式茶摘機の スローワに 關する 研究 (第1報) Vol. 32 No.1 43-46.
23. ______________ 1970. スローワ内における 茶葉の 運動 農機誌 Vol. 32 No. 2 129-134.
24. ______________ 1970. スローワの 改良に關する (第3報) 農機誌. Vol 32. No.3 211-214.