農家用 小型 飼料粉碎機 改良에 關한 研究(II)+

Development of a Small Size Hammer Mill for Farm Use (II)+

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要 約

현재 축산농가에서 쉽게 구할 수 있는 곡류, 조사료및 부산물을 활용하여 사료의 자급율을 높이는 것은 농가의 소득증대를 위하여 바람직한 일이다.

이러한 사료의 자급자족 체계를 위하여 소형이며 조작이 간편한 사료분쇄기가 요구된다.

따라서 농가에 많이 보급되어 있는 5~10 마력(3.7-7.5kw)의 동력경운기에 의하여 작동될 수 있는 소형 햄머타입의 사료분쇄기 시작기를 설계 제작하였다. 그리고 시작기의 성능을 분석하기 위하여 보리, 옥수수, 볏짚, 건초를 시료로 하여 시료의 공급율과 스크린의 구멍크기를 변화시켜가며 실험을 수행하였다. 이상과 같은 햄머 밀 시작기의 설계및 성능시험을 통하여 얻어진 결과를 요약하면 다음과 같다.

1. 시작기의 평균분쇄능력은 보리의 경우 평균입자직경이 543 마이크론일 때 82.7 kg/kw·h 였으며, 옥수수의 경우에는 평균입자직경이 408 마이크론일 때 132.7 kg/kw·h였다.

2. 최대 공급율로 분쇄할 때 소요동력은 보리의 경우 1.9kw, 옥수수의 경우 5.3kw, 볏짚의 경우 1.5kw, 건초의 경우 1.6kw을 필요로 하였으며, 5-10 마력(3.7-7.5kw)의 동력경운기로 개발된 햄머 밀을 작동함에는 별 문제가 없는 것으로 분석되었다.

3. 시작기로 시료를 분쇄할 때 곡류 분쇄는 물론 조사료 분쇄도 가능한 것으로 분석되었다.

4. 시작기에 의해 시료를 분쇄했을 때 분쇄물의 평균온도 상승폭은 7.2-10.0°C였다. 이러한 온도는 분쇄물의 영양소 파괴및 저장상의 안정성을 고려할 때 안전한 범위의 온도상승으로 판단되었다.

5. 원료공급율과 스크린 구멍크기가 분쇄량과 분쇄정도에 5% 수준에서 유의성 있는 영향을 미쳤다.

I. INTRODUCTION

Since the GNP of Korea has been increasing, the pattern of food consumption is changed. While the annual consumption of grain per man was reduced in the past and projected to be down in the future too, those of meat, vegetables and fruits were increased and expected to be grown. In view of this situation, the livestock farming would be recommended to the farmers as main or a supplemental income sources. For livestock production, the feed is required in any forms. Unfortunately, the most farmers raising livestock are purchasing the commercial formular feed which is relatively

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expensive. If farmers would develop a feed self-sufficiency system utilizing home-grown feedstuffs and agricutural by-products, it would be desirable for increasing farm income. Therefore, it is required to develop a small and handy feed mill for such a system.

The objective of this study was to develop a small hammer mill driven by a 3.7-7.5KW (5-10hp) power tiller for farm use.

II. REVIEW OF LITERATURES

The grinders are generally classified such as hammer mills and burr mills. Hammer mill can be used for grinding various materials and it is free from significant damage due to foreign objects. Its grinding efficiency is little affected by the wear of hammers. Most materials can be ground finely by it, even though, they are fibrous such as barley and forage. Since the hammer mill has such advantages, it is relatively often used for feed grinding.

According to Duffee (1930), the velocity of hammer tip is one of the most important factors for hammer mill performance and it is a function of rotor diameter. O'Callaghan et al. (1963) reported that the critical speed for power consumption was 75m/sec for 480mm rotor diameter.

Duffee (1930) reports that there is some difference in performance of thick and thin screens, and screens that are slightly worn apparently grind finer than new screens, but if the wear becomes excessive, the opposite would be the case. Thomas (1958) states that capacity varies directly with the percentage of open screen area.

The product fineness is proportional to the clearance between the hammer tip and the casing or the screen. It will vary from 3.2-9.5mm, depending on the material being ground (Thomas,1958). Friedrich(1959) has shown that the optimum clearance is 8mm for most grains.

For the arrangement of hammers, Krueger (1927) said that four rows of T-shaped hammers gave better results than two rows on the Rowell mill; also on the Prater mill three rows gave better results than two rows. And Duffee (1930) reported that four rows were preferred to eight rows for T-shaped hammers.

There is an advantage of reducing hammer width as far as production and efficiency are concerned. By reducing hammer thickness from 8mm to 3mm, capacity and efficiency are increased by 15% and 15 hammers per 100mm of rotor width is desirable (Friedrich, 1959).

Thomas (1958) states that an increase in feed rate is associated with a coarser end product. Also, power requirement is directly proportional to the feed rate.

Chang et al. (1983) report that the economical power requirement of hammer mill for Korean farm is at least 3.7KW (5 hp).

III. DESIGN OF PROTOTYPE HAMMER MILL

The prototype hammer mill was designed by the following criteria. It should be:

1) Able to be driven by the 3.7-6.0KW (5-8 hp) power tiller.
2) Small and economical for farm use.
3) Able to grind grains and agricultural by-products.
4) Easily operated.

The final prototype hammer mill was designed with the above criteria as the following:

A. Power Requirement

According to Chang et al. (1983), the otpimum power requirement of hammer mill for Korean farm is at least 3.7KW (5 hp). Since 3.7-7.5KW (5-10hp) power tillers are currently used at farm, the power requirement of prototype is design to be 3.7-6.0KW (5-8hp).

B. Diameter and Speed of Rotor

It is very important to determine the optimum diameter and rotating speed of rotor which are dominating factors for the performance of hammer mill. They are designed by the test results of O'Callaghan et al. (1963), which indicate that power requirement become independent of mill speed above 3000 rpm when rotor of 480mm was driven by 3.7KW.

C. Power Transmission

When the power transmission system is designed, the pitch diameter of pulley is determined by the pitch diameter and rotating speed of power tiller's pulley. The pitch diameter of V-pulley is 55mm and three B-type V-belts are used. A regular hexagonal rod of 15mm edge length is used for main shaft for supporting discs and strength. KBC Bearing #6205 (C = 1090 Kg) is selected, which is suitable for high speed.

D. Rotor Assembly

When the rotor assembly is designed, several elements should be designed for hammers such as arrangement, support, number, type, thickness, width and size of hole.

The hammers are arranged with 4 rows based on the studies of Krueger (1927) and Duffee (1930). Also spacer is designed to maintain the arrangement of hammers and its diameter is 200mm and thickness is 4mm. Hammer support is a swing-type in consideration of safety and easiness of manufacturing and services. The number of hammers are 16. Friedrich (1959) claimed that 15 hammers per 100mm of rotor width are desirable. O'Callaghan et al. (1963) report that though the number of hammers are increased, performance is not improved proportionally. The shape of hammer is rectangle for effective grinding and easy manufacturing, and its thickness is 4mm based on Friedrich (1959). The width of it is 30mm as reported by Duffee (1930) and O'Callaghan et al. (1963). The length and hole diameter of hammer are designed as 180mm and 13mm, respectively. The diameter of rod holding hammers is 13mm which is designed by the stress analysis.

E. Clearance

The clearance between tips of hammers and screen is 8mm as reported by Friedrich (1959).

F. Position of Intake

The position of feed intake is located on the periphery between 12 and 1 o'clock, which is recommended by Duffee (1930) and Friedrich (1959), though there are two feeding methods, one at the center of the rotor and the other tangential to the rotor.

G. Screen

Screen is a very important design factor which is seriously affecting the performance of hammer mill. Screen design includes screen holder, hole diameter of screen and total area of holes in the screen. The length of screen holder is 540mm and its width is 151mm. The length and width of screen are 535mm and 150mm, respectively. The diameters of holes in screen are 6.35mm, 4.76mm, 3.18mm and 2.38mm and the total area of holes in the screen is 40% of that of screen.

Table 1 shows the main specifications of the prototype designed as the above. A drawing of the rotor assembly is shown in Fig. 1, which is an essential part of the prototype and Fig. 2 shows the picture of hammer mill operated by a power tiller.

IV. MATERIALS AND METHODS OF PERFORMANCE TESTS

In order to test the performance of the prototype

Table 1 Specifications of the prototype hammer mill

Element	Specification	Element	Specification
Power required	3.7−5.2 kw	Screen:	
Rotor diameter to tip	480mm	Inside diameter	496 mm
R. P. M.	3000	Width	150 mm
Hammer:		Length	535 mm
Number	16	Thickness	1 mm
Arrangement	4 row	Feeder	Semiautomatic
Width	30mm	Bearing	Ball (= 6205)
Length	180mm	Pulley:	
Thickness	4mm	Type	V-pulley
Shape	Rectangular	Diameter	65 mm
Support	Swinging	Height	1300 mm

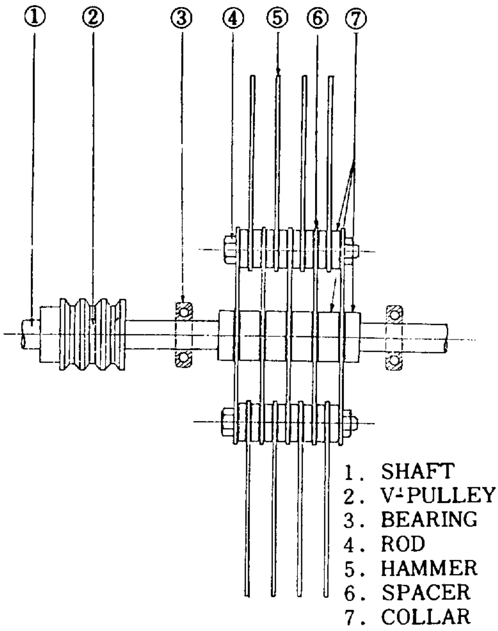

Fig. 1 The drawing of the rotor assembly.

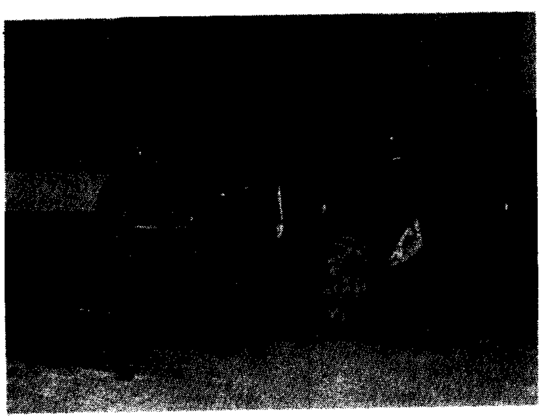

Fig. 2 The prototype hammer mill operated by a power tiller.

hammer mill, experimental investigation was carried out as the following:

1) The experimental work was conducted with a prototype hammer mill driven by a 8hp power tiller (Kukje Machinery).

2) The tested materials were barley, shelled corn, rice straw and forage. Barley was a squirreltail bareley and its moisture content and temperature were 11-12% (w.b.) and 24-25°C, respectively. Corn was a synthesized variety of Buyeor family that moisture content was 13.5-15.5% (w.b.), and temperature was 16-18°C. Rice straw came from a japonica rice variety; moisture content was 11-13% (w.b.) and temperature was 21-22°C. Forage was composed of several kinds of grasses and dried under the shadow; moisture content was 18.5-22% (w.b.), and temperature was 21°C. Rice straw and forage were cut to 3-5cm by forage cutter and fed to hammer mill, in order to make it easy to feed.

3) The factors studied in this performance test were grinding capacity, fineness modulus (FM) and uniformity, particle sizes, and temperature rise of product during reduction, which should be subjected by screen openings and feed rates. In experimental design, screen openings were 6.35mm, 4.76mm, 3.18mm and 2.38mm and feed rates were controlled by a sliding gate of hopper as 1/3, 2/3 and 3/3 of flow rate of full opening. All tests were conducted with three replications. Since it was not easy to control the feed rates for rice straw and forage, only 3/3 feed rate was applied for them.

4) In tests, power requirements were measured with a prony brake, V.S. Motor (15 hp), recording wattmeter and stop watch. Temperatures were measured by a digital thermometer, and moisture content by the oven method. Modulus of fineness and uniformity were analyzed according to the ASAE R246.1 and particle sizes by ASAE S319.

V. RESULTS AND DISCUSSION

Table 2 to 5 show the test results of the prototype hammer mill. The results are the average values of three replications. The fineness modulus and mean diameter indicate average particle size. The uniformity modulus shows the fineness distribution of ground feed. Performance is expressed by weight per unit power and time for griding capacity. Temperature shows the temperature rise of ground feed during grinding.

According to these results, the maximum power requirement for barely was 1.9kw; 5.3kw for shelled corn; 1.3kw for rice straw; 1.6kw for forage. They can be driven by the 3.7-6.0kw (5-8hp) power tiller without any problems.

The difference of power requirement between barley and shelled corn was due to the different density which governed the feed rate per time.

The average grinding capacity of the prototype for barley is 82.7kg/kw.h with particle diameter of 543 microns; for shelled corn, 132.7kg/kw.h of 408 microns;

Table 2 Results of performance tests of prototype hammer mill for barley.

Screen openings	Feed rate (Item)	Fineness modulus	Uniformity modulus* C	M	F	Particle Mean dia (Microns)	Particle Stand. dev**	Power required (kw)	Performance (kg / kw·h)	Temp (℃)
6.35mm	1 / 3	3.5	1	7	2	679	2.2	0.7	82.6	8.1
	2 / 3	3.5	1	7	2	682	2.1	1.2	104.5	8.4
	3 / 3	3.4	1	7	2	700	2.2	1.9	115.3	8.7
4.76mm	1 / 3	3.0	0	7	3	515	2.1	0.9	69.7	10.1
	2 / 3	3.1	0	7	3	519	2.1	1.2	80.5	11.7
	3 / 3	3.1	1	7	2	557	2.2	1.6	100.8	11.9
3.18mm	1 / 3	2.7	0	6	4	401	2.0	0.7	46.5	10.9
	2 / 3	2.7	0	6	4	415	2.0	1.2	67.6	11.2
	3 / 3	2.7	0	6	4	420	2.1	1.6	77.0	11.9
Mean values		3.1				543		1.2	82.7	10.2

*C=Coarse M=Medium F=Fine

** Standard deviation = (Particle dia. at 84 % probability) / (Particle dia. at 50 % probability)

Table 3 Results of performance tests of prototype hammer mill for shelled corn.

Screen openings	Feed rate (Item)	Fineness modulus	Uniformity modulus* C	M	F	Particle Mean dia (Microns)	Particle Stand.dev.**	Power required (kw)	Performance (kg / kw·h)	Temp. (℃)
6.35mm	1 / 3	2.8	1	5	4	427	2.0	1.1	141.5	8.7
	2 / 3	2.9	1	5	4	454	2.0	1.6	180.9	8.5
	3 / 3	2.9	1	5	4	469	2.1	2.4	205.0	7.5
4.76mm	1 / 3	2.7	0	6	4	410	1.8	1.2	112.8	7.3
	2 / 3	2.7	0	6	4	423	1.8	2.1	159.6	7.7
	3 / 3	2.8	0	6	4	433	1.9	2.4	175.3	7.3
3.18mm	1 / 3	2.5	0	5	5	359	1.6	1.5	117.9	10.6
	2 / 3	2.6	0	6	4	385	1.7	2.3	90.9	9.5
	3 / 3	2.7	0	6	4	416	1.7	4.4	131.4	11.8
2.38mm	1 / 3	2.4	0	4	6	333	1.6	1.6	79.7	9.8
	2 / 3	2.6	0	6	4	381	1.6	4.8	97.4	12.1
	3 / 3	2.7	0	7	3	405	1.6	5.3	99.4	12.1
Mean values		2.7				408		2.6	132.7	9.4

* C=Coarse M=Medium F=Fine

** Standard deviation = (Particle dia. at 84 % probability) / (Particle dia at 50 % probability)

Table 4 Results of performance tests of prototype hammer mill for rice straw.

Screen openings	Feed rate	Fineness modulus	Uniformity modulus* C M F	Particle Mean dia. (Microns)	Particle Stand.dev.**	Power required (kw)	Performance (kg / kw·h)	Temp. (℃)
4.76 mm	3 / 3	3.1	1 6 3	512	2.4	1.0	20.8	4.9
3.18 mm	3 / 3	2.4	0 5 5	330	2.0	1.5	14.8	8.7
2.38 mm	3 / 3	2.1	0 4 6	269	2.0	1.3	12.9	10.2
Mean values		2.5		370		1.3	16.2	7.9

Table 5 Results of performance tests of prototype hammer mill for forage.

Screen openings	Feed rate	Fineness modulus	Uniformity modulus* C M F	Particle Mean dia. (Microns)	Particle Stand.dev.**	Power required (kw)	Performance (kg / kw·h)	Temp. (℃)
4.76 mm	3 / 3	3.2	2 6 2	582	2.4	0.8	25 .5	4.2
3.18 mm	3 / 3	2.6	1 5 4	386	2.4	1.6	20 .8	7.0
2.38 mm	3 / 3	2.4	0 5 5	333	2.1	1.0	17 .8	10.5
Mean values		2.7		434		1.1	21 .4	7.2

* C=Coarse M=Medium F=Fine

* * Standard deviation= (Particle dia. at 84% probability)/(Particle dia. at 50% probability)

for rice straw, 16.2kg/kw.h of 370 microns; for forage, 21.4kg/kw.h of 434 microns. Comparing them with those of others which are commercially available at home and abroad, they are not less than others (Chang et al., 1983).

The fineness modulus are ranged from 2.7 to 3.5 for barley and from 2.4 to 2.9 for shelled corn. Comparing these with the fineness of grinding recommendations for livestock (Chang et al., 1983), feed can be ground with the reasonable fineness.

The modulus of uniformity was slightly different to each feed and more balanced as the screen openings became larger. Therefore, if coarsely ground feed is required, it is recommended to use large screen openings.

When feed was ground, temperature rises of ground feed were checked for each feed. The average rises were 10.2°C for barley, 9.4°C for shelled corn, 7.9°C for rice straw, 7.2°C for forage. Since it is reported that the temperature over 40°C may destroy the nutritional elements of feed and cause the storage problems, the above rises are belonged to a safe range as compared with the above criterion. Therefore, the design of the prototype would be reasonable.

The effects of feed rates and screen openings on grinding capacity are shown in Fig. 3 and 4. They were statistically analyzed and results showed that feed rates, screen openings and interactions of two factors had the significant effects on grinding rates of bareley and shelled corn at the 5% level; for rice straw and forage, screen openings only.

Fig. 5 and 6 show the effects of feed rates and screen openings on fineness modulus of ground feed. They were examined statistically for each feed, too. The results showed for barley and shelled corn that feed rates, screen openings and interactions of two factors had the significant effects on fineness modulus at the 5% level; for rice straw and forage, screen openings was significant at the 5% level.

The effects of feed rates and screen openings on geometric mean diameter of ground particles (Fig. 7 & 8) were analyzed statistically. For shelled corn grinding, feed rates and screen openings had the significant effects

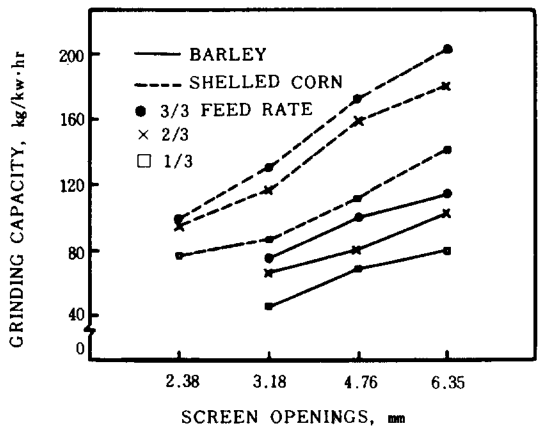

Fig. 3 The effects of feed rates and screen openings on grinding capacity for barley and shelled corn.

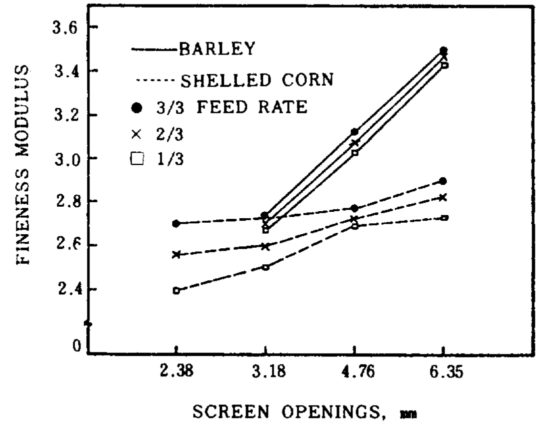

Fig. 5 The effects of feed rates and screen openings on fineness modulus when grinding barley and shelled corn.

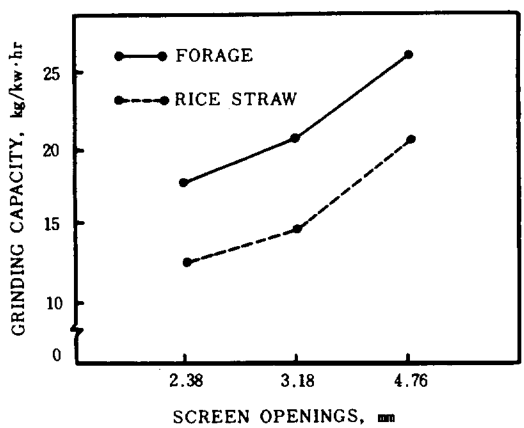

Fig. 4 The effects of screen openings on grinding capacity for rice straw and forage.

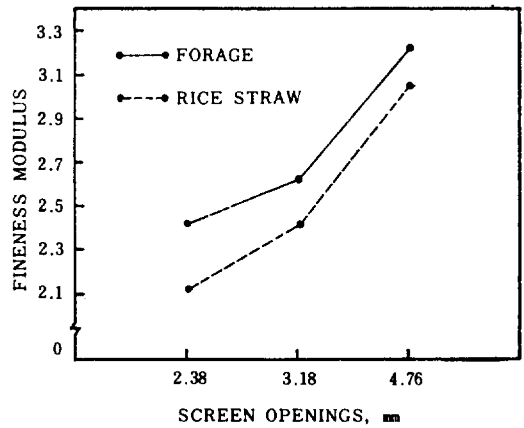

Fig. 6 The effects of screen openings on fineness modulus when grinding rice straw and forage.

on geometric mean diameter at the 5% level. For barley grinding, only screen openings had the effects. The reason of the different effects between shelled corn and barley grinding may be due to the physical characteristics of barley which is harder and smaller than shelled corn. For rice straw and forage grinding, screen openings also had a significant effect on geometric mean diameter within each feed rate at the 5% level.

As the results indicate, feed rates and screen openings are very important design factors, and give significant effects on the performance of hammer mill. The fineness moduli of ground feed are also within the range recommended for livestock. Therefore, it would be evaluated that the prototype hammer mill is designed reasonably. But, since some particles were dispersed out during grinding operation, it would be desired to develop an effective receiving hopper for ground feed.

VI. CONCLUSIONS

The following conclusions may be drawn from this study:

1. The average grinding capacities of the prototype hammer mill were 82.7 kg/kw.h with particle diameter

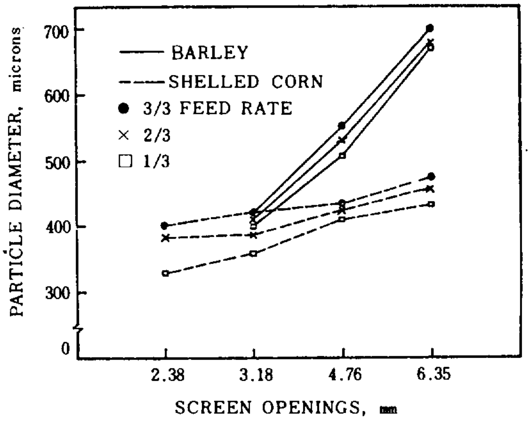

Fig. 7 The effects of feed rates and screen openings on particle diameter when grinding barley and shelled corn.

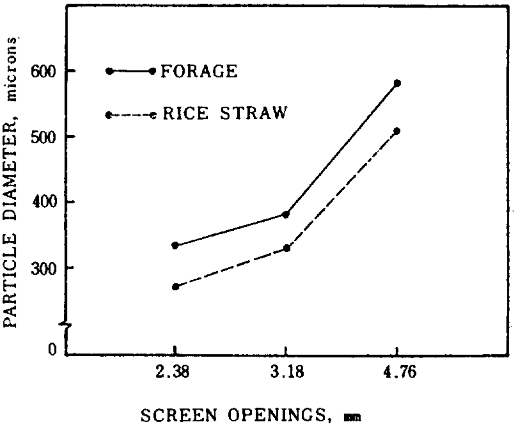

Fig. 8 The effects of screen openings on particle diameter when grinding rice straw and forage.

of 543 microns for barley, 132.7 kg/kw.h with particle diameter of 408 microns for shelled corn.

2. From the grinding tests, the power requirements were analyzed such as 0.7-1.9 kW for barley, 0.7-5.3 kW for shelled corn, 1.0-1.5 kW for rice straw, 0.8-1.6 kW for forage, which could be driven by 3.7-7.5 kW (5-10 hp) power tiller.

3. When material was ground, the average temperature rise of ground feed was about 7.2-10.2°C. In view of nutritional destruction and safe storage, it was within a safe range.

4. It was proved that the prototype could be used for grinding rice straw and forage as well as grains.

5. Feed rates and screen openings were very important design factors, and gave significant effect on the performance of hammer mill at the 5% level. And fineness modulus of the ground feeds were within the range of the grinding recommendations for livestock.

References

1. Chang, D.I., S.R. Kim, M.S. Kim, B.D. Lee and K.J. Yi. 1983. Development of a small size hammer mill for farm use (I). Research Reports of Agr. Sci and Tech. 10(2):334-344. Chungnam National Univ.
2. Duffee, F.W. 1930. The design and performance of small hammer type feed mills. Agricultural Engineering 11(5):171-176.
3. Friedrich, I. 1959. Factors affecting the particle reduction process in hammer mill. Die Muhlem Helf 48:648-658 and Helf 49:660-661.
4. Hendrix, A.T. 1937. Design and Performance of a small automatic hammer mill. Agricultural Engineering 18:445-447.
5. Krueger, W.C. 1927. Basic principles involved in the design of the small feed grinder. Agricultural Engineering 8(7):167-171.
6. Martin, J.W. and J. Roberts. 1941. Feed grinding with small electric motors. Ext. Bull. 87, Kansas State College, Manhattan, KS.
7. O'Callaghan, J.R., M.E. O'Hangan and B.G. Rice. 1963. Performance of hammer mills. Journal of Agricultural Engineering Research 8(1):92-104.
8. Pfost, H.B. 1976. Feed Manufacturing Technology. American Feed Manufacturers Association, Inc., Arlington, MA.
9. Rumpf, H. 1959. Stress theory of impact grinding. Chemie-ing-Tech. 31(5):343-347.
10. Silver, E.A. 1932. Characteristics of feed mill performance. Agricultural Engineering 13(2):31-34.
11. Thomas, G.F. 1958. Basic facts in focus on grinding, mixing, conveying with air. The Feed Bay 34(4):88-90.