

# Design and Development of Rasp Bar Mill for Size Reduction of Maize

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**Abstract:** Particle size affects many characteristics in the manufacturing process. Controlling the particle size helps to assure that the milled material will be consistent and repeatable with respect to firstly color, that is, uniform particles assure batch-to-batch color consistency, Secondly, flowability that is critical to packaging, tableting, weighing. Thirdly, uniformity, that is, consistent bulk density. Fourthly, density - helps control shipping costs and minimize dust. Fifthly, reconstitution, that assures the desired dissolution rate, Sixthly, chemical reaction that is vital for uniform, controlled chemical change. Finally, taste that allows precise portion control for consistent taste. The aim of this project is to design and develop a rasp bar mill for size reduction of maize seeds for different purposes. The fabricated rasp bar mill is capable of feeding maize around 60-180 kg/h, delivering of grits 60-90%, with sieve effectiveness 90-100% at a power requirement of 800-1400W, for different sieve perforation sizes of 5, 6, 7, 8 mm respectively.

**Key words:** Size reduction, Rasp bar mill, Maize gritting

## 1. Introduction

Maize (*Zea mays*) is the most important coarse grain cereal crop in the Lowland cropping systems, such as Badulla, Moneragala, Ampara, Anuradhapura and Batticalo where in dry zone of the country as well as in the Uplands like Matale, which around 30,000 ha of land area devoted annually, the second highest extent of land next to rice in Sri Lanka[15]. Total Maize production of the country was 202.3 million metric tons in 2012[16]. For the rural farmers to maximize profit from their maize, appropriate technology that suits their needs must be used. The processing of agricultural products like maize into quality forms not only prolongs the useful life of these products, but increases the net profit farmers make from mechanization technologies of such products. One of the most important processing operations done to bring out the quality of maize is milling. There are two methods of milling, i.e. dry milling and wet milling. Gritting or size reduction is one of the operations in dry milling. There is no machine in Sri Lanka for this purpose. The objective of

this project is to fabricate and evaluate an affordable gritting machine for size reduction of maize.

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**1.1 Literature review:** In general “size reduction” is taken to mean the disintegration of solid substances by mechanical forces without altering their solid state. This also includes the division of liquids into drops or gases into bubbles. However, the physical and chemical condition of the disintegrated material may alter, particularly when inhomogeneous substances are present. The preparation for separation according to material components, e.g. grinding grain, is therefore, one of the classical tasks of size reduction techniques. Size reduction or ‘comminution’ is the unit operation in which the average size of solid pieces of food is reduced by application of grinding, compression or reduction of particle size is an important operation in many chemical and other industries. The important reasons for size reduction are:

- Easy handling
  - Increase in surface area per unit volume
  - Separation of entrapped components
- impact forces

In all types of size reduction, there are three types of forces used to reduce the size of foods:

1. compression forces,
2. impact forces, and
3. shearing (or attrition) forces.

Cereal grains generally are the primary source of energy in feedlot diets. Availability of energy from the grain depends largely on the type of grain used as well as processing of that grain.[13].

A variety of grain processing techniques are used including grinding, steam flaking, and compiling high moisture corn to ferment. Each processing method differs in its nutritional efficacy [13] and each has a unique associated cost. [14].

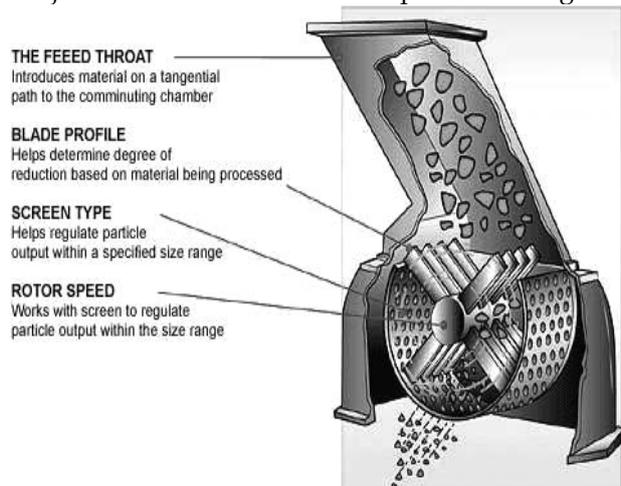
Criteria for size reduction An ideal crusher would

- (1) have a large capacity,
- (2) require a small power input per unit of product, and
- 3) yield a product of the single size.

## 2. Design details

The Comminutor operates by feeding material uniformly into a chamber in which a rotating blade assembly reduces the particles of the material by cutting or impacting them. The material discharges through a screen which

regulates final particle size at the outlet of the milling chamber. The blade and screen act in conjunction to determine final product-sizing.



**Figure 1- Sketch of rasp bar mill in operation [9]**

**2.1 Feed Throat:** The feed throat introduces material into the milling chamber. There are several designs of feed throats.[9] A gravity feed throat introduces material tangentially to the rotation of the blades. Other throats are available for production machines, such as a metered feed throat, liquid inlet throat, etc. Here, in this project feed throat was located 90° to the face plate of the mill machine.

**2.2 Blade Profile:** [9]The type, quantity and shape of blade helps to determine the degree of reduction achieved based on the material being processed. Some blade styles offer flexibility of knife on one side and impact on the other. Knife-edged configuration is for gentle granulation and impact-edged for more aggressive reduction. In this project, stainless steel flat bars were used as it is food grain processing. Since it is low energy size reduction, reduction of the rasp bar speed should be done to decrease the percentage of cracked seeds by maintaining 600-1400rpm speed range. [3] Therefore 3 hp motor is used to supply power to have rotating speed 2880 rpm for machine operation and the rasp bar rotor speed is kept at 1440 rpm.



Photograph 1- Interior view of the gritting chamber

**2.3. Design calculation of shaft:** The main shaft transmits 3kW at 1440 rpm and is carrying a pulley (D) and a rotor (A) with four sets of rasp bars. The torque (T) transmitted by the shaft,

$$(T = \left( \frac{3 \times 60}{2 \times \pi \times 1440} \right) = 19.89 Nm. \dots\dots\dots(1)$$

T1 and T2 are tensions in the tight side and slack side of the belt on the double v grooved pulley D respectively. Rotor weight =1250N, pulley weight= 1000N

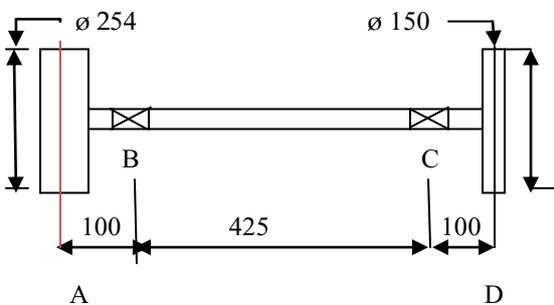


Figure 2 - Rotor and pulley mounted on the shaft and shaft mounted on the bearing B and C

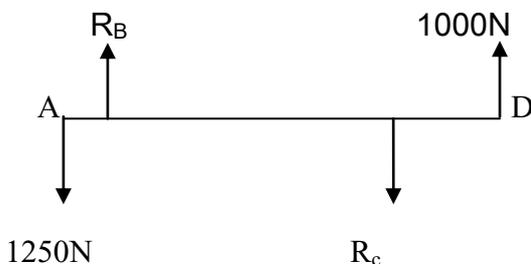


Figure 3 - Force diagram on the shaft

Taking moments around the support C

$$(R_B \times 425 = 1250 \times 525 - 1000 \times 100 \dots\dots(2)$$

$$R_B = 1309N$$

$$(R_B + 1000 = R_C + 1250 \dots\dots(3)$$

$$1309 + 1000 = R_C + 1250$$

$$1059N = R_C$$

Where  $R_B$  - Reaction at bearing B

And  $R_C$  - Reaction at bearing C

Bending moments at B and C are zero.

Bending Moment at A is,

$$1250 \times 100 = 125 \times 10^3 \text{ Nmm}$$

Bending moment at D is,

$$1000 \times 100 = 100 \times 10^3 \text{ Nmm}$$

Maximum bending moment  $M_{max} = 125 \times 10^3$  Nmm

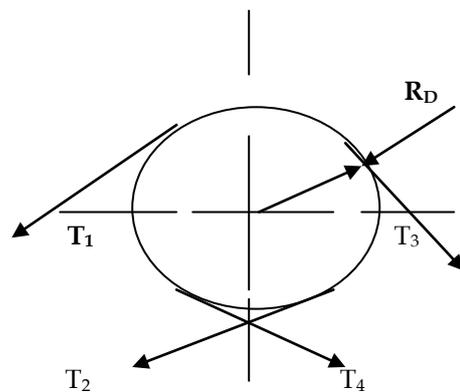


Figure 4-Tensions of the belts acting on the driving pulley D

$$T_1 = T_3, T_2 = T_4$$

$$((T_1 + T_3) - (T_2 + T_4))R_D = 19.89 = (2T_1 - 2T_2) \dots\dots\dots(4)$$

Where,

T1 & T2-fan belt tight side and slack side tensions

T3&T4-motor belt tight side and slack side tensions

$R_D$ -Diameter of pulley, mm

$$(2.3 \log \left( \frac{T_1}{T_2} \right) = \mu \theta \dots\dots\dots(5) [2]$$

Coefficient of friction between the belt and pulley is 0.3 [ 2]

When  $\theta = \pi$ ,

$$\left( \frac{T_1}{T_2} \right) = 2.57$$

$$(2.57T_1 - T_1) = 9.945 \Rightarrow T_1 = 6.33N, T_2 = 16.27N$$

Equivalent twisting moments is determined by

$$T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2} \dots\dots\dots(6)$$

Where  $K_m$  -Shock factor

M - Maximum bending moment, Nmm

$K_t$  - Fatigue factor [2]



Shock and fatigue factors for bending and torsion [2]

$$Km=2, Kt=1.5$$

$$T_e = \sqrt{(2 \times 125 \times 10^3)^2 + (1.5 \times 16.27)^2}$$

$$= 3968 \text{ Nmm}$$

$$(T_e = \frac{\pi}{16} \times \tau \times d^3 \dots\dots\dots(7)$$

$$3968 = \frac{\pi}{16} \times \tau \times d^3 = \frac{\pi}{16} \times 19.89 \times d^3$$

$$d=10\text{mm}$$

considering the safety factor as 4.6 as there are impact loads [2] d=46mm

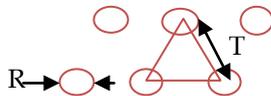
Used 50.8 mm stainless steel bar as the main shaft.

### 2.4 Energy and power requirements in size reduction[2]

The cost of power is a major expense in crushing and grinding, so the factors that control this cost are important.

### 2.5 Open area[11]

Open area or perforation area for a sieve having triangular pitch is determined by



$$\left( \frac{R^2 \times 90.69}{T^2} \dots\dots\dots(8) \right.$$

Where R-hole diameter, mm

T-Triangular pitch, mm

According to the equation

for 5mm sieve, perforation area is 22.7mm<sup>2</sup>

for 6mm sieve, perforation area is 32.6mm<sup>2</sup>

for 7mm sieve, perforation area is 19.8mm<sup>2</sup>

for 8mm sieve, perforation area is 25.8mm<sup>2</sup>

### 2.6 Crushing efficiency

Empirical relationships determined by Rittinger's and Kick's law: The work required in crushing is proportional to the new surface created. This is equivalent to the statement that the crushing efficiency is constant and, for a given machine and material, is independent of the sizes of feed and product. If the sphericities  $F_a$  (before size reduction) and  $F_b$  (after size reduction) are equal and the machine efficiency is constant, the **Rittinger's law** can be written as

$$\frac{P}{\dot{m}} = K_r \left( \frac{1}{\bar{D}_s} - \frac{1}{\bar{D}_p} \right) \dots\dots\dots(9)$$

where P - the power required, W

$\dot{m}$  - the feed rate to crusher, g/s

$\bar{D}_s$  - the average particle diameter before crushing, mm

$\bar{D}_p$  - the average particle diameter after crushing, mm

$K_r$  - Rittinger's coefficient.[12]

Rittinger's law is applicable for feed size less than 0.05mm.

### 2.7 Bond crushing law [12]

Bond crushing law is applicable for feed size in between 0.05mm to 50mm. The work required to form particles of size  $D_p$  from very large feed is proportional to the square root of the surface-to-volume ratio of the product,  $s_p/v_p$ .

Since  $F_s = 6/D_p$ , it follows that

$$(P/\dot{m} = K_b/(D_p)^{0.5} \dots\dots\dots(10))$$

where  $K_b$  - is a constant that depends on the type of machine and on the material being crushed

P- power required, W

$\dot{m}$ - feed Rate, kg/h

From experimental results, following parameters were derived on

$$P=2112 \text{ W}, \dot{m}=55\text{kg/h } D_p=6\text{mm},$$

$$K_b=3.4 \times 10^5 \text{ Jmm/kg}$$

$$\dot{m}=72 \text{ kg/h } D_p=7\text{mm}, K_b=3.4 \times 10^5 \text{ Jmm/kg}$$

$$P=3.4 \times 10^5 \times 72 / 2.65 \text{ kg/h}$$

$$= 92.3 \times 10^5 / 3600 = 2563 \text{ W}$$

Therefore 3 hp motor is selected.

$$\text{Overall efficiency} = \frac{\text{Energy output}}{\text{Energy input}} \times 100 \dots\dots(11)$$

$$\text{Overall efficiency} = 1400 / 3000 \times 100 = 47\%$$

### 3. Materials and method

Maize rasp bar milling or the corn gritting is a kind of dry milling, which can be simply defined as process of impacting corn grains, that leads to grain size reduction and passing through a screen. Electrically operated small scale Rasp Bar Mill was developed and tested for maize. The mill consists with 5 major components; feeding funnel, grinding chamber, power supplying unit, blower unit and collecting outlet. Grinding chamber consists of four (04)



sets of rectangular blades attached to a rotor shaft that leads to size reduction of grains and a sieve, that has round perforations, enclosed the blades to prevent leaving grits from the grinding chamber until they are at least as small as the sieve openings. There are four sieves having 5mm, 6mm, 7mm and 8mm diameter perforations that can use separately according to the preference. Three horse power (03hp)with rotating speed 2880 rpm motor supplies power for machine operation.

Following parameters were determined

- Physical properties of the maize
- Out put efficiency(%)
- gritting capacity (kg/h)
- feeding capacity (kg/h)
- percentage of grits (%)
- screen effectiveness (%)

Machine and operating parameters

- Screen dimensions
- Sieve size
- Screen pitch
- Hopper capacity
- Rpm of the unit

The motor was started and spined the rasp bars. Dried maize was fed through the hopper. The hopper capacity was around 1000g. Small bits of plant material exit through the punched holes at the bottom.

### 3.1 Testing methodology

Performance of the developed gritting unit was evaluated in terms of output capacity, gritting efficiency, power requirement against different moisture levels.(i.e.8%,9%,10%,11%) Different moisture levels were obtained by oven drying. The Moisture content was measured by Grain Moisture meter GMK 303A G-WON manufacturer. Maize grains flowed under gravity to the gritting chamber where impact of revolving gritting occurs. Rotor with 4 sets of rasp bars gritted the grain. Pneumatic cleaning is used to remove light, chaffy and dusty materials out of the grain while heavier materials move downward. Air is generated by a mechanical fan. Light material get collected into the cyclone of which inlet is fixed into the grain falling path.



Photograph 2- Fabricated Rasp bar mill

## 4. Results and discussion

Figure 5 shows the change of gritting efficiency with the sieve size. When the perforation size is larger efficiency is higher.

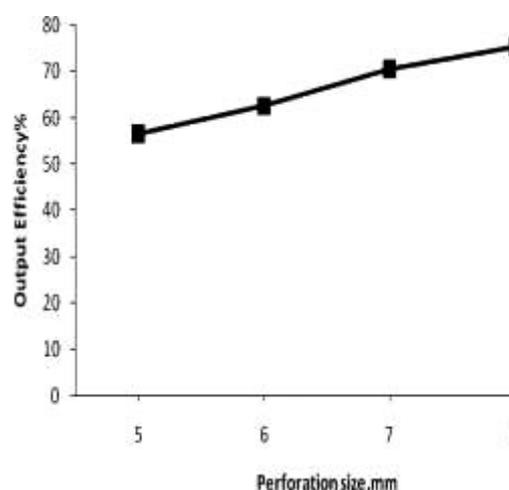


Figure 5 - Gritting efficiency vs perforation size

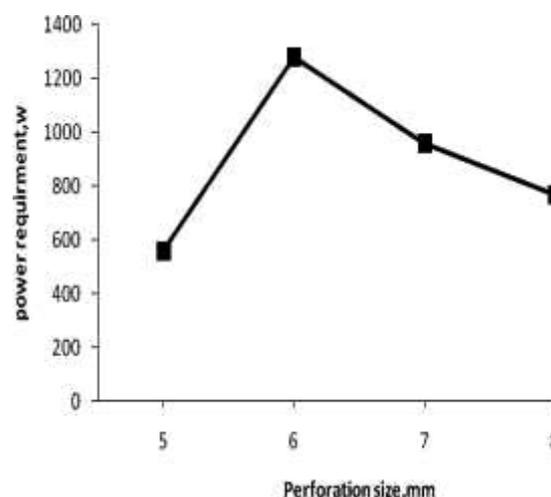


Figure 6- power requirement vs perforation size



Figure 6 shows the change in power requirement for size reduction of maize, with respect to the perforation size at moisture level 11%. Maximum power requirement was recorded in the perforation size of 6mm. This may be due to higher perforation area of this sieve compared to the other sieves.

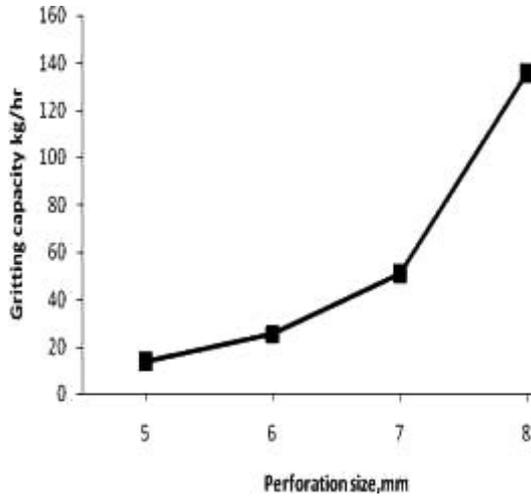


Figure 7 - Gritting capacity vs perforation size

Drastic change of gritting capacity at 11% (wet basis) moisture content was observed in the perforation size 8mm. This may be due to higher opening area in the sieve.

Figure 8- shows the change of feeding rate with the perforation size.

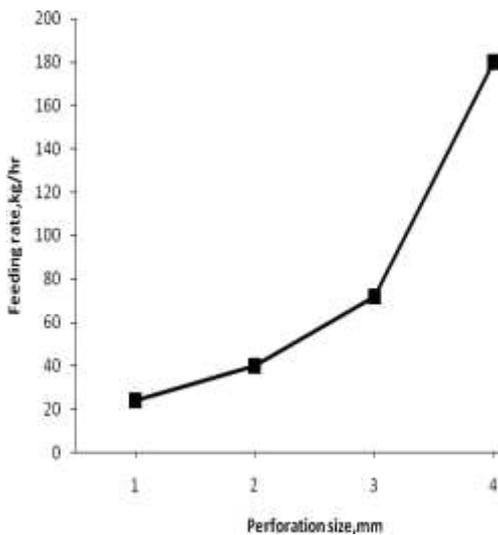


Figure 8 - Feeding rate vs perforation size.

Drastic change of feeding rate was observed in the perforation size 8mm at moisture level 11% (wet Basis). This may be due to the higher

opening area in the sieve. In all cases, sieve effectiveness are greater than 86%. The speed of the rasp bar rotor and speed of the fan were kept at 1440 and 2880 rpm respectively.

Table 1- Results of the performance testing

hole size (mm)	Feeding rate (kg/h)	Gritting capacity (kg/h)	Out put efficiency (%)	Power requirement (W)
5	24	13.58	56.6	560
6	40	25.07	62.6	1280
7	72	50.87	70.6	960
8	180	135.78	75.4	768

Table 1 shows the important results of the performance testing. In early performance testing the fan power was inadequate. Fan was modified by trial and error method. The table give results obtain after fan modification

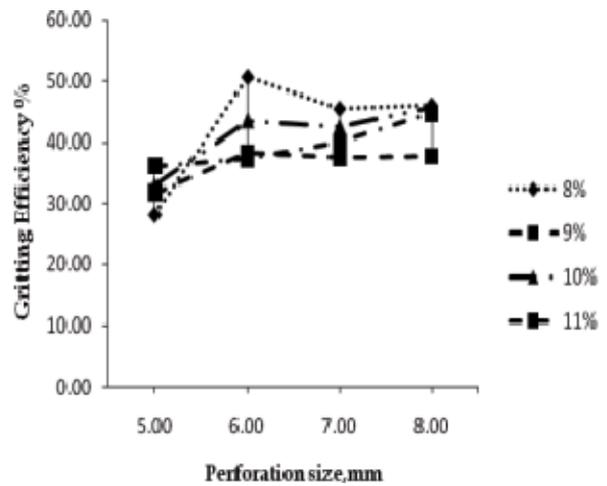
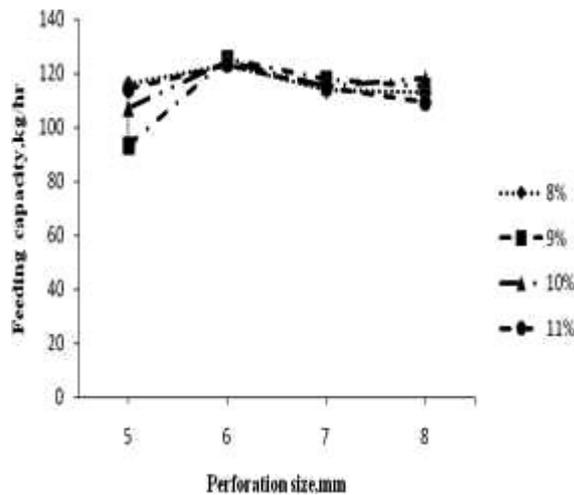


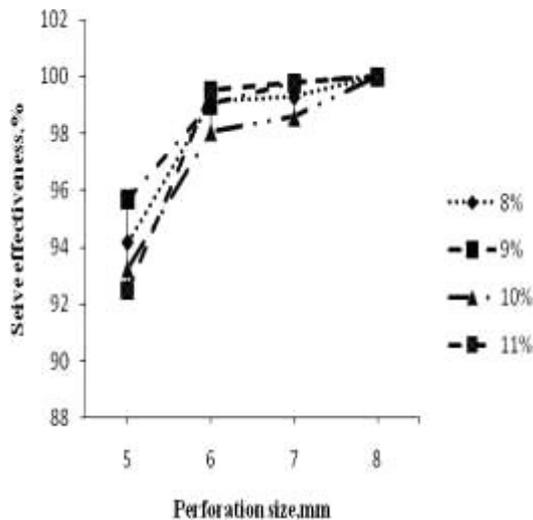
Figure 9- Gritting Efficiency vs perforation size

The same experiments were carried out to different moisture levels. i.e. 8%, 9%, 10%, 11% (wet basis). An increase of gritting efficiency was noticed at perforation size 6mm. This may be due to highest perforation area as the pitch of this sieve was 10mm compared to other sieves.



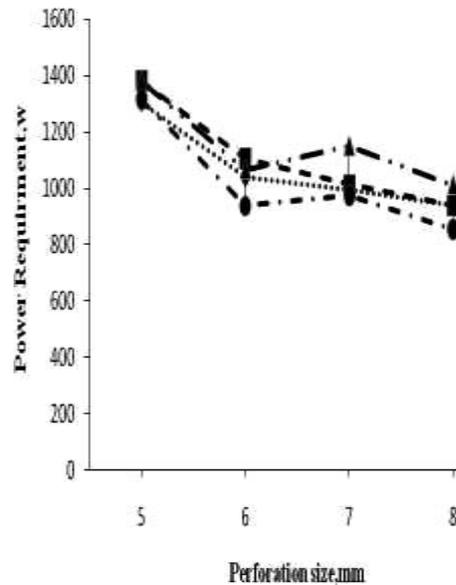
**Figure 10- Feeding capacity vs perforation size**

Higher feeding capacity was observed at perforation size 6mm. This may be due to higher perforation area of this sieve. Human error may be the reason for different capacities of the sieve with perforation size 5mm.



**Figure 11- Sieve effectiveness vs perforation size**

A low sieve effectiveness was observed in perforation size 5mm at all moisture levels. This may be due to lower perforation area of this sieve.



**Figure 12 - Power requirement vs perforation size**

High power requirement was observed at perforation size 5mm. This may be due to the lower perforation area of this sieve. Power was supplied by 3hp motor. The speed of the rasp bar rotor and the speed of the fan were kept at 1440 and 2880 rpm respectively in all experiments

## 5. Conclusions and recommendations

The study revealed that the fabricated maize gritting machine is capable of gritting maize at different moisture levels of maize and different sieve perforation sizes. i.e. 5 , 6 , 7 , 8 mm in diameter. The product comes out is grits without cover and germ. The optimum performance was obtained at the perforation size 6 and the moisture content of 8% (wet basis). The overall efficiency of unit is 47% as calculated. Size reduction creates heat while in operation but it can be neglected. The broken do not contain much heat. Therefore no color change appears. The manufacturing cost is calculated as Rs. 150,000/= according to the present market prizes.(2013). This can be a self employment for a person. The broken can be boiled as it is for consumption with coconut scrapes and can be mixed with milk rice or can be used for making corn flakes.



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## References:

1. Watson, A., Stanly, Rama, E. Paul, 1987, Com:Chemistry and Technology, American Association of Cerial Chemistry, Inc., St.Paul, Minnesota, USA.
2. Khurmi, R. S., Gupta, J. K., 2005, A textbook of Machine Design, Eurasia Publishing House, New Delhi, India.
3. Dong, A., and Edberg, R. J., *Hammer mill grain thresher*. original version (8/1994). Retrieved 24 October 2013 from of feedlot cattle: [http://members.efn.org/~itech/HTM/Converted\\_Grain\\_Thresher.html](http://members.efn.org/~itech/HTM/Converted_Grain_Thresher.html)
4. <http://lorien.ncl.ac.uk/ming/particle/cpe124p3.html> visited on 11/08/2013
5. <http://www.lavorazionetutolofollador.it/en/Applications/corn-cob-abrasive-granulates-for-the-vibratory-finishing-and-sifting-of-metal-surfaces.html> visited on 14/08/2013
6. <http://www.fourleafmilling.com.au/products.php?id=14> visited on 15/08/2013
7. [https://www.google.lk/?gws\\_rd=cr&ei=16CyUq6bD6efiAfDwIHQAQ#q=Macken+et+al.%2C+2006&start=20](https://www.google.lk/?gws_rd=cr&ei=16CyUq6bD6efiAfDwIHQAQ#q=Macken+et+al.%2C+2006&start=20) visited on 15/08/2013
8. <http://benefitof.net/benefits-of-maize/>
9. [http://www.fitzmill.com/chemical/size\\_reduction/theory/theory\\_sr.html](http://www.fitzmill.com/chemical/size_reduction/theory/theory_sr.html) visited on 17/08/2013
10. [https://www.google.lk/?gws\\_rd=cr&ei=UvizUpmSHsWpiAfj6IHQDA#q=Mackenn+et+al.%2C+2006&start=20](https://www.google.lk/?gws_rd=cr&ei=UvizUpmSHsWpiAfj6IHQDA#q=Mackenn+et+al.%2C+2006&start=20) visited on 01/09/2013
11. <http://www.rmig.com/en/technical+info/formulae/calculation+open+area> visited on 02/09/2013
12. <http://books.google.lk/books?id=QdEDzpQ9TCIC&pg=PA89&lp=PA89&dq=Rittinger%E2%80%99s+coefficient&source=bl&ots=HGAAUuFan6n&sig=AsRnOCsN3v6vYUfb49ygnt1hpf&hl=en&sa=X&ei=EUi9UuaZJIqhgfvjoCoDg&ved=0CFoQ6AEwCA#v=onepage&q=Rittinger%E2%80%99s%20coefficient&f=false> visited on 03/09/2013
13. Owens, F. N., Secrist, D. S., Hill, W. J., Gill, D. R., 1997, The effect of grain source and grain processing on performance a review. *J. Anim., Sdi.*, 75(3) : 868-879
14. Macken, C. N., 2 Pas, Erickson G.E., 3 PAS, and Klopfentein, T.J. 2006, The cost of corn processing for finishing cattle. *J. The professional Animal Scientist*: 22:23-32
15. Department of Agriculture, Sri Lanka Bulletin, 2006,
16. Central Bank of Sri Lanka, (2012)

### Breakdown of cost estimate

Description	Unit	Quantity	Amount
01 HP single phase motor	no	1	14950
1" shafting	ft	3	1395
6"B double V pulley	no	1	960
3"B single V pulley	no	2	980
1/8" B.I.Sheet	sheet	0.5	6950
16G B.I.Sheet	Sheet	1	7200
2" stainless steel round bar	ft	3	16350
1" stainless steel flat iron	ft	6	2310
transport charges			450
59"B V belt	belt	1	300
62"B V belt	belt	1	400
1.5"x1.5"x4mm Angle Iron	bar	1	2200
2" pillow block bearing	no	2	8000
1" pillow block bearing	no	2	2200
1/4" M.s.Sheet	sheet	0.25	6750
Flat iron 1'x4mm	bar	1	1200
Flat iron 1.5"x4mm	bar	2	750
16mmx1.5" nut & bolt	bolt	8	70
5/16" nut & bolt	g	500	100
1/4" nut & bolt	g	250	75
cock sheet			200

Spray paint	L	1	1600
Tinner	L	o2	650
Screen(0.5)	no	1	475
Arc welding rod packet	no	1	650
D.O.L.starter	no	1	5900
2" round iron	ft	6	1000
gas oxygen welding			500
	Sub Total		84565
Welder/Mechanic			24083
Labour			21000
sub			
total			129648
Profit 15%			19447
Grand total			149095
selling price			150000

