

## PERFORMANCE EVALUATION OF ANIMAL DRIVEN OIL EXPELLER USED IN BANGLADESH

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[ Date Received : 03.11.1996 ]

Key words : Oil expeller, Animal draught, Performance

### ABSTRACT

Mechanical analysis was done for the animal driven rural oil expellers. The result obtained from force analysis was used to estimate the various forces involved in crushing process. For the mustard seed, the oil extraction pattern at different batch and moisture content were determined. Physical properties of different varieties of mustard seed were determined and correlated with optimum moisture added during crushing. The optimum percentage of water added prior to crushing was found to be the functions of initial moisture content of seed, moisture added for maximum angle of repose and maximum bulking.

### INTRODUCTION

Mustard oil is one of the predominantly used cooking oil in many countries of South East Asia including Bangladesh. Formerly only indigenous equipments, either operated manually or animal driven, were used for extracting oil from mustard seed. They are being replaced gradually by electric or diesel powered oil expellers. Nevertheless, a considerable number of indigenous oil expellers are still in use.

Animal powered ghani (local term for oil expellers) was first developed in India for extracting oil from mustard and sesame seeds, but in some places they are used for coconut and ground nut crushing (UNIFEM, 1987).

The main problems with animal operated oil mills are:

- 1) It is an inefficient device for expelling oil as in the case of groundnut (Singh, 1989).
- 2) Crushing capacity of ghani is very low. Animal powered ghani has approximate capacity of 2 kg/hr. "Stamper and wedge" press has an

estimated capacity of 550 kg/day and hydraulic press has maximum capacity of 175-200 kg/hr (Khan and Hanna, 1983).

- 3) It needs a good sunny day to dry the seeds.

Despite these difficulties, it is still in operation because it is not possible for all owners of these ghanies to replace existing ghanies by modern expensive electric powered ghanies. Oil extracted by animal driven ghanies are sometimes preferred by the consumers.

The improvement of crushing efficiency may be achieved through study of the process and principle involved in the animal crushers. This may be done step by step as:

- 1) Performance study of existing mills and analysis of force requirement.
- 2) Study of the effect of different parameters on oil recovery e.g. moisture content and time of crushing.
- 3) Improvement of design and maximization of oil output.

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### WORKING PRINCIPLE

The mustard seeds are spread under the sun for about 5 hours while a little amount of water sprayed time to time to compensate the moisture loss during the process. About 5 kg of mustard is taken in a basket and about 150 ml of water is poured on it. The mustard is then stirred to mix water uniformly. Then it is poured into void space between pestle and mortar (Fig. 2). A scraper is tied with katari projection, as shown in Fig. 1, which rotates along with katari. The scraper makes the mustard seeds of upper bore to fall into lower bore. The process is continued until all the mustard fall into lower bore and been adequately compressed. About 5 kg of mustard is crushed at a time in a batch.

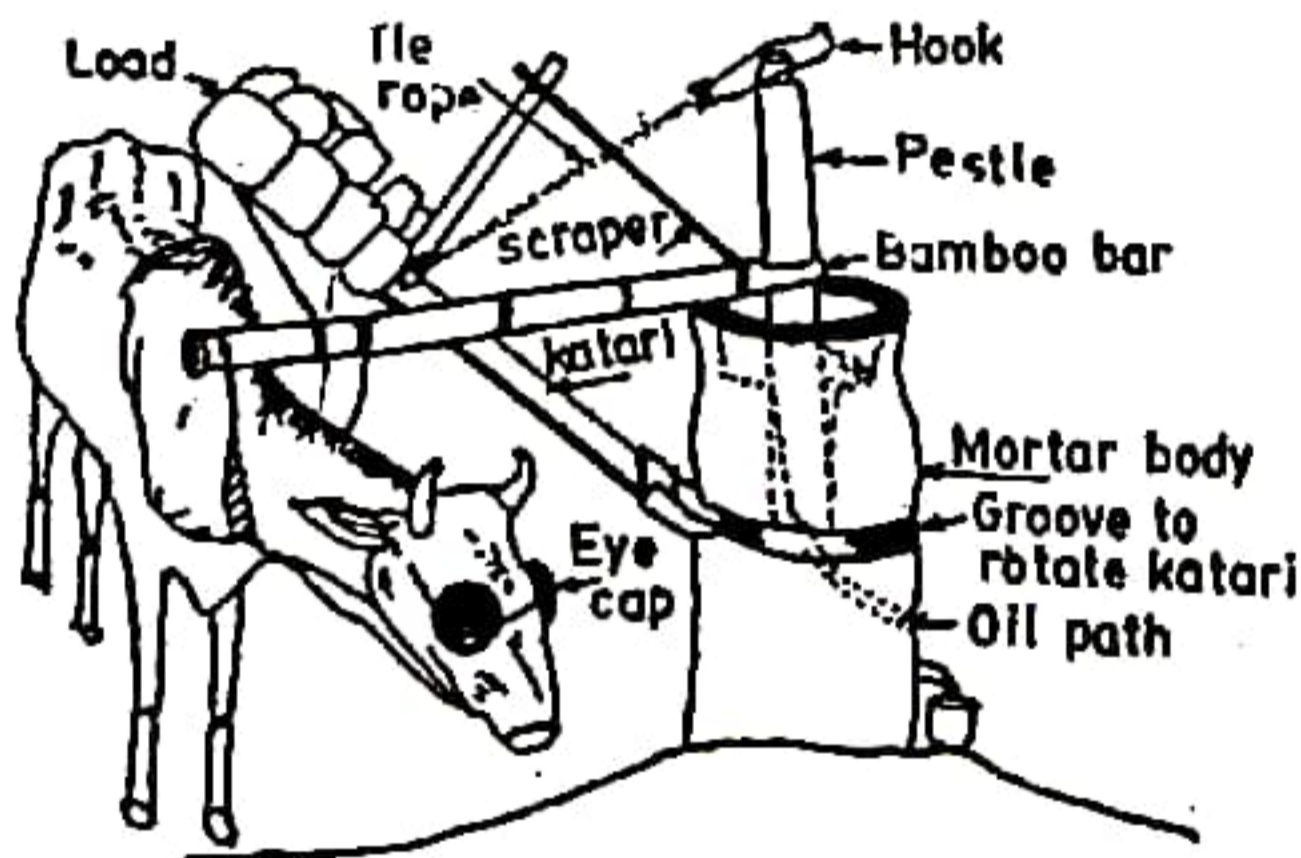


Fig. 1 Animal driven ghani

### METHODOLOGY

The mustard seeds used in the study were collected from the local market. The samples were weighed by a balance. The batch was varied from 4 kg to 5 kg at the interval of 0.5 kg. The moisture content of the mustard seed was varied from 2 to 4 % (wet basis) at the interval of 1 %. The physical parameters of the oil seeds were determined (Table 1).

The pulling force exerted by a bullock on the beam of the crusher was measured by a spring loaded dynamometer. Angles were measured making a

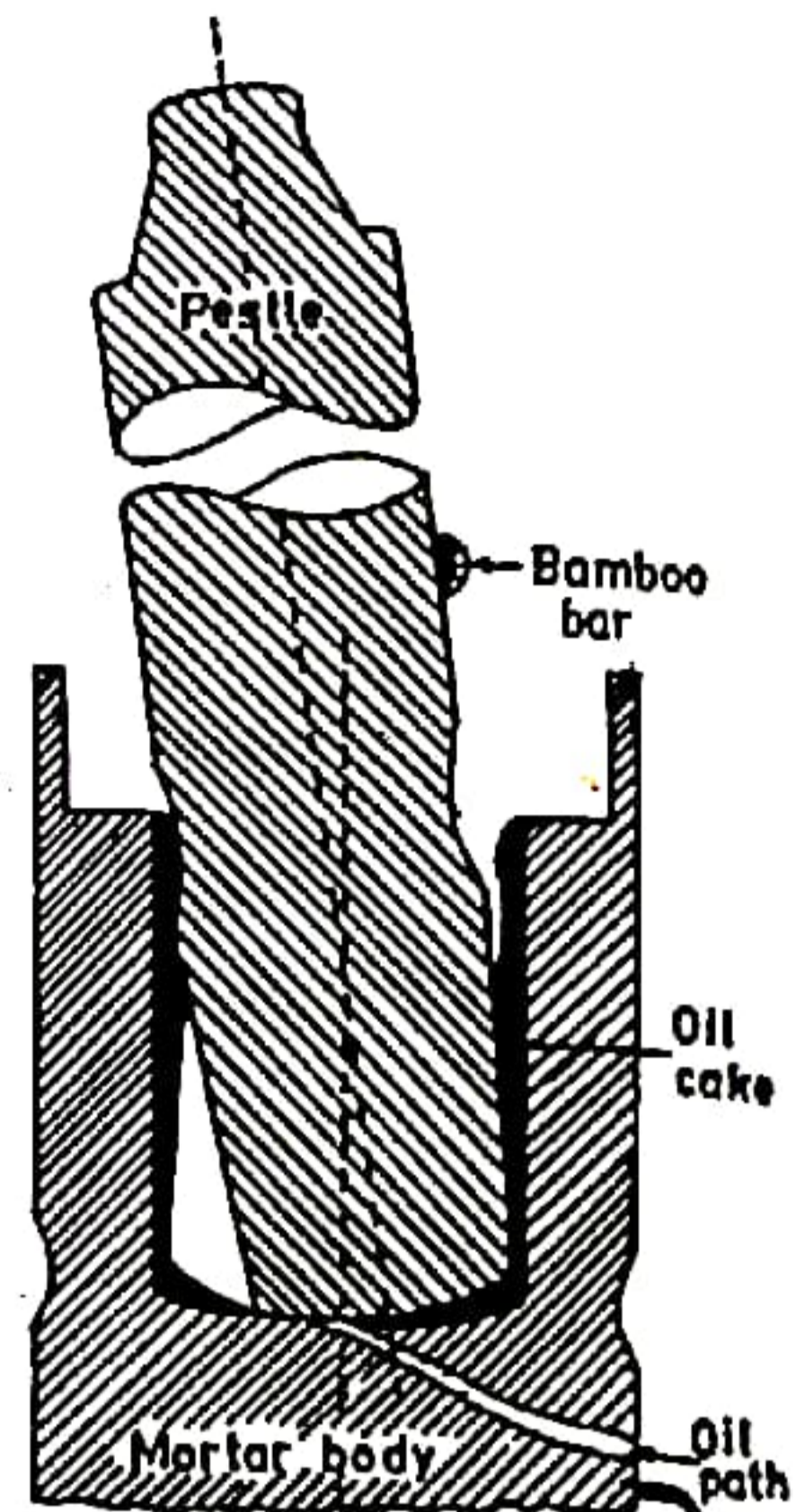


Fig. 2 Cross-sectional view of mortar pestle assembly

suitable triangles and measuring the arm lengths. The density of oil was determined by using a density bottle. The oil content of seed was determined by Nuclear Magnetic Resonance (NMR) method. The angle of repose at different moisture content, bulk density, particle density, bulking etc. were also measured. The moisture content of seed was determined by heating the seeds for 6 hours at 130°C in an oven drier as recommended by Whitley (1951).

### Force Analysis

Assuming constant angular velocity  $\omega$ , the tension  $T$  will not lie on  $xz$  plane (Fig. 3) since there is some frictional force between pestle and mortar. To overcome these friction,  $T$  force has to incline in  $y$ -direction. Establishing equilibrium in  $xz$  plane, centrifugal force on  $m$  due to rotation is given by

$$F_{CF} = m\omega^2 (x_3 - h \tan \alpha) \cos \alpha \dots\dots\dots(1)$$

Table 1 Some physical properties of different varieties of mustard seed

Variety	Bulk-Density g/cc	Particle density g/cc	Mean Diameter (mm)	Mean Volume ( $\times 10^{-3}$ cc)	Void ratio	Oil content (w/w)	Density of oil. (g/cc)	Moisture content (% w. b)
Local	0.682	1.11	1.61	2.2	0.386	42.9	0.853	9
Sonali	0.673	1.09	1.93	3.75	0.383	43.5	0.908	7.59
Dhali	0.7035	1.11	1.66	2.41	0.366	45.6	0.88	7.25
Sampad	0.698	1.09	1.67	2.425	0.36	44	0.904	10.14
Tori-7	0.668	1.11	1.62	2.235	0.398	43	0.86	7.15

\* Local variety is a mixed variety which is readily available in market.

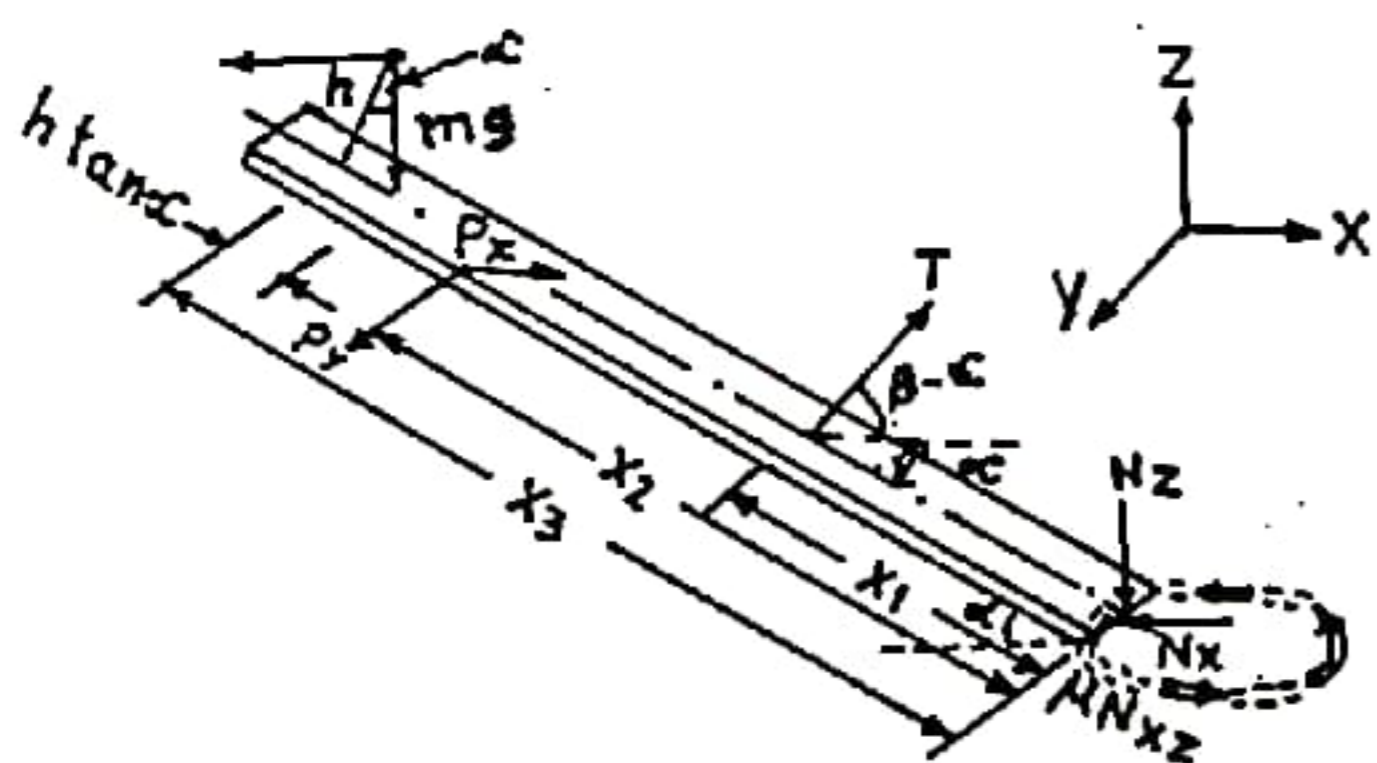


Fig. 3 Free body diagram of katari

Taking moment at contact point between katari and mortar body, tension in tie rope T can be expressed as

$$T = \frac{mg(x_3 - h \tan \alpha) \cos \alpha + F_c \left[ \frac{h}{\cos \alpha} + (x_3 - h \tan \alpha) \sin \alpha \right] - x_2 P_x \sin \alpha}{x_1 \sin \beta} \dots\dots\dots(2)$$

Balancing the forces in x and z direction separately, following equations can be derived

$$N_x = T \cos (\beta - a) - F_c + P_x \dots\dots\dots (3)$$

$$N_z = T \sin (\beta - a) - mg \dots\dots\dots(4)$$

$$N_{xz} = \sqrt{(N_x^2 + N_z^2)} \dots\dots\dots(5)$$

Pestle touches the mortar at points C, D and E (Fig. 4). Let co-efficient of friction between wood to wood at points A and E be  $\mu_1$ , between pestle and oil cake at point C and D be  $\mu_2$ , and between wood and bamboo at point B be  $\mu_3$ . Bamboo is pressing the mortar (Fig. 1) with force  $R_3$  which can be determined from free body diagram of bamboo arm (Fig. 5).

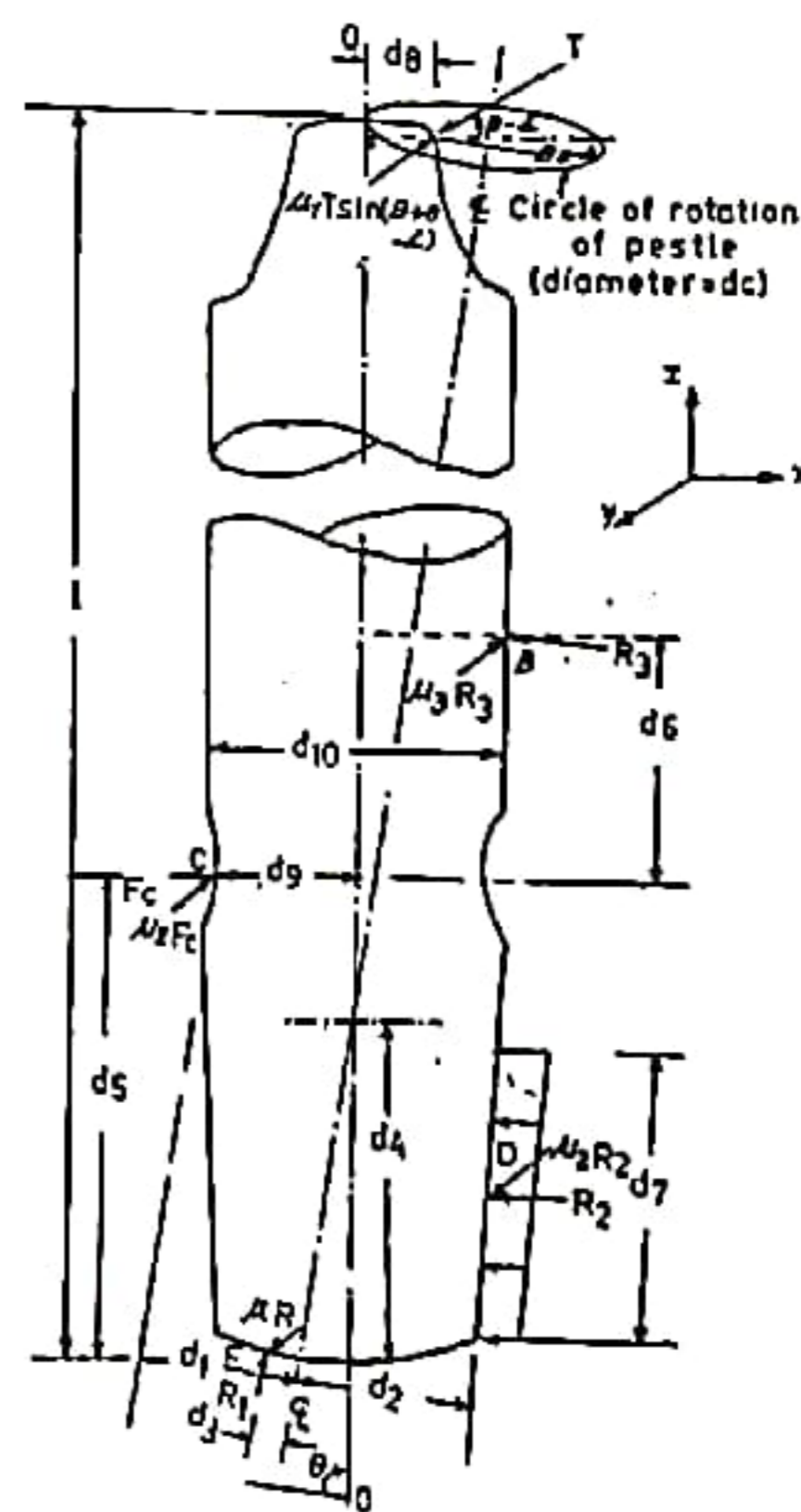
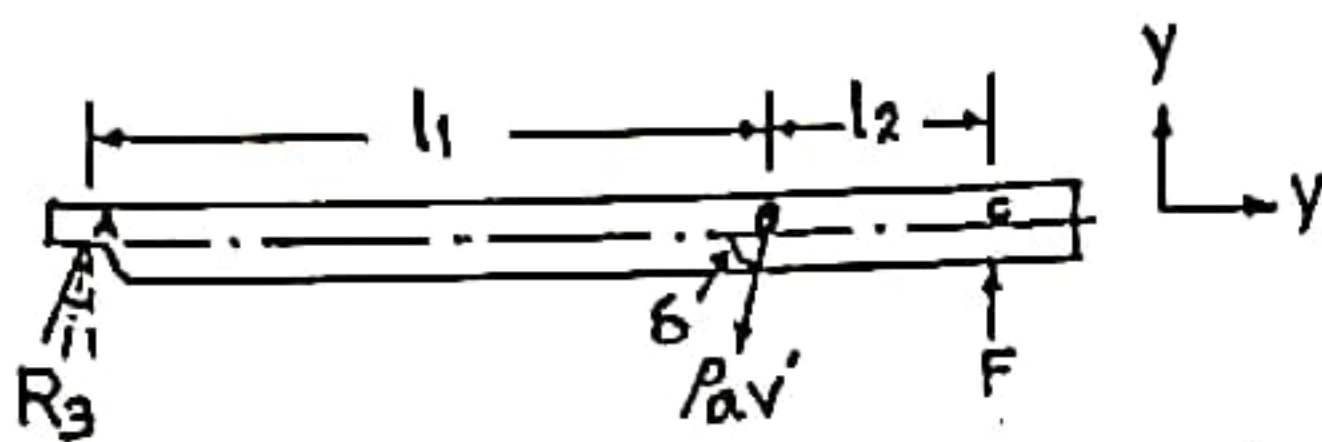


Fig. 4 Free body diagram of pestle



$R_3$  = Normal force on pestle  
 $F$  = Force exerted by bullock

Fig. 5 Free body diagram of bamboo bar

From Fig. 4, diameter of the circle of rotation of tip of pestle,  $dc = 2(1 - d_4) \sin(90^\circ - \theta)$

or,

$$d_4 = 1 - \frac{dc}{2 \cos \theta} \quad \dots\dots\dots(6)$$

It is assumed that pestle presses on oil cake evenly and acts perpendicular to the axis of pestle. Balancing the force in the direction of axis of pestle (Z-axis) and neglecting the weight of the pestle,

$$R_1 = \frac{T \sin(\beta - \theta - \alpha - 90^\circ) - R_3 \cos \theta}{\sin \theta} \quad \dots\dots\dots(7)$$

Taking moment at C (Fig. 4)

$$R_2 = \left[ R_1(d_1 - d_3) + R_3 \cdot d_6 \sin \theta + R_3 \cdot d_{10} \cos \theta + T \sin(\beta + \theta - \alpha) \times (l - d_5) - T \cdot (d_8 + d_9) \cdot \sin(\beta - \alpha + \theta - 90^\circ) \right] / \left( d_5 - \frac{d_7}{2} \right) \quad \dots\dots\dots(8)$$

By  $\left[ \sum F_x = 0 \right]$

$$F_c = R_2 + R_3 \sin \theta + T \sin(\beta + \theta - \alpha) - R_1 \cos \theta \quad \dots\dots\dots(9)$$

Since the pestle is revolving around centre line of bore, due to pivot action at C, a frictional force  $\mu_2 \cdot F_c$  will be produced. This force will try to rotate the pestle around Z-axis in clockwise direction when observed from top side. If the pestle rotates, the frictional force  $\mu_2 \cdot R_2$  will also help to rotate the pestle in the same direction. But the frictional forces at point A, B and E will try to resist the rotation. The pestle will rotate in Z-axis if,

$$\mu_2 F_c \cdot d_9 + \mu_2 R_2 \times \frac{d_{10}}{2} > \mu_1 T \sin(\beta + \theta - \alpha) \times d_8 + \mu_3 R_3 \times \frac{d_{10}}{2} + \mu_1 \cdot R_1 (d_3 + d_4 \cos \theta) \sin \theta \quad \dots\dots\dots(10)$$

Torque required to overcome the frictional resistances to revolve around centre line is given by

$$T_f = \mu_2 F_c \times d_1 + \mu_1 R_1 \times d_3 + \mu_2 R_2 \times \left( d_2 - \frac{d_7}{2} \cos \theta \right) + \mu_3 R_3 \times \left( \frac{d_{10}}{2} - (d_5 + d_6 - d_4) \cot \theta \right) + \mu_1 T \sin(\beta + \theta - \alpha) \times (dc / 2 - d_8 \cos \theta) \quad \dots\dots\dots(11)$$

This torque is necessary to initiate the rotation of the pestle, which is obtained by inclination of T from x-z plane. Let  $T_y$  be the force causing rotation. Then

$$T_y = \frac{T_f}{\frac{dc}{2} - d_8 \cos \theta} \quad \dots\dots\dots(12)$$

Now, referring Fig. 2, Fig. 3 and Fig. 4, let outer diameter of the mortar body at contact point with katari =  $D_{out}$ . Then

$$P_y = \frac{\frac{1}{2} \mu N_{xz} \times D_{out} + T_f}{x_2 \cos \alpha + \frac{1}{2} D_{out}} \quad \dots\dots\dots(13)$$

Since  $P_y$  is y component of average pull ( $P_{av}$ ) and it makes angle  $t$  with x-axis,

$$\text{Average pull requirement, } P_{av} = \frac{P_y}{\sin \tau} \dots\dots\dots (14)$$

### RESULT AND DISCUSSION

Fig. 6 shows the percentage of oil collected against different moisture content and different batch. It is obvious from the figure that 4.5 kg batch and 3 % moisture addition is most desirable.

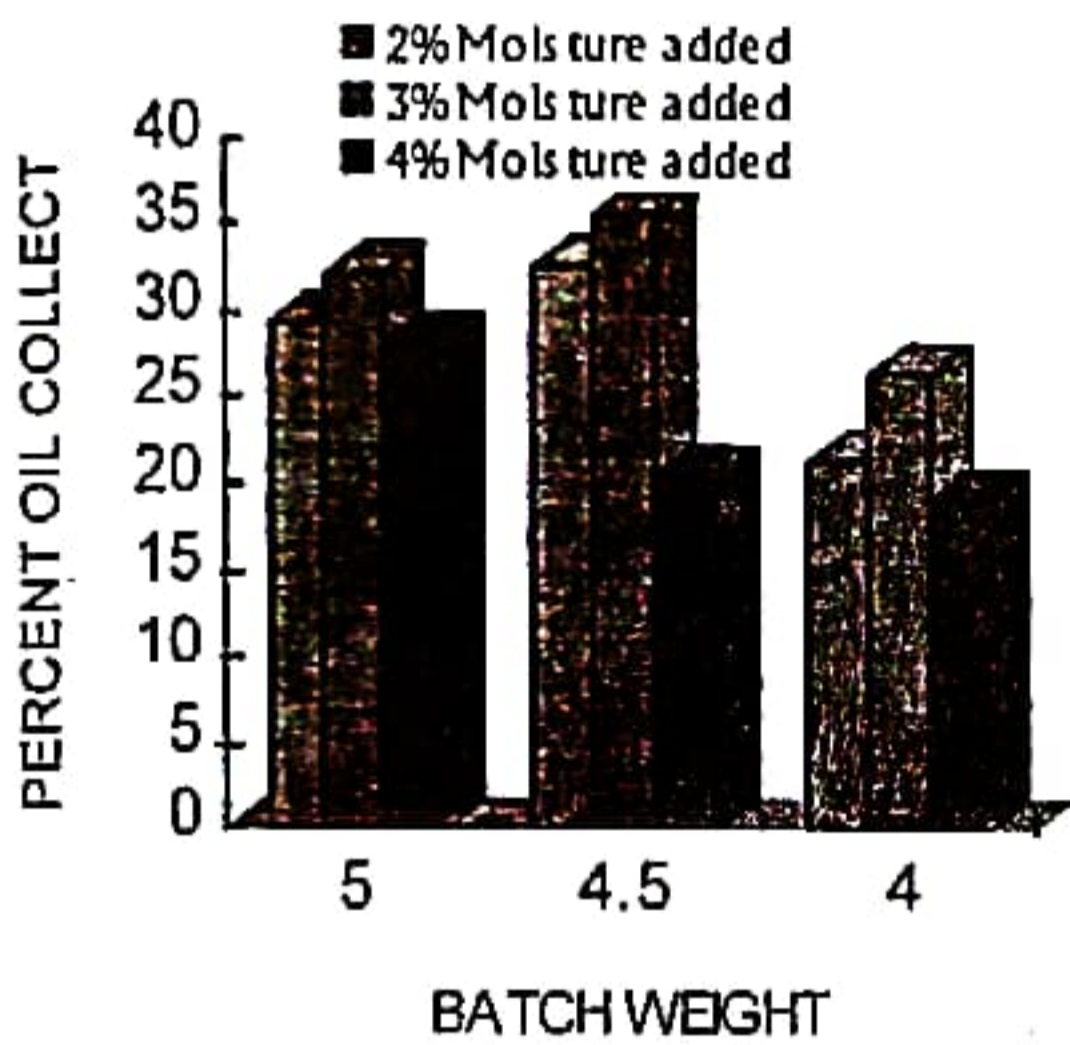


Fig. 6 Percentage of oil collected at different percentage of moisture added and at different batch weight

It is found that the moisture added for crushing sensitively affect the oil yield. If moisture added is less than optimum, the oil initiates to ooze out earlier (Fig. 7 to Fig. 9). This may be because of lower moisture giving less bulking or void ratio (Table 2). So, oil fills up the voids and makes the oil to flow out quickly. If the moisture added is greater than optimum, the initialization of coming out of the oil is delayed. This can be explained in the same manner as before.

The excess moisture affect the oil yield more adversely. This may be because as pestle rotates a void space will be created just behind the pestle and it should be filled with uncrushed mustard promptly

for effective crushing. As the moisture content is increased the mustard seeds will be reluctant to fill the voids because of increased friction angle. This develops the unevenness of distribution of oil seed and oil cake results in the drastical decrease of oil yield. For optimum production of oil, the water  $m$ , that must be added in mustard seed before crushing, was found to be the function of three variables,  $m_a$ ,  $m_b$  and  $m_c$ . The relation is given by following empirical equation,

$$m = k (m_a)^a (m_b)^b (m_c)^c$$

where

$m$  = moisture added as percentage of sun-dried sample before crushing.

$m_a$  = percentage of water added to the sun dried seeds (by weight) which makes the angle of repose maximum.

$m_b$  = percentage of water added to the sun dried seeds (by weight) which makes the bulking maximum.

$m_c$  = moisture content of sun-dried seed (w. b)

$k$ ,  $a$ ,  $b$  and  $c$  are constants.

After transposition and multiple linear regression, the value of  $k$ ,  $a$ ,  $b$  and  $c$  are estimated as

$$k = 0.0385; a = -0.2503; b = 3.1825; c = -0.839$$

Standard error was estimated to be 1.12 %.

The left side of the equation (10) is always greater than right side indicating the rotation of the pestle in its own axis in clockwise direction. For efficient oil extraction the oil seed membrane must be ruptured and pressed adequately. The oil seeds break out due to compression and shearing action. If pestle is allowed to rotate in its own axis, the shearing action is greatly reduced; thus reducing the rate of oil extraction and ultimately oil production. To stop the pestle to rotate in its own axis, the right side of equation 10 must be made greater than left side. This can be done by (1) reducing the value of coefficient of friction between pestle and oilcake  $\mu_2$ , (2) decreasing diameter of pestle at the point of contact with upper portion of bore hole, or otherwise

Table 2 Angle of repose and bulking of different varieties of mustard seed as affected by addition moisture

Variety	Moisture added				
	2%	4%	6%	8%	10%
Local	37.09* (10)	48.72 (16)	60.19 (20)	49.15 (23)	39.00 (20)
Sonali	32.71 (2.1)	40.11 (4)	45.73 (7)	46.83 (12)	37.18 (18)
Dhali	34.2 (10)	47.13 (15)	57.19 (22)	46.3 (24)	34.9 (23)
Sampad	35.23 (12)	49.78 (18)	58.2 (21)	54.73 (25)	43.16 (22)
Tori-7	36.22 (10)	44.72 (16)	56.28 (18)	47.91 (22)	36.29 (22)

\* Angle of repose is in degrees. The figure in parenthesis is the bulking (the percentage of volume increased with respect to water added).

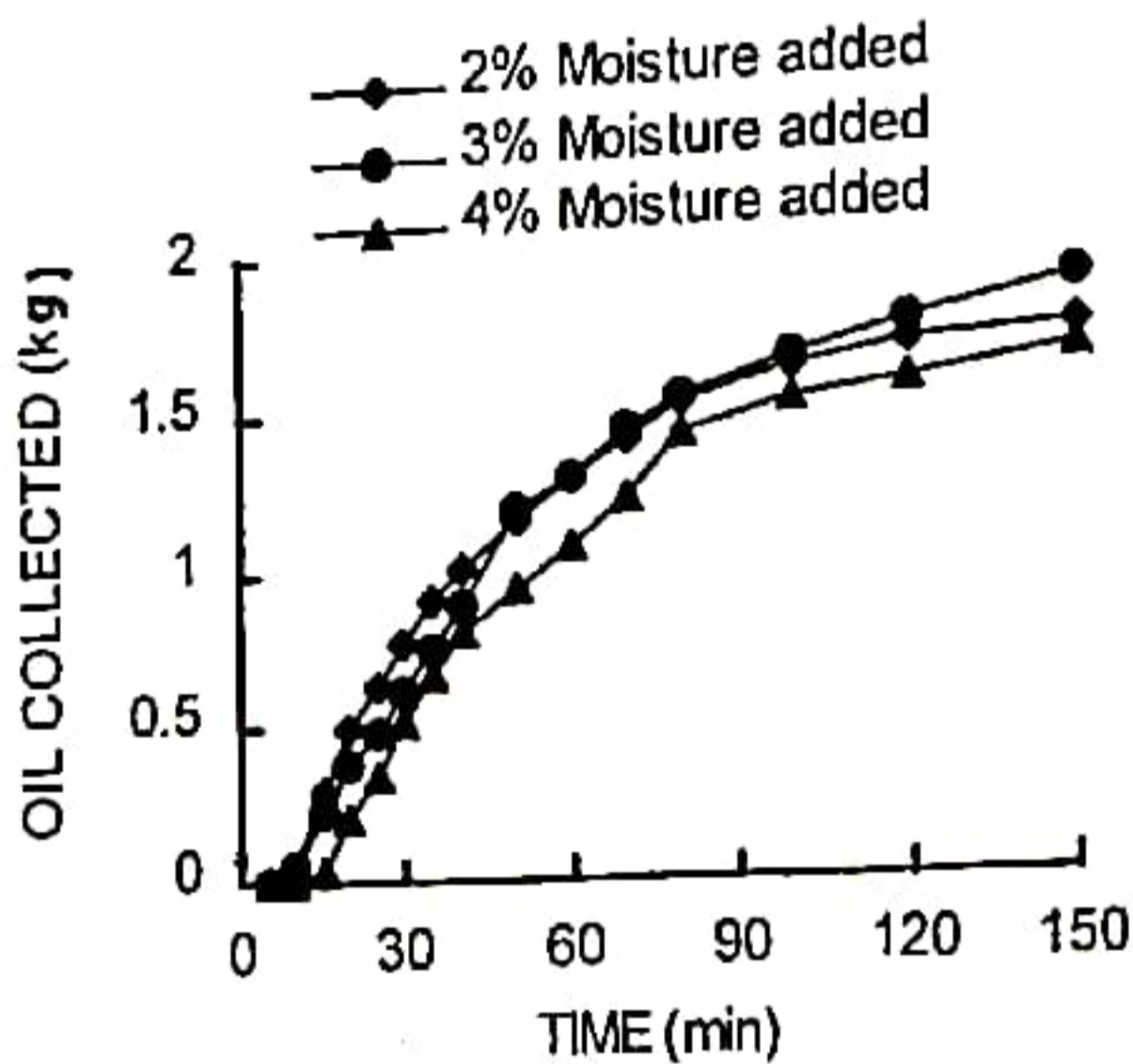


Fig. 7 5 kg batch oil extraction pattern

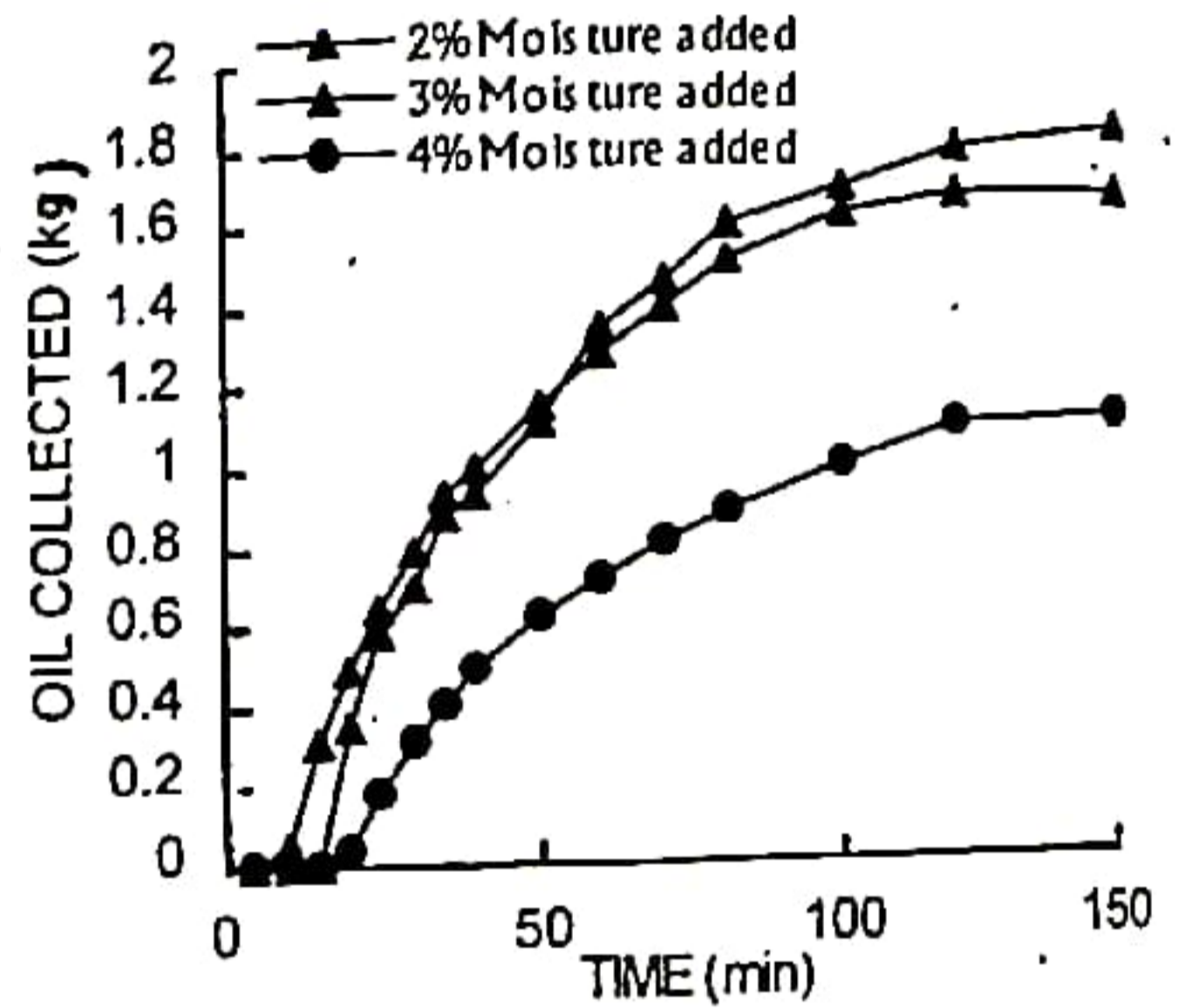


Fig. 8 4.5 kg batch oil extraction pattern

arranging the parameters of equation (10) which eventually makes the right side greater than left side.

As  $\alpha$  increased, angle  $\beta$  also increased, while the pressure applying on oil-cake i.e.  $R_2$ ,  $F_c$  and  $P_{av}$  required decreased (Table 3). But it was observed that while rotating, the pestle does not rest on diametrically opposite corners of the bore. This makes the common tangent of pestle and bore at point D (Fig. 4), non-horizontal. It develops the upward force on pestle while rotating at its own axis due to frictional resistance and the contact point D tries to move in a helical path rather than horizontal circular path. So, whenever  $R_2$  exceeds certain critical value pestle starts to move upward and

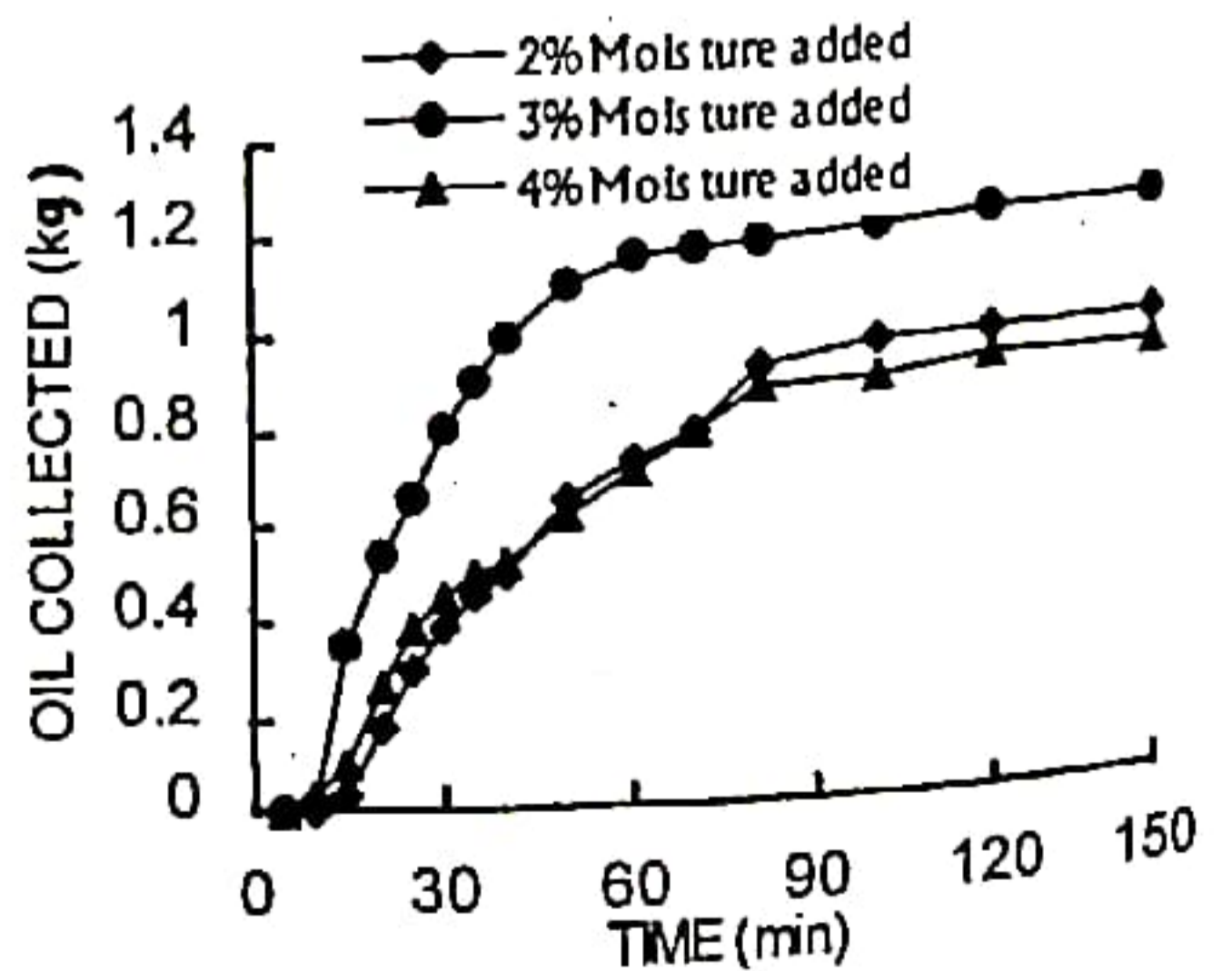


Fig. 9 4 kg batch oil extraction pattern

eventually comes out of the bore causing serious accident. It is called "riding of pestle". This may also occur at lesser value of  $R_2$  if angle  $\theta$  is decreased. It is because as  $\theta$  decreases the common tangent at point D makes greater angle with horizontal line thus increasing the lifting component of force. As angle  $\alpha$  decreases  $R_2$  increases and angle  $\theta$  decreases, facilitating the riding of pestle. It was observed that the limiting value of  $\alpha$  was nearly  $6^\circ$ . Though, for the sake of safety this angle should not be less than  $10^\circ$ .

If  $\alpha$  reaches  $20^\circ$ , the force  $N_2$  (Fig. 3) becomes negative indicating that  $N_2$  will start to act from downward. The forces that develops the pressure on mustard are  $F_c$  and  $R_2$ . From Table 1 it can be seen that  $F_c$  is nearly 1.25 times greater than  $R_2$ . But from the observation of oil cake,  $F_c$  is applied in nearly 16 cm of bore height while  $R_2$  covers lower 10 cm of bore height. So, although  $F_c$  is apparently greater than  $R_2$ , the actual pressure on the oil cake is greater at lower portion. But the oil seeds and oil cake has the tendency to slide towards bottom due to gravitation, making lower portion of oil cake thicker than that of upper portion. Thicker is the oil cake greater will be the pressure required to extract the equal percentage of oil. So, the unequal distribution of pressure seems to be balanced by uneven thickness of oil cake. Though  $F_c$  is 1.25 times greater than  $R_2$  because of unequal length it is covering, the pressure per unit length available in lower portion becomes 1.28 times greater than upper portion; while thickness of oilcake observed was 2.8 times greater in lower portion. That is why it can be concluded theoretically that oil extracted from upper portion is more efficient than that of lower portion. Table 1 shows that actual measured pulling force ( $P_{av} = 206 \text{ N}$ ) nearly equals the calculated pulling force ( $P_{av} = 205.41 \text{ N}$ ) for  $\alpha = 15^\circ$ .

From Fig. 9 the maximum percentage of oil extracted was 35.3 percent. The original oil content was 42 % (w/w). So, 84% of total oil content could be expelled, from this method, leaving 16 percentage to oilcake. This value is slightly greater than recommended value of 14 percent (Singh, 1989).

## CONCLUSION

Oil crushing by animal driven oil crusher is a very slow process. The katari angle should not be less than  $10^\circ$ . For heavier load or other conditions of operation the angle may be adjusted as required. Tapering of the lower section of pestle may increase the final oil yield. 4.5 kg batch gave the optimum yield of oil. Calculated amount of water (using the empirical equation) is to be added with mustard seed prior to crushing for maximum oil extraction.

## SUGGESTIONS

The main problem with this ghani is its slowness. For small scale production of oil it is satisfactory. The efficiency of ghani may be increased by (1) tapering the portion of pestle which comes inside the bore so that more mustard is crushed by upper pressure causing even distribution of pressure per unit length per unit thickness, and (2) stopping the pestle to rotate in its own axis. This demands higher power input, the amount of which is not estimated in this paper.

## NOMENCLATURE

$h$	Perpendicular distance of c.g. of load including katari from the middle of katari
$m$	Mass of the applied load including katari
$N$	Resultant force on xz plane at contact point of katari and mortar body
$\omega$	Angular velocity of rotation
$P$	Pulling force of bullocks
$P_x$	x-component of $P$
$P_y$	y-component of $P$
$\alpha$	Angle made by katari with X-axis
$\beta$	Angle between tie rope and katari
$\mu$	Coefficient of friction between katari and mortar body
$T$	Tension in tie rope
$t$	Angle that $P_{av}$ makes with x-axis
$dc$	Diameter of the circle of rotation of tip of pestle

Table 3 Effect of Angle  $\alpha$  on the forces acting at different points

Angle, $\alpha$	5	10	15	20	25
$\beta$	51.01	54.40	57.40	60.37	63.40
$F_d$	51.32	55.05	57.53	54.98	51.98
T	3700.01	3440.04	3100.08	2933.50	2674.18
$N_x$	2001.43	2537.80	2437.27	2318.51	2182.31
$N_y$	741.02	407.02	204.58	-47.13	-288.20
$N_{xz}$	2722.47	2580.57	2445.85	2318.99	2200.99
$R_1$	2412.00	2140.85	1894.20	1655.34	1430.89
$R_2$	10100.85	9732.77	9290.77	8783.32	8213.69
$F_c$	12757.74	12300.10	11754.90	11125.45	10415.86
L.S. in eq (10)	59.18	57.00	54.44	51.50	48.19
R.S. in eq (10)	38.00	35.58	32.26	29.03	25.89
$T_x$	180.48	159.16	150.91	141.77	131.79
$T_y$	1054.28	1007.93	955.67	897.77	834.59
$P_y$	148.73	143.23	138.16	133.48	129.15
$P_{av}$	221.13	212.94	205.41	198.45	192.00

All forces are in Newton and angles are in degree.

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