Iran. J. Agric. Res. Vol. 4, No. 1, 1976

ANALYSIS OF HUSKING ACTION IN THE RUBBER–ROLL RICE SHELLER[1]

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ABSTRACT

In this paper, analysis has been made for the forces involved in the husking action of the rubber-roll rice sheller. The husking action has been assumed to be the function of contact pressure and shearing force between rubber-roll and rough rice. Expressions are developed for angle of nip, contacting time, contact pressure and frictional force. Predictions are made from these expressions about the distribution of contact pressure, the effect of speed, speed difference, diameter and clearance of the rolls and feeding pose of rough rice on the overall husking action and its efficiency.

INTRODUCTION

The rice grain is covered by an outer husk which must be removed before the rice can be used. The outer-most bran layers have also to be removed because they are relatively coarse, nearly impermeable to water and difficult to digest (3). The removal of the husk and the bran layers is, therefore, the primary step in the processing of rice. Because of the consumer's preference for the whole grain, the most important criterion for milling is the yield of head rice or the percentage recovery in the form of whole grain.

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The difference between the potential and the actual yields represents losses in the present rice milling practices and is due to various reasons. The loss could be in the form of powder, or medium broken grains not recovered for use. Attempts to obtain maximum yields of total rice from any rough rice should, therefore, be in three directions: (a) the raw material should be improved so as to experience minimum breakage during the milling process, (b) the milling machinery used should be efficient, gentle and precise in operation so that breakage or aspiration losses are minimized and (c) broken grains should be recovered from the bran and used as food. It is the second direction to which this paper is related.

The splitting and removal of husk is more effectively done in three different types of shellers: (a) horizontal, circular, stone shellers covered with emery, (b) rubber belt shellers which convey the rice on a rubber belt under a ribbed steel rotor and (c) modern shellers with a pair of horizontal rubber rollers. Breakage of grains is the greatest in the first type and the least in the third type. Rubber roll shellers have proved satisfactory wherever reliable and continuous operation is the decisive factor (2).

Rubber roll shellers offer advantages over disc shellers; i.e., breakage practically eliminated, the outer layer of rice kernel remains undamaged insuring safer storage of brown rice, no waste of germs which when using disc shellers and rollers are generally separated with the husk and often account for a loss of 1.0 to 2.0 percent of final product and easier separation of the husk which after shelling generally appears in two uniform halves.

While using rubber roll type shellers, it is advisable to provide at least one extra rubber roll sheller as a standby unit. Thus, the shellers operate alternately, allowing the rubber to recover from the expansion caused by the heat being generated during the shelling process.

When shelling the bulk of rough rice, a thorough precleaning of the grain and extra strong aspiration to reduce frictional heat to minimum are essential. These two factors are of paramount importance in prolonging the life of rubber rolls. Maximum durability of the rubber rolls also varies with the moisture content of rough rice and with the weight of husk which is normally about 20% of the total weight of rough rice (2). Since wear and tear of rolls differ, the faster one wearing quicker than the slower one, it is imperative to interchange the rolls after 30 to 40 hr of running. thereby securing a further increase in the life of rubber rolls.

A full labelled line diagram of the rubber roll rice sheller is shown in Fig. 1. The

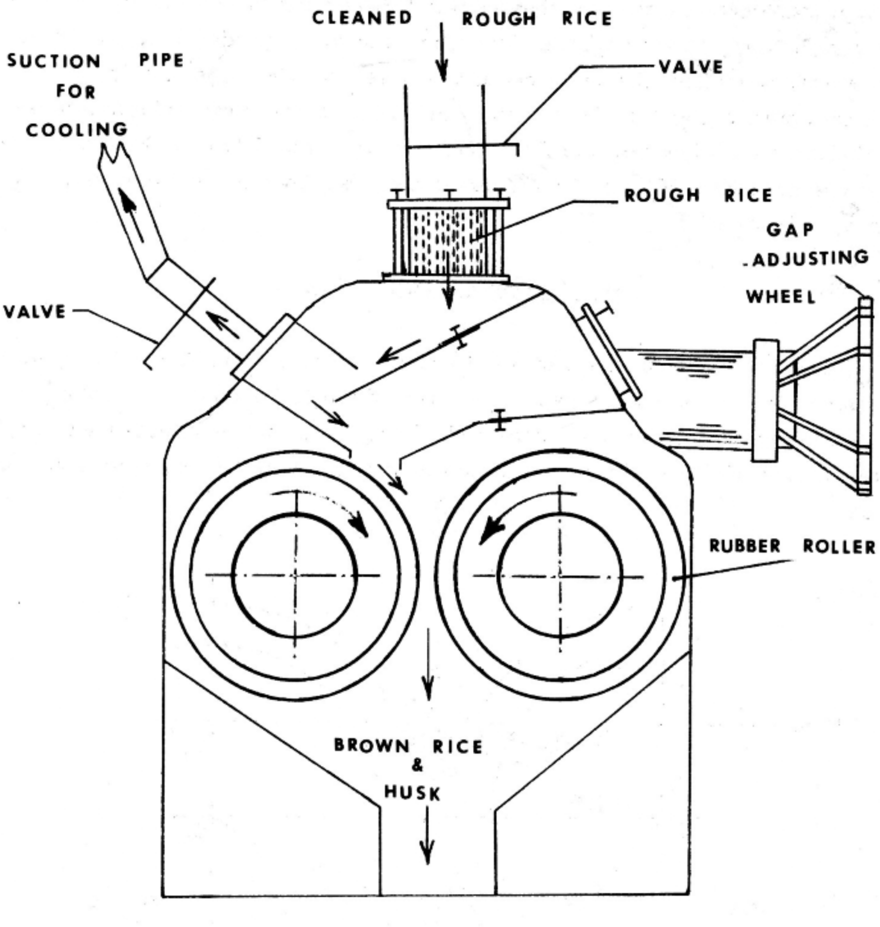

Fig. 1. Front view of the rubber rice sheller.

main part of the rubber roll rice sheller is a pair of rubber rolls. A typical Schule (German) type rice husker has the following dimensions: roller width of 260 mm, external diameter of 220 mm, internal diameter of 160 mm, rubber sheathing thickness of 30 mm and 12 kg as the weight of a pair of rubber rolls (2). However, the dimensions may vary from one manufacturing plant to another. The rubber sheathing cylinder is fixed to an iron core. Mostly synthetic rubber and other polymers are used. The rubber rolls are set parallel to each other as shown in Fig. 1, with a clearance in between them and rotate in opposite directions at different speeds. The speed may vary from 900 to 1400 rpm for the faster one and 600 to 800 rpm for the slower one. The rubber rolls are compressed with a spring attachment (2).

ANALYSIS AND DISCUSSION

The rough rice which is fed to the clearance between the rolls (Fig. 1) goes under the husking action (peeling of the outer covering of rough rice)which is caused by the forces between rough rice and the rubber rolls. Thus, it is essential to analyze these forces which, in turn, will lead to the optimization of the conditions for the overall husking action.

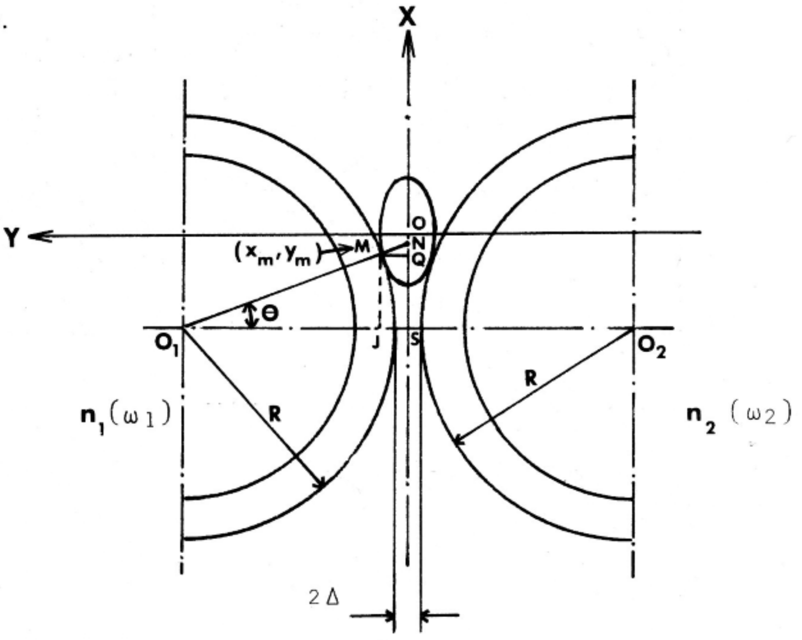

Fig. 2. Geometry of rice kernel in sheller.

It is conceivable that the husking action of the rubber rolls is a function of the contact pressure and the shearing force. Contact pressure is mainly caused by the deformation of rubber at the contacting point between rolls and rough rice. The shearing force is caused by friction which in turn is caused by the difference in the two speeds of rubber rolls. The forces acting on the rough rice under the husking action are the function of diameter of rolls, clearance between rolls, speed of rolls, speed difference, compression force of spring, viscoelastic behavior of rubber, size, shape and moisture content of rough rice, feeding direction of rough rice, frictional coefficient between rubber and rough rice and pose of rough rice (2, 4).

Angle of Nip: Fig. 2 shows the geometrical representation of a rice kernel when making initial contact with the rubber rolls. Here,

R = radius of rolls $\doteq L$
n_1, n_2 = rpm of the two rolls $\doteq T^{-1}$
$2\triangle$ = clearnace between the two rolls $\doteq L$
θ = angle of nip $\doteq [1]$
x_m, y_m = coordinates of contacting point M with reference to the rough rice $\doteq L$

We assume rotation of rough rice is prevented by the large contact pressure. However, if the clearance is large and rough rice is not fed with its pose lengthwise, rotation is likely to occur and in that case rotation of rough rice can not be neglected. It is fairly reasonable to assume the shape of the rough rice as ellipsoidal (Fig. 3) and describe it by

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \qquad [1]$$

where x, y and z are coordinates and a, b and c are radii of ellipsoid as shown in Fig. 3.

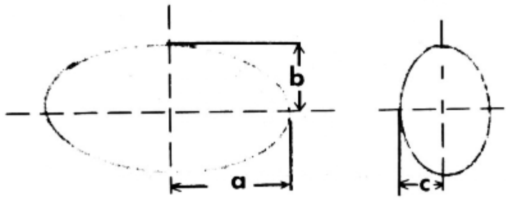

Fig. 3. Ellipsoidal shape of rice kernel.

From Fig. 2

$$y_m \text{ (with reference to the rolls)} = O_1S - O_1J$$

or

$$y_m = R + \triangle - R\cos\theta \qquad [2]$$

Also, y_m (with reference to rough rice) can be found from the two dimensional equation of ellipsoid (Equation [1]).

Thus $y_m = (\frac{b}{a})\sqrt{a^2 - x_m{}^2} = MQ$ [3]

Let the eccentricity be e for M, then

$$MN = (\frac{b}{a})\sqrt{a^2 - e^2x_m{}^2} \qquad [4]$$

From Fig. 2:

$$\frac{MQ}{MN} = \cos\theta$$

or

$$y_m = MN\cos\theta$$

Substituting the value for MN from Equation [4], we get

$$y_m = (\frac{b}{a})\sqrt{a^2 - e^2x_m{}^2}\cos\theta \qquad [5]$$

combining Equations [2] and [5] we get

$$R + \triangle - R\cos\theta = (\frac{b}{a})\sqrt{a^2 - e^2x_m{}^2}\cos\theta$$

or $\cos\theta = \dfrac{R + \triangle}{R + \frac{b}{a}\sqrt{a^2 - e^2x_m{}^2}}$ [6]

From Equation [5], we get

$$\cos\theta = \frac{y_m}{\frac{b}{a}\sqrt{a^2 - e^2x_m{}^2}}$$

Substituting the value for y_m from Equation [3], we have

$$\cos\theta = \frac{\frac{b}{a}\sqrt{a^2 - x_m{}^2}}{\frac{b}{a}\sqrt{a^2 - e^2x_m{}^2}}$$

or

$$\cos\,\theta = \frac{\sqrt{a^2 - x_m^{\;2}}}{\sqrt{a^2 - e^2 x_m^{\;2}}}$$

Substituting this value in Equation [6], we get

$$\frac{R + \triangle}{R + \frac{b}{a}\sqrt{a^2 - e^2 x_m^{\;2}}} = \frac{\sqrt{a^2 - x_m^{\;2}}}{\sqrt{a^2 - e^2 x_m^{\;2}}} \qquad [7]$$

Thus, x_m can be determined from this equation.

Arc of contact: Let l denote the arc of contact made on the rubber roll with the rough rice, then

Arc of contact= 2 (radius of rubber roll) x (angle of nip)

or $l = 2\,R\theta$ [8]

Contacting time: Let t denote the contacting time during which the rough rice kernel is in contact with the rubber roll, then

$$t = \frac{l}{v}$$

Substituting the value for l from Equation [8], we get

$$t = \frac{2R\theta}{R\omega}$$

or

$$t = \frac{2\theta}{\omega} \qquad [9]$$

where v = mean velocity of rough rice passing through the roll clearance and

ω= angular velocity of rice kernel.

Contact pressure: Let two bodies be pressed together so that the resultant pressure between them is P. The parts of the bodies near the points of contact will be compressed, so that there is contact over a small area of the surface of each. This common area will be called the "compressed area" and the curve that bounds it, the "curve of compression."

It is quite reasonable to assume that the compressed area is bounded by an ellipse (1).

If R_1 and R_1' are the principal radii of curvature at the points of contact for the rubber roll (cylindrical shape) and R_2 and R_2' those for the rice kernel (ellipsoidal shape), we have then by Hertz theory (1):

$$2\,(A+B) = \left(\frac{1}{R_1} + \frac{1}{R_1'}\right) + \left(\frac{1}{R_2} + \frac{1}{R_2'}\right)$$

The angle (ω^*) between those normal sections of the two surfaces in which the radii of curvature are R_1 and R_2 is given by the equation

$$4\,(A-B)^2 = \left(\frac{1}{R_1} - \frac{1}{R_1'}\right)^2 + \left(\frac{1}{R_2} - \frac{1}{R_2'}\right)^2 + 2\left(\frac{1}{R_1} - \frac{1}{R_1'}\right)\left(\frac{1}{R_2} - \frac{1}{R_2'}\right)\cos 2\,\omega^*$$

where A and B are constants and having positive values. The values for the four principal radii of curvatures in the problem in question are:

$$\left.\begin{aligned} R_1 &= R \\ R_1' &= \infty \end{aligned}\right\}\ \text{for cylindrical rubber roll}$$

and

$$\left.\begin{aligned} R_2 &= \frac{(a^4 y^2 + b^4 x^2)^{3/2}}{a^4\, b^4} \\ R_2' &= \frac{(c^4 y^2 + b^4 z^2)^{1/2}}{b^2} \end{aligned}\right\}\ \text{for ellipsoidal rice kernel}$$

Using the bulk modulus and shear rigidity, the stress-strain relationship of classical elasticity can be developed (5).

With the help of Hertz's and Love's work (5), in elastic cases, the force developed between two bodies in contact over curved surfaces is determined by the following equation:

$$\alpha^{3/2} = C\ (\theta_1 + \theta_2)\ P \qquad [10]$$

Where α = distance by which the centers of mass of the two colliding bodies approach each other after contact has been made,

θ_1, θ_2 = material constants and

C= parameter incorporating geometry of the two curved surfaces which is a function of R_1, R_1', R_2 and R_2'.

Final equation for P can be developed in terms of relaxation time of viscoelasticity, mass of the moving bodies involved in the impact, a, Lame's constant, modulus of compression and displacements.

Pao (6) carried out numerical calculations using polyethylene as viscoelastic material and steel surface for determining relaxation time. He showed that all other factors being the same, smaller loads and stresses are developed in materials with lower values of modulus of elasticity. The duration of impact is longer in the case of less rigid material.

The relaxation spectrum for normal stress of different types of synthetic rubbers (GR–S, BUTYL, BUNA–N and Natural Rubber) can be found in some standard polymer and applied physics books.

Frictional force: The frictional force F_c is caused by the speed difference of rolls and is equal to the product of coefficient of friction, f, between rough rice and rubbersheathing and contact pressure, P. Thus

$$F_c = f.P \qquad [11]$$

From the foregoing analysis, it could be inferred that the brown rice is mainly compressed before the center line and is sheared because of the roll speed difference after the center line. Increase in speed difference may cause an increase in the acceleration and irregular motion of the rough rice. The speed of the rolls should be determined for the given viscoelastic properties of rubber and wear and temperature rise of the rolls. However, the higher the roll speed, the higher should be the relaxation spectrum of the rubber roll used. The distribution of pressure depends largely on this relaxation spectrum of the rubber.

It may also be mentioned that smaller roll clearance gives a larger a, because P increases in proportion to 3/2 power of a, thus resulting in a longer contact time.

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