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### DESIGN, FABRICATION AND EVALUATION OF A MOISTURE-BASED FIG SORTER

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**ABSTRACT** Iran produced 88,000 tonnes of dried figs in 2006 which ranked 4<sup>th</sup> in the world. However, much of the production is downgraded due to traditional methods of harvesting and drying in which producers let the figs dry on trees until they fall down on the ground. This method of harvesting is laborious, time consuming, and somehow unhygienic. Using shakers would be a good option for mechanized fig harvesting, but with this method, harvested figs have different moisture contents. To dry the figs appropriately, a suitable sorter should be designed to sort the harvested figs based on their moisture content. The main objective of the study is to design and fabricate a moisture-based fig sorter. Based on some preliminary experiments on physical properties of fig which are affected by moisture content, the coefficient of friction and rolling resistance were introduced as the key characteristics in fig sorting. Considering the mentioned characteristics, a test rig was fabricated. The rig consists of an horizontal feeding belt and three sloped sorting belts driven by an electric motor. The angle of each sorting belt can be manually adjusted. A basket was placed at the bottom of each belt to collect the sorted figs. In order to evaluate the sorter, freshly harvested figs with different moisture contents were fed into the sorter. A factorial experiment with two factors including four levels of belt speed (7.2, 8.4, 9.4 and 10.6 m/min) and two levels of belt slope arrangement (8, 9, 10 and 10, 11, 12 degree) was conducted in a completely randomized design in three replications. A sorting index was introduced to show the performance of the sorter. Results have shown that the belt slope arrangement and belt speed both have very significant effect on sorting accuracy. The best sorting accuracy of around 80% was obtained at belt speed of 9.4 m/min and belt slope arrangement of 8, 9, 10 degrees.

**Keywords:** Fig, Sorter, Physical properties

## NOMENCLATURE

|           |   |         |  |
|-----------|---|---------|--|
| $m$       | Mass, kg                                  | $V_b$   | Belt speed, m/s                          |
| $r$       | Rolling radius, m                         | $\mu_s$ | Coefficient of static friction, decimal  |
| $\bar{I}$ | Mass moment of inertia, kg.m <sup>2</sup> | $\mu_k$ | Coefficient of dynamic friction, decimal |
| $\bar{a}$ | Acceleration, m/s <sup>2</sup>            | $X_b$   | Distance traveled by belt, m             |
| $\alpha$  | Angular acceleration, rad/s <sup>2</sup>  | $X_f$   | Distance traveled by fig on belt, m      |
| $R$       | Rolling resistance, N                     | $X_e$   | Deposit distance of fig on belt, m       |
| $N$       | Normal surface reaction, N                | $t$     | Time, s                                  |
| $\theta$  | Angle of belt, degree                     | $\ell$  | Belt length, m                           |

**INTRODUCTION** Fig has a fairly good nutritious value which contains sugar, starch, fat, cellulose, minerals and water. The nutritious value of a dry fig is more than that of a fresh fig because it has lost some water which has no nutritious value. Iran produced 88000 tones of dried figs (*Ficus carica* L. cv. Sabz) in 2006. In respect to cultivated area, after Portugal, Egypt and Turkey, Iran ranks forth in the world. With regard to the amount of production, after Egypt, Turkey and Algeria, Iran possesses the 4<sup>th</sup> rank in the world (FAO 2006).

In Iran, much of the product is downgraded due to traditional methods of harvesting and drying in which producers let the figs dry on trees until they fall down on the ground. This method of harvesting is laborious, time consuming, and somehow unhygienic. In order to prevent damages associated with traditional harvesting, shake harvesting would be a good option for mechanized fig harvesting, but in this method harvested figs have different moisture content. To dry the figs appropriately, a suitable sorter should be designed to sort the harvested figs based on their moisture content.

Some methods are introduced for sorting fruits and vegetables in agricultural process engineering, such as screens, diverging belts, roller sorters and weight sorters. Also in order to sort grain, nuts and seeds, using of screens, pneumatic, gravitational, spiral, disk and cylinder separators can be useful based on the properties of products (Henderson & Perry, 1976). A non-destructive impact test was conducted by Jaren for sorting fruits according to their firmness and a software was developed to control and manage the impact test in sorting the fruits (Jaren and Garcia-Padro, 2002).

A method has been introduced for measuring date moisture content in which a simple electronic circuit was used to sense the voltage response as the date was held in contact with the moisture sensor (Ismail and Alyahya, 2003). Urbano Bron et al. (2004) studied chlorophyll fluorescence as a tool to evaluate the ripening of Golden papaya fruit. They determined that this non-destructive method might assist the evaluation of fruit ripeness.

A modern technique of time resolved reflectance spectroscopy was used to assess the maturity of nectarines. With this technique the light absorption at 670 nm in the fruit flesh was measured and a kinetic model was used as a biological shift factor to express firmness reduction during ripening (Tijskens et.al, 2007). A developed sensor which is based on the analysis of fruit impact on a load cell and its integration in a pre-commercial

sorting line was described by Gutierrez et al. (2007). They successfully classified peaches in 3 groups (very firm, firm and not firm) with 80% repeatability. Tabatabai and Hashemi (2009) utilized a rotational plate with inclined semi conical edges in order to grade citrus. They have employed centrifugal and gravitational forces to achieve their goal.

Recently, Terdwongworakul et al. (2009) have used physical, mechanical, physiological and acoustic properties of coconuts to determine their maturity levels. Another way to assess fruit quality is using visible/near infrared spectroscopy. Sun et al. (2009) have manipulated this approach in order to determine fruit quality.

As far as we know there is no information available on fig sorting based on moisture content. Therefore the objective of this study is to design, fabricate and evaluate a moisture-based fig sorter.

**MATERIAL AND METHODS** The figs used in the study were harvested manually from fig orchards of Estahban valley fig research station in Fars Province in September 2009. The harvested figs were sorted into 4 groups based on their moisture content and sealed in zip lock polythene bags and stored in a refrigerator at 5°C for 48 h to ensure uniform moisture distribution. Moisture content of samples randomly taken from each group was determined using oven method (AOAC, 1995). The moisture contents (% w.b.) were (32.5– 34.4), (43.9– 45.7), (61.4– 62.4), and (74.2 –75.2) for groups 1, 2, 3 and 4, respectively. Before each experiment, the figs were kept in the polythene bags at room temperature for five hours to equalize with ambient temperature.

In order to design a moisture-based figs sorter some physical properties affected by moisture content are to be known. Based on some preliminary experiments, sphericity, coefficient of static friction and rolling resistance were introduced as the key characteristics in fig sorting. There is no published work relating to moisture-dependent physical properties of figs, so they have been measured for this study.

For calculating the sphericity, the length, width and thickness of 10 fig samples from each moisture group was measured individually, and the sphericity was found to be 90 to 94 percent.

The coefficient of static friction of fig in each moisture group was found on rubber surface by using an adjustable inclined table (Dutta et al., 1988 and Owolarafe and Shotonde, 2004). The table was gently raised and the angle of inclination at which the figs started sliding were read as 31.75, 34.75, 35.75 and 36.75 degree for group 1, 2, 3 and 4, respectively. The tangent of the angles was introduced as the coefficient of static friction. For measuring the angle of rolling resistance a fig was placed on the surface of the table. The angle of inclination at which the fig started rolling was reported as the angle of rolling resistance which are 13, 13.75, 14.40 and 14.7 degree for groups 1, 2, 3 and 4, respectively, from which rolling resistance was determined.

Regarding mentioned experiments, it was concluded that moisture content has significant effect on coefficient of static friction and rolling resistance.

Before designing a sorter which works based on these two physical properties, theory of motion on a moving sloped surface was studied (Fig.1.).

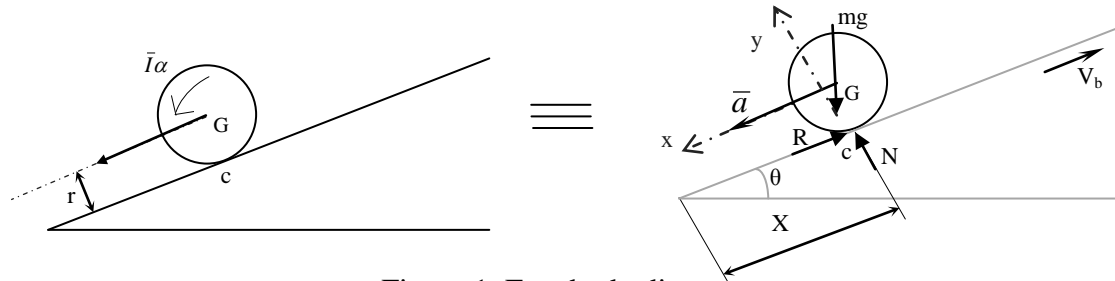


Figure 1. Free body diagram

It was assumed that fig is spherical in shape (average sphericity of 92%) and rolls without slipping, so that  $\bar{a} = r\alpha$

$$\sum F_x = m\bar{a}_x \rightarrow mg \sin \theta - R = m\bar{a} \quad (1)$$

$$\sum F_y = m\bar{a}_y = 0 \rightarrow N - mg \cos \theta = 0 \quad (2)$$

$$\sum M_G = \bar{I}\alpha \rightarrow Rr = \frac{2}{5}mr^2\alpha \rightarrow R = \frac{2}{5}mr\alpha \quad (3)$$

Substitute eq.3. into eq.1. gives:

$$mg \sin \theta - \frac{2}{5}mr\alpha = m\bar{a} \rightarrow \bar{a} = g \sin \theta - \frac{2}{5}r\alpha \quad (4)$$

$$r\alpha = \bar{a} \rightarrow \bar{a} = g \sin \theta - \frac{2}{5}\bar{a} \rightarrow \frac{7}{5}\bar{a} = g \sin \theta \rightarrow \bar{a} = \frac{5}{7}g \sin \theta \quad (5)$$

Alternatively, with our assumption of  $\bar{a} = r\alpha$  for pure rolling, a moment sum about C, gives  $\bar{a}$ , directly. Thus,

$$\sum M_C = \bar{I}\alpha + m\bar{a}d \rightarrow mgr \sin \theta = \frac{2}{5}mr^2\alpha + m\bar{a}r \rightarrow g \sin \theta = \frac{2}{5}\bar{a} + \bar{a} = \frac{7}{5}\bar{a} \rightarrow \bar{a} = \frac{5}{7}g \sin \theta \quad (6)$$

To check our assumption of no slipping, we calculate R, N, and compare R with its limiting value, from eq.1.

$$R = -m\bar{a} + mg \sin \theta = -\frac{5}{7}g \sin \theta m + mg \sin \theta = (1 - \frac{5}{7})mg \sin \theta \rightarrow R = \frac{2}{7}mg \sin \theta \quad (7)$$

$$\text{And } N = mg \cos \theta \quad (8)$$

But the maximum possible friction is:

$$R_{\max} = \mu_s N = \mu_s mg \cos \theta \quad (9)$$

If  $R < R_{\max}$  our assumption is right.

If  $R > R_{\max}$  then our assumption of pure rolling is wrong, therefore, the fig slips as it rolls and  $\bar{a} \neq r\alpha$ , the friction force or rolling resistance become:

$$F = \mu_k N = \mu_k mg \cos \theta \quad (10)$$

The motion equation becomes:

$$\sum F_x = m\bar{a}_x \rightarrow mg \sin \theta - \mu_k mg \cos \theta = m\bar{a} \rightarrow \bar{a} = g \sin \theta - \mu_k g \cos \theta \quad (11)$$

$$\sum M_G = \bar{I}\alpha \rightarrow \mu_k mg \cos \theta = \frac{2}{5}mr^2\alpha \rightarrow \alpha = \frac{5\mu_k g \cos \theta}{2r^2} \quad (12)$$

The time required for fig to move x(m) from rest with constant acceleration would be obtained as:

$$X_f = \frac{1}{2}at^2 \rightarrow t = \sqrt{\frac{2X}{a}} \quad , \quad X_b = V_b.t \quad (13)$$

Criterion for separation by considering  $X_e$  (Fig.2.):

$$\text{If } X_b - X_f \geq X_e \longrightarrow \text{Fig will be carried up by belt} \quad (14)$$

$$\text{If } X_b - X_f \leq X_e \longrightarrow \text{Fig rolls down on the belt.} \quad (15)$$

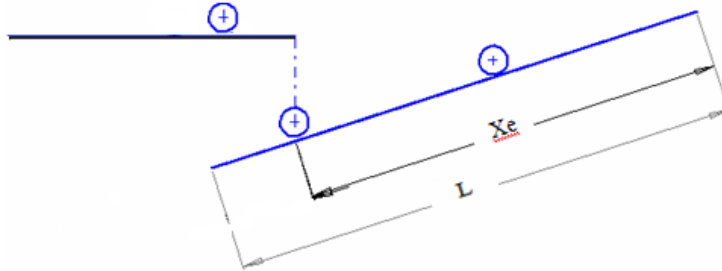


Fig.2. Deposit distance of fig on belt

From equation 14 and 15:

$$X_b - X_f \geq X_e \longrightarrow V_b.t - \frac{1}{2}at^2 = V_b.t - \frac{1}{2}(g \sin(\theta)) - \frac{R}{m}.t^2 \geq X_e \quad (16)$$

$$X_b - X_f \leq X_e \longrightarrow V_b.t - \frac{1}{2}at^2 = V_b.t - \frac{1}{2}(g \sin(\theta)) - \frac{R}{m}.t^2 \leq X_e \quad (17)$$

If belt speed ( $V_b$ ), time of separation ( $t$ ), and deposit distance of fig on belt ( $X_e$ ) are known, the inclination angle of each belt ( $\theta$ ), for separation of figs having different moisture content can be determined.

Based on dynamic analysis it was concluded that proper combination of different belt speeds and belt angles can be used for sorting process of figs at different moisture content levels.

**Design and fabrication** Considering the theoretical analysis and using the experimental values of coefficient of friction and rolling resistance for each group of figs, using a sorter equipped with a set of belt conveyor system and having the capability of adjusting belt angles and speeds was suggested.

Because of having four groups of moisture content, a three stage slopped belt sorter with a horizontal feeding belt was designed and fabricated (Fig.3).

The inclination angle of each belt can be adjusted manually by sliding the rollers through the slotted supports. A basket was placed at the beginning of each belt as well as at the end of the last belt to collect the sorted figs. Each belt overlaps the next one, so the figs which do not drop into the basket would drop on the next belt. In order to prevent dropping down the figs from the belt sides, four conical idler rollers were used at both sides of each belt to raise them up.

Test rig was powered by a 2.2 kW continuous variable speed electric motor. By using an electric volume control on a digital board, the speed of the motor could be varied continuously from 0 to 1400 rpm.

The main chassis was made of rectangular steel tube sections (10×30 mm). To lighten the moving parts and reduce energy losses, the supporting rollers of the belts were constructed with circular aluminium tube section having 40mm diameter.

Each roller was supported by two ball bearings to reduce the friction in moving parts. Transmission of power from the motor shaft to each belt was done by using V-belt drive system.

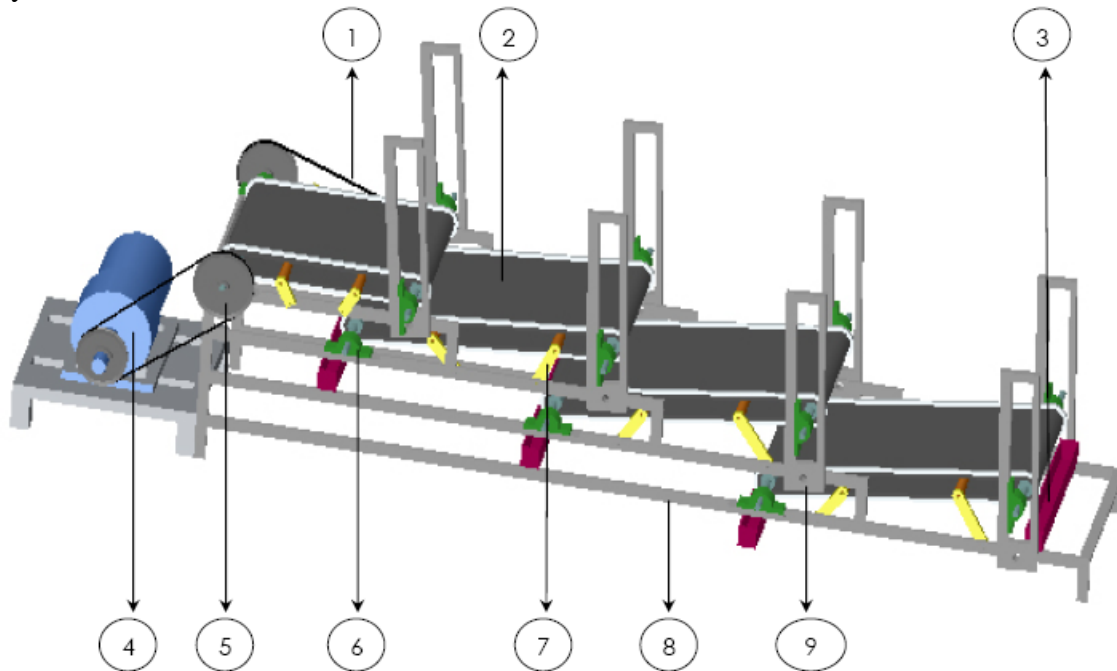


Figure 3. Schematic diagram of sorter (1. Power transmission belt 2. Belt conveyor 3. Basket 4. Electric motor 5. Driven Pulley 6. Fixed journal bearing 7. Idler roller 8. Chassis 9. Slotted support)

**Test and evaluation of the rig** In order to evaluate the sorter, 10 freshly harvested figs from each group of moisture contents were randomly selected and mixed together and then fed into the sorter. A factorial experiment with 2 factors including four levels of belt speed (7.2, 8.4, 9.4, 10.6 m/min) and two levels of belt slop arrangement (8, 9, 10 and 10, 11, 12 degree) was conducted in a completely randomized design in three replications. According to the discussed theory, some figs are expected to move down and the others are carried up and fall on the next belt. At the end of the test, figs collected in the basket at the bottom of each belt were counted. A sorting index was introduced to show the performance of sorter as bellow:

$$\text{If } n \leq 10 \rightarrow I_{accuracy} = \frac{n_{exp} + 0.66n_{(unexp)1} + 0.33n_{(unexp)2}}{10} \times 100 \quad (18)$$

$$\text{If } 10 < n < 20 \rightarrow I_{accuracy} = \frac{n_{exp} + 0.66n_{(unexp)1} + 0.33n_{(unexp)2}}{n_{total}} \times 100 \quad (19)$$

$$\text{If } n \geq 20 \rightarrow I_{\text{accuracy}} = 0 \quad (20)$$

$I_{\text{accuracy}}$  = accuracy index of fig sorting

$n$  = number of figs in each basket

$n_{\text{exp}}$  = number of figs from expected group in each basket

$n_{(\text{unexp})1}$  = number of unexpected figs from the nearest group to the expected group in each basket

$n_{(\text{unexp})2}$  = number of unexpected figs from the second nearest group to the expected group in each basket

**RESULTS AND DISCUSSIONS** The accuracy index calculated for each basket in three replications for different combinations of belt speeds and belt slop arrangements is shown in table1.

Table 1. Accuracy index for different belt speeds and belt slop arrangements (%)

| Slop (degree) | Speed (m/min) |       |       |       |
|---------------|---------------|-------|-------|-------|
|               | 7.2           | 8.4   | 9.4   | 10.6  |
| 8,9,10        | 65.36         | 68.68 | 79.28 | 60.99 |
| 10,11,12      | 18.76         | 20.15 | 20.18 | 35.31 |

Based on analysis of variance (Table 2.) belt slop arrangements and interaction of belt slops and belt speeds have significant effect on fig sorting ( $P < 0.01$ ). Furthermore, there was no significant difference between replications.

As shown in table 1. The arrangement of (8, 9, 10 degree) has better accuracy in fig sorting than the second arrangement (10, 11, 12 degree). The best accuracy of about 80% belongs to belt speed of 9.4 m/min and belt slop arrangement of 8, 9, 10 degree.

In the first arrangement, as belt speed is increased, the sorting accuracy increases and reaches to the maximum value at speed of 9.4 m/min, but the sorting accuracy decreases at speed of 10.6 m/min, whereas for the second arrangement, the accuracy increases as speed of belt increases.

Table 2. Analysis of variance for the effect of belt speed and belt slop arrangement on sorting accuracy.

| Source              | Sum of Squares | df | Mean Square | F         | Sig. |
|---------------------|----------------|----|-------------|-----------|------|
| replication         | 23.062         | 2  | 11.531      | .237      | .792 |
| speed               | 198.759        | 3  | 66.253      | 1.360     | .295 |
| arrangement         | 12271.804      | 1  | 12271.804   | 251.980** | .000 |
| arrangement * speed | 923.433        | 3  | 307.811     | 6.320**   | .006 |
| Error               | 681.820        | 14 | 48.701      |           |      |
| Corrected Total     | 14098.878      | 23 |             |           |      |

\*\* Significant at  $P < 0.01$

**CONCLUSION** With the aid of suggested sorter, which is designed based on two physical properties including the coefficient of friction and rolling resistance it is possible to sort the figs based on their moisture content. This sorter works with reasonable sorting accuracy of 80% that helps to reduce postharvest losses.

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