International Journal of Agriculture and Crop Sciences.
Available online at www.ijagcs.com
IJACS/2014/7-14/1417-1430
ISSN 2227-670X ©2014 IJACS Journal

Designing and building a mechanical system for separating stigmas from the saffron's petals

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ABSTRACT: This study was conducted to examine the feasibility of separating saffron (stigma) from stamens and petals with a vertical air flow in order to mechanize this task. In this study, a system for separating the stigma from the saffron petals was designed in a way that the initial design involved the specified requirements for reducing the time and the human force needed in harvesting. Based on the investigations, it was found that mean wind velocity at the threshold of moving the saffron flower's components, including petals of 1, 3, and 5 days old, three-filament stigmas of one day old, single-filament stigmas, and stamens should be respectively 0.65 m/s, 1.99 m/s, 1.15 m/s, and 1.28 m/s. Moreover, the horizontal distance wended by the saffron's components from heights 90, 75, 60, 45, and 30 cm in the wind tunnel with the air flow velocity of 210 m/min was as follows: 6.8 cm, 7.3 cm, and 7.6 cm respectively for petals of 1, 3, and 5 days old; 0.06 cm, 0.31 cm, and 1.14 cm respectively for three-filament stigmas of 1, 3, and 5 days old; 4.5 cm, 4.64 cm, and 5.13 cm respectively for single-filament stigmas of 1, 3, and 5 days old; and 4.28 cm, 4.40 cm, and 3.85 cm respectively for stamens of 1, 3, and 5 days old per 10 cm decrease in height. The separation capacity of the system was 11 kg per hour with 70% efficiency.
Keywords: Saffron, stigma, stamen, petal, separator, equipment, style, feeding container

INTRODUCTION

Saffron is the world's most expensive spice and is known as red gold. Iran ranks first in the world in terms of cultivated area and production of saffron, as over 90% of the world's saffron is produced in Iran (Kafi, 2002). Separation of stigmas is one important step in the process of saffron production (Atefi, 2006) and the most costly step for agricultures. The traditional method of separation is time-consuming and non-hygienic. Some suggestions, such as the use of friction cylinder and wind tunnel, have been provided for mechanical separation of stigmas, as preliminary designs (Mehri and Khahani, 2003). Shamsi et al (2007) also conducted a research and made a small lab air blower using aerodynamic properties for separation of stigmas from other components of the saffron. Some other researchers suggested the use of aerodynamic properties and cascade or freefall systems (Sama et al, 2000; Emadi and Saeidirad, 2011). In this study, the system for separating stigmas from the saffron flower was designed in a way that covered the requirements specified in the initial design. The following general characteristics, based on the calculations, were considered in designing the system:
About 10 kg/h capacity;
About 85% efficiency;
As simple a mechanical system as possible
Chaffy saffron as the output.

Accordingly, the system was designed, and the details of each part are provided in next sections. The design consisted of a feeder (conveyor belt), a vertical feeding channel, an accordion conveyor, and a wind tunnel. The schematic separation line is shown in Figure 1. The deficiencies and limitations of the design are as follows:
Limited season of harvesting flowers from farms;
Lack of scientific and practical records about the mechanism for separating stigmas from the petals
The flexibility of saffron flowers during harvesting.

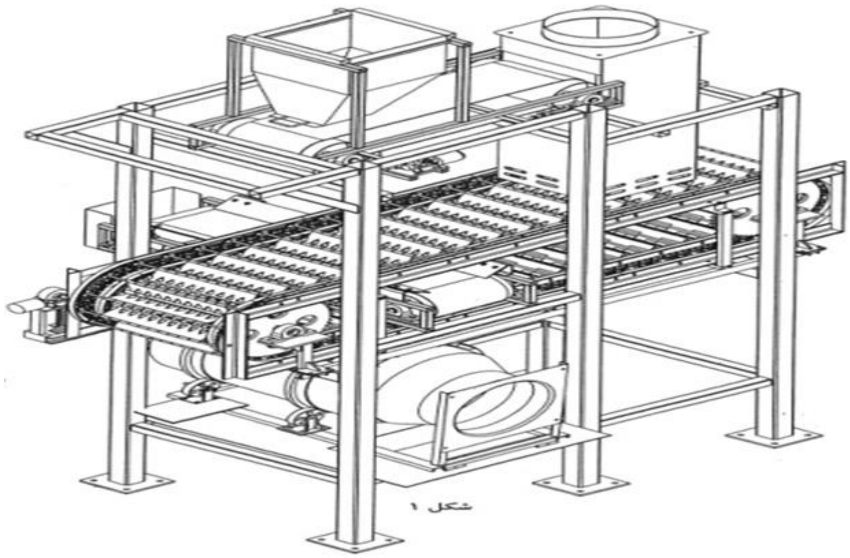

Figure 1. Schematic of the system

MATERIALS AND METHODS

The system consists of the following parts:

Feeding

This part has two components

Conveyor belt: It consists of a conveyor belt and a reservoir that adjusts the capacity and line feed velocity. The conveyor belt receives saffron flowers from the relevant part (feeding container) and transfers them to the next part (feeding channel).

Vertical feeding channel: It consists of a fan and a wind tunnel. The fan creates airflow in a direction opposite to the flowers' movement and makes them fall on their receptacle and enter the accordion conveyor.

Cutting flowers

This part has two components

Accordion conveyor: It is one of the most important basic components of the system and of special sensitivity. It receives the flowers from the feeding channel and, holds them fixed to be cut through a series of plates. After cutting, the accordion conveyor transfers the flowers to the next part (separation).

Flowers cutting system: It cuts saffron flowers from their sepals when they are received by the accordion conveyor plates.

Separation

Once the flowers are cut from the sepals, that is, the petals are plucked, they entered the separation step. This part consisted of an angled/oblique rotating cylinder and a fan. The cylinder rotation velocity can be adjusted, and the fan creates airflow in a direction opposite to the flowers' movement in a way that the petals and stamens move in the direction of airflow, and stigmas are separated from the petals in a direction opposite to the airflow and directed outside on the slope.

Output

The output includes two products as follows

Clean stigmas as their three filaments remain attached together (literally known as chaffy saffron)

Stamens and petals of saffron flowers.

The procedures performed in designing the system are as follows:

Using the results of the previous studies on the preliminary design, the detailed design began based on the preliminary design's specific characteristics, including the capacity, efficiency, type of mechanism, and type of technology.
Different parts of the system were designed using engineering design methods and acceptable standards and preparing executive plans.
Computing and cartography software programs such as QBasic and Mechanical Desktop 2004 were used for preparing and analyzing the results.

RESULTS OF DESIGNING THE SEPARATION SYSTEM

The system consists of a fan and a rotating cylinder. The cut flowers enter the cylinder through a conveyor belt and a chute which were separated from each other using the wind force generated by the fan.

Selecting the fan

The most important matter in designing the system is the calculation or selection of the wind velocity because the system should be able to separate different components of flowers regarding their difference in surface area and density. In this respect, separation velocity was calculated using the following equation:

$$V_P = 7655.4 \times \sqrt{\frac{m}{A}}$$

Where, *Vp* is the wind velocity (pick-up velocity) at the threshold of moving the object; m is the weight of each component in gram; and A is the effective surface of the object in mm^2.
Vp was the wind velocity that could lift every component from its surface. The weight of each saffron component varies with the time of plucking. Therefore, different velocities could be obtained considering the interval between harvesting and separating. The above reference specified ages of 1, 3, and 5 days for flowers and calculated the effective cross-sectional area and *Vp* based on the specified ages. The relevant values are shown in Table 1.

According to Table 1, maximum wind velocity (almost 210 m/min) at the threshold of lifting components was related to the three-filament stigma of one day old. In this respect, the above velocity was determined for the separation velocity because Iranian farmers usually collect and separate saffron flowers on the first day. In designing the wind tunnel, the diameter specified for the rotating cylinder was 600 mm. Thus, the required flow rate was calculated using the following equation (Colijn, 1987):

$$Q = A \times V$$

Where, Q is the airflow in m^3/h; A is the cross-sectional area the air passes through; and V is the wind velocity in m/s.

Table 1. Wind velocity at the threshold of moving saffron's components

Saffron's components	Weight (g)	Effective surface (mm^2)	Pick-up velocity $(V_p)^2$	Mean pick-up velocity
1-day old petal	0.02761	300.5	73.4	
3-day old petal	0.02882	404	64.7	65.2
5-day old petal	0.03074	545.5	57.5	
1-day stigma (three-filament)	0.02603	35	208.8	
3-day stigma (three-filament)	0.02963	41.85	203.7	199.8
5-day stigma (three-filament)	0.0365	61.25	186.9	
1-day stigma (single-filament)	0.0087	35	120.5	
3-day stigma (single-filament)	0.0099	41.85	117.6	115.3
5-day stigma (single-filament)	0.0122	61.25	107.9	
1-day old stamen	0.01063	40	124.8	
3-day old stamen	0.00717	28	122.5	126.9
5-day old stamen	0.00667	22	135.5	

$$Q = \frac{\pi d^2}{4} \times V_P = \frac{\pi}{4} \times 0.6^2 \times \frac{210}{60} = 0.9896\frac{m^3}{s} \cong 1\frac{m^3}{s} = 3600\frac{m^3}{h}$$

To obtain various velocities, a fan with a higher flow rate and variable rpm was selected. The fan blower had the following characteristics:
Model: VIE-40 TUS, Volt: 220 V, RPM: 1400, m^3/h: 4350, Fan: DIA.: 400 mm
The selected fan is axial type and can help separating flower components with its vertical airflow.

Calculating the appropriate angle for the rotating cylinder

Table 2, shows the horizontal distance wended through the wind tunnel by the saffron components. As shown by the table, flowers of 1, 3, and 5 days old were tested at different heights.

Table 2. The horizontal distance wended by the saffron components dropped from various heights through the wind tunnel with the airflow 210 m/min.

Falling height (cm)	90	75	60	45	30
The horizontal distance wended by the saffron components (mm)					
Petals					
1-day old	97.53	89.02	79.62	68.96	56.3
3-day old	103.74	94.49	84.69	73.35	59.89
5-day old	108.89	99.38	88.88	76.99	62.86
Three-filament stigmas					
1-day old	0.86	0.78	0.7	0.61	0.49
3-day old	4.5	4.11	3.67	3.18	2.6
5-day old	16.49	15.05	13.46	11.66	9.52
Single-filament stigmas					
1-day old	63.9	58	52.16	45.81	36.89
2-day old	65.97	60.21	53.85	46.65	38.09
3-day old	72.9	66.54	59.51	51.14	42.08
Stamens					
1-day old	60.83	55.52	49.66	43.01	35.11
2-day old	62.48	57.02	51	44.17	36.06
3-day old	54.76	49.98	44.7	38.72	31.61

According to Table 2, if the separated components of flowers are fed into the rotating cylinder at the height of 30 cm and maximum horizontal distance of 35 mm from the end of cylinder, petals and stamens will fall outside the cylinder from the very beginning. However, this was not practical (all the flowers could not be dropped from the height of 35 mm due to the large feed opening) because the flower components are not separated from one another completely, and consequently, it is highly possible that stigmas fall out with other components, and the system efficiency decrease. Therefore, the separated components of flowers should be dropped into the cylinder from a height over 35 mm, and this procedure should be performed repeatedly until all the components exit from the system. In this regard (directing the flower components from the bottom to the top of the cylinder), radial blades were embedded in the cylinder with appropriate intervals. Figure 2 shows the rotating cylinder with α angle and movement direction of petals and stamens (ABC …) and stigmas (AGL …). According to the figure 2 , the distance petals and stamens return to the front of cylinder (BF) and the distance stigmas return to the front of cylinder (GP) depend to the slope of the rotating cylinder with α angle, as the distance the components return to the front of cylinder increase with α angle.

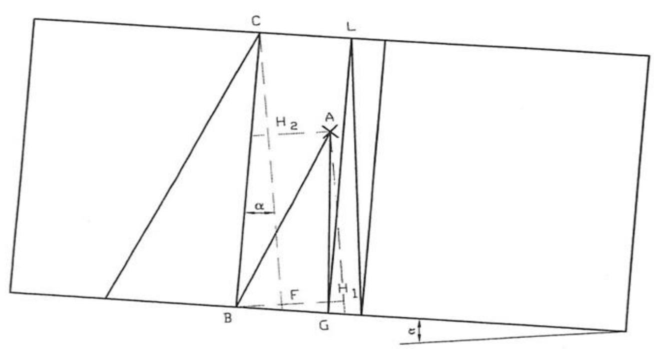

Figure 2. Rotating cylinder

If α angle exceeds a certain amount, all the components will exit from the beginning of the rotating cylinder. In such a situation, the distance the components return to the front depends on the airflow velocity and falling height. Therefore, the amount of AH_2 should not be less than the difference between horizontal movements of the two consequent falls. Regarding the figure and trigonometry, the amount of AH_2 was calculated using the following equation:

$$BF = BC\sin\alpha = d\sin\alpha$$

$$AH_2 = BH_1 - BF$$

Where, d is the diameter of the rotating cylinder (mm); α is the angle of the rotating cylinder with horizon (°); BH1 is the amount of each component's horizontal movement caused by the airflow (mm); and BF is the distance the components return to the front of cylinder under the impact of α angle (mm).

The degree of the angle could be calculated for each component, and then minimum degree is chosen for the cylinder angle, assuming the diameter of the cylinder as 600 mm, and the initial falling height (the interval between feed opening and the cylinder surface) as 300 mm. Regarding the above explanations, AH_2 was calculated for petals and stamens. Therefore, using Table 2, it can be argued:

Petals: $AH_2 \geq 56.3 - 79.62 = -23.32mm$

Stamens: $AH_2 \geq 35.11 - 49.66 = -14.55mm$

Consequently, maximum degree for petals is as follows:

$BH_1 = 56.3mm$ and $BF = 600\sin\alpha$

$$AH_2 = -23.32 = 56.3 - 600\sin\alpha \Rightarrow \sin\alpha = 0.1327 \Rightarrow \alpha 7.6$$

Maximum α angle for stamens is as follows:

$$BH_1 = 35.1mm$$

$$AH_2 = -14.55 = 35.11 - 600\sin\alpha \Rightarrow \sin\alpha = 0.0828 \Rightarrow \alpha = 4.7$$

In this respect, α angle should not be greater than 4.7° for petals and stamens getting out of the cylinder. However, faster exit of petals and stamens seems more essential than that of stigmas due to the high volume they occupy. In this regard, α angle for the cylinder was determined as 3° after trial and error.

Selecting rotational velocity of the cylinder

Considering the rotational velocity 15 rpm was selected for the separation capacity 5 kg/h. Thus, the velocity 30 rpm was selected for the cylinder because the rotational velocity has a direct correlation with the separation capacity. However, the velocity was selected completely experimentally. In this respect, the drive system had the variable rotation mechanism for reaching the final capacity 10 kg/h. (Negbi et al, 1999).

Calculating the power of the rotating cylinder

To supply the rotational movement, the cylinder was placed on four rubber rollers of which one roller was the drive and others acted like fulcrums. In this respect, the power required for rotation of cylinder equaled to the power required for overcoming the weight of the cylinder and the friction between the roller and cylinder. Considering the size and thickness of the plate used for the cylinder body and appurtenant of the cylinder, weight of the cylinder is 5.1 kg, and the coefficient of friction between rubber and steel (μ) is 0.5. Therefore, weight of the cylinder is:

$$W = 51 \times 10 = 510N$$

The vertical force exerted on each roller by the cylinder's weight is:

$$F_N = \frac{1}{4}W = \frac{510}{4} = 127.5N$$

The friction between rollers and cylinder is:

$$F_N = \frac{1}{4}W = \frac{510}{4} = 127.5 = 63.75N$$

As there were four rollers, the total friction is:

$$(F_f)_t = 4F_f = 255N$$

The torque required for rotating the cylinder is:

$$T = (F_f)_t \times d/2$$

Diameter of the rubber rollers:

$$d = 125mm$$

The torque required for rotating the cylinder:

$$T = 255 \times 125/2 = 15937N.mm = 15.9N.m$$

As mentioned before, the rotational velocity 30 rpm is selected for the cylinder, so that, the rotational velocity of rollers is:

$$n/n' = d'/d$$

Where, n' and d' are respectively the rotational velocity and diameter of cylinder.

$$d' = 600mm$$

$$n' = 30rpm$$

The rotational velocity of motor gearbox:

$$n = \frac{n'd'}{d} = \frac{30 \times 600}{125} = 144rpm$$

Therefore, the power required for motor gearbox is:

$$P = \frac{T.\frac{\pi.n}{30}}{e}$$

Where, e is the mechanical efficiency of the power transmission system. Considering 80% efficiency for the system, it can be argued:

$$P = \frac{15.9 \times \pi \times 144}{30 \times 0.8} = 300w = 0.4hp$$

In this respect, regarding the catalogue of Sharif Co., the proper electro gearbox with the power 0.5 hp and output velocity 80 rpm was selected (Sama et al, 2000).

Designing the accordion conveyor

The accordion conveyor is the most important part of the system for separating stigmas from saffron flowers. In this part, all the flowers should be cut from their sepals in a way that all the components of flowers are separated from one another, but the three-filament stigmas should remain attached together. The acceptable tolerance for cutting was ±1. The accordion conveyor consists of a number of plates hinged together on one side and move on a specific path (rail), as the gap between them could vary with changing the gap between rails. The plates are located between two chains that supply their linear movement via the hinge axis. According to Figure 3, the decreased intervals of rails cause the plates near one another, and vice versa. Therefore, the flowers can be fixed at their cutting site and be cut more accurately.

After measuring diameter of sepals (the cut site) in 50 flowers, the researchers found that mean diameter of open sepals was approximately 8 mm varying between 6 mm and 10.6 mm, and mean diameter of closed sepals was approximately 2.1 mm varying between 1.5 mm and 2.6 mm. Based on the measurements, the conveyor was designed in a way that the distance between the edge of plates and the site the flowers fall from the feeding channel outlet is 10 mm that decrease to 2 mm at the cut site and increase to 40 mm at the site of discharging cut flowers. In this situation, the cut flowers are directed to the stigma separation tunnel through a horizontal conveyor belt.

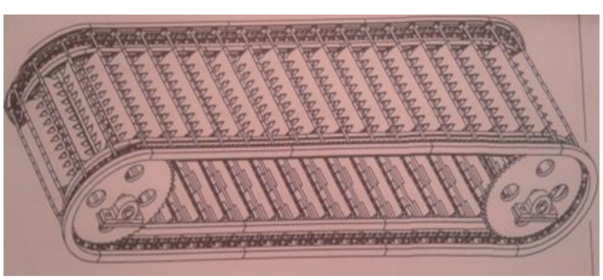

Figure 3. Accordion conveyor

Selecting the chain and sprocket wheel (Oberg et al, 1967)

The power required for moving plates along with saffron flowers is little, thus, the chain is not selected based on the power rather the size of plates and shafts determined the grade of chain. In this respect, a grade 80 chain was selected. As mentioned above, a conveyor belt directs the cut flowers to the stigma separation tunnel. The conveyor belt is placed in the path the accordion conveyor goes and back. Thus, the size of conveyor belt determines minimum diameter of the sprocket wheel. According to the executive plans, minimum diameter of the sprocket wheel is approximately 660 mm. Therefore, the number of sprocket wheel's teeth is calculated as:

$$dp = \frac{P}{\sin(180/N)}$$

Where, d_p is the pitch diameter of the sprocket wheel (mm); P is the pitch diameter (mm); and N is the number of sprocket wheel's teeth.

The grade 80 chain has the pitch $1'' = 25.4$ mm, therefore:

$$\sin\left(\frac{180}{N}\right) = \frac{P}{dp} = \frac{25.4}{440} = 0.057 \Rightarrow N = 54.4$$

As the number of sprocket wheel's teeth should be a round number, thus:

$$N = 55 \Rightarrow dp = \frac{25.4}{\sin(180/55)} = 444.92mm$$

Other dimensions of the sprocket wheel could be determined using DIN 8196 standard that was considered in the executive plans.

Calculating the linear velocity of the chain

Regarding the selected chain with 1" pitch and size of plates, the pitch of plates equals to 5 pitches of the chain, that is, 127 mm. Nominal capacity of the conveyor was 10 kg/h, so that, to reach this capacity, the nominal capacity is increased by 10%.

$$C = 10 + 0/1 \times 10 = 11kg/h$$

Given that one kilogram of the flowers comprises 2170 flowers (Mollafiabi, 1991), capacity of the conveyor based on the number of flowers is:

Flower/h = 6.6, flower $/s \cong 7$ flower/s

$$C = 11 \times 2170 = 23870$$

Considering the length of each plate and the size of each flower, 10 flowers can be placed between every two plates (in each row). However, due to the uneven distribution of flowers in the feeding channel, and consequently in the accordion conveyor, 8 flowers are assumed to be placed in each row. Therefore, as the distance between every two plates is 127 mm, linear velocity of the chain is:

$$C = \frac{V \times m}{P_1}$$

Where, V is linear velocity of the chain (mm/s); m is number of flowers in each row; and P_1 is the pitch of rows (the distance between consecutive rows).

$$V = \frac{V \times 8}{127} \Rightarrow V = 111.5 \, mm/s$$

Regarding the diameter of the sprocket wheel, its rotational velocity is:

$$V = \frac{\pi n}{30} \times \frac{dp}{2} \Rightarrow n = \frac{60V}{\pi.dp} = \frac{60 \times 11.5}{\pi \times 444.92} = 4.8rpm$$

Based on the rotational velocity of 5 rpm, the linear velocity of the chain is:

$$n = 5 \Rightarrow V = \frac{\pi \times 5}{30} \times \frac{444.92}{2} = 116.5 \, mm/s$$

With rounded rotational velocity and mean weight of each flower, capacity of the system equals (Mollafiabi, 1991):

$$C = \frac{116.5 \times 8}{127} = 7.3$$

$$flower/s \cong 12.2\,{}^{kg}\!/_{h}$$

Calculating the length of chain (Oberg et al, 1967)

Regarding the requirements of different parts of the system, the distance between centers of sprocket wheels (D) is calculated as 2020 mm. Pitch diameter of the sprocket wheels is 444.92 mm, therefore, length of the chain can be calculated through the following equation in which: N is the number of teeth of the large sprocket wheel; n is the number of teeth of the small sprocket wheel; R is the radius of the large sprocket wheel; and r is the radius of the small sprocket wheel.

As the diameters of the drive and moving sprocket wheels are equal, thus:

$$\sin\alpha = 0 \Rightarrow \alpha = 0$$

The number of teeth of the drive and moving sprocket wheels are the same and equal 55, and pitch of the chain (p) is 25.4 mm, therefore:

$$L = \frac{180}{360} \times 55 \times 25.4 + \frac{180}{360} \times 55 \times 25.4 + 2 \times 2020 = 5437mm$$

Number of chain's rings is:

$$m = \frac{L}{P} = \frac{5437}{25.4} = 214.1$$

Number of rings should be a round number, thus:

$$m = 215 \Rightarrow L = m \times p = 215 \times 25.4 = 5461mm$$

The distance between centers in such a situation is:

$$D = \frac{L - NP}{2} = \frac{5461 - 55 \times 25.4}{2} = 2032mm$$

Calculating the required power (Oberg et al, 1967)

The accordion conveyor is a kind of chain conveyor. The power required for this conveyor is calculated through the following equation:

$$HP = \frac{1.15 \times 5 \times P_m}{33000}$$

In the above equation, the efficiency of system is regarded as 87%. However, taking account of the mechanism of the accordion conveyor and the large number of ball bearings and hinged plates, the efficiency is much less than the above percent and decreased to almost 70%. In this respect, the power is calculated as:

$$HP = \frac{1.43 \times S \times P_m}{33000}$$

Where, S is the linear velocity of the chain (sf/min), and P_m is tensile force of the chain (lb) and calculated using the following equation:

$$P_m = f_1.L(2W_c + W_m) + W_m H + \frac{f_2 \times DP \times h^2}{100} \times L$$

Where, f_1 is the chain-rail friction coefficient; f_2 is the materials-channel friction coefficient; BD is the density of the carried materials (lb/ft^3); W_m is the weight of materials in each foot (lb/ft); W_c is the weight of moving pieces in each foot of the chain (lb/ft); L is the horizontal distance between centers of sprocket wheels (ft); and H is the vertical distance between centers of sprocket wheels (ft).

Considering that the materials (flowers) are placed on the conveyor, f_2 = 0, and as the conveyor is installed horizontally, H = 0.

Thus, the equation for calculation of Pm is summarized as follows:

$$P_m = f_1 L(2W_c + W_m)$$

The weight of flowers on the conveyor (W_m) is much less than that of the moving pieces and could be ignored, therefore,

$$P_m = f_1.L.2W_c$$

The f_1 friction coefficient for the rolling chains is calculated through the following equation:

$$f_1 = f_r \frac{d_a}{d_r}$$

Where, d_a is diameter of the axis; d_r is the outer diameter of the roller (outer diameter of the ball bearing) (mm); and f_r is the material-dependent coefficient that is 0.4 for steel rollers in the dry state (Oberg et a., 1967).
The da and d_r diameters are:

$$d_a = 10mm$$

$$d_r = 22mm$$

Therefore:

$$f_1 = 0.4 \times \frac{10}{44} \cong 0.2$$

The distance between centers of sprocket wheels is:

$$L = 2032mm = 6.7\,ft$$

The weight of moving pieces regarding the executive maps is:

$$\omega_c = 25\,{}^{kg}\!/_{m} = 16.9\,{}^{lb}\!/_{ft}$$

In this respect, tensile force of the chain is as follow:

$$P_m = 2 \times 0.2 \times 6.7 \times 16.9 = 45.3lb$$

The linear velocity of the chain is:

$$S = 111.5\,{}^{mm}\!/_{s} = 22\,{}^{ft}\!/_{\min}$$

Therefore:

$$HP = \frac{1.43 \times 22 \times 45.3}{33000} \cong 0.04 = 33W$$

Selecting motor gearbox

Regarding the low rotational velocity of sprocket wheels, the most appropriate gearbox is the helical gearbox. Referring to the catalogue of helical gearboxes made by Mashhad Gearbox Co., the suitable electro-gearbox is selected as follows:
The rotational velocity of sprocket wheels is 5 rpm that is not available in the catalogue. Therefore, the velocity should be reduced two times in order to reach the above velocity. Through selecting a gearbox with a conversion ratio of 1 to 60 in the first step and selecting a pulley belt with a conversion ratio of 1 to 3 in the second step, the power of gearbox is calculated as follows:

$$P_1 \geq \frac{P}{\eta d} \times S.F$$

Where, P_1 is the input power of gearbox (kw); P is the output power of gearbox (the required power) (kw); ηd is the gearbox efficiency; and $S.F$ is the coefficient of working conditions.
According to Figure 4, gearbox efficiency is 62% for the conversion ratio i=60.

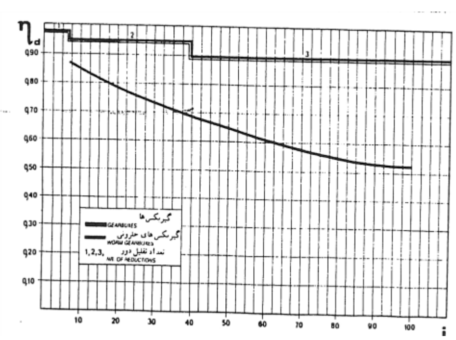

Figure 4

Based on Table 3, the coefficient of working conditions with light and constant overload is 2. Therefore:

$$SF = 2$$

$$P_1 \geq \frac{31}{0.62} \times 2 = 100W = 0.1KW$$

Table 3.

FRICTION FACTOR (C) AND LENGTH FACTOR (Lo) FOR CONVEYOR TENSION FORMULAS

Class of Conveyor	Friction Factor (C) *	Length Factor (L_o), ft *
For conveyors with permanent or other well-aligned structures and with normal maintenance	0.022	200
For temporary, portable, or poorly aligned conveyors. Also for conveyors in extreme cold weather that are either subject to frequent stops and starts or are operating for extended periods at -40 deg. F or below	0.03	150
For conveyors requiring restraint of the belt when loaded	0.012	475

* The C and L_o factors have proven to be satisfactory for the great majority of conveyor belt tension and horsepower calculations. However, when long, relatively level, heavily loaded conveyors are encountered where power requirements are large and made up primarily of friction, it is recommended that a belt manufacturer be consulted for additional engineering assistance in selecting these factors.

Using the catalogue, the VF44/N gearbox with 900 rpm electromotor is selected. The above electro-gearbox has the output rotation of 15 rpm. The diameter of output shaft was 18 Ø.

Designing the channel for vertically feeding the flowers onto the accordion conveyor

Experiences have shown that when flowers fall freely, their tail is always downward, and petals and sepals are downward. This physical property is used for lining flowers and designing the feeding channel. The channel is designed in a way that flowers have enough time to change into the desirable state. Through practical tests, the height necessary for flowers' fall is estimated one meter. Moreover, mild airflow opposite to the direction of flowers' fall should be created in order that the flowers would change into the desirable state more rapidly. The mild airflow is the important point in designing the channel and should be created by a fan that is installed in one of the following two ways:

In the inner space of the accordion conveyor as an air blower (Figure 6); or

On the top of the channel as an air vacuum (Figure 7).

Figure 6

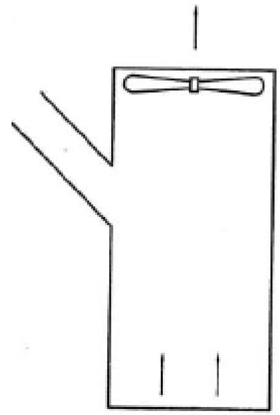

Figure 7

The above two ways are analyzed as follows

According to Figure 6, if the fan is embedded in the inner space of the accordion conveyor, weeds around the flowers or farm soil collected along with the flowers plucked in the farm would fall on the fan through the feeding channel. Furthermore, another problem of this way is that the airflow passing through the gap between plates would much accelerate and might effect on the position of flowers. The second way in which the fan is installed as an air vacuum above the feeding channel seems more suitable than the first way due to the technical matters of installation and operation, maintenance and repair, and creation of the mild even airflow in the tunnel. Therefore, the fan is installed above the feeding channel.

Determining the size of feeding channel

Considering that the length of each plate of the accordion conveyor is about 455 mm, and also for the purpose of better distribution of the flowers on the accordion conveyor, the channel opening is supposed to be to the extent that it could cover at least three pitches of the conveyor per moment, that is, 3×127=381 mm. Thus, the channel's cross-section is determined to be a 400×400 mm square. As mentioned before, the height required for flowers' fall should be at least 1 m. Therefore, the height of channel from flowers' point of entry is determined as 1 m.

Selecting the fan

Given that there is no specific criterion for selecting a fan, a fan with a variable-rotation motor is selected in order to supply the required airflow. The specifications of the selected fan from the catalogue are as follows:

$$n_{\max} = 1360 rpm$$

$$Q_{\max} = 2500 {m^3}/{h}$$

$$Fandia = 350 mm$$

$$\text{mod}el = VIE - 355L4S$$

Designing the feeding conveyor belt

The conveyor belt actsas the main feeder (adjuster of the number of input flowers) of the feeding channel. As mentioned before, the nominal capacity of the conveyor is calculated as 11 kg/h. In this respect, regarding the mean weight of each flower:

$T = 11 {kg}/{h} = 7$ Flower/s

The conveyor belt is installed in the middle of the feeding channel, and distribution of flowers on the conveyor could be controlled through embedding a feeder at the beginning of the conveyor. The feeder should not be large because the accumulations of a large amount of flower make the flowers crush and stick together. Therefore, the capacity of the feeder is supposed to be maximum 5 kg that could be discharged within half an hour with regard to the conveyor's capacity. The conveyor belt could not be inclined because the flowers might fall down due to their light weight. Thus, the conveyor belt is installed horizontally, and a staircase is embedded for the purpose of accessing the feeder of the conveyor belt.

Determining the width of the conveyor

The conveyor belt should feed the flowers into the channel in a way that the flowers spread over the channel's cross-section equally. Given that the width of the feeding channel is 400 mm, and the width of the conveyor should be less than 400 mm, the conveyor is determined to be 300 mm wide.

Determining linear velocity of the conveyor

The linear velocity of the conveyor should be determined in a way that the conveyor could feed seven flowers into the channel per second. Dimensions of a flower are 15×15×45 mm (Mollafiabi, 1991). Therefore, 20 flowers could be placed across the conveyor's width (300 mm), but this assumption is ideal rather real. Therefore, at least seven flowers are supposed to be placed in each row as they are not over one another. Moreover, as the length of each flower is 45 mm, an interval of minimum 45 mm is supposed between every two rows. In this respect, the conveyor's velocity is:

$$x = s.t \Rightarrow s = x/t = 45/1 = 45\,mm/s$$

To establish the above conditions, the feeder's outlet should be adjustable that could be placed in a way that the flowers on the conveyor are not over one another.

Regarding the assumptions accounted in calculation of the linear velocity of the conveyor belt, the drive system is equipped with remote switching tools in order to adjust the velocity and ensure its reliability.

Calculating the power required for the conveyor belt's motor (Colijn, 1987)

The power required for the conveyor belt is calculated through the following equation:

$$HP = \frac{T_E \times S}{33000}$$

Where, *S* is the linear velocity of the conveyor (ƒt/min); and T_E is the tensile force of the conveyor (lb) that is calculated as:

$$T_E = C(L + L_0)\left(Q + \frac{100T}{3S}\right) + \frac{100T}{3S}H$$

Where, C is the friction coefficient of the composite; L is the length of the conveyor belt (the distance between centers of drums) (ƒt); L0 is the equivalent length (ƒt); Q is the weight coefficient (lb/ƒt); T is the capacity of the conveyor belt (ton/h); and H is the difference in height of drums (ƒt).

$\Rightarrow C = 0.022$ Class of Conveyor: for conveyor with permanent or … $l_0 = 200\,ft$

The width of the conveyor belt

$$300Mmm = 11.8in \Rightarrow Q = 7\frac{lb}{ft}$$

$$S = 45\,mm/s = 8.9\,ft/\min$$

$$T = 11\,kg/h = 0.011$$

According to the executive maps, the distance between centers of drums (L) is 1.5 m, and the conveyor is installed horizontally. Regarding the 80% efficiency for the drive system, the required power is:

$$HP = \frac{32 \times 8.9}{0.8 \times 33000} = 0.01 = 7.5W$$

Selecting the belt

The tensile force of the belts:

$$T_E = 32lb = 143N$$

Therefore, as the width of the belt is 300 mm, the tensile force per unit of width is:

$$T_E = {}^{143}\!/_{300} = 0.5\,{}^{N}\!/_{mm}$$

In this respect, $E_P 100/3$ belt with a very high confidence coefficient would be suitable. The above belt has the tensile force limit 100 N/mm and three layers, including one cotton layer and two rubber layers, with the thickness 4 mm.

Determining diameter of drums and calculating their rotational velocity

The minimum diameter of drums could be calculated using the standard BS2890. Based on this standard, for the tensile force 0.5 N/mm and the thickness 4 mm, minimum diameter (d) suggested for the drive pulley is 200 mm.

The linear velocity of the belt is 45 mm/s, thus, the rotational velocity of drums would be:

$$S = \frac{\pi n}{30} \times {}^{d}\!/_{2} \Rightarrow n = \frac{60S}{\pi d} = \frac{60 \times 45}{\pi \times 200} = 4.3rpm$$

Selecting the gearbox

Considering the low rotational velocity of drums, the most appropriate gearbox is the helical gearbox. Referring to the catalogue of helical gearboxes made by Mashhad Gearbox Co., the suitable electro-gearbox is selected as described below:

The rotational velocity of drums is 3 and 4 rpm, and the required power is 7.4 w, but these velocities and power are not available in the catalogue. Therefore, the velocity should be reduced two times in order to reach the above velocity. Through selecting a gearbox with a conversion ratio of 1 to 70 in the first step and selecting a pulley belt, the power of gearbox should fulfill the following formula:

$$P_1 \geq \frac{P}{\eta d} \times S.F$$

Where, P_1 is the input power of gearbox (the power available in the table) (kw); P is the output power of gearbox (the required power) (kw); ηd is the gearbox efficiency; and $S.F$ is the coefficient of working conditions.

According to Figure 1 in the previous section, gearbox efficiency is 57% for the conversion ratio i=70.

$$\eta d = 57\%$$

According to Table 3, the coefficient of working conditions with light and constant overload is 2.

$$S.F = 2$$

Therefore:

$$P_1 \geq \frac{7.5}{0.57} \times 2 = 26.3W$$

Using the catalogue, the VF44/N gearbox with 900 rpm electromotor and the conversion ratio (i) 70 is selected. The above electro-gearbox has the output rotation of 13 rpm, and its output shaft has a diameter 18 mm. Other dimensions and sizes of the gearbox are available in the catalogue.

CONCLUSION

The separation of saffron's components, including petals, stigmas, and stamens, through the wind tunnel is possible regarding the high difference between floating velocities of stigmas and those of other components of the saffron. The threshold floating velocity of petals and stamens is respectively 0.65 m/s, 1.99 m/s and 1.28 m/s., and the vertical distance wended by the petals and stigmas at air flow velocity of 210 m/min is respectively 43.28 cm and 24.82 cm.

ACKNOWLEDGEMENTS

The researchers herby appreciate Ms. Esmaeili, Ms. Bagheriyeh Yazdi, and Ms. Ghavami for their support in this project.

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