Design and Development of a New Multipurpose Machine for Pistachio Process

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Abstract

The greatest pistachio producer and exporter country in the word is Iran. Within the fifteen years ago, the average product of this kind of fruit has been 232000 tons per year, which it constitutes almost 52.5% of the world production. Fine processing, post processing and transportation of pistachio, have great effects on its quality, food value, physical properties and marketability of this product. Then any applicable research for processing of pistachio, have direct and indirect effects on developing technology of this industry and as a result, farmers can get more income. In this study, various methods of pistachio processing in recent years have been carefully investigated and after that, new suitable and multipurpose machine for pistachio processing has been presented and then its mechanical designing and analyzing process has been explained. This new multipurpose machine is equipped with adjustable parts of hulling, drying, and feeding individual pistachio nuts for sorting. Maximum demanded power and safety factor for this machine were achieved 11.94 (Kw) and 2.1 respectively. Some of the advantages of this new machine are simple mechanisms, avoiding from using any complex part, capability of automation, simple usage, simple maintenance and finally low cost of the machine.

Key words: Pistachio; Processing; Hulling machine; Cleaning and drying; Machine designing.

1. Introduction

Ever-increasing pistachio usage, high food value, production- exportation growth and Iran's portion in world pistachio production, necessitated more investigation and attention toward this product. Mechanized process of pistachio before and after the harvesting has great impacts on quality, food value, competitive market and the world production of this strategic product. Considering the 232000 ton per year average production of pistachio in Iran which includes almost 52.5% of the world production (FAO 2005), highlights the significance of mechanization of pistachio process in Iran. Therefore any analytical and applicable investigation for the better production process, directly or indirectly, has pronounced effects on farmers' income.

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Nomenclature

h	Processing chamber length, (mm)	τ_u	Ultimate shear stress of green hull of Pistachio, (Mpa)
D_1	Diameter of outside abrasive cage, (mm)	T_{ht}	Torque needed for rotation of the outside abrasive cage, (N.m)
D_2	Diameter of inside abrasive cage, (mm)	T_{h1}	Torque needed for rotation of the inside abrasive cage, (N.m)
V_b	Total volume of processing chamber, (m^3)	T_{h2}	Torque needed for rotation of the abrasive curved bottom, (N.m)
V_e	Total porosity volume of pistachio into processing chamber, (m^3)	T_{hs}	Torque needed for rotation of the IAC and the bottom, (N.m)
V_a	Total volume of pistachio into processing chamber, (m^3)	P_t	Maximum required power of Electromotor 2, (kw)
ε_p	Porosity of pistachio, (%)	P_s	Maximum required power of Electromotor 2, (kw)
ρ_{ap}	Seed density of the pistachio without green hull (24 hours after harvesting), (gr/cm^2)	P	Total required power, (kw)
ρ_{bp}	Mass density of the pistachio, (gr/cm^2)	F	The total force inserted on the bottom (Sum of the pistachio and water while washing), (kN)
k	Meshing coefficient,	$F.S.$	Safety factor,
k_{am}	Area and agitation coefficient	W_w	Weight of the water in the porosity of the pistachio under washing process
n_h	Required rev at hulling process, (RPM)	W_p	Total weight of pistachio inside the processing chamber, (kN)

Different methods of pistachio process have been proposed by corresponding large companies. Pistachio process algorithm in one of the largest centers of this product process, in California (Vincent Corp 2007), is shown in Fig.1. Throughout this process, the green hull is removed which is performed by so rough abrasives with water. Thereafter, the product is transferred directly to the water tank, so floating pistachio nuts which have low quality are separated from the sinked high quality pistachio nuts. The next step is to dry the product and finally it is sorted based on color, size etc. packed and transported to the market. Based on the researches conducted by the specialists, hull removing process of pistachio requires more energy consumption compared to other processes. Consequently, comparisons of different pistachio hullers have been made and studied throughout this article (Mahmoodi et al. 2007; Vanmark Corp 2004; Joseph & Benjamin 1993 and 1981; Jay et al. 1977). Pistachio washing is performed after or simultaneously with the hulling process, while in newly made machines, some injectors are provided to spray water on pistachio (Jay & Bertram 1997). While water spraying, performs the washing, it increases the efficiency of the hullers remarkably (Vanmark Comp 2004).

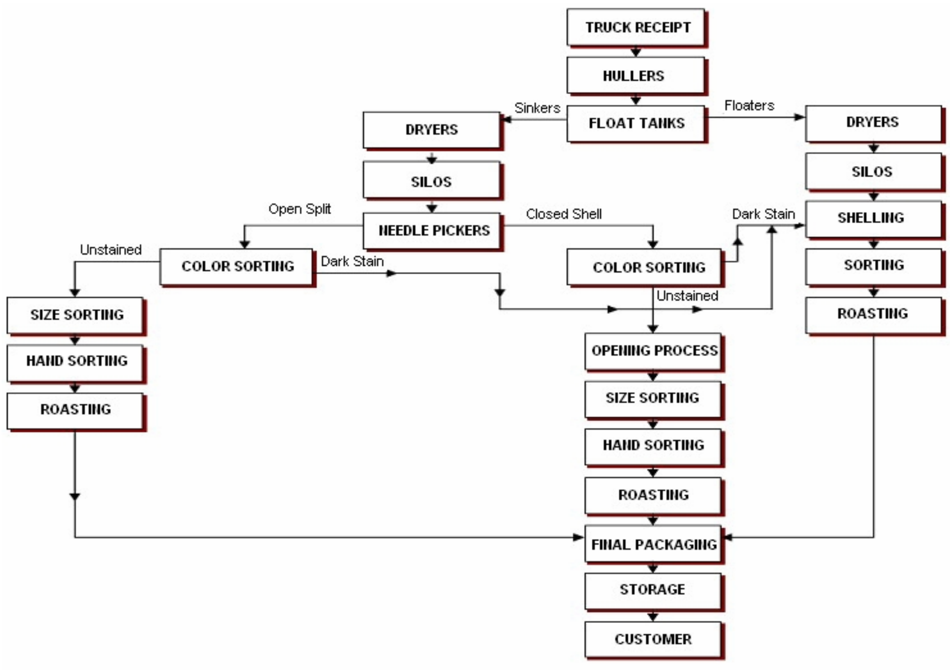

Fig. 1. Diagram of pistachio process steps in California (Vincent Corp 2007).

Based on the researches performed by some specialists (Hyang et al. 2006), drying pistachio immediately after washing process has great effects on fungous dieses growth reduction such as Aflatoxin. Drying machine constructed by Nakhaeinezhad (2002), includes an oscillating grain and a warm air blower, which perform the drying process. In 2005 a kind of precise dryer was constructed by Kashaninejad et al, which was equipped with some temperature, moisture and blown air pressure sensors which were able to measure those parameters online (Kashaninejad et al. 2004 and 2005).

2. Material and methods

1.2. Machine description

A general view of the machine is shown in Fig. 2. Modeling and mechanical analysis of this machine is performed using Catia V5 R16 software (Dassault Systems Corp 2006) which would enable us to analyze the components and do the optimization. The major components which the machine includes are the frame, electromotors, control panel, transmission power systems, outside abrasive cage (OAC), inside abrasive cage (IAC), curved bottom, air blower lid, collecting waste hull and water chamber and quick and one nut discharge gates. As we see in the Fig. 2, the restricted space among the outside and inside abrasive cages and the bottom constitutes the pistachio process room. Pistachio will be poured into this chamber and then, hulling, washing, drying and discharging processes will be performed respectively. The required power for different processes is provided by two 220V electromotors with maximum speed of 3600 rpm. As shown in Fig.2 and 4, the OAC is rotated by the electromotor 1 while IAC and the curved bottom are rotated by the electromotor 2.

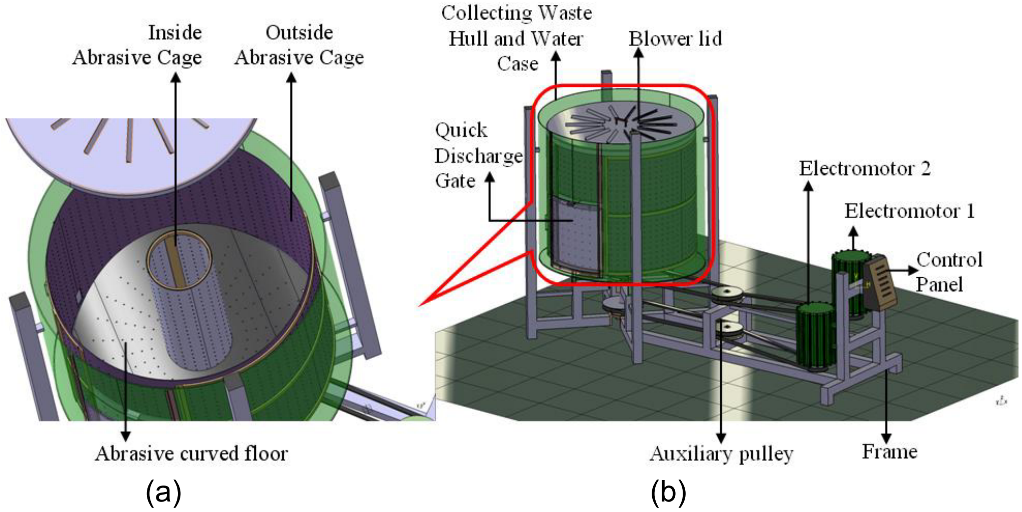

Fig. 2. General view of the proposed multipurpose machine: (a) Machine process chamber, (b) Different parts of the machine.

Controlling the speed and direction of rotation by the control panel, help perform the processes. Control panel, includes control circuit, contactors, relay, thermocouple, stop and start switches and some chronometers.

1.1.2 Hulling operation

For hulling operation, pistachio will be poured into the machine processing chamber. Now we have three modes. The first one is the clockwise rotation of the OAC, the second one is the counter clockwise rotation of the IAC and the bottom and the third mode is the simultaneously opposite rotation of the former and the latter which each has a portion in performing the hull removing step (Fig. 2). As we know, different species and sizes of pistachio nuts have various strengths against the mechanical damages. So modification of the hulling aggressiveness, can improve the efficiency of this step. Rotation of the OAC, IAC or their opposite simultaneous rotations and alternation of the speed of the electromotors, can provide different pistachio hull removing aggressivenesses. The highest capacity of hull removing, which has direct relation to its aggressiveness, occurs when these two cages rotate oppositely. One of the efficient parameters on performance of pistachio hull removing machines and other similar ones is the agitation. Therefore, the machine bottom has a curvature design (Fig. 3c) which rotates by the inside cage simultaneously. This curvature causes the agitation. This method is used widespread in different machines such as washing machines. The bottom curvature, during the rotation, more than agitating the pistachio helps abrasion of the green hull due to the contact with the vertical abrasive walls (Fig. 3b) which improves the efficiency and machine capacity. The way green hull is removed is shown in Fig. 3a. Inside/outside abrasive cages and curved bottom, have 4 mm diameter holes which perform like the kitchen grates. The jutting edges of the holes in contact with the pistachio nuts, remove the hull partially. Removed hull, passes the holes and the water and hull wastes are collected in the provided chamber (Fig. 2b) and finally exhaust from the machine. The forces exerted on the pistachio nut which helps it stand against the wall holes include the internal friction among the nuts, friction due to the nut- wall contact and the eccentric force.

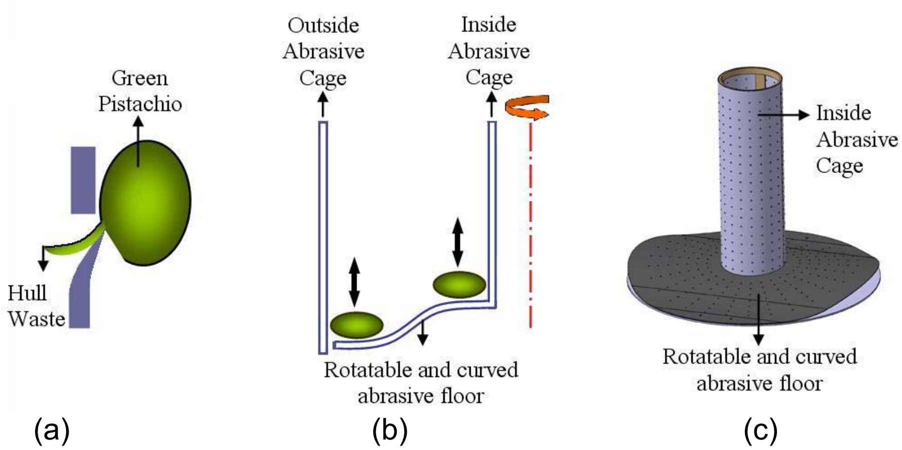

Fig. 3. Schematic view of the working principles of pistachio multipurpose machine: (a) hull removing method, (b) hull removing principles, (c) Inside abrasive cage and curved bottom

2.1.2 Washing operation

We do this operation immediately after the hull removing step. The shorter transferring the hull removed pistachio nuts take to the washing machine, the less possibility of diseases spread exists. In this machine, instantly after hull removing, electromotor1 is stopped and the rotary speed of the electromotor2 is decreased while continues to fulfill the agitation during washing. The lid on the OAC has radial grooves which help the approximately steady distribution of water on pistachio nuts, kept in pistachio process chamber when water faucet becomes opened. Water distribution and rotation of curved bottom cause the washing operation finishes soon. Waste materials and removed hull pieces which have not left the pile of the pistachio nuts, go out of the washing container through the holes provided on the bottom and the walls by water flow and get trapped in collecting waste materials chamber(Fig. 2b). The collecting waste material and water chamber has a slopped bottom which carries those waste materials through a channel to the outside (Fig. 4b). Two ways for reduction of rotary speed of the bottom for the desirable agitation are provided. The first method is application of an electromotor with varied rotary speed and the second one is loosening the belt connecting the electromotor1 and auxiliary pulleys by belt lightener (Not shown in the Fig. 2). To decrease the cost of manufacturing we selected the second way.

3.1.2 Drying Operation

In common methods of pistachio process, drying operation follows the washing one. In the multipurpose machine presented in this article, the drying operation is performed without any need for transferring the nuts out of machine to another independent drying machine and consequently helps save time and cost. For performing this operation, both of the electromotors rotate in the same direction to prevent the friction between the abrasive cages and nuts. Here we use the maximum speed of electromotors. Throughout this method, two parameters help drying. The fist one is the flow of air through the pile of pistachio nuts which comes from the high rotary speed. Due to the eccentric force, a portion of the moisture is taken from the porosities among the nuts and the surface of them and consequently goes out through the holes of the OAC. The second parameter which increases the rate of drying is the flow of the warm air blown through the radial grooves provided on the lid. These grooves work the same as fan blades and blow a huge amount of air into the chamber (Fig. 4a). The air flow as shown in Fig. 4 comes vertically to the chamber, absorbs the moisture and finally leaves it in radial direction. For increasing the rate of drying the blower lid can be equipped with thermal elements. The heater shown in Fig. 4b has 10 thermal elements which are heated by electricity flow and the heater can be mounted on the frame whenever it is needed. As we know, if agitation and drying operations are performed simultaneously the efficiency of the machine increases remarkably. Some pulleys provided under the machine bottom to rotate the OAC and the bottom (Fig. 4a) and are designed with a slight difference in diameter to make a difference between the rotary speeds of OAC and the bottom in chamber the two drive electromotors have the same direction and speed of rotation. This slight difference in speed causes the smooth agitation.

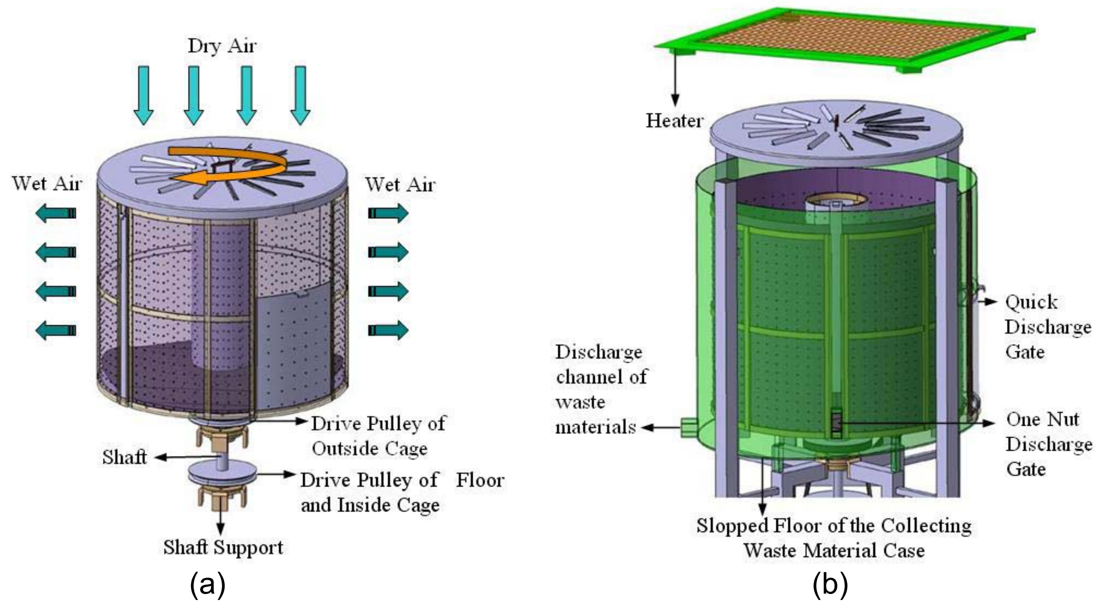

Fig. 4. (a) Drying operation method, (b) Different discharge channels.

4.1.2 Discharging Operation

Two discharge ways have been considered in this machine. The first one is called the quick discharge. To use this method, electromotor1 is stopped and the rotary speed of the eletromotor2 is decreased as much as possible. Then we adjust the quick discharge gates provided on both OAC and collecting waste materials and water chamber (Fig. 2, 4), stand facing each other and after that the OAC is locked to the frame with a pin provided on the frame and the hole on the OAC (not shown in the figures), and it keeps the OAC fixed and finally the gates are opened by their levers and Consequently the processed production is discharged quickly. The second method is named one nut discharge which is used for sorting operation. For fulfilling this method, any thing is performed exactly the same as previous one prior to the quick discharge gate opening, in turn, the one nut discharge gate (Fig. 4b) opens to the extent that the number of discharged pistachio nuts reaches the desirable one. Here those nuts are directed on a conveying belt for the sorting operation.

4.2 Required Power Calculation

Here we have analyzed the machine, and as it looks it requires the maximum power through the hulling stage. So this stage of the process, generally ascertains the maximum required power. The dimensions of the OAC, IAC, and curved abrasive cage are brought in Fig. 5.

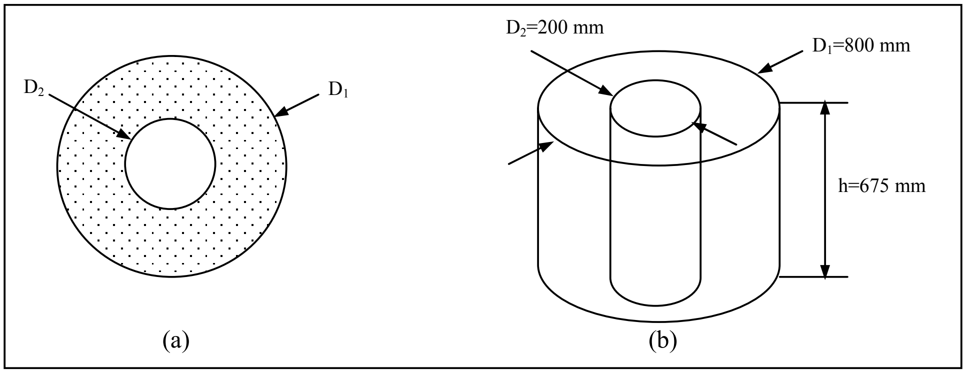

Fig. 5. Dimensions of the processing chamber: (a) inside and outside abrasive cages, (b) Rotatable and curved abrasive bottom.

Calculating the torque needed for rotation of the OAC (T_{ht}), with respect to the relations of mechanic of materials (Beer & Johnston 1981), the lateral area, meshing coefficient (k), ultimate shear stress of green hull of pistachio (τ_u) and the inside radius of OAC were multiplied by each other. Dividing the total area of the holes by the lateral area of the OAC gives us the Meshing coefficient k. Based on the investigations about the present nut hullers (Kusel Equipment Company 2005) and also depending on the research performed by the authors (Mahmoodi *et al*. 2007), k and τ_u are taken 0.01137 and 0.002 MPa respectively. Consequently, we have the following:

$$T_{ht} = \frac{\pi}{2}.D_1^{\ 2}.h.\tau_u.k \Rightarrow T_{ht}=154.29(N.m) \qquad (1)$$

The torque needed for the rotation of the IAC ,T_{h1}, is calculated by the same method as following:

$$T_{h1} = \frac{\pi}{8}.D_2^{\ 2}.h.\tau_u.k \Rightarrow T_{h1}=9.66(N.m) \qquad (2)$$

To calculate the torque needed for the rotation of the curved abrasive bottom, T_{h2}, two parameters were investigated. The first one was the ultimate shear stress of green hull, τ_u, which must be multiplied in bottom area to result the torque needed for hulling operation and the second one is the extra torque needed for the extra action of agitation performed by the bottom besides the hulling. To take theses two factors into account, area and agitation coefficient, k_{am}, is applied. The ratio of curved bottom to its horizontally projected area (Fig. 2b) is calculated by Catia V5R16 software. For calculation of the k_{am}, that ratio is multiplied by 2 to include the agitation parameter. Consequently it resulted in $k_{am=}$ 2.26. Finally T_{h2} is gained by projected area, mean radius, area and agitation coefficient, τ_u and Meshing Coefficient multiplied together. So we have the following:

$$T_{h2} = \frac{\pi}{8}.(D_1^{\ 2} - D_2^{\ 2}).(D_1 + D_2).\tau_u.k_{am}.k \quad => \quad T_{h2}=121.14 \ (N.m) \tag{3}$$

Accordingly, torque needed for the rotation of the IAC and the bottom is the sum of T_{h1} and T_{h2}:

$$T_{hs} = T_{h1} + T_{h2} \quad => \quad T_{hs}=130.8 \ (N.m) \tag{4}$$

Based on the researches performed upon the pistachio hullers of the Kusel Equipment Company (2005), n_h has been taken 400 rpm. According to equation 5, the power needed for rotation of the OAC is calculated (Georing & Hansen 2005):

$$P_t = \frac{2\pi.T_{ht}.n_h}{60} \quad => \quad P_t=6.46 \ (kw) \tag{5}$$

And also the power needed for rotation of the IAC and the bottom is calculated in the same way (Equation 6):

$$P_s = \frac{2\pi.T_{hs}.n_h}{60} \quad => \quad P_s=5.48 \ (kw) \tag{6}$$

Thus the total power needed for the machine is brought as following:

$$P = P_t + P_s \quad => \quad P=11.94 \ (kw) \tag{7}$$

4.3 Essential Parts Analysis and Safety Factor Determination

Given the structural characteristics of the machine, IAC/bottom drive shaft and its support are the most sensitive parts of the machine concerning the maximum stress (Fig. 4a). Shaft has 7.5 mm thickness, 35 mm outside diameter and is made from St37 material, σ_y=250 MPa (Fig. 6a). The two following parameters result in critical stresses. The first is the torque exerted on the shaft through the pulley which its quantity has been calculated before, T_{hs}=130.8 N.m, and the second one is the weight of water and pile of pistachio seeds being washed exerted on the shaft vertically. To calculate this force, we have made assumptions that in the most critical state during the washing, all the porosities among the seeds are filled with water. In this case, having the pistachio seed density of the pistachio, water density, porosity of the peeled pistachio and the total volume of the chamber give us the weight. Based on the researches, the following quantities are applied:
ρ_{ap}=0.3 gr/cm^3 ; water density (ρ_w =1 gr/cm^3); $\varepsilon_{p=}$ 47%; (Kashaninejad 2006). Initially the weight of pistachio inside the chamber is calculated and then the weight of water among the porosities is added to give us the total weight exerted on the shaft and support. According to the equation 8 (Mohsenin 1980) the apparent density of the pistachio pile is calculated:

$$\varepsilon_p = \frac{\rho_{ap} - \rho_{bp}}{\rho_{ap}} \times 100 \quad \text{=>} \quad \rho_{bp}=1.6\ (gr/cm^3) \tag{8}$$

Thus, pistachio weight is the multiplication of the pistachio specific weight by the chamber volume:

$$\text{=>} \quad W_p = \rho_{ap}.g.V_b \tag{9}$$

$$V_b = \frac{\pi}{4}.h.(D_1^{\ 2} - D_2^{\ 2}) \quad \text{=>} \quad V_b=0.318\ \ (m^3) \tag{10}$$

And consequently:

$$W_p = \frac{\pi}{4}.h.\rho_{ap}.g.(D_1^{\ 2} - D_2^{\ 2}) \quad \text{=>} \quad W_p=0.936\ \ (kN) \tag{11}$$

To calculate the weight of the water inside the porosities of the pile, specific weight of the water was multiplied by the porosity volume. The porosity volume is calculated by the subtraction of the particle volume of the product pile from apparent volume of it (Mohsenin 1980). The actual volume is calculated by the following equation 12:

$$\varepsilon_p = \frac{V_b}{100 + \varepsilon_p} \times 100 \quad \text{=>} \quad V_a=0.216\ \ (m^3) \tag{12}$$

As the result, the porosity volume is calculated as followes (Mohsenin 1980):

$$V_e = V_b - V_a \quad \text{=>} \quad V_e=0.102\ \ (m^3) \tag{13}$$

So the water weight is calculated:

$$W_w = \rho_w.g.V_e \quad \text{=>} \quad W_w=1\ \ (kN) \tag{14}$$

According to the calculations done above, the vertical force exerted on the machine shaft is:

$$F = W_p + W_w \quad \text{=>} \quad F=1.936\ (kN) \tag{15}$$

The shaft support is made of a 10 mm, St37 steel sheet, by σ_y=250 MPa (Fig. 6b). As it transmits the whole weight of the pile and water to the machine frame, it necessitates the investigation of the stress through it. Shaft support analysis based on Von Misses criterion was performed through the finite element method by Catia V5R16 software (Fig. 6).

(a) (b)

Fig. 6. stress distribution of Von Misses in sensitive components of the machine: (a) Shaft, (b) Shaft support.

3. Discussion and Conclusions

As we know, pistachio process is a costly operation for the producers. If these costs are reduced, not only the pistachio consumption but also the competitions of producers in world scale increases. All the expenses of the whole pistachio process include the followings: the costs of machineries used, production wastes, workers wages, transportation and the time consumed during the process. Among those, the first two constitute the highest portion. Consequently, performing some operations of process only in one machine seem beneficial from several aspects. First of all, the expenses for maintenance and repair of one machine are remarkably lower than a number of machines involved. Secondly, expenses due to the transportation are approximately omitted and eventually, automation of the machine for the automatically continuous fulfillment of the steps of the process increases. Regarding the low maximum consumed power 11.94 (kw) and the suitable safety factor 2.1, the simple mechanism of belt and pulley for the power transmission, easy and simple assemblage, capability of being equipped with automatic systems for the process and other predicted advantages for the machine, it can reduce a lot the total expenses.

Present innovative mechanism can be used for hulling other nuts such as walnut or hazelnut, but with some modification and adaptation in design. Any way researcher can study this proposal for other nuts and after that design and fabricate suitable machine with different capacity. Also waste material discharged from these machines (green hull), can be used for colors industry or others industry.

4. References

[1]. Beer. F. P., R. Johnston., (1981), Mechanics Of Materials. McGraw-Hill Book Company, ISBN 0-07-004284-5.

[2]. Dassault Systems Corporation., (2006). Catia Version 5 Release 16 Engineering Software. Available in <Http://www.dassaultsystems.com>.

[3]. Fabbri. A., Ferguson. L., Polito. V,S., (1998), Crop load related deformity of developing Pistacia vera cv 'Kerman' nuts, Journal of science horticulture, 77, 219-234.

[4]. FAO., (2005), <http://www.FAO.org>

[5]. Goering. C. E. & A. C. Hansen., (2005). Engine And Tractor Power, 4th edition, 1-16. St. Joseph, Michigan, ASAE.

[6]. Hyang, S. C., Hyun, J.K., Hyun, E. O. (2006). Determination of Aflatoxin levels in nuts and their products consumed in South Korea. Journal of Food Chemistry, 102, 385-391.

[7]. Jay. J, M., Bertram. E, S., Pistachio Huller, United States Patent, Patent Number; 4,034,665, Filed; July, 12, 1977.

[8]. Joseph. V., Benjamin. V., Method of hulling pistachio nuts, United States Patent, Patent Number; 4,353,931, Filed; Jun. 19, 1981.

[9]. Joseph. V., Benjamin. V., Pistachio Nuts Hulling Apparatus, United States Patent, Patent Number; 5,245,918, Filed; Sep. 21, 1993.

[10]. Kader, A. A., Henitz, C. M., Labavitch, J. M. & Rae, H. L. (1991). Review of Studies related to the description and evaluations of pistachio nut quality. Journal of the American Society for Horticultural science, 107(5), 812-816.

[11]. Kashaninejad, M., & Tabil, L. G. (2004). Drying characteristics of purslane (Portulaca oleraceae L.). Drying Technology, 2(9), 2183–2200.

[12]. Kashaninejad. M, A. Mortazavi, A. Safekordi & L. G. Tabil, (2005), Thin-layer drying characteristics and modeling of pistachio nuts. Journal of Food Engineering, 78, 98–108.

[13]. Kashaninejad. M, A. Mortazavi, A. Safekordi, L.G.& Tabil, (2004), Some physical properties of Pistachio (Pistacia vera L.) nut and its kernel, Journal of Food Engineering, 72, 30–38.

[14]. Kusel Equipment Company, (2005), RC "WATERLESS" Peeler & Scrubber, Patent Number;5, 106, 641, < http://www.kuselequipment.com>

[15]. Mahmoodi. E., Khazabi. K., Jafari. A., (2007), Analysis and investigation of different drying methods of Pistachio. The First Congress of Processing and Packaging Pistachio in Iran.

[16]. Mahmoodi. E., Khojastehnazhand. M., Khazabi. K., Jafari. A., (2007), Analysis and Investigation of the Efficient Parameters for Pistachio Peeler Design. The First Congress of Processing and Packaging Pistachio in Iran.

[17]. Mahmoodi. E., Mohamadi. A., Jafari. A., Fathollahzadeh. H., (2007), Performance Analysis and Comparison of Different Pistachio Peelers. The First Congress of Processing and Packaging Pistachio in Iran.

[18]. Mohsenin. N. N., (1980). Physical properties of plants and animal materials. New York: Gordon and Breach Science Publishers, NW.

[19]. Nakhaeinezhad, M., Pistachio Blanks Separator, United States Patent, Patent Number; US 6,527,124 B1, Data of Patent; Mar.4, 2003.
[20]. Nakhaeinezhad, M., Pistachio Pre- Dryer, United States Patent, Patent Number; US 6,499,228 B2, Data of Patent; Dec.31,2002.
[21]. Vanmark Corporation, Peeler, Scrubber and Washer series 2800, (2004), Equipment For The Food Industry, <Http://www.vanmarkcorp.com>
[22]. Vincent Corporation., California Pistachio Processing Plant Flow Chart, (2007), <Http://www.VincentCorp.Com>