

PHYSICAL PROPERTIES OF SWEET CHERRIES
IN MICHIGAN

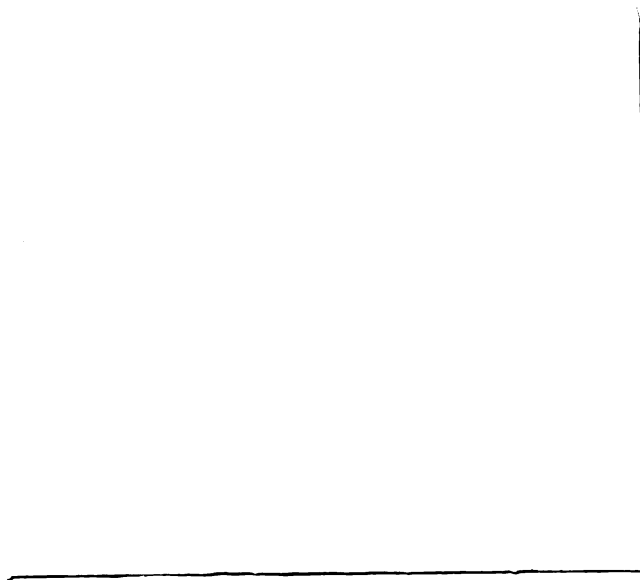
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PHYSICAL PROPERTIES OF SWEET CHERRIES

IN

MICHIGAN

by

Bernard Robert Tennes

AN ABSTRACT OF A THESIS

Submitted to the Colleges of Agriculture and Engineering of
Michigan State University
in partial fulfillment of the requirements
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MASTER OF SCIENCE

IN

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ABSTRACT

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by Bernard Robert Tennes

The sweet cherry industry has been exploring mechanical methods for separating stemmed sweet cherries from stemless fruit. Principally because of labor conditions, hand separation of the stemmed and stemless fruit is becoming both uneconomical and unattainable. The premium prices received for stemmed cherries motivate further search for successful mechanical means of separating stemmed and stemless cherries.

In order to establish the design criteria for equipment to separate stemmed cherries from stemless fruit, this study was initiated to determine some of the physical properties of the two main varieties of brined cherries (Napoleon and Windsor) grown in Michigan.

The first phase of the investigation consisted of measuring the weight, cheek, suture, apex diameter, and volume of each fruit tested. The theoretical terminal velocities in water were calculated using the average measured diameters obtained from the cherries and then a theoretical diameter was computed using three different formulas. For the two brined varieties, each tested fruit was dropped into a water column, first with the stem attached and then with the stem detached. The rate of fall and behavior during fall was recorded with a movie camera. The

average experimental terminal velocities obtained were compared with the calculated terminal velocities.

The second phase of the investigation was to determine if orientation of the Napoleon and Windsor varieties on an orbiting belt would be possible. If orienting of the cherry stems could be accomplished, then a mechanism for separation of the cherries by their stems would be tested for feasibility. The orbiting diameter was varied from $1/4$ inch to 1 inch in $1/4$ inch increments. The orbiting frequency was varied from 1200 rpm to 2800 rpm in 200 rpm increments. A 35 mm camera was used to photograph the orbiting fruit. The number of stems one inch above the belt surface and higher was recorded. From this data the percent of stems up per observation was computed. For fresh Windsor fruit, the best responses obtained for orbiting diameter and orbiting frequency were at $1/4$ inch and 1600 rpm respectively. At this setting 55 percent of the observations indicated the fruits' stems were one inch or higher above the belt surface. Fresh Napoleon cherries responded best at an orbiting diameter and frequency of $1/2$ inch and 2200 rpm. With this setting 67 percent of the observations showed the fruits' stems to be one inch or higher above the belt surface.

Approved: B. A. Stout
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INTRODUCTION

During the period 1961-65, Swanson (1967) reported sweet cherry production in the United States totaled approximately 98,236 tons annually and was valued at over \$30 million. Analysis of this figure indicated that annually California produces 26,220 tons; Oregon, 24,660 tons; Washington, 17,040 tons; and Michigan, 7,260 tons. Thus, Michigan's sweet cherry crop represents approximately 13.5 percent of the national crop.

Nationwide slightly less than half the sweet cherry crop proceeds to the fresh market, with the major portion of these fresh market cherries being from California and Washington. As Table 1 of the four top sweet cherry producing states indicates, approximately 78 percent of Michigan's sweet cherry crop is sold for brining. VanCleave (1967) estimates that the Napoleon variety constitutes approximately 80 percent of Michigan's brined tonnage, while the Windsor variety represents 12 to 15 percent. Consequently, the two varieties of sweet cherries, Napoleon and Windsor, constitute the major bulk of the brined fruit in Michigan's maraschino industry.

To assure a uniform color, brining of maraschino cherries is necessary. Watters et al. (1963) reported that brining or bleaching of sweet cherries is done with a calcium bisulfite which is usually prepared in one of three methods: (1) bubbling sulfur dioxide gas into a suspension of calcium hydroxide; (2) bubbling sulfur dioxide into a suspension of calcium carbonate; (3) dissolving calcium chloride and sodium bisulfite in water and adjusting the pH with

commercial hydrochloric acid. Depending on which method is used, a final pH of 2 to 3.5 will be obtained for the brining solution.

Brined sweet cherries in Michigan were not marketed as the premium cocktail pack, while most of the brined sweet cherries in Oregon were marketed as the cocktail cherry with stems. Thus, when the average prices received per ton (Table 1) for sweet cherries from Oregon and Michigan are compared, it is apparent that the difference in price received for the two different types of maraschinos contributed to the \$107 per ton difference in average price received for the sweet cherry crop in 1961 to 1965.

Table 1

Sweet cherry prices and analysis of consumption.

	\$ Per Ton	Percent of Crop			
		Brined	Fresh Market	Canned	Frozen
California	\$462	34	55	95	-
Washington	\$412	17	53	11	3
Oregon	\$377	68	16	12	1
Michigan	\$270	78	7	2	-

The era of mechanical harvesting of sweet cherries is rapidly approaching. Levin (1967) reported that in 1967, 47 percent of Michigan's tart cherry crop was harvested by mechanical shakers. It has been estimated of the 1967 sweet cherry crop in Michigan that 2.2 million pounds or 13 percent of the crop was harvested mechanically. Depending on various conditions, some 50 percent of sweet cherries shaken from trees will maintain attached stems.

At present there is no economical way for separating this fruit into stemmed and stemless cherries for the fresh and brining markets.

Moser (1967) stated that in Germany, fresh market sweet cherries are required to have stems attached. For fresh market, fruit with stems still attached is most desirable because the stem inhibits drying out of the cherry while in transit to market.

Sweet cherries bleached in a brining solution are marketed either with the stem attached for cocktail packs or without the stem for use in ice cream, pastries, candies, drinks, fruit cocktail, etc.

Currently, the price received for large stemmed maraschino cherries ranges from 5 to 7 cents per pound in excess of the selling price for small stemless sweet cherries.

Cherries destined to be brined for maraschinos must be sorted immediately prior to packing. A major maraschino cherry producer in Michigan estimated that approximately fifty percent of the stems are lost (during brining, handling, pitting, and sorting) from fruit which initially had stems. Therefore, it is estimated that under existing practices only 25 percent of sweet cherries that are mechanically harvested will result in maraschinos with stems.

Presently, the stemless fruit is removed from the stemmed fruit by human sorters immediately prior to canning of the maraschino cherries. Thus, this sorting is done on fruit that originally was picked with stems attached; hand sorting is necessary to remove fruit that has lost stems during the brining, conveying and dyeing processes. With the advent of mechanical harvesting of sweet cherries, the

number of stemless cherries to be sorted out will be doubled approximately. Therefore, the cost for sorting by existing methods will increase considerably the production cost of stemmed maraschino cherries.

This study was initiated to determine some of the physical properties of the Napoleon and Windsor varieties to enhance the development of sorting equipment. In addition, previously developed methods for separation of stemmed fruit from stemless fruit were explored. Then new approaches to this sorting operation were tested. Thus, with a better understanding of the physical properties of the two main brining varieties in Michigan, methods of mechanically separating the stemmed fruit from the stemless cherries needs further investigation.

LITERATURE REVIEW

Mechanisms to remove stemmed cherries from the stemless cherries have been studied extensively. A commercial machine developed and manufactured by A. B. McLauchon Co., Salem, Oregon, (Figure 1) utilized a bean washer with a friction cloth wrapped in the direction of rotation from the bottom side of the washer drum to the top. The spacing between rods was $3/8$ inch with the rods extending the length of the washer drum. Cherries were fed into the elevated end of the drum and passed down the entire length of the drum. During the rotation of the drum and cherries, the attached stems passed between the rods and were held between the outer surface of the drum and the friction cloth. Therefore, these cherries with stems were carried up the side of the drum and dropped when the friction cloth was discontinued at the top of the drum. Located inside the drum near the top was a catching flume for the cherries which were released at the point where the friction cloth was discontinued.

This mechanism has a separating capacity of approximately 8 barrels of cherries per hour. Zoss (1967) stated that this machine does not have the production capacity which maraschino processors in Michigan maintain.

Two other studies were made by the author. First, a separating mechanism was constructed (Figure 2) that looks similar to a conventional cherry pitter drum. Cherries were fed into holes in a large rotating drum. The cherries with developed

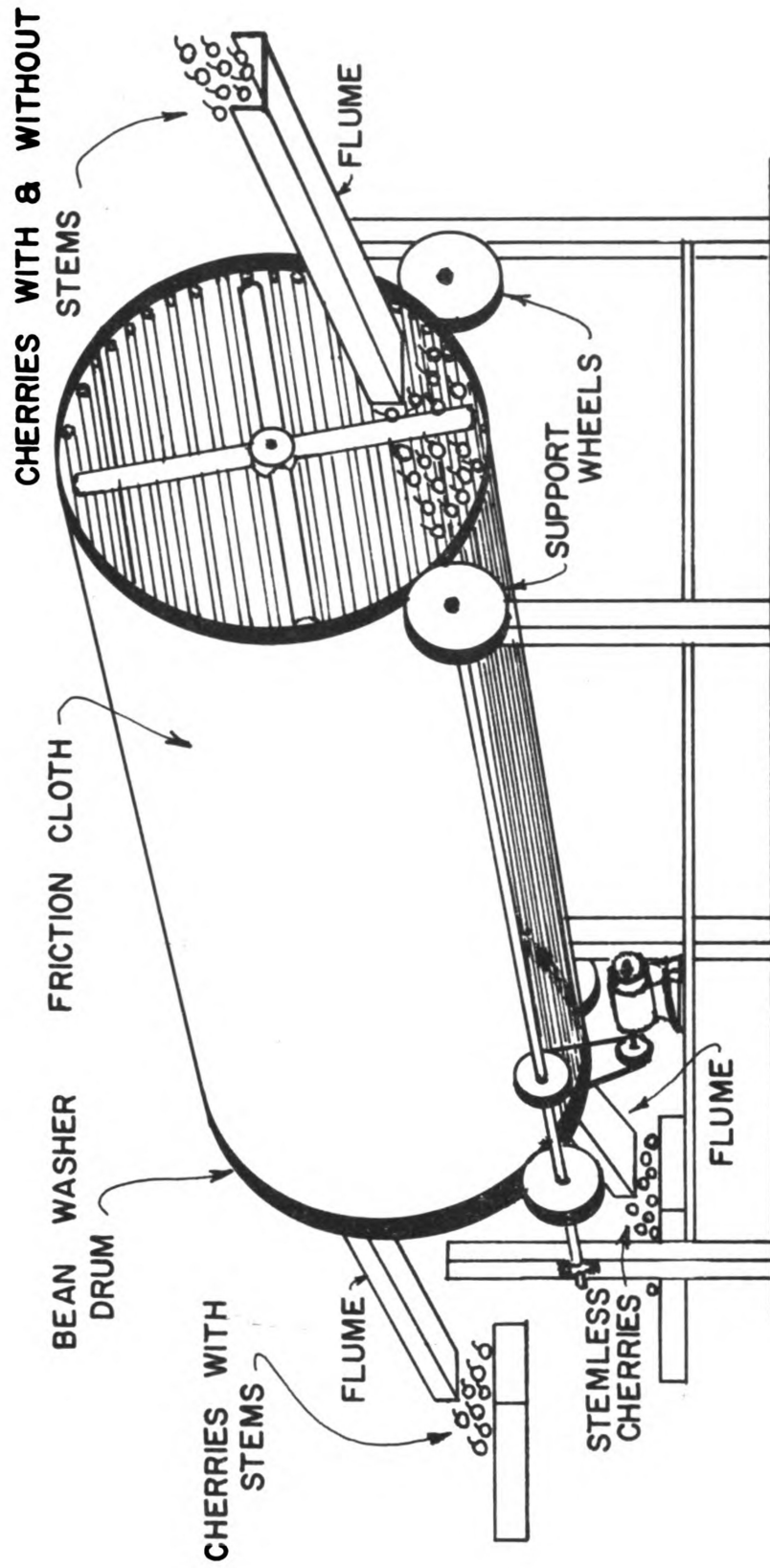


Figure 1. A commercial separator for removing cherries with stems from the stemless fruits. (A. B. McLauchon Co., Salem, Oregon)

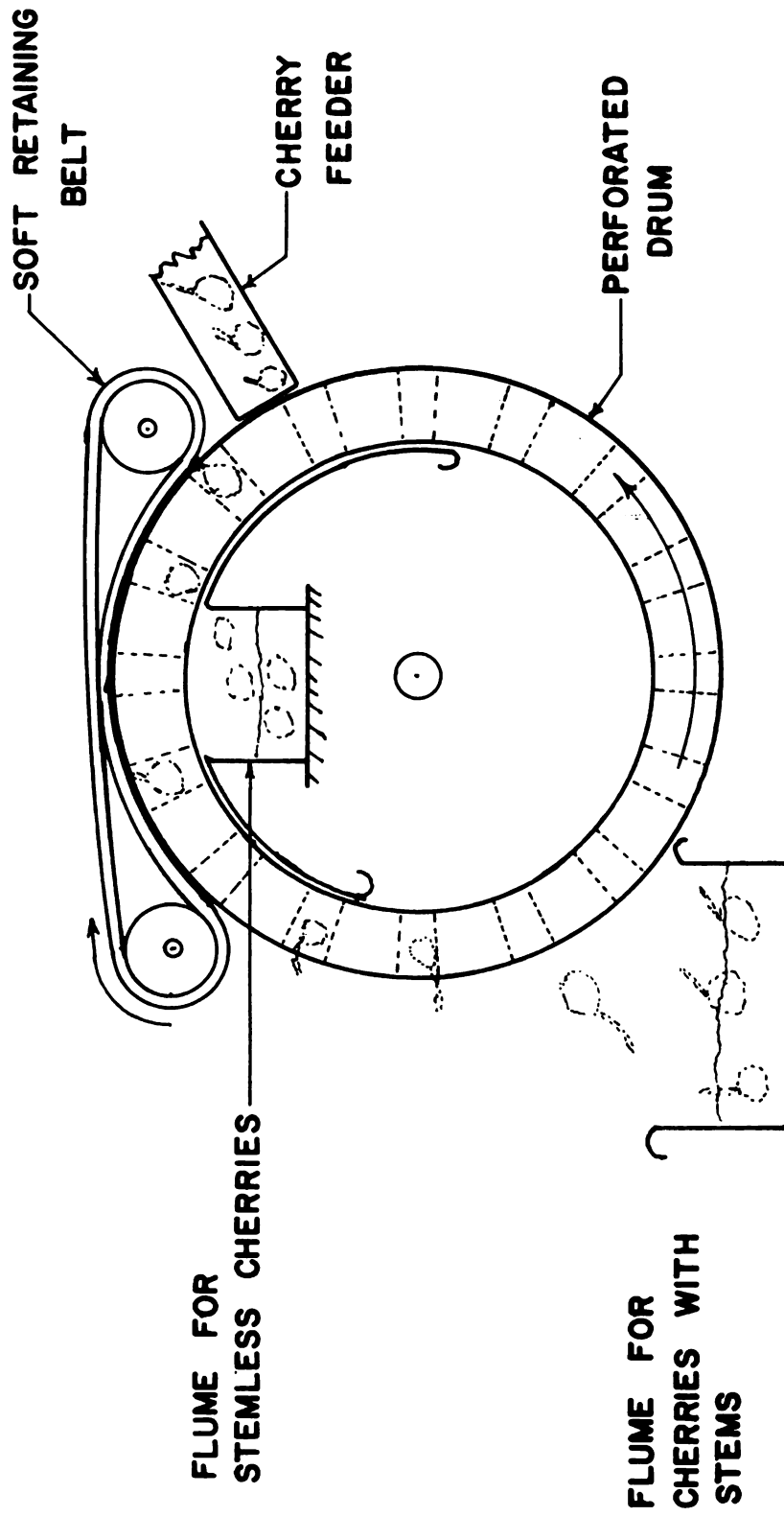


Figure 2. An experimental machine designed to separate cherries with stems from stemless fruits.

stems could only enter the holes with the stem extending outward from the hole. As the drum rotated, a soft flat belt that wrapped around the top portion of the drum pressed down on the cherry stem. Thus, the stem was held securely between the belt and the drum. When the drum rotated, the bottom plate on the inside of the perforated drum was discontinued. Therefore, the fruit was held in the hole by the attached stem. Stemless cherries then dropped into a flume located inside the drum. The cherries with stems were carried around the drum and dropped on the opposite side. A prototype of this machine was built and given a preliminary test, but no conclusions have been reached.

The second method tried by the author used a destemmer constructed by Smeltzer Brothers at Frankfort, Michigan. This device employed an orbiting moving surface to flip the cherries' stems upward so they would be destemmed. The destemming blade rotated approximately one inch above the table surface. Therefore, when the stem flipped up, it was carried away by the destemming blade.

A test was made to determine if the Smeltzer Brothers' destemmer would position the cherry stem in an upward direction. By removing the destemming blade and placing finger bars on a chain conveyor arrangement (Figure 3), an attempt was made to lift the stemmed cherries by catching the stems. However, this test resulted in lifting approximately 10 percent of the stemmed fruit. A further study of the orbiting table by a high speed motion picture showed that a cherry with a stem was in an upward position

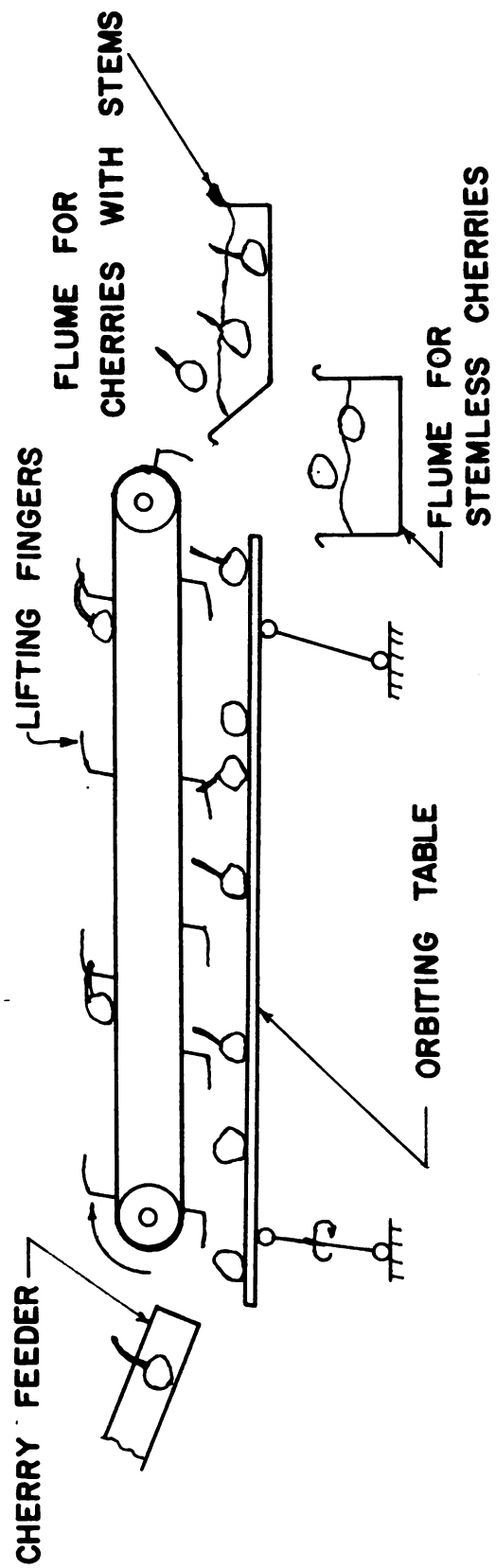


Figure 3. An experimental machine to separate cherries with stems from stemless fruits.

for only a very short period of time. Consequently, the probability of catching the stem during the time when the stem was in an upward position was relatively low.

FRUIT SHAPE AND SIZE

Fruit Shape

Marshall (1965) described cherries as being rather long, heart-shaped, and nearly as long as broad. The cross-section is oval or broadly oval, usually considerably flattened on the suture side. The cavity is rather narrow, medium depth considerably shallower at the surface. The apex is rounded or somewhat pointed. The suture is moderately conspicuous.

By using the equation for sphericity developed by Wadell (1934).

$$\text{Sphericity, } \sigma\% = \left[\frac{bc}{a^2} \right]^{1/3} \quad (1)$$

where

a = Major diameter of the particle

b = Intermediate diameter measured perpendicular to diameter a

c = Minor diameter of the particle measured perpendicular to diameters a and b

A value of 100 percent indicates that the particle was exactly spherical. A typical value for the sphericity of cherries was given as 94.8 percent by Mohsenin (1966).

Fruit Size

Nine properties or characteristics of the cherry and the stem that may affect the ability of the fruit to be separated mechanically were investigated. These included: (1) weight,

(2) cheek diameter, (3) suture diameter, (4) apex diameter, (5) volume, (6) length of stem, (7) maximum diameter of the cherry stem at the middle, (8) maximum diameter of the cherry stem at the abscission layer, and (9) terminal velocity in water.

Procedure

The weight of each fruit was recorded both with and without the stem. All fresh fruit were weighed with 24 hours after they had been hand picked. Fruit and stem diameters were recorded by a PL meter developed by Parker, et al. (1966).

To measure the volume of each fruit, a 15 degree sloping 5 mm glass tube was attached to a 100 ml graduated cylinder. Three drops of a wetting agent were added per 100 ml of distilled water to reduce capillary action. The solution was then poured into the graduated cylinder and removed, thus wetting the inside of the glass tubing and cylinder. The system was then calibrated by using a 10 ml pipette. From a plot of the values of displacement versus volume, a constant of 0.435 inches per ml was obtained. The linear displacement along the sloping tube was measured for each fruit. Then the volume was obtained by dividing the recorded value by 0.435 inches per ml.

Results and Discussion

Table 2 of physical properties was constructed using the data collected. The three diameters of the fruit recorded were: a. cheek, b. suture, and c. apex. Thus, these three diameters represent the dimensions of a sweet cherry.

Table 2

Physical Characteristics of Several Sweet Cherry Varieties
Both in the Fresh Condition and Brined Condition

Cherry Data ¹										Stem Data				
Cherry Variety	Wt. x10 ³ lbs.	Axial Dimen., in.		Vol. by water Displacement, in ³	Av. Dia., in Equiv. Sphere [abc] ¹ / ₃ [(a+b+c)/ ₃]	Sphericity 1/3 [^{bc} / ₂] a %	Specific Gravity	Length, in.	Dia., in.		Detach- ment Force, lbs.			
		a	b						Mid	End				
		Cheek Dia.	Suture Dia.	Apex Dia.					X10	X10				
Napoleon Brined	6.50	.718	.641	.649	.146	.652	.669	.669	74.7	1.242	1.66	.45	0.66	1.41
S. D.	0.07	.027	.023	.018	.018	.027	.020	.020	1.4	0.044	0.15	.00	0.03	
Napoleon Fresh ²	13.50	.891	.778	.887	.356	.879	.850	.852	88.3	1.053	1.27	.44	1.03	--
S. D.	0.12	.034	.034	.047	.021	.018	.026	.026	2.0	0.085	0.12	.01	0.03	
Windsor Brined	8.64	.795	.664	.729	.180	.699	.727	.729	78.5	1.335	1.35	.42	0.92	1.63
S. D.	0.13	.049	.027	.042	.026	.033	.033	.033	2.3	0.078	0.10	.01	0.03	
Windsor Fresh ²	11.73	.898	.720	.804	.314	.842	.804	.807	83.4	1.043	1.45	.37	1.04	0.67
S. D.	0.10	.043	.018	.025	.039	.034	.023	.024	1.4	0.070	0.17	.01	0.02	
Schmidt Fresh ³	14.23	.954	.800	.831	.362	.883	.859	.862	87.3	1.094	1.50	.36	1.03	0.44
S. D.	0.15	.039	.033	.033	.042	.035	.031	.032	2.1	0.059	0.20	.00	0.03	
S. D. = Standard Deviation														
1. Cherries measured are not necessarily from the same orchard														
2. Average Soluble Solids content was 14.5%														
3. Average Soluble Solids content was 18.1%														

S. D. = Standard Deviation

1. Cherries measured are not necessarily from the same orchard

2. Average Soluble Solids content was 14.5%

3. Average Soluble Solids content was 18.1%

From Table 2, the range of values obtained for sphericity of a fresh fruit was 83.4 to 88.3 percent and brined fruit 74.7 and 78.5 percent. Because of the lower values obtained for sphericity for brined cherries, the brining process must cause different amounts of shrinkage in the different axial dimensions. Furthermore, the brining process caused the fruit to lose weight and volume. The stem detachment force and specific gravity increased after the cherries were brined.

THEORETICAL ANALYSIS

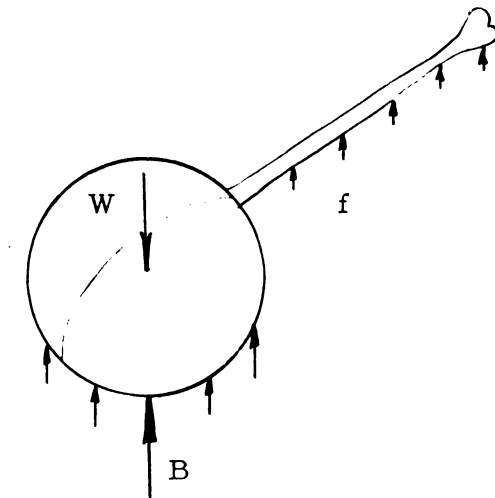
Terminal Velocity

The sorting of cherries with stems from stemless fruit in a water column will be influenced by the drag coefficients of the two types of fruit. Therefore, if the theoretical terminal velocities can be calculated that agree with the experimental results, then calculations for the required column depth can be made.

A particle in free fall will reach a steady state velocity that depends upon the physical characteristics of the particle, the fluid in which it is falling, and the acceleration of gravity.

The net force acting on a particle in a given direction is the sum of the frictional drag force, weight, and buoyant force. The following analytical procedure is adapted from a treatment of particle characteristics by Lapple and Shepherd (1940).

For a particle falling in a fluid



the forces acting on it are

$$M \frac{dV}{dt} = B - W + f \quad (2)$$

where

M = mass of particle, lb. sec.²/in.

V = relative velocity ($V_w + V_p$), ips. (inches per second)

t = time, sec.

W = particle weight, lb.

B = buoyant force, lb.

f = drag force, lb.

V_p = velocity of particle, ips.

V_w = velocity of the water, ips.

By definition, the drag force is

$$f = \frac{C_D V^2 \gamma A}{2g} \quad (3)$$

where

γ = fluid specific weight, lb./in.³

C_D = particle hydrodynamic drag coefficient, dimensionless

A = projected area of particle, in.²

g = acceleration due to gravity, 386.4 in./sec.²

Assuming that the sphere reaches terminal velocity, then

$dV/dt = 0$ for a steady state condition. Thus, Equation 2 becomes

weight of cherry - buoyant force = drag force

$$w_c(v) - w_o(v) = \frac{C_D \gamma A V^2}{2g} \quad (4)$$

where

w_c = specific weight of cherry, lb./in.³

w_o = specific weight of water, lb./in.³

v = volume of cherry, in.³

By making the appropriate substitutions and transformation Equation 4 becomes

$$V = \left[\frac{\text{Dia} \left(\frac{w_c}{v} - .03598 \right)}{C_D (7.016 \times 10^{-5})} \right]^{1/2} \quad (5)$$

where Dia = diameter of cherry, in.

A direct solution of Equation 5 for velocity, V , is impossible unless values of drag coefficient can be determined.

Because of the values obtained for sphericity of the cherries, the assumption was made that the fruits were spheres.

A graph of drag coefficient versus Reynolds number (Re) was given by Dalla Valle (1948). Reynolds number is given as dimensionless and is

$$R_e = \frac{V(\text{Dia}) \rho}{\mu} \quad (6)$$

where

V = velocity, ips.

Dia = diameter, in.

$\frac{\mu}{\rho}$ = kinematic viscosity, in.²/sec.

Kinematic viscosity for water at 70°F is 152.49×10^{-5} in.²/sec.

Therefore, equation 6 becomes

$$R_e = \frac{V(\text{Dia})}{152.49} \times 10^5 \quad (7)$$

By means of the digital computer, calculations were made for the theoretical terminal velocity (Table 3) using the mean diameters calculated from equivalent sphere, $abc^{1/3}$, and $a+b+c/3$.

Checks were made by calculating the corresponding Reynolds number for each assumed value of C_D . By comparing the assumed values for the drag coefficient with the obtained values for the Reynolds number along the line given for a sphere on a diagram versus Reynolds number, values for coefficient of drag were determined.

Matthews (1963) used a rubber ball to compare the experimental and theoretical velocities for a sphere. The theoretical analysis applies for a sphere when dropped in an infinitely large container. He reported a correction value of 1.06 for a 15 inch diameter glass cylinder.

The factor was obtained by comparing the velocity of a sphere (rubber ball) with the theoretical velocity computed. The correction equation for the terminal velocity is

$$V_a(F_1) = V_t \quad (8)$$

where

V_a = actual observed velocity, ips.

V_t = theoretical velocity, ips.

F_1 = correction factor = 1.06

Table 3

Calculated Terminal Velocity, Reynolds Number and Coefficient of Drag for Napoleon, Windsor and Schmidt Sweet Cherries

Cherry Variety	Diameters used in the Calculation					
	Equivalent Sphere	[abc] $1/3$		[$\frac{a+b+c}{3}$]		
	Coefficient of Drag	Terminal Reynolds Number	Coefficient of Drag	Terminal Reynolds Number	Coefficient of Drag	Terminal Reynolds Number
	Velocity ips.		Velocity ips.		Velocity ips.	
Napoleon Brined	0.38	14.58	6,235	0.40	14.39	6,309
Napoleon Fresh	0.38	8.01	4,618	0.38	7.86	4,389
Windsor Brined	0.42	16.96	7,769	0.44	16.90	8,065
Windsor Fresh	0.38	6.71	3,707	0.38	6.56	3,461
Schmidt Fresh	0.38	10.54	6,106	0.38	10.40	5,862

The theoretical velocity with and without the correction and the experimental values for terminal velocity are listed in Table 4.

Table 4. Terminal velocity of sweet cherry fruits in water.

Fruit Variety	Fruit Condition	Specific Gravity	Terminal Velocity, ips.	Terminal Velocity $V_a(1.06)$, ips.	Terminal Velocity, ips. (Dia = $\frac{a+b+c}{3}$)	$F_2 = \frac{V_a F_1}{V_t}$
Napoleon	Brined					
	Stemless	1.242	4.54	4.84	14.40	
	With Stems		5.24	5.55		0.28
	Fresh	1.053			7.88	
Windsor	Brined					
	Stemless	1.335	4.58	4.86	16.93	
	With Stems		5.44	5.76		0.35
	Fresh	1.043			6.58	
Schmidt	Fresh	1.094			10.42	

Orbiting Surface

It is desired to orient the stem of a cherry in a vertical position by placing the cherry on an oscillating surface with properly chosen amplitude and angular frequency. It was observed by Phleps and Hunter (1965) that when the supporting pivot of a long thin rod supported at its base was driven horizontally in a sinusoidal manner, under certain conditions a pendulum like motion about the unstable vertical position occurred. It is assumed that (1) the cherry can be approximated by a sphere and the stem by a rod; (2) the surface moves in a horizontal plane with each point on the surface moving

in a simple harmonic motion; (3) when the surface moves the cherry moves with the surface without slipping, thus maintaining the same amplitude and angular frequency as the orbiting surface; (4) the cherry is free to roll on the surface; (5) through random motion the stem becomes vertical after an initial period of acceleration and the angle of the stem from the vertical remains small, so that $\sin \theta \approx 0$, and the cherry does not accelerate in the Z direction; (6) the non-symmetric mass and the rolling friction are small; (7) the contact is a point, thus no torque is transmitted between the plane and the cherry relative to the x and y axis.

The motion of a cherry in two dimensions is illustrated in Figures 4 and 5. An illustration of the motion of the cherry relative to initial coordinates as a combination of (1) rolling of the cherry on the surface and (2) translation of a non-slipping cherry with the surface. From Figure 5 the following geometric relations can be obtained

$$X_c = X_A + r_1 \sin \theta \quad (9)$$

where

$$X_A = A \cos \omega t + r\theta$$

and simple harmonic motion of the surface

$$X_c = A \cos \omega t + r\theta + r_1 \sin \theta \quad (10)$$

taking the second derivative yield

$$\frac{d^2 X_c}{dt^2} = -A\omega^2 \cos \omega t + r \frac{d^2 \theta}{dt^2} + r_1 \frac{d^2 \sin \theta}{dt^2} \quad (11)$$

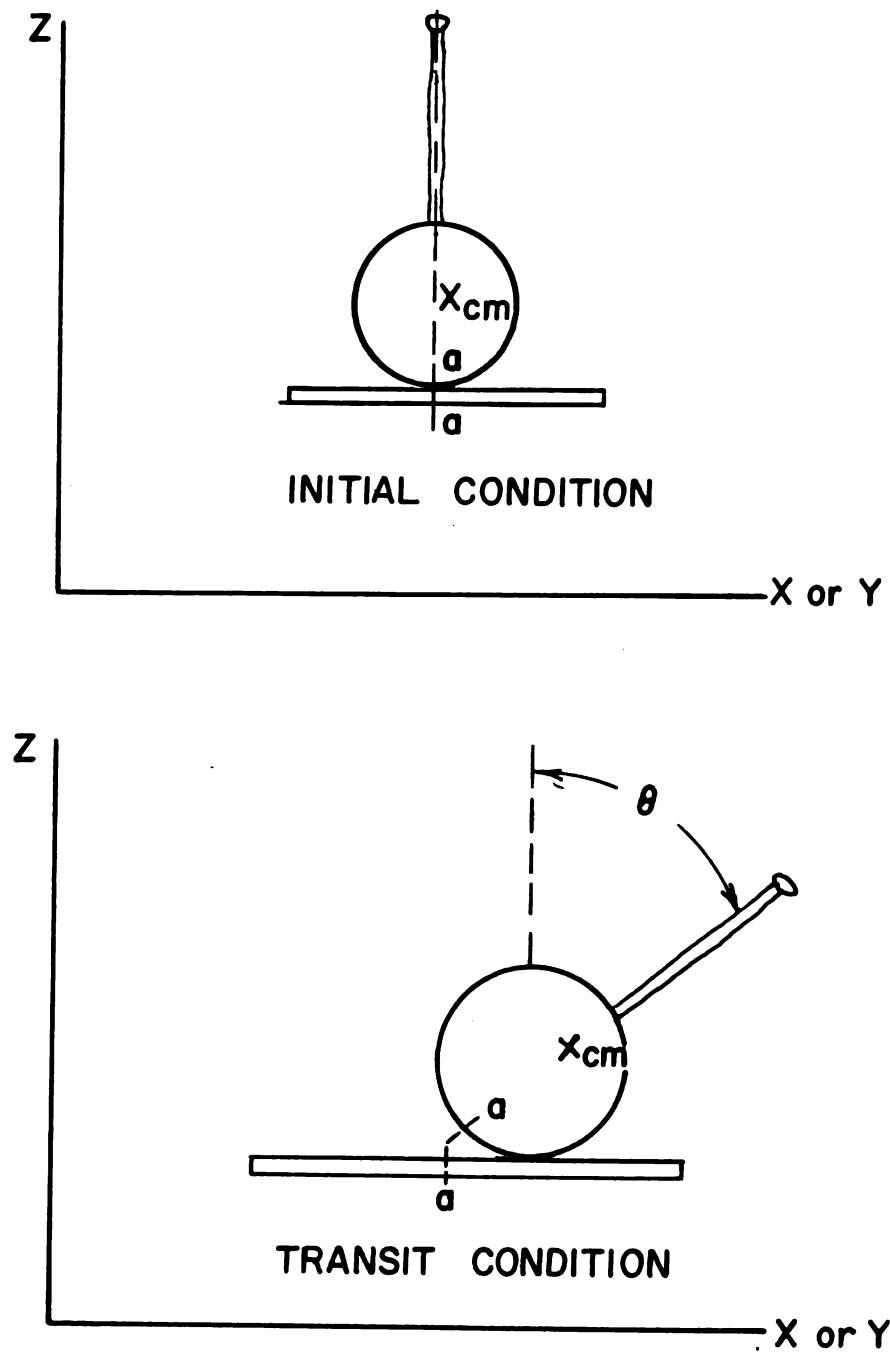


Figure 4. Model of fruit relative to orbiting surface.

- θ = angle fruit stem makes with vertical
- a = point of contact between cherry and surface in initial condition
- cm = concentrated mass for fruit and stem

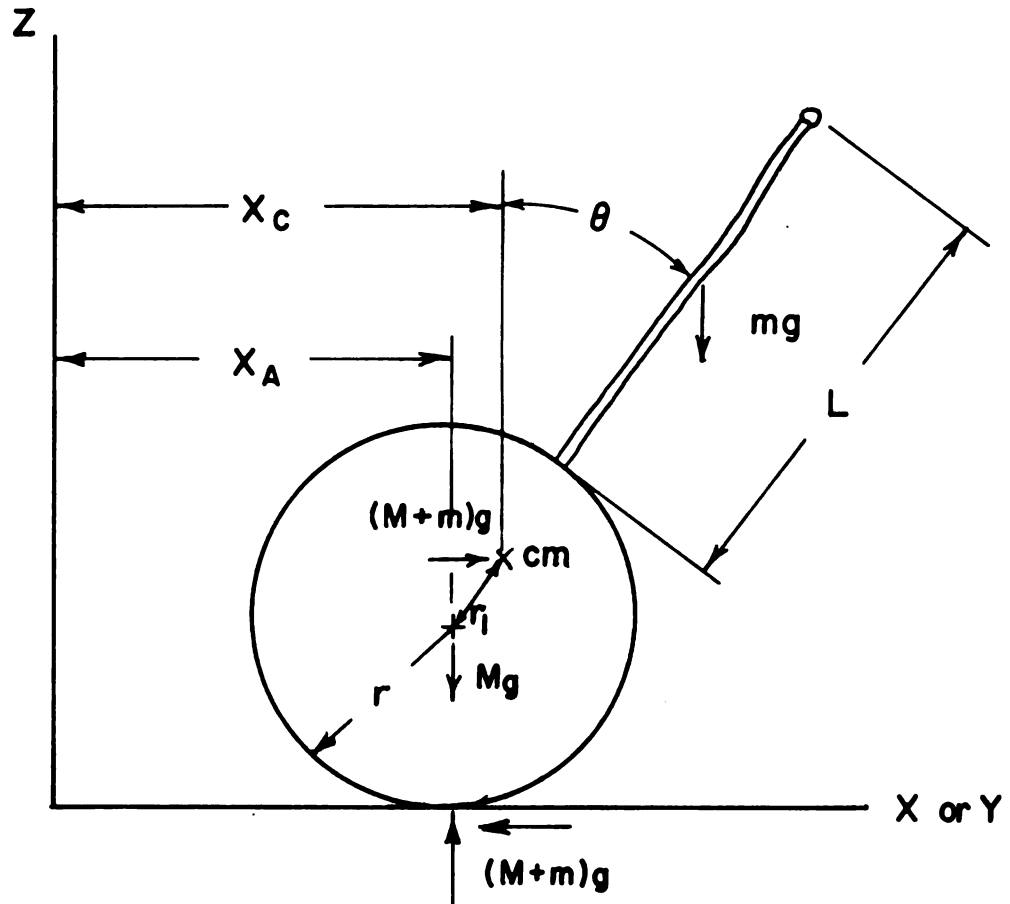


Figure 5. Model of cherry and stem.

- θ = angle the stem makes with the Z axis
- X_C = distance the combined center of mass is located from the Z axis
- X_A = distance the center of mass of the cherry fruit is located from the Z axis
- mg = weight of cherry stem
- Mg = weight of cherry fruit
- r = radius of cherry fruit
- r_1 = the distance the combined mass of the fruit and stem is located from the center of gravity of the fruit
- cm = center of mass of the fruit and stem
- L = length of cherry stem
- A = average amplitude

and taking the moment about the contact point of the cherry, at the base

$$(r+r_1 \cos \theta)(m+M) \frac{d^2 X_c}{dt^2} - m g h \sin \theta + I_p \frac{d^2 \theta}{dt^2} = 0 \quad (12)$$

where

$$h = (r + \frac{L}{2})$$

I_p is given in Figure 6

$$\sin \theta \approx \theta$$

assuming the angle from the vertical is small, the combined Equations 11 and 12 result in the governing Equation 13.

$$\frac{d^2 \theta}{dt^2} + \frac{m g h \theta}{(r+r_1)^2 (m+M) - I_p} = \frac{(r+r_1)(m+M) A \omega^2 \cos \omega t}{(r+r_1)^2 (m+M) - I_p} \quad (13)$$

the solution to this equation is periodic when

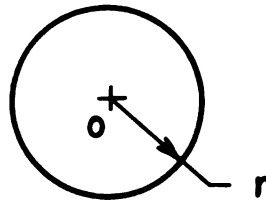
$$\frac{m g h}{(r+r_1)^2 (m+M) - I_p} > 0 \quad (14)$$

Therefore, Equation 14 is periodic if

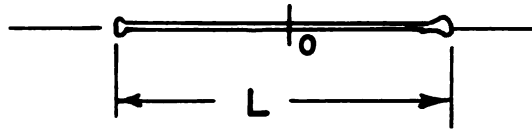
$$(r+r_1)^2 (m+M) > I_p . \quad (15)$$

Substitute into Equation 15 the values for I_p and r , in terms of L , r , M , and m

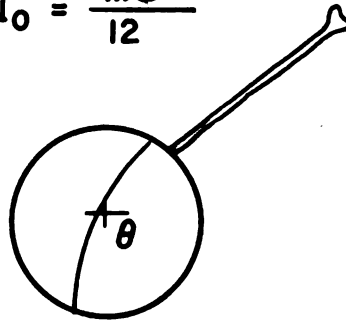
$$r_1 = \frac{L/2 + r}{\frac{m+M}{m}} . \quad (16)$$



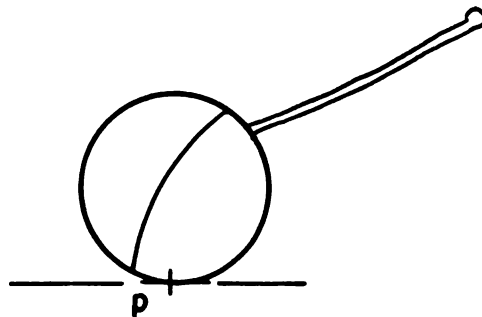
$$I_O = \frac{2Mr^2}{5}$$



$$I_O = \frac{mL^2}{12}$$



$$I_O = \frac{2Mr^2}{5} + \frac{mL^2}{12} + \left(r + \frac{L}{2}\right)^2 m$$



$$I_P = I_O + r^2(M+m)$$

$$I_P = \frac{7}{5}Mr^2 + \frac{1}{3}mL^2 + 2r^2m + rLm$$

Figure 6. Rotational inertia of cherry and stem.

When inserting numerical values for the ratios M/m and L/r , Equation 15 was found to be true. Consequently, Equation 14 is periodic.

EXPERIMENTAL ANALYSIS

Terminal Velocity

One possible method of separating the stemmed cherries from stemless fruits is by a fluming or a water settling method. The preliminary study of this method was done with a hydraulic demonstration channel.* This proved too difficult to work with because of the different flow patterns in the flume. Therefore, the study was continued in a vertical water column.

Apparatus

The apparatus for the terminal velocity experiment (Figure 7) consisted of a 15-inch diameter, 24-inch high pyrex container filled with water to a depth of 22.5 inches. An electrically controlled device was constructed for releasing the cherries one-half inch above the water level. As the fruit fell to the bottom, they were photographed with an 8 mm movie camera at 32 frames per second. A surveying rod calibrated in $1/4$ inches and a large faced electric timing clock which read in $1/10$ seconds were photographed in each frame on the film. Thus, variations in the movie camera speed had no effect on the timing accuracy. From the analysis of the film, a graph of the displacement versus time was made and the terminal velocity was obtained from the slope of the curve.

*Basic Channel Unit Model B, Manufactured by Engineering Laboratory Design Inc., 2714 Oakland Road, Minnetonka, Minnesota.

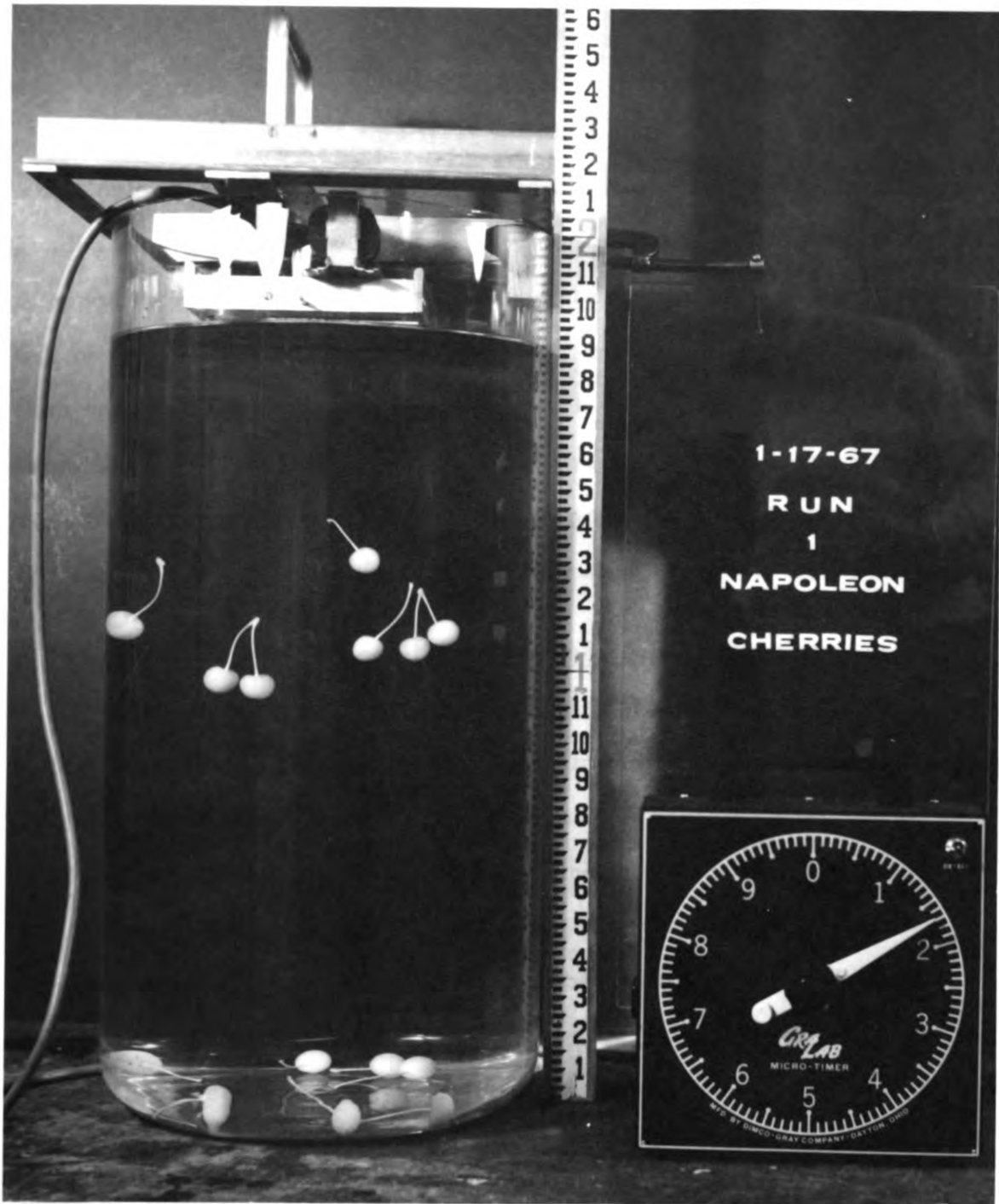


Figure 7. Terminal velocity testing apparatus.

Procedure

Each fruit tested was first weighed and the diameters measured while dry. Then the cherry was placed in the water displacement graduated cylinder to determine its volume. Next the fruit was dropped into the water column with the stem attached and the free fall of the fruit was recorded by a movie camera. The fruit was then removed from the water cylinder. Next the stem was detached from the fruit by a continuous pull and the detachment force was recorded. The above procedure was repeated for the fruit without the stem. Seventy-five cherries were tested using this procedure.

Results and Discussion

The theoretical terminal velocity (Table 4) was more than twice the results obtained for the experimental tests. The theoretical calculations assumed the cherry fruit to be a sphere. In Table 2, the values for sphericity for the Napoleon and Windsor brined cherry fruits were 74.7 and 78.5 percent respectively. Thus, these two sweet cherry varieties differ considerably from a spherical shape in the brined condition.

Because of the cherry's irregular shape, the behavior of the fruit during free fall was not similar to a sphere. The cherries when dropped with the stem attached inscribed a snake-like path down the water column. Apparently, the stem reduced the viscous drag because the stemmed fruit fell at a higher terminal velocity than did the stemless fruit (Figures 8 and 9). However, when the stem was detached from the cherry, the fruit had a tumbling action as it fell in the water column. Therefore, the tumbling motion

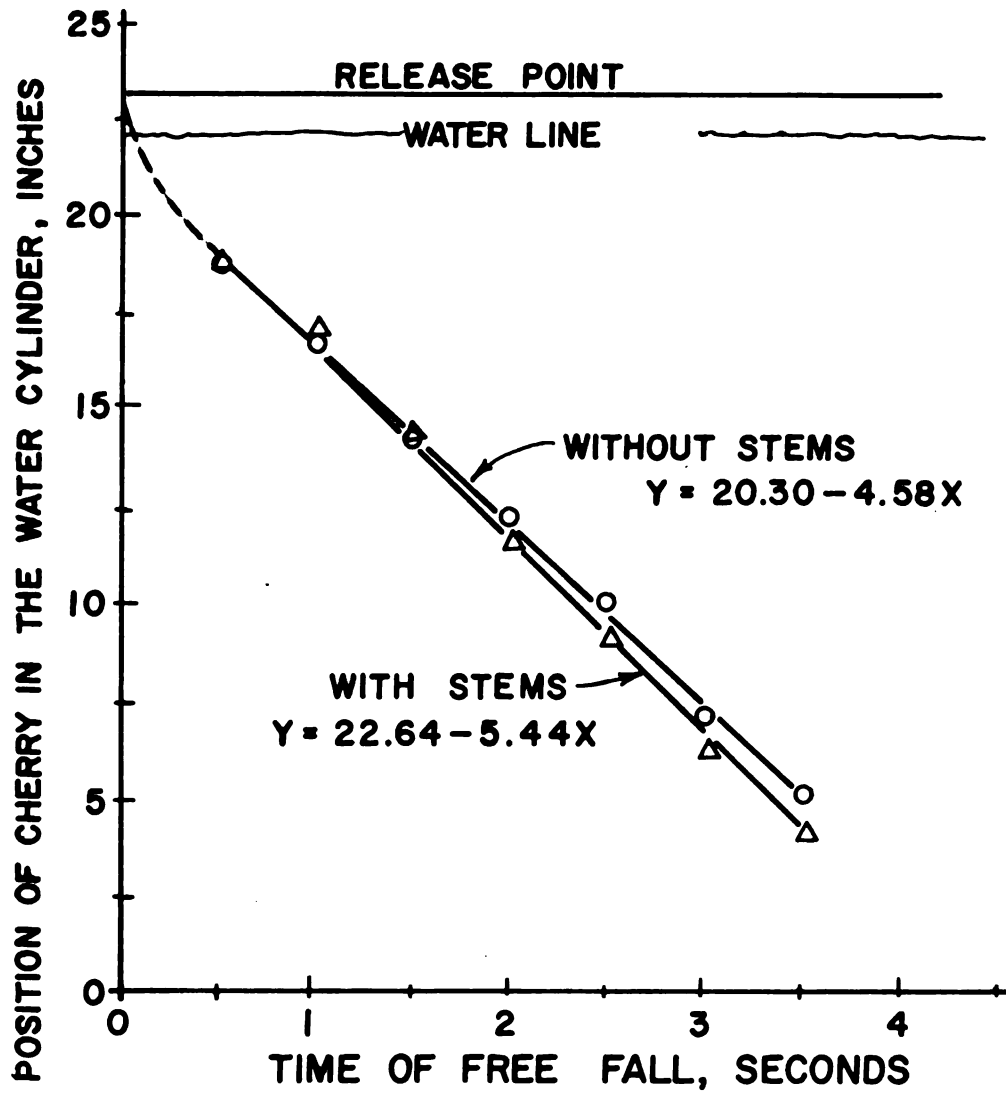


Figure 8. Terminal velocity in water for Napoleon cherry fruit (indicated by the slope).

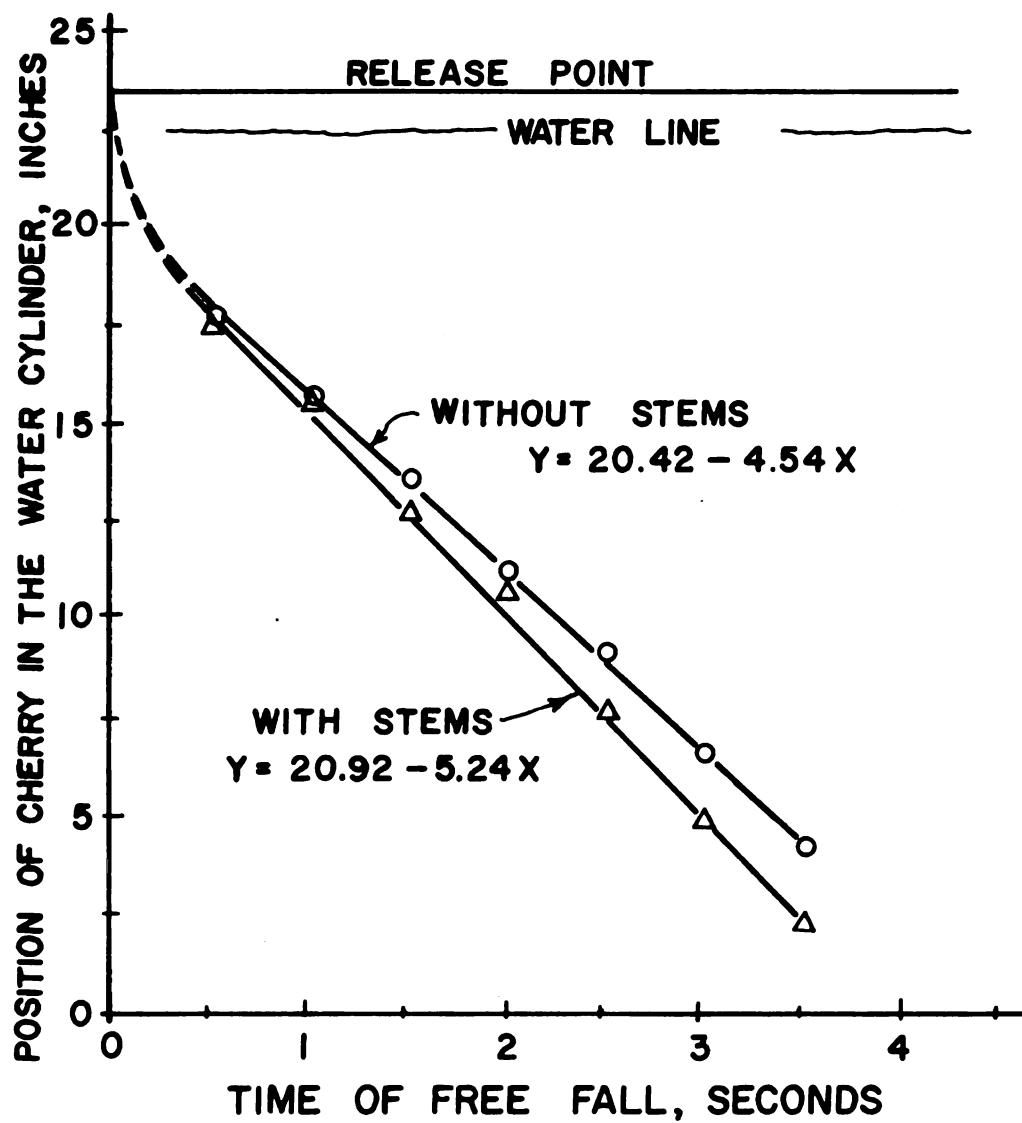


Figure 9. Terminal velocity in water for Windsor cherry fruit (indicated by the slope).

apparently increased the drag. Consequently, the viscous drag coefficient for both the fruit with the stem and without the stem is greater than that of a sphere.

Tietjens (1934) stated that the drag forces caused by the rotational inertia of a sphere in a fluid is greater in many cases than the drag forces caused by the falling of a sphere in a fluid. Therefore, this could explain the slower terminal velocity of the stemless fruit. Even though the zigzag motion of the cherries with stems contributed to a slower terminal velocity than the theoretical terminal velocity, drag caused by the rotation of the fruit was greater. Therefore, the actual drag of a sphere in a fluid is a combination of drag forces that must be calculated by empirical methods.

Krumbein (1951) stated that the effect of sphericity on the settling velocity of quartz grains was directly proportional to the sphericity for large particles.

Pettyjohn and Christiansen (1948) developed the relationship between the coefficient of resistance and the particle shape as

$$C_r = 5.31 - 4.88 \psi \quad (17)$$

where

C_r = coefficient of resistance

ψ = sphericity

Taking the average value for sphericity (Table 2) for the brined cherries as 76.6 percent and substituting this value into Equation 17, a value obtained for the coefficient of resistance is 1.57. Consequently,

the effect of the cherry's shape had a tremendous influence on the drag coefficient. This factor and the particular motions of the cherries could explain the disagreement between the theoretical and the experimental results obtained for terminal velocity.

Matthews (1963) developed the equations to solve for the true coefficient in the following way:

$$V_t(F_2) = V_a \quad (18)$$

where

V_t = theoretical velocity, ips.

V_a = actual velocity in large tank, ips.

The average value of F_2 obtained from the two varieties was 0.31 (Table 4).

Drag coefficient and velocity are related by Equation 19

$$V = \sqrt{\frac{2g_w}{C_D A} \left(\frac{\gamma - \gamma_p}{\gamma_p} \right)} \quad (19)$$

which reduces to

$$V = \sqrt{\frac{K}{C}} \quad (20)$$

where

K = constant, $\text{ft.}^2/\text{sec.}^2$

C_D = particle hydrodynamic drag coefficient, dimensionless

Using Equation 20 to compare the velocity of a cherry fruit with the results obtained for a sphere

$$\frac{v_p}{v_s} = \frac{\sqrt{\frac{K}{C_{DC}}}}{\sqrt{\frac{K}{C_{DS}}}} = \sqrt{\frac{C_{DS}}{C_{DC}}} \quad (21)$$

where

C_{DC} = drag coefficient for cherries

C_{DS} = drag coefficient for sphere

Substituting into Equation 21 the value of 0.31 for C.F., Equation 21 becomes

$$\frac{1(0.31)}{1} = \sqrt{\frac{C_{DS}}{C_{DC}}} \quad (22)$$

$$C_{DC} = 10.40 C_{DS}$$

By assuming the drag coefficient of a sphere to equal 0.40 ($2000 < R_e < 7000$), a calculated value for the drag coefficient for the tested cherry fruits was 4.16. This value for the drag coefficient of 4.16 is more than twice the value of 1.57, obtained for the correction caused by a low value for sphericity. Therefore, the variation that exists between these two methods for obtaining the actual drag coefficient of the cherry indicates that other drag factors are present for these cherries. When the computed value for the coefficient of drag (4.16) was substituted into Equation 5, the values (Table 5) obtained for terminal velocity were in agreement with the experimental results.

Table 5

Calculated Terminal Velocity and Coefficient of Drag for
Brined Napoleon and Windsor Sweet Cherries

$$\text{Dia} = \frac{a+b+c}{3}$$

Cherry Variety	Experimental Velocities (Fig. 8 and 9)	Methods used to obtain the Coefficient Drag					
		Assumed values for C_D and checked a graph for Reynolds Numbers (assuming a spherical shape)		By Equation 4		By Equation 17	
		Coefficient of Drag (average)	Terminal Velocity ips.	Coefficient of Drag (average)	Terminal Velocity ips.	Coefficient of Drag (average)	Terminal Velocity ips.
Napoleon							
With Stem	5.24						
Stemless	4.54	0.40	14.46	4.16	4.49	1.57	7.25
Windsor							
With Stem	5.44						
Stemless	4.58	0.44	16.93	4.16	5.26	1.57	8.94

Practical Applications

In an attempt to use the different terminal velocities of the cherries with stems and the cherries without stems, a practical problem will be worked. Assuming that a 24 inch separation between the fruit were required to effectively flume the cherries into different tanks, what will be the required depth of water to separate the Napoleon and Windsor fruit into lots with stems and without stems?

If the fruit were released at the surface without an initial velocity, the Napoleon variety would require 180 inches or approximately 15 ft. and the Windsor variety would require 146 inches or approximately 12 ft. to cause a 24 inch spread between the stemless fruit and stemmed fruit. Practically speaking, a 15 foot deep flume would not be feasible in most cherry processing plants.

Orbiting Surface

A second method of separating the stemmed fruit from the stemless fruit would be to orient the stems and then remove the fruit with stems by lifting them from the belt.

The Smeltzer's orbiting table destemmer was used in an attempt to orient the stems in a vertical direction, to enable lifting the fruit off the belt by the stems. This method did not work because the stem was in a vertical position only about 10 percent of the time. Therefore, if an orbiting frequency and orbiting diameter could be obtained that would give optimum conditions to enable the stems to remain in a vertical direction, then this mechanism may have possibilities as an orienting device.

Apparatus

Since the commercial orbiting surface was not equipped with a variable speed drive and adjustable orbiting diameter, a laboratory model (Figure 10) with these features was constructed. The mechanism was counterbalanced to reduce vibrations. The same Buna-N belt surface was used on the laboratory mechanism as is used on the Smeltzer's destemmer. A stroboscope was used to select the orbiting frequency and a 35 mm camera was used to photograph the orbiting surface. The photographs (Figure 11) were analyzed to determine the number of fruit with stems in the vertical direction.

Procedure

The samples of Napoleon and Windsor cherries were obtained from a receiving station in the Bailey, Michigan, area. Twenty cherries were selected for each test run and two replications were made at each setting. The orbiting diameter and frequency were selected and the data recorded by photography.

The results were analyzed by counting the number of cherry stems one inch or higher above the belt surface in a stem-up position. By selecting the one inch height, this eliminated those settings which caused the stems to assume a horizontal position parallel to the orbiting surface. Thus, the total number of observations of the fruit with the stems above the one inch level were compared to the total number of observations made. The results were reported as the average percentage of stems one inch or higher above the belt surface for the recorded observations.

DIA 0-
 1" 2800
 ORBIT rpm

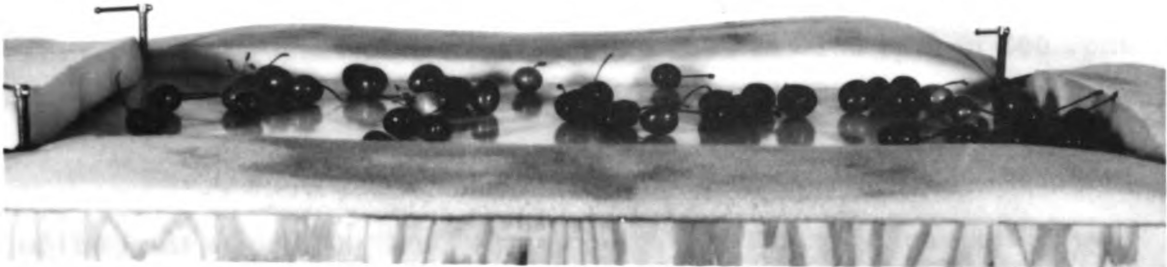


Figure 10. A cherry sample on the orbiting belt surface. Cushioning material was used to keep the fruit from rolling off the table during testing.

20 DIA. 2200
 NER 1/2
 ORBIT rpm

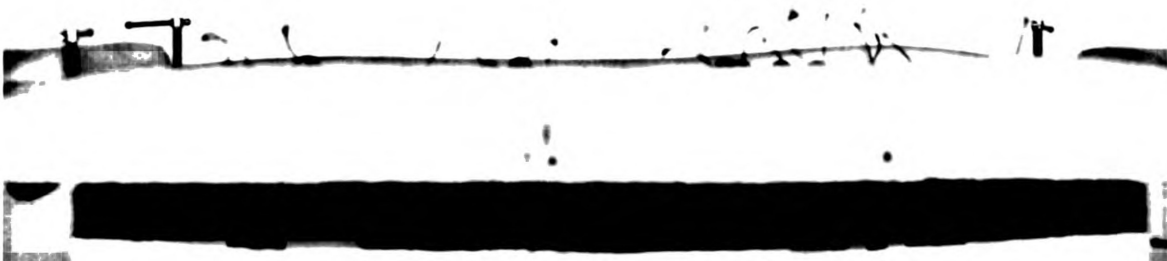


Figure 11. Napoleon fresh cherries on the orbiting surface. Note the high proportion of stem pointing upward.

Results and Discussion

The preliminary runs with the orbiting surface were made at 800 to 2800 rpm and a 1/4 inch orbiting diameter. It was observed that the fruit did not respond until the frequency was about 1200 rpm. Therefore, the frequencies tested were 1200 to 2800 rpm in 200 rpm increments for the 1/4 inch diameter orbit.

The 1/2 inch orbiting diameter testing caused a low response of the fruit at orbiting frequencies below 1800 rpm. Consequently, all settings of orbiting frequency below 1800 rpm were not tested for the 1/2, 3/4 and 1 inch orbiting diameters. Nevertheless, a personal observation was made on each of these orbiting diameter settings to substantiate the first observation.

The motion of the cherry fruit at the orbiting frequencies between 800-1800 rpm and 1/2, 3/4 and 1 inch diameters was generally a rolling action about the point where the stem lay on the surface. Some fruit would lift the stem to a 30 to 45 degree angle with the orbiting surface and then drop the stem back to the belt surface. Rotations of the fruit through a 180 degree arc, causing the stem at one point to be approximately perpendicular to the belt surface, did occur. However, this motion was a quick flip type behavior, thus causing the stem to be in an upward direction for a fraction of a second.

As the angular frequency increased, the behavior of the fruit tended to become more systematic with the fruit rolling about on the apex end and the stem inscribing a circle above the surface with the circle's radius perpendicular to the axis of rotation of the orbiting surface. As the angular frequency increased, this behavior

would develop, reach a maximum, and disappear.

At the higher frequencies, 2400 to 2800 rpm, the fruit would spiral about an axis perpendicular to the apex-stem axis, thus maintaining the stem parallel to the orbiting surface. This behavior occurred at different frequencies for the various orbiting diameters but it appeared for all diameters tested in the range of 2200 to 2800 rpm.

A plot of percent of stems one inch or higher above the belt surface versus orbiting speed (Figures 12 and 13) for each orbiting diameter tested indicated that a periodic condition did exist as expressed by Equation 14.

For the Napoleon variety, the $1/2$ inch orbiting diameter gave a maximum response at 2200 rpm. Two definite peaks were obtained with the first peak coming at approximately 1400 to 1600 rpm.

The optimum settings for fresh Napoleons were at 2200 rpm and a $1/2$ inch diameter of orbit. Surprisingly, this was the same angular frequency that gave the optimum response for the $1/4$ inch and $3/4$ inch diameter settings.

For the Windsor variety, the $1/4$ inch diameter at 1600 rpm represented the optimum settings. For angular frequencies between 1800 and 2800 rpm, there was no significant difference between the different diameters except for the 1 inch setting. From Table 6, it was concluded that Windsor cherries were not affected by the orbiting surface as were Napoleon cherries.

A possible reason for the different type behavior of the two tested cherry varieties was the shape of the cherry. From Table 2, the values for sphericity were given for Napoleon and Windsor cherries

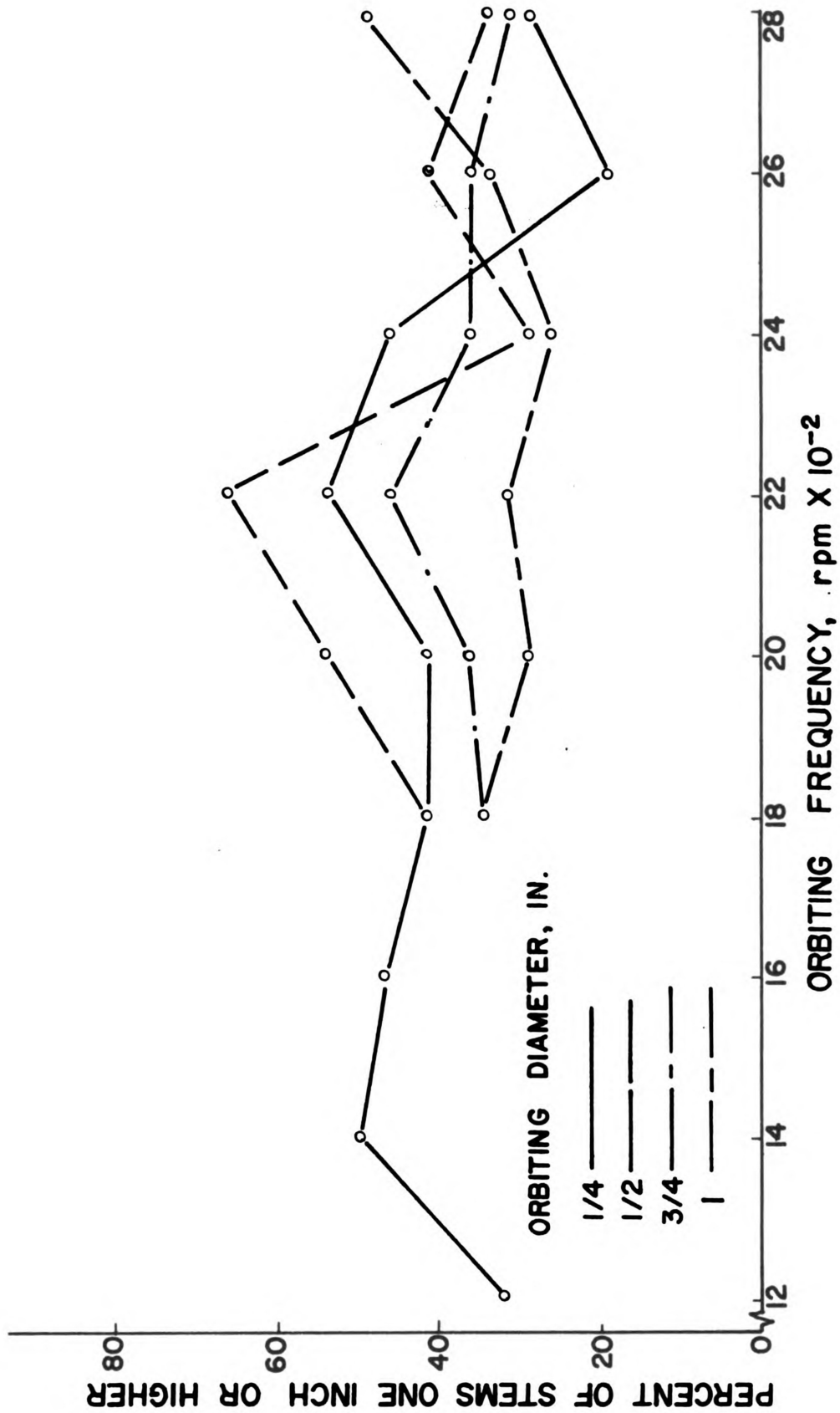


Figure 12. Effect of orbiting frequency on number of Napoleon cherries with stems one inch or higher above the surface.

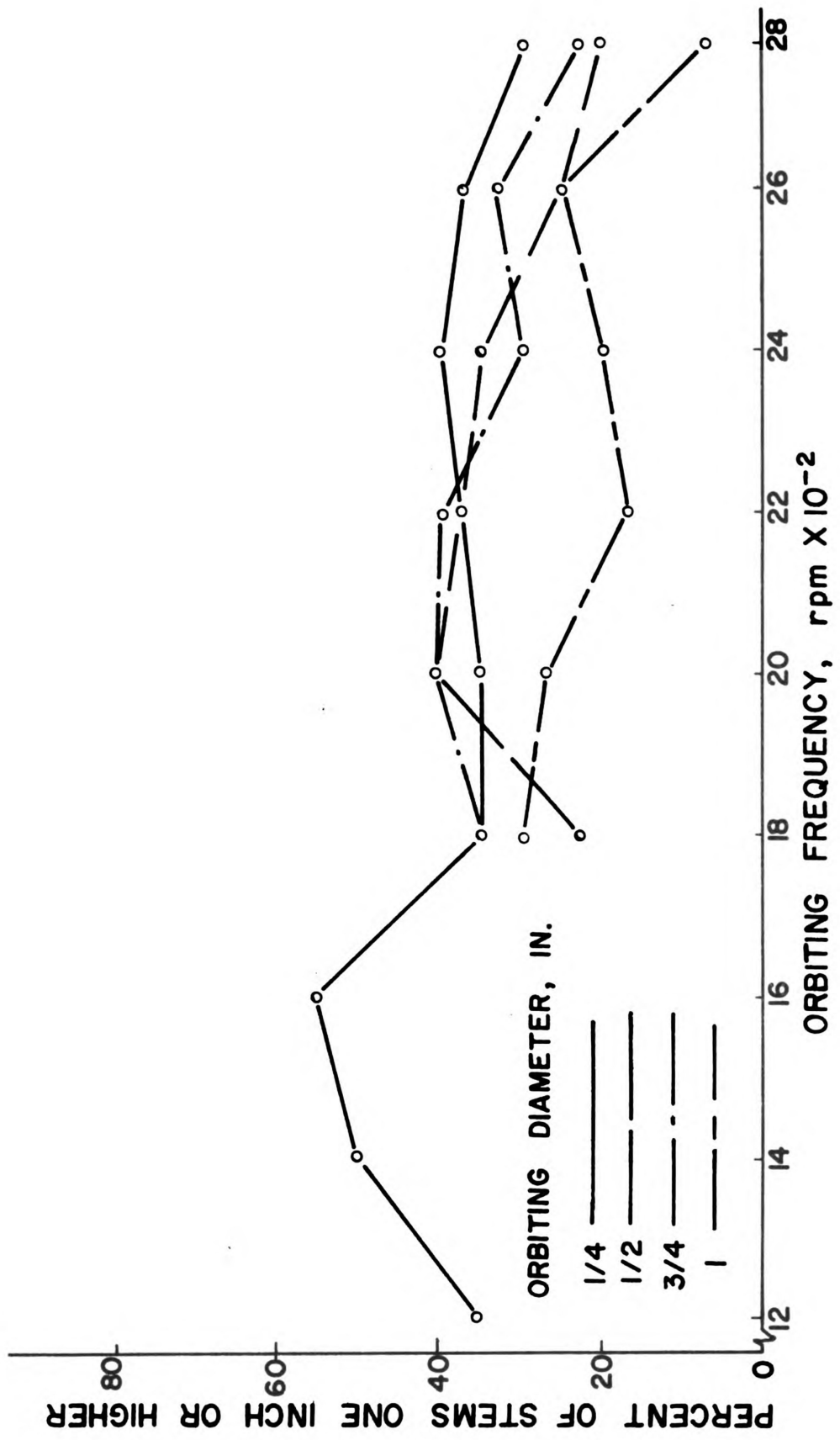


Figure 13. Effect of orbiting frequency on number of Windsor cherries with stems one inch or higher above the surface.

as 88.3 and 83.4 percent respectively. Thus, the fresh Napoleon cherry shape was slightly more spherical than the fresh Windsor cherry. However, the converse was found for these two varieties in the brined condition.

The fresh Napoleon cherry fits Marshall's (1965) description of cherries. He described a cherry as being heartshaped, nearly as long as broad, the cross-section is oval or broadly oval, and usually considerably flattened on the suture side. The cavity is rather narrow, having a medium depth which is considerably shallow at the surface. The apex is rounded or somewhat pointed. The fresh Windsor cherry fits this same general description except for the apex end. Instead of being rounded or somewhat pointed, the Windsor fruit is rather flattened on the apex end. By taking the cheek diameter as a base and calculating the percent difference in the cheek diameter versus the suture and apex diameters (Table 7), the shape difference of the two varieties is apparent. Thus, the brining operation caused the greatest shrinkage for the Napoleon variety through the apex diameter and for the Windsor variety through the cheek diameter.

Table 6. Percent of cherries with stems one inch or higher above the orbiting surface.

Orbiting Diameter, inches	Napoleon		Windsor	
	Mean ¹	Standard Deviation	Mean ¹	Standard Deviation
1/4	39.5	11.8	36.0	9.1
1/2	45.4	16.3	30.0	8.4
3/4	37.9	8.0	33.3	7.1
1	35.0	10.4	21.2	10.0

¹ The mean represents the percent of stems one inch above the orbiting surface.

Table 7. Comparison of axial dimensions in percent.

	Cheek diameter versus suture diameter	Cheek diameter versus apex diameter
Fresh Napoleon Cherries	12.7	0.4
Fresh Windsor Cherries	19.8	10.4

The means and standard deviation (Table 6) were computed for each orbiting diameter. By means of the coefficient of orthogonal polynomials test for means, the effect of stems in a vertical direction was tested at the 95 percent confidence level. Checks were made for the first, second, and third order polynomials for both varieties tested.

For the Napoleon variety (Figure 14), the comparisons for the first, second, and third order polynomials were not significant. Thus, the treatment variation among data points was so large that varying the orbiting diameter did not demonstrate any significant trends for the Napoleon variety.

For the Windsor variety, significance was obtained at the 95 percent confidence level for the first and third order polynomials. Analysis of this significance for the first order polynomial indicated that as the diameter of orbit was increased, the percent of cherry stems pointing in a vertical direction decreased. The significance obtained from the third order polynomials meant that significant "bumps" did exist (Figure 14). Thus, the fact that significance was obtained for the first and third order polynomials and no significance

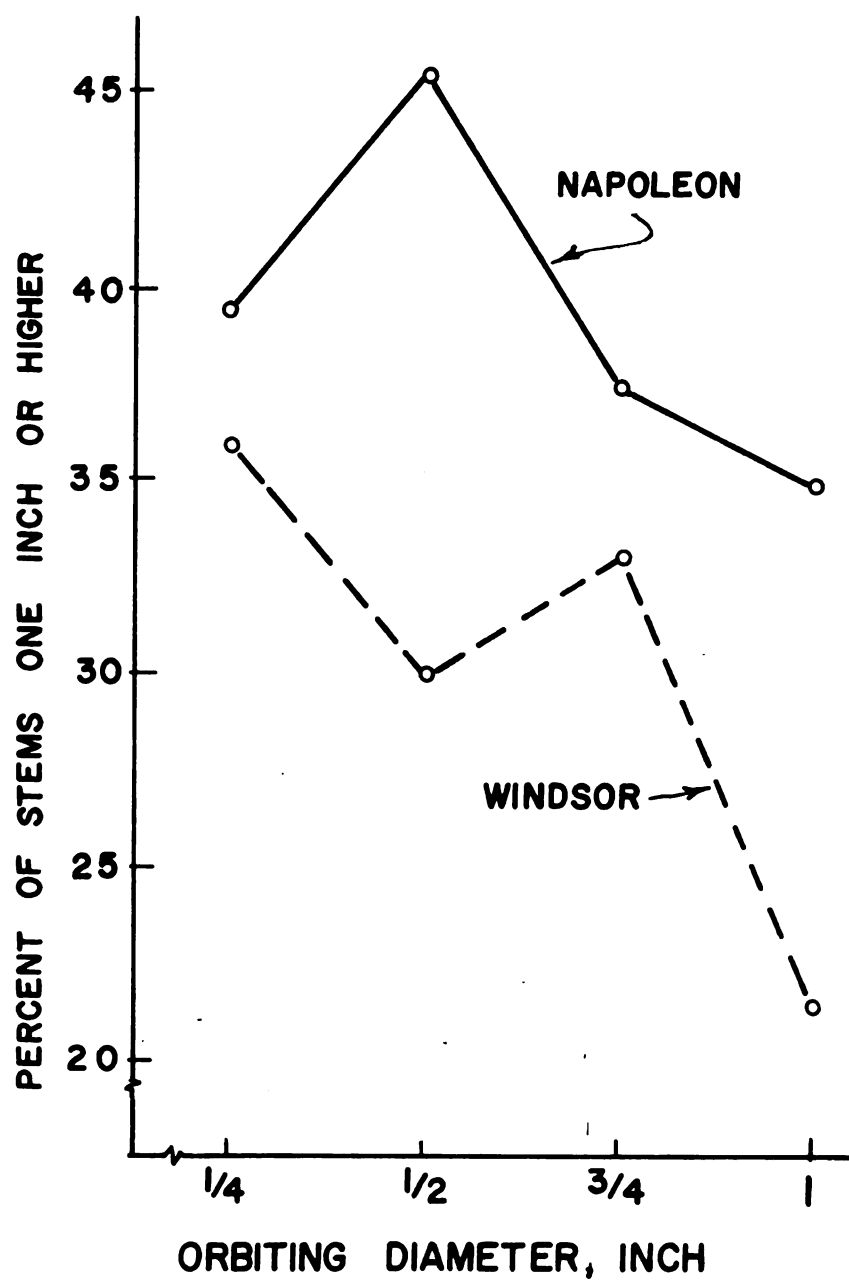


Figure 14. Response of Napoleon and Windsor cherry stems to orbiting diameter.

was obtained for the second order polynomial indicated the inability to locate a potential maximum response within the tested range for the orbiting diameter. Therefore, a possible maximum point may be outside the tested range of 1/4 inch to one inch orbiting diameter settings. An observation of Figure 14 would indicate that the potential maximum value was less than 1/4 inch for the orbiting diameter for the Windsor variety.

CONCLUSIONS

The conclusions derived from this study were:

1. Brined cherry fruit of the Napoleon and Windsor varieties had a significantly higher terminal velocity when the stems were attached to the fruit than the same fruits without stems.
2. Shrinkage in weight and volume of the cherry fruit occurred during brining. The shrinkage was not necessarily proportional to all dimensions of the fruit. The different cherry varieties had more shrinkage in different axial planes.
3. The stem detachment force (Table 2) for the Napoleon and Windsor varieties was greater for the brined fruit than the freshly picked cherries.
4. Each variety tested on the orbiting surface responded to different orbiting frequencies and diameters.
5. A possible maximum response for the Windsor variety was not in the tested range of orbiting diameters.

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