

A HYDRO-HANDLING SYSTEM FOR
PRESORTING AND PRESIZING APPLE FRUITS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Ralph Wells Matthews
1963



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**A HYDRO-HANDLING SYSTEM FOR PRESORTING
AND PRESIZING APPLE FRUITS**

By

Ralph Wells Matthews

AN ABSTRACT

**Submitted to the Colleges of Agriculture and Engineering
of Michigan State University in partial fulfillment
of the requirements for the degree of**

**MASTER OF SCIENCE
IN
AGRICULTURAL ENGINEERING**

Department of Agricultural Engineering

1963

ABSTRACT

Controlled atmosphere storage for apples has increased at an extremely rapid rate accounting for 31 percent of Michigan's stored apple crop in 1962. The high cost of CA storage and the fact that field run fruit average 15 to 30 percent cull and utility justifies a pre-sorting operation. Presizing could easily be performed at the same time. However, fruit bruising must be minimized. Therefore, the use of water as a handling medium was investigated.

The objectives of this study were to investigate basic fruit hydro-handling characteristics and to develop components for a complete apple presorting and presizing system, using water as a handling medium.

The experimental investigation was divided into two main areas. Six fruit characteristics related to hydro-handling and three components for a presorting and presizing system were studied.

Floating orientation of several varieties was investigated because it may affect the performance of the hydro-sizers. Delicious fruits had the greatest variation in floating positions with 27 percent floating side up. Ninety-eight percent of the McIntosh fruits floated with either stem or calyx up and 96 percent of Jonathan fruits floated with stem up.

Submerging characteristics and methods were studied and it was found that a flight conveyor worked best and required less power than other water flow methods. Underwater pyramiding, such as might occur when filling an inverted bulk box under water, was investigated. Angles of repose varied slightly with fruit size and ranged from 30 degrees for 2 1/2-inch fruits to 36 degrees for three-inch fruits.

There was concern that appreciable amounts of water might be forced into the core when apples were submerged in hydro-sizing and

box-filling operations. Tests indicated that Delicious fruits absorb much more water than McIntosh, but the low hydrostatic pressures encountered in hydro-handling would cause no problem even for Delicious fruits.

The buoyant velocity of apple fruits was investigated to determine whether bruising might result from contact with mechanical components under or just above the water surface. The terminal velocity of apple fruits is a function of the weight per unit cross sectional area ($\frac{W}{A}$), specific gravity, and fruit shape, which determines the fluid drag coefficient. Comparison of experimental and theoretical results yielded an average drag coefficient for apple fruits of 0.68. Terminal velocity varied from 1.3 to 1.9 feet per second, depending on fruit size and specific gravity.

The coefficient of friction and rolling resistance were measured for three fruit varieties on several surfaces. Identical tests were conducted in air and under water. Sliding friction in air and water differed little, but rolling resistance was nearly twice as great in water as in air.

The three presorting and presizing system components investigated were hydro-sorters, sizers and box fillers. Several types of each component were designed, constructed and evaluated.

Fruit sorting can be performed more efficiently out of water and since very little bruising occurs on sorting tables, hydro-sorting was not investigated. A reverse roll sorting table having lanes for cull fruit was tested with satisfactory results, but the lanes reduced capacity by 25 percent. A sorting device in which cull fruits were forced through the table into water below was tested. Brushes were used in place of wooden rollers which permitted fruits to be forced

through but this device proved unsatisfactory unless fruit size varied less than 1/2 inch.

Four types of sizers were developed and evaluated. All were dimension-type sizers utilizing buoyant force of the fruit and most experienced wedging problems. The square link chain sizing device operated underwater performed best in all respects and had high potential capacity because it could be operated at chain speeds up to 50 feet per minute.

Two of the three box filling methods appeared promising and full-size plans of one type were drawn. The flume type box filler was unsatisfactory because of excessive bruise damage. The direct fill type had good prospects, but experienced several problems which were not present in the accumulator type.

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INTRODUCTION

Apple production, storage, handling and marketing is a dynamic industry which has experienced many rapid changes in the past fifteen years.

Bulk handling in 20-bushel pallet boxes (approximately 47 x 47 x 28 inches high), increased storage capacity which has brought a lengthening of the storage and market season, and centralization of storage, packing and marketing operations are a few of the recent developments.

Controlled atmosphere storage (hereafter referred to as CA storage) has been very rapidly accepted. A 164 percent increase in CA storage capacity has occurred over the past four years in the United States. CA storage accounted for 31 percent of Michigan's 5,623,000 bushels of stored apples and 13 percent of the total crop of 13,500,000 bushels in 1962.

Traditionally, Michigan apples have been stored field-run without sorting or sizing until removed from storage for sale. If presorting and presizing were performed, however, the storage space would be used only for marketable fruit. Culls, undersized and poorly colored fruit would not need to occupy valuable (50 to 70 cents/bu) storage space. Several storage-packing plant managers have indicated that cull and utility fruit accounts for 15 to 50 percent of the field-run fruit volume stored. Dewey (1958) found that field-run apples in Michigan CA storages in 1957 averaged 60.2 percent sound fruit for all lots and only 55.5 percent sound fruit for the McIntosh variety. The cost for storing fruit containing 45 percent cull and utility grade apples was 70 percent higher than for fruit containing only 5 percent culls and utilities, which could be the case if presorting were practiced.

With the fruit presized, presorted, and refilled into pallet boxes before storage, the operators of apple storages and packing houses would have a more accurate inventory of their current stocks of apples. Separations by grade, size, and variety would provide operators and salesmen the information needed to conduct good merchandising programs. Sales orders could be more readily filled as they are received. Advertising programs could be arranged to promote sizes and qualities in keeping with supply and demand.

If presorting is to be practical, however, the bruise damage incurred during the box dumping, sorting, sizing and box filling operations must be minimized or it would more than offset the gain obtained by eliminating the cull fruit from storage. In order to minimize bruising, water is proposed as a handling medium. Hydro-dumpers employing the water submergence principle (Pflug and Dewey, 1960) have been successful for fruit dumping with minimum bruising and possibly a complete hydro-handling system would substantially reduce the bruise damage normal in conventional "dry" systems.

A presorting and presizing system must have high capacity and be relatively trouble-free to handle the large volume of fruit stored daily by centralized storage houses. Volume ranges up to 8,000 bushels per day for some Michigan operations. The overall system must be highly mechanized, since it may be operated 24 hours per day at the time when labor is at a premium, during the harvest season. Although economics were not considered in this preliminary study, costs must be minimized because they may well be the determining factor in the general adoption of a hydro-presorting and presizing system.

The objectives of this study were: (1) to investigate the properties and characteristics of apple fruits related to hydro-handling and (2) to design, construct and evaluate the various components for a complete apple presorting and presizing system, using water as the handling medium.

LITERATURE REVIEW

Hydro-handling for apple fruits has not been extensively studied. A model hydro-box dumper, sorter, sizer and one-bushel box filler was built and 8 mm films were produced by W. M. Martin (1962) in the early 1950's. He received a patent on a helical type sizing device in 1962. Since little work on hydro-handling has been done, related areas such as fruit injury and present handling methods were studied in this review of literature.

Mechanical Injury

Mechanical injury to apple fruits is primarily bruising, stem punctures, scarring, and skin breaks.

Fruit bruising caused by vertical drops on flat surfaces, sharp corners, and 1/8-inch diameter wire was studied by Gaston and Levin (1951). Data for drops up to 24 inches showed that fruit damage, based on length of bruise, compared as follows: flat board--1.0, 90-degree corner--2.5 to 3.0, 1/8-inch diameter wire--2.2 to 2.7. They also found that a three-inch diameter McIntosh fruit received bruises three times as large as 2 1/4-inch diameter fruit in the same two-inch drop. This observation is supported by the energy-bruise relationship developed by Mohsenin and Goehlich (1961), since a large fruit would have more potential energy at a given height than a small fruit.

Mohsenin and Goehlich (1962) described new techniques and instruments developed for studying the mechanical properties of fresh fruits and vegetables. Apples used in their tests were subjected to mechanical treatments such as compression under static load, compression under increasing load, impact loading and puncturing forces.

Determination of the stress, deformation, and energy required to initiate flesh discoloration and damage immediately below the skin was the primary objective of the work. They developed relationships between bruises and the energy causing those bruises and presented a formula relating energy and bruise size.

$$E_b = W_v \times V_b \quad (1)$$

where:

E_b = energy of bruising, in-lb

W_v = work per unit displaced volume, in-lb/in³

V_b = displaced volume caused by the bruise, in³

The energy of impact required to cause bruising was found to be 1.5 to 2.7 times the energy of compression which is found from Equation 1.

It was found that the energy required to cause visible injury to the fruit was three to five times the energy required to cause bruising as defined by Mohsenin, that is, the minimum energy required to initiate flesh discoloration and damage immediately below the skin.

Dewey (1958) studied the origin and quantity of defects of apples from CA storages and found that most damage occurs in the harvesting and handling operations and very little damage occurs in storage. An average for all lots showed 19.5 percent of the fruits were injured during harvesting and handling and only 4.8 percent during storage.

Factors Affecting Mechanical Injury

There are many factors that affect the injury which fruit will incur from the time it leaves the tree until it reaches the consumer.

Varieties of apples vary considerably in their susceptibility to bruising due to handling operations. Tests by Mohsenin and Goehlich (1962) revealed that Golden Delicious fruits require 1.05 inch-pound

of energy for impact bruising and McIntosh fruits require only 0.126 inch-pound, differing by a factor of 8.3. According to their data maturity, although important, had a less pronounced effect on fruit bruising than variety. The critical bruising energy (minimum energy required to initiate bruising) declined rapidly with maturity from pre-harvest to about fifteen days after harvest, when it begins to increase slowly. This general trend applied to most varieties, although the point of minimum critical energy varied by two or three days and the rate of increase varied considerably for different varieties.

Handling and hauling methods have great effect on fruit condition when it reaches the consumer. Gaston and Levin (1951) compared "careful" and "careless" handling in picking, dumping into field crates, orchard handling, dumping onto receiving belt, grading, and filling market containers. They reported the cumulative effect of careful handling to be 35 square inches of bruised area per 100 apples compared to 210 square inches per 100 apples for careless handling.

The forces which cause apple fruit damage are primarily impact forces, but static forces should also be considered, especially in the design of market containers and bulk pallet boxes. Gaston and Levin (1951) reported the critical pressures required to cause bruising between flat plates. The static loads which caused a 3/8-inch diameter bruise on a 2 1/2-inch apple were 7.5 pounds for Wealthy, 8.5 pounds for McIntosh, and ranged up to 18 pounds for Jonathan.

Time of static loading has considerable effect on the forces required to cause injury and since static loading will generally be imposed on stored fruit for long periods, these effects should be considered. Mohsenin and Goehlich (1962) investigated critical static load conditions and found that the approximate static load required to bruise the apple fruit was 0.75 to 0.85 times the force required to bruise the fruit in compression tests. The static load tests indicated that a 5-pound load,

which is 75 percent of the bruising force by the compression machine, bruised the McIntosh fruit over the 100-hour test period. These results can be applied to practical problems such as the safe depth of apples in storage or in a bulk bin. For example, if a 47 x 47 x 28-inch bulk bin is loaded with 35 cubic feet of apples at 35 pounds per cubic foot and there are, on the average, 20 apples per square foot area of the bin, it can be shown that each apple of 2.7 inch diameter on the bottom layer carries a maximum static load of 4.10 pounds.

Equipment Presently Available

Bulk Box Dumper

The several experimental bulk box unloaders utilizing water flotation have been quite successful in Michigan. Pflug and Dewey (1960) reported that during the 1960 season several million bushels of apples were unloaded from bulk boxes by the six commercial units in Michigan and the several units in Washington. In all cases the dumper caused little or no bruising or stem punctures.

Hydro-dumpers, which are now commercially manufactured by several companies, have received excellent acceptance by apple packers.

Fruit Sorting

Roller conveyors are the most commonly used sorting devices. They are usually placed in the line ahead of the sizing area and present the fruit to workers who remove cull and utility fruit.

Hunter (1958) made a study of roller sorters and found that dividing the sorting table or conveyor into lanes improved sorting efficiency and that 3 1/2 inches was the best lane width. Uniform rotation of the fruit on light colored rolls also improved sorting efficiency. A "reverse roll" conveyor, one whose rolls turn backwards

causing the fruit to roll forward (in direction of translation), was superior to other types. Rotational rates of 1.0 to 1.5 revolutions per foot of translation at 35 to 25 feet per minute (fpm) translational speed, respectively, were found best.

Fruit Sizing

Although belt type sizing chains are still extensively used, most modern commercial sizers carry the fruit without transfer directly to the proper size compartment. Commercial weight and dimension sizers use this carrying principle to reduce fruit handling and bruising. Fruits are introduced into individual cups from the sorting area by a singulator, and remain in the cup until weight or the opening in each cup bottom has become large enough to permit passage.

Bulk Box Fillers

One commercial machine which is being used primarily on the West Coast elevates the fruit by means of a canvas flight conveyor over the side and down into the rotating bulk box. The elevator automatically raises as the box fills to minimize fruit drop. This machine has not proven acceptable for the delicate McIntosh variety.

Another experimental bulk box filler (Herrick, 1962) consists of a series of rotating padded disks and cones which are lowered into the bulk box and gradually raised as the box fills. This device had a capacity of only 12 bulk boxes per hour and averaged 21.5 bruises per 100 Delicious apples. Since Delicious require over twice as much energy for bruising as McIntosh (Mohsenin and Goehlich, 1962), it would appear that bruise damage on McIntosh would be excessive.

The research work reviewed here was useful in designing a hydro-presorting and presizing system, but it did not adequately cover the subject of hydro-handling apple fruits. Therefore a large portion of this study was devoted to apple fruit characteristics related to hydro-handling.

APPLE FRUIT CHARACTERISTICS RELATED TO HYDRO-HANDLING

Six properties and characteristics of apple fruits that may affect their behavior and response to hydro-handling procedures were investigated. They were: (1) floating orientation, (2) submerging methods and underwater pyramiding, (3) water penetration into submerged fruits, (4) specific gravity, (5) buoyant velocity and expected bruise damage, and (6) coefficient of friction and rolling resistance of apple fruits.

Floating Orientation

The performance of several hydro-handling components in this study depended partially on fruit orientation while floating on the water surface and while submerged. Floating orientation was studied using McIntosh, Delicious, and Jonathan fruits under three conditions: (1) still water, (2) moving water, and (3) still water with fruits mechanically translated.

Apparatus

A 3 x 12 x 2-foot deep laboratory test tank was used for all floating orientation tests. A 20 horsepower, 880 gallon per minute (gpm) pump circulated water in the tank. Three two-inch pipes at the water level provided flow up to 150 feet per minute for the surface velocity tests. A metal screen device held in the hand was used for pushing fruits in the mechanically translated tests.

One-bushel fruit samples were used for the still water tests and randomly selected individual fruits were used for the surface velocity and mechanically translated test conditions.

Procedure

Still water orientation tests were conducted by submerging a one-bushel box of fruits in the test tank. This box dumping method was used because it closely simulated the hydro-dumpers presently used for bulk boxes. The floating orientation was then observed and recorded. This procedure was repeated five times for each of the three varieties.

Floating orientation tests with surface velocity or mechanical translation were performed using individual fruits so that each could be carefully observed.

Results and Discussion

Floating orientations of Delicious, Jonathan and McIntosh fruits are summarized in Table 1. There was considerable difference in the floating orientation of each variety. Delicious fruits, due to their longer dimension parallel to the core, quite frequently floated on their side although stem up was the most common orientation. Jonathan fruits floated stem up over 95 percent of the time and very infrequently (0.7 percent) floated with calyx up. McIntosh, due to their rather small dimension parallel to the core floated with either the stem or calyx up 98 percent of the time. They floated with stem up about twice as frequently as with calyx up.

Table 1. Floating orientation of apple fruits in still water.

	Number of observations	<u>Stem up</u>	<u>Calyx up</u> Percent	<u>Side up</u>
Jonathan	875	95.6	0.7	3.7
McIntosh	965	64.1	34.1	1.8
Delicious	924	70.9	2.5	26.6

McIntosh fruits generally floated in the position in which they were placed in water, either stem or calyx up. A secondary experiment was performed which indicated that the floating position of McIntosh fruit was not purely chance, as might be inferred from the fact that they generally floated in the position they are placed. An average of 34 percent of the total sample of 193 fruits floated with calyx up after submersion dumping. Those fruits floating calyx up were then separated and submersion dumped again. In this dumping test an average of 67 percent floated calyx up, indicating that individual fruit shape factors do have considerable effect on floating orientation. The fact that only 67 percent rather than 100 percent of the second sample floated calyx up indicated, however, that chance also has some effect on the floating position of McIntosh fruits.

Floating orientation was apparently unaffected by movement of the water because fruits of all varieties oriented themselves the same in moving water as they did in still water.

Orientation when fruits were mechanically moved through still water was not different from still water results. It was noted, however, that fruits always moved down in the water, sometimes submerging themselves as much as one inch, while they were being accelerated by the mechanical pushing device. This fact partially explains why fruits rolled over only one flight of the submerging conveyor (Figure 1) near the intake end while they were being accelerated.

Submerging Methods and Underwater Pyramiding

The operation of hydro-sizers and bulk box fillers may require submerging the fruits to depths as great as three feet. Two of the box fillers in this study utilized fruit buoyancy to fill the box while it was inverted under water and underwater pyramiding, or angle of repose

of the fruit was of direct concern. Hydro-handling equipment of the future may require submerging and underwater movement of the fruits. Therefore, the submerging characteristics, submerging methods, and under water pyramiding of apple fruits were investigated.

Apparatus

A laboratory test tank with plexiglass windows on the side and bottom was used for observing the operation of the various devices described below.

A flighted rubber belt submerging conveyor, shown in Figure 1, was constructed and mounted in the tank so that the angle of incline could be adjusted. The conveyor was five feet long and 18 inches wide with two-inch flights spaced ten inches apart. It was powered by a hydraulic motor so that speed was adjustable from 0 to 100 fpm.

Three-inch and 3 3/4-inch inside diameter plexiglass tubes were tested for use as submersion devices. An adjustable plexiglass tube of rectangular cross section was also tested as a submerging device. Its dimensions could be varied from 3 x 10 to 8 x 10 inches.

A shallow wooden box was inverted under water for the pyramiding study. Fruits were introduced through a 3 1/2-inch diameter tube and allowed to float upward 18 inches to the inverted box (Figure 2).

Procedure

All tests were conducted with three varieties: Delicious, Jonathan and McIntosh.

The submerging conveyor was mounted at a 30-degree angle from horizontal in the laboratory test tank. Its speed was varied from 40 to 100 fpm.

The circular and rectangular plexiglass tubes were used under both suction velocity conditions and under positive velocity conditions.

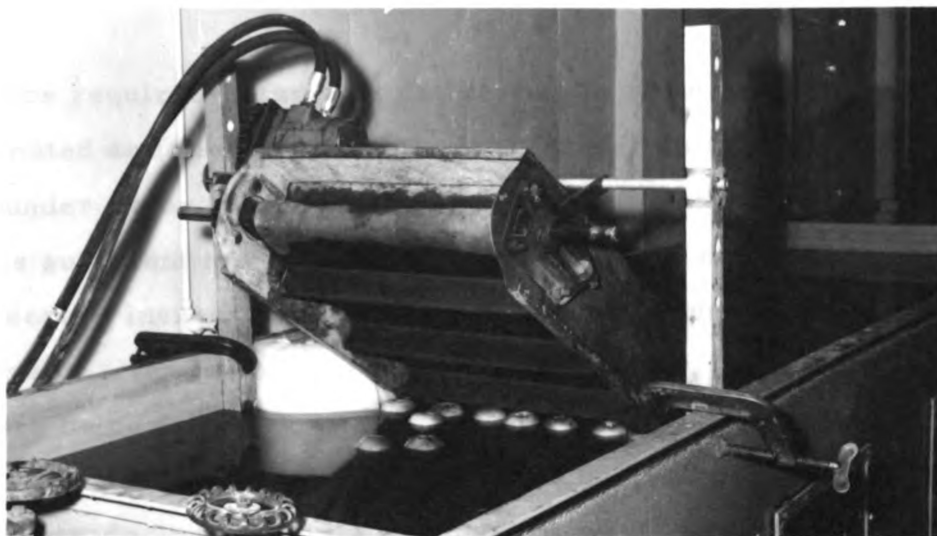


Fig 1. Rubber belt submerging conveyor in laboratory test tank (631455-5).*

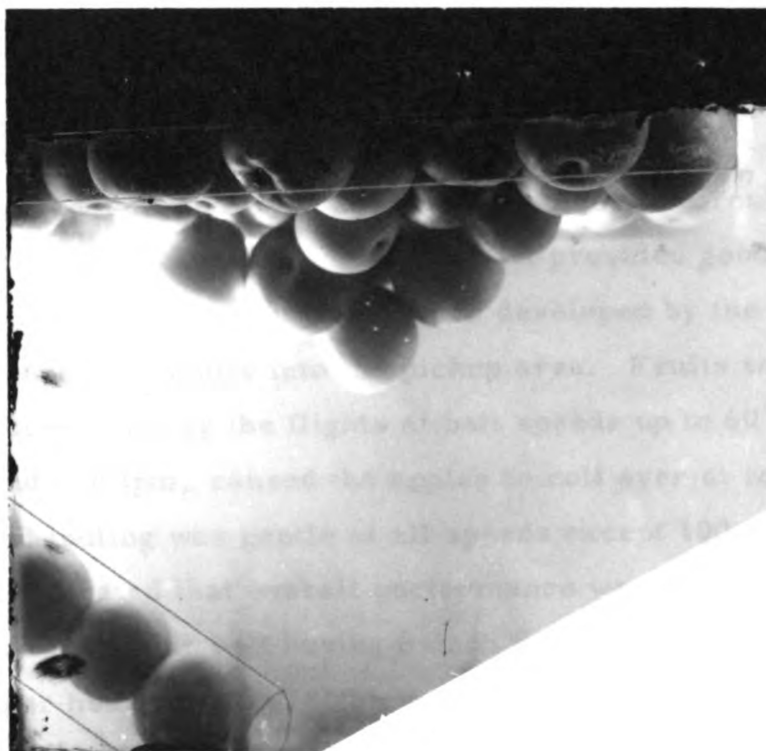


Fig 2. Underwater pyramid and introduction tube seen through tank side window (631455-4).

* Negative number on file at MSU Photographic Laboratory.

Force required to move fruits vertically down submerged tubes was estimated as follows. The tube was filled with fruits in a vertical position under water and then slowly raised until the weight of fruits in air was sufficient to cause all the fruits to move downward in the tube. This procedure insured that the friction force between the tube walls and the fruits acted in a direction to oppose motion, as it would if the fruits were being forced down the tube in a submerging system.

The pyramiding tests were conducted by holding the inverted box fixed and introducing the fruits through a tube. Use of the tube insured that each fruit was introduced in exactly the same spot, which was the desired condition in this study. The shape of the pyramid was observed through the side window of the tank. When fruits began to roll up the incline and over the box edge, introduction was stopped and the angle of repose^{*} was recorded.

Results and Discussion

The flighted-belt conveyor appeared superior to circular or rectangular tubes as a submerging device. It provided good pickup of floating fruit because water currents were developed by the flights which pulled incoming fruits into the pickup area. Fruits were carried downward successfully by the flights at belt speeds up to 60 fpm, higher speeds, 80 and 100 fpm, caused the apples to roll over at least one flight. Fruit handling was gentle at all speeds except 100 fpm, but observations indicated that overall performance was best at 60 fpm. At 60 fpm a 36 inch wide belt having 6-inch flight spacing would have 500 bushels per hour capacity. The maximum angle of incline for two-inch perpendicular flights was 30 degrees, but flight shape and size could be designed for operation at greater angles.

^{*} Angle of maximum slope at which a heap of any loose solid material will stand without sliding.

Tests showed that tube submerging devices must fit the apple quite closely. Effects of loose fit were especially noticeable in the suction-generated velocity tests. When using apples 2 1/2 to 2 3/4 inches in diameter the three-inch tube performed considerably better than the 3 3/4-inch tube. The 6 x 10-inch rectangular tube was completely unsatisfactory in the suction tests because of the large quantities of water necessary to generate the critical velocity in such a large tube. Critical velocity is hereby defined as that velocity which develops a frictional drag force on the fruit equal to the net buoyant force. Results from the buoyant velocity section indicate that 1.7 feet per second (fps) is a good estimate of critical velocity for most apple fruits. Over 300 gpm flow rate would be required to generate this velocity in a 6 x 10-inch tube.

The force required to submerge apples vertically through a tube, as might be done in a bulk box filler, was found to be approximately 70 percent of the total fruit weight. Buoyant force accounted for 20 percent and wall friction for the remaining 50 percent of total fruit weight. Wall friction was less for larger fruit in the same size tube. Small fruits tended to wedge sideways whereas larger fruits rested on each other and therefore wedged less severely.

Angles of repose were measured for each of three varieties in the pyramiding study. The averages of three replications are listed in Table 2.

Table 2. Average angles of repose for submerged apple fruits.

Variety	Angle of repose, degrees
Delicious	36
Jonathan	30
McIntosh	33

The differences in angles of repose were due to fruit size rather than to variety with the larger fruit developing larger angles of repose. Delicious fruits used in the test averaged three inches, Jonathan fruits 2 1/2 inches, and McIntosh fruits 2 3/4 inches in diameter.

It was noted that when the outer fruits of the pyramid were free to move horizontally, the pyramid collapsed when the angle of repose was between 25 and 28 degrees.

The magnitude of these angles indicated that inverted bulk boxes cannot be evenly filled by introduction of the fruit at one side. A distributing device might be necessary even if the bulk box were filled from its center.

Water Penetration into Submerged Fruits

There was concern that appreciable amounts of water might be forced into the core when apples were submerged, as might occur in hydro-sizing and box filling devices. Samples of Delicious and McIntosh fruits were subjected to various pressures for three time intervals to investigate this condition.

Apparatus

A retort was used which allowed complete submergence of the fruits and provided constant pressures up to 30 pounds per square inch (psi). The direct reading scale employed provided readings to 0.01 gram and were accurate to the nearest 0.1 gram.

Procedure

Five samples of ten average size fruits of each variety were selected and each fruit numbered. A different sample was used for each pressure (3, 5, 10, 20 and 30 psi). Fruits were initially weighed

after wetting and drying with a cloth to provide the same surface moisture condition as would prevail after a test. The sample of ten fruits was then placed in the retort and held submerged. The specified pressure was applied for a total of 15 minutes, and individual weights were recorded at one, five, and fifteen minute intervals.

The water temperature was held equal to fruit temperature to avoid internal pressures caused by a sudden temperature change of the fruit.

Results and Discussion

Figure 3 shows the average water penetration per fruit at various hydrostatic pressures. Pressure, time, and maturity were contributing factors to the amount of water forced into the fruit.

McIntosh fruits took up very little water, perhaps because of a closed calyx tube. Delicious fruits, which frequently have an open calyx, gained appreciable amounts of water.

Cuts were made of the Delicious fruits after the tests to locate the water. There was no general pattern of flesh tissue saturation area in the fruits. Saturated areas often radiated outward from the core, but areas near the skin were often saturated with no apparent water path from the core. Removal of the fruit skin before applying pressure greatly increased the area of saturation. Cell structure was apparently disrupted in the saturated areas as evidenced by a soft flesh texture similar to severely bruised flesh.

Fruits from the crop of the previous year tested in July absorbed nearly twice as much water as those tested earlier in February which suggested that degree of ripening affected water penetration.

It is believed that the low hydrostatic pressures resulting from submerging 0 to 6 feet for hydro-handling should present no problems of water penetration even for the Delicious variety.

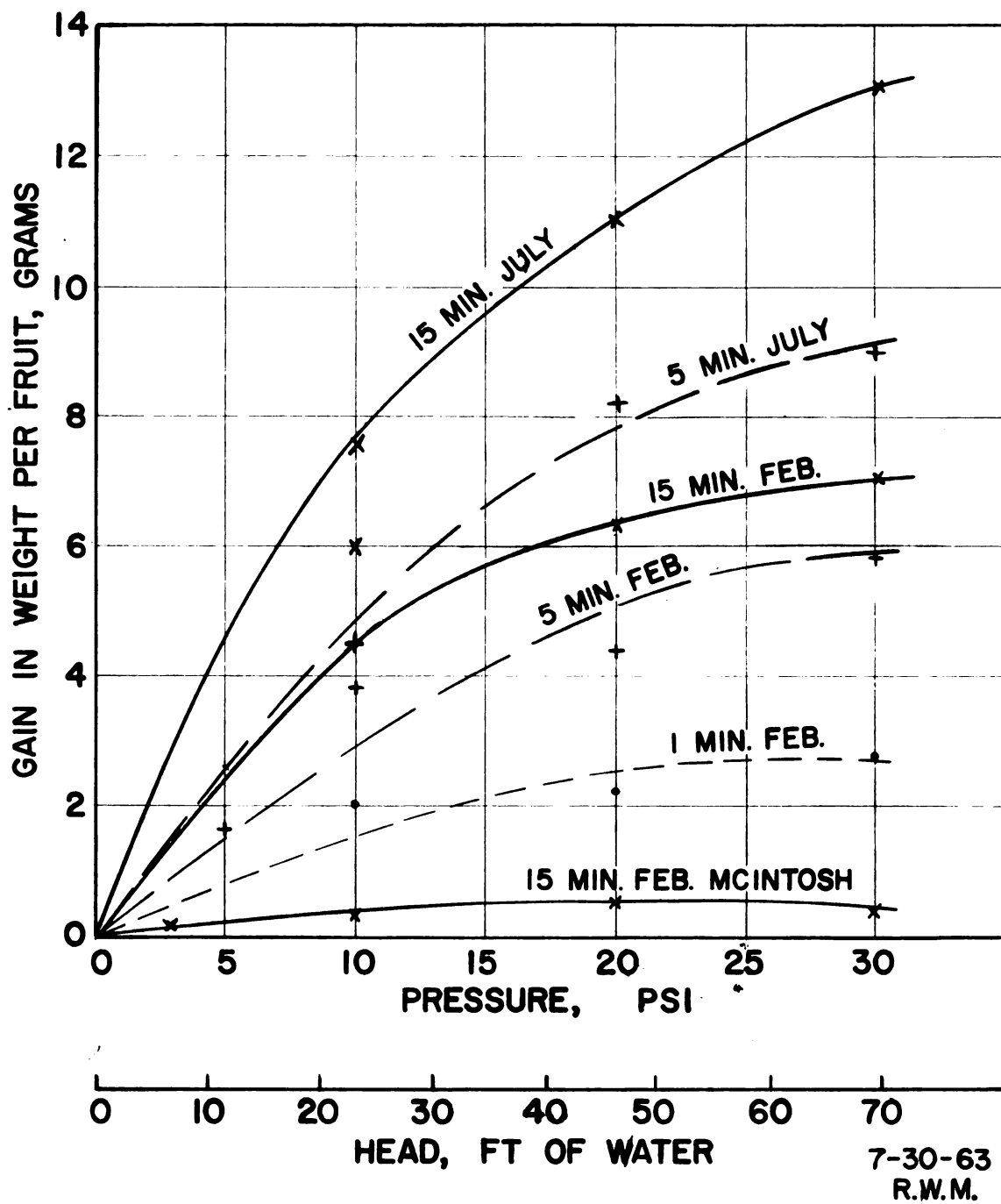


Fig 3 Relation between water penetration into apple fruits and hydrostatic pressure.

Specific Gravity

The specific gravity of fruit is the controlling factor for buoyant force, and therefore affects many movements of the fruit when handling in water. Limited values for specific gravity of the various apple varieties are presently available.

Procedure

Weight, dimension and volume for McIntosh fruits both before storage and after one year of CA storage were obtained from Blaisdell (1963). Samples of 60 and 84 fruits, respectively, were recorded using water displacement to measure volume. These data are presented in Figures 4 and 5.

Cooper (1962) determined specific gravity values for several apple varieties at varying stages of maturity. The results of his experiment for fruits at harvest time are presented in Table 3. Westwood (1962) also studied seasonal changes in specific gravity of apple fruits. His data for 150 days after full bloom are presented in Table 3.

Table 3. Specific gravity of apple fruits at harvest time.

Variety	Specific gravity	
	Cooper	Westwood
Delicious	0.832	0.85
Golden Delicious	0.806	0.81
Jonathan	.	0.78
Melba	0.790	
McIntosh	0.805	
Rome Beauty	0.821	0.83
Stayman	0.861	
Winesap		0.87

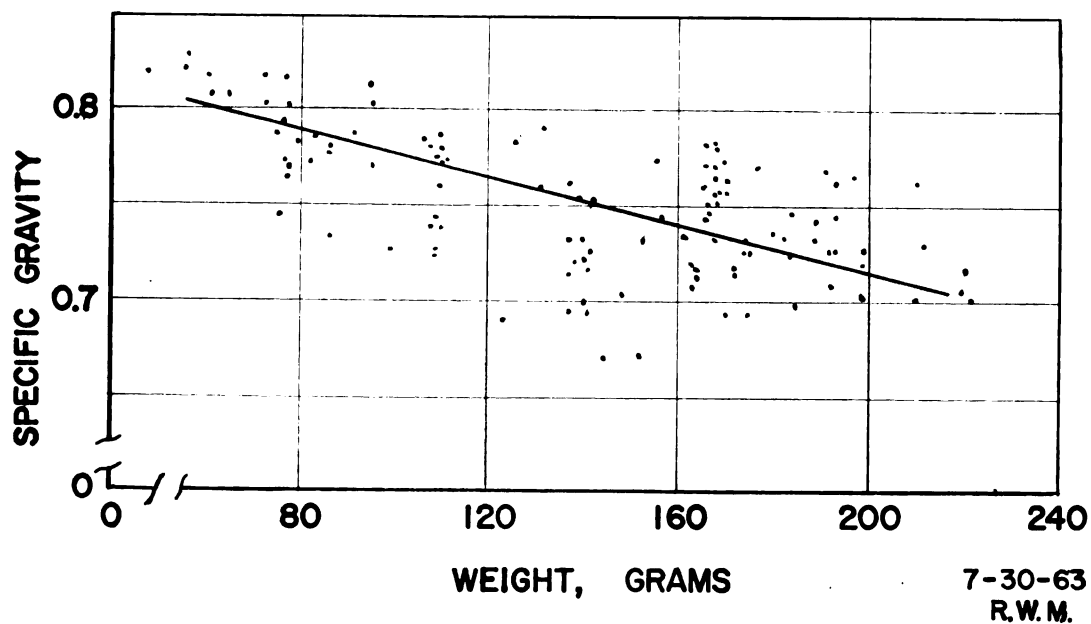


Fig 4 Relation between specific gravity and weight for McIntosh fruits after one year CA storage. (data from Blaisdell, 1963)

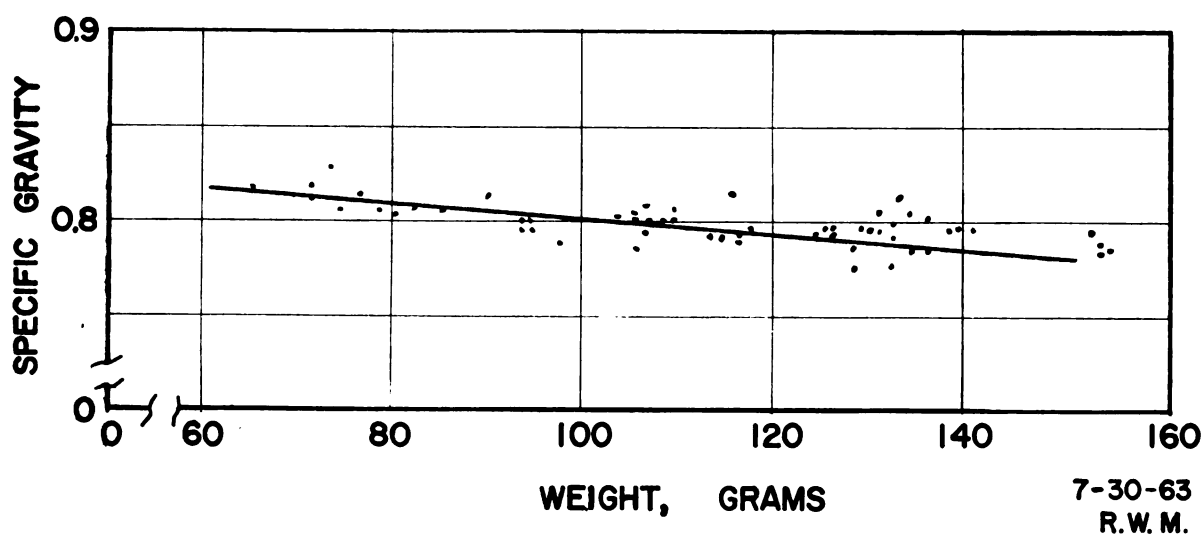


Fig 5 Relation between specific gravity and weight for McIntosh fruits at harvest time. (data from Blaisdell, 1953)

Discussion

Specific gravity values vary slightly with season and locale just as other fruit characteristics like size, color, and flesh firmness. Therefore, a range of expected specific gravity values should be established from a large sample taken over a period of several years. Values given by Cooper (Table 3) were established from relatively small samples taken during the 1961 season. Their accuracy appears acceptable, however, because the mean specific gravity obtained from Blaisdell's data for McIntosh fruit at harvest was 0.806 compared to Cooper's value of 0.805. Since Cooper's data were collected in Pennsylvania and Westwood's in Oregon in 1961 and Blaisdell's were collected in Michigan in 1962, it would appear that season and locale may have only a small effect on specific gravity of apple fruits.

Figures 4 and 5 indicate that specific gravity for McIntosh fruit decreases slightly with increasing fruit size, and that this trend is much more pronounced after storage. The small variation at harvest time indicates that one value of specific gravity could be used for fruits of any size for most hydro-handling needs. Cooper's values presented in Table 3 were used in this study.

Buoyant Velocity and Expected Bruise Damage

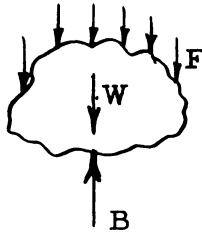
A major reason for proposing an apple sorting and grading system in water is to reduce bruising. One factor affecting bruise damage is the velocity attained by fruits as they rise toward a water surface. Buoyant velocity values were obtained to estimate the impact of an apple fruit upon contact with an object located in the water or just above the water surface. Comparisons were made to drops of varying distances in air for amount and type of bruising.

Theoretical Analysis

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 (vertical in this case) 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 rising vertically in water,



the forces are

$$m \frac{dV}{dt} = B - W - F \quad (2)$$

where:

m = mass of particle

V = relative velocity ($V_w + V_p$), fps

t = time, sec

W = particle weight, lb

B = buoyant force, lb

F = frictional drag force, lb

By definition, the drag force is

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

where:

γ = fluid specific weight, lb/ft³

C = particle aerodynamic drag coefficient, dimensionless

A = projected area of particle, ft²

g = acceleration due to gravity, 32.2 ft/sec²

therefore Equation 2 becomes

$$m \frac{dV}{dt} = v_p (\gamma - \gamma_p) - \frac{C V^2 \gamma A}{2g}$$

or

$$\frac{dV}{dt} = g \left(\frac{\gamma - \gamma_p}{\gamma_p} \right) - \frac{C V^2 \gamma A}{2W} \quad (4)$$

where:

V_p = velocity of the particle, fps

V_w = velocity of the water, fps

γ_p = particle specific weight, lb/ft³

v_p = volume of particle, ft³

Equation 4 must be solved by a method of approximations since it cannot be solved explicitly. For steady state conditions, however, dV/dt equals zero and Equation 4 can be solved for terminal velocity* giving

$$V = \sqrt{\frac{2g W}{C A} \frac{\gamma - \gamma_p}{\gamma_p}} \quad (5)$$

A direct solution of Equation 5 for velocity, V , is impossible unless values of drag coefficient can be determined. To utilize existing data for drag coefficients, the assumption was made that the apple fruits were spheres. Dalla Valle (1948) presented a graph of drag coefficient versus Reynolds number (Re). Reynolds number is dimensionless and is equal to $\frac{V d \gamma}{\mu}$, where d is the diameter of the sphere and μ is the viscosity of the fluid.

* The velocity attained by a body in free fall when drag force and net weight (weight minus buoyant force) are in equilibrium.

For a particle having vertical motion in a gravitational field, Dalla Valle presented the following three equations which cover the range of the curve mentioned above.

- a) Streamline motion $10^{-4} < Re < 2$, $C = 24/Re$
- b) Intermediate motion $2 < Re < 500$, $C = 0.4 + 40/Re$
- c) Turbulent motion $500 < Re < 10^5$, $C = 0.44$

To establish which value of drag coefficient to apply to apple fruits, an average buoyant velocity was taken from experimental data and a Reynolds number computed. Reynolds numbers ranged from 20,200 to 41,500 for two-inch and three-inch McIntosh fruits, respectively, at a water temperature of 70 degrees. Therefore, a drag coefficient of 0.44 was used for all apple fruits, and Equation 5 was solved directly for terminal velocity. Substituting for the known quantities, Equation 5 reduces to

$$V = 18.4 \sqrt{\frac{W}{A} \left(\frac{1-s}{s} \right)} \quad (6)$$

where:

V = particle theoretical velocity, fps

s = specific weight of the fruit, dimensionless

W = fruit weight, lb

A = projected area, in²

Equation 6 was used to compute the theoretical fruit velocities listed in Table 4.

Apparatus

The apparatus for the buoyant velocity experiment (Figure 6) consisted of a 15-inch diameter, 12-inch high glass container filled with water to a depth of 0.70 feet. A device was constructed for holding the apple fruit at the bottom of the container and releasing it at the proper time. As the fruit rose to the surface it was photographed on a 16 mm

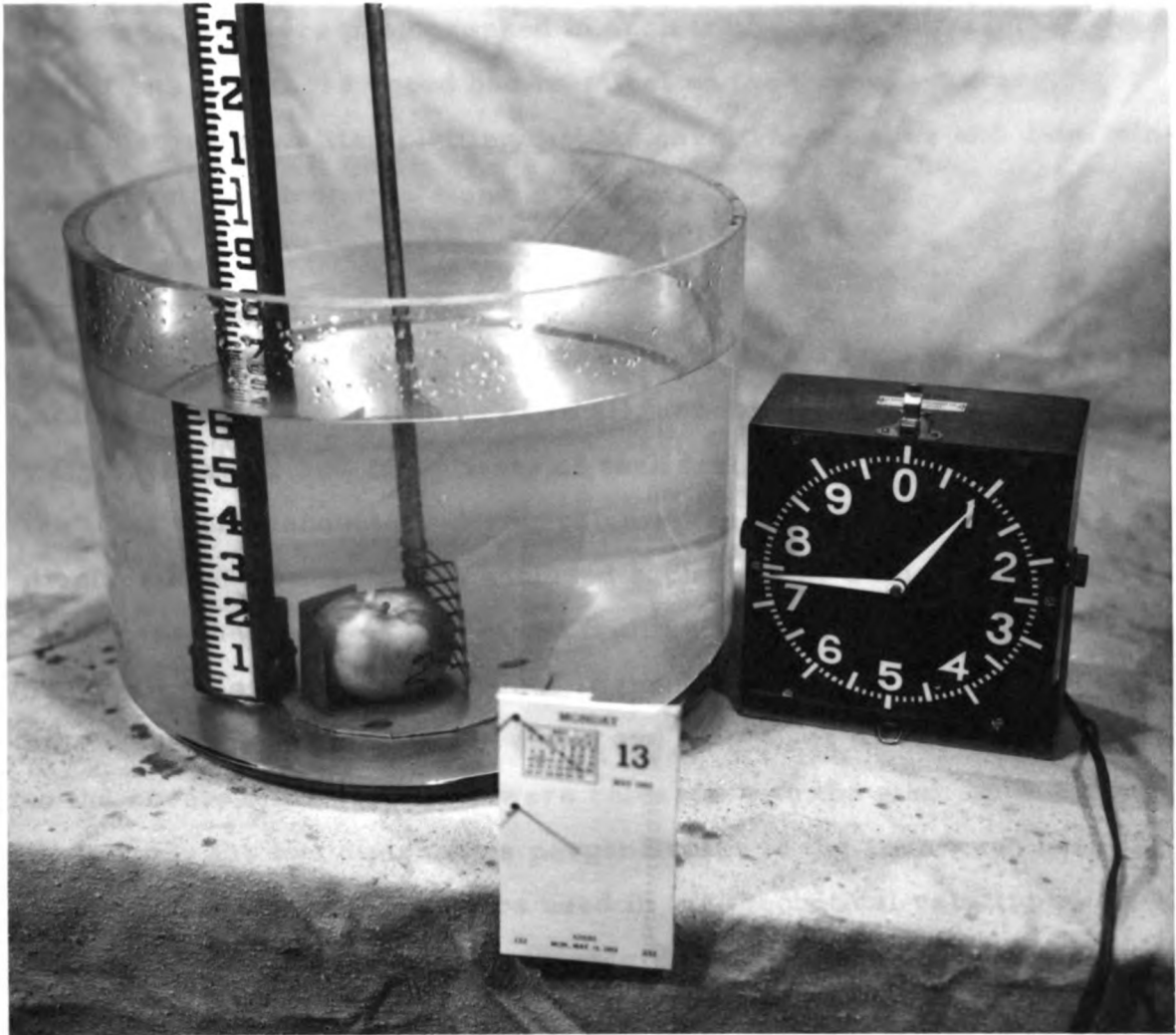


Fig 6 . Buoyant velocity test apparatus ready for run number 13 (63792-2).

movie film at 64 frames per second. A surveying rod calibrated in hundredths of feet and a timing clock which made one revolution every three seconds were photographed in each frame of the film. Thus variations in camera speed had no effect on the timing accuracy. This method permitted plotting displacement versus time and determining the velocity from the slope of the curve.

Procedure

Duplicate tests were made of each of the six fruit used--three McIntosh and three Delicious of small, medium and large size. The weight, volume, and dimensions of each fruit were measured before the tests were conducted. Fruit volume was measured with an oil displacement device^{*} which enclosed each fruit by a thin rubber film that conformed to the shape of the fruit under a pressure of five psi. The fruit diameter was measured in three directions, largest and smallest perpendicular to the core, and height, or dimension parallel to the core. Since the fruits were released with the stem up in all tests, only the two dimensions perpendicular to the core were used in computing cross sectional area used in the theoretical velocity calculations. Water temperature was recorded throughout the tests because water viscosity is a function of temperature.

After tests with fruits in their natural condition, additional trials were conducted with one fruit of each variety whose specific gravity had been increased in steps, first by injecting water into the core, then by adding steel or lead weights. The volume and shape remained unchanged, which permitted a comparison of experimental terminal velocity with theoretical terminal velocity over a wide range of specific gravity values for a given fruit.

^{*} Patent pending by Joseph Molitorisz, Agricultural Engineering Department, Michigan State University.

A rubber ball was used to compare experimental and theoretical velocities for a sphere. The theoretical velocity applies to a sphere in an infinitely large container and the wall effects of the 15-inch diameter container were unknown. The rubber ball test permitted evaluation of the wall effects of the container.

Dropping tests were performed using apple fruits in their natural condition and the rubber ball. Drops were made from heights of 0.2 feet, measured from water surface to the bottom of each fruit.

Results and Discussion

Results of the buoyant velocity tests are presented in Table 4 and Figures 7 and 8.

The corrected velocity in Table 4 was obtained by multiplying actual velocity by $F_1 = 1.06$, which was the wall correction factor. This factor was obtained by comparing the velocity of a sphere (rubber ball) with the theoretical velocity computed from Equation 6). The following values were obtained:

$$V_a(F_1) = V_t \quad (7)$$

$$3.30 (F_1) = 3.49$$

$$F_1 = 1.06$$

where:

V_a = actual observed velocity, fps

V_t = theoretical velocity, fps

Each corrected velocity value in Table 4 is the predicted terminal velocity for that fruit in an infinitely large tank.

There was a considerable difference between fruit corrected velocity and theoretical velocity, apparently due to the use of an inaccurate drag coefficient in the theoretical velocity formula. The drag coefficient for a perfect sphere was used in the calculations. All fruits

Table 4. Terminal buoyant velocity of apple fruits in water.

Fruit Variety and Number	Ave. Dia. Perpendicular to Core, in	Specific Gravity	$\frac{W}{A}$, $\frac{\text{lb}}{\text{in}^2}$	Actual Velocity, fps	Corrected Velocity $V_a(1.06)$, fps	Theoretical Velocity, fps	$F_2 = \frac{V_a}{V_t}$
McIntosh							
1	2 15/16	.761	.051	1.83	1.94	2.340	0.831
2	2 21/32	.754	.044	1.70	1.80	2.165	0.832
3	2 3/16	.797	.029	1.36	1.44	1.915	0.753
Delicious							
1	2 27/32	.818	.058	1.59	1.68	1.940	0.866
2	2 11/16	.795	.056	1.56	1.65	2.210	0.748
3	2 7/16	.833	.050	1.15	1.22	1.840	0.664

2

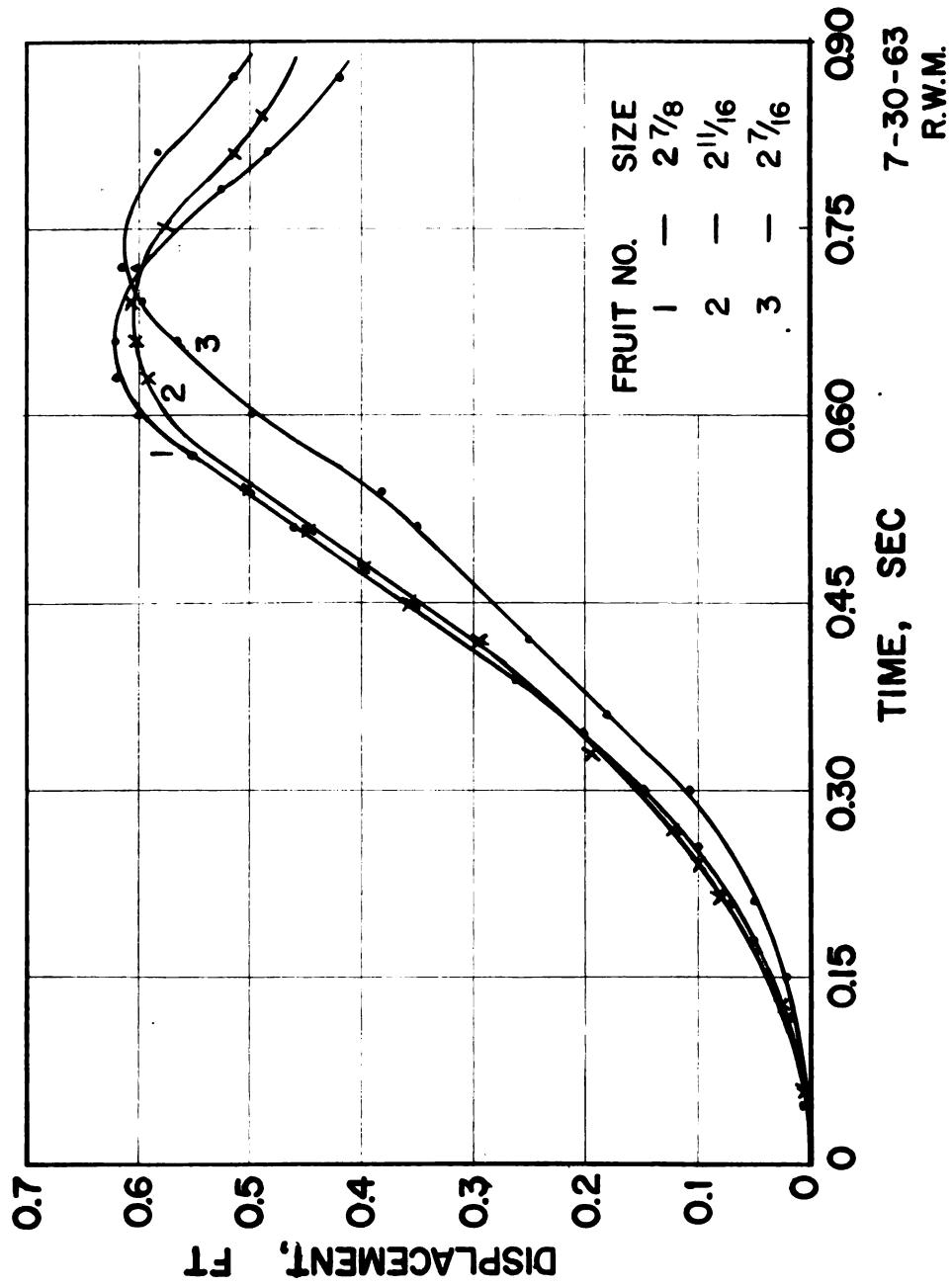


Fig 7 Buoyant velocity (indicated by slope) for three sizes of Delicious fruits.

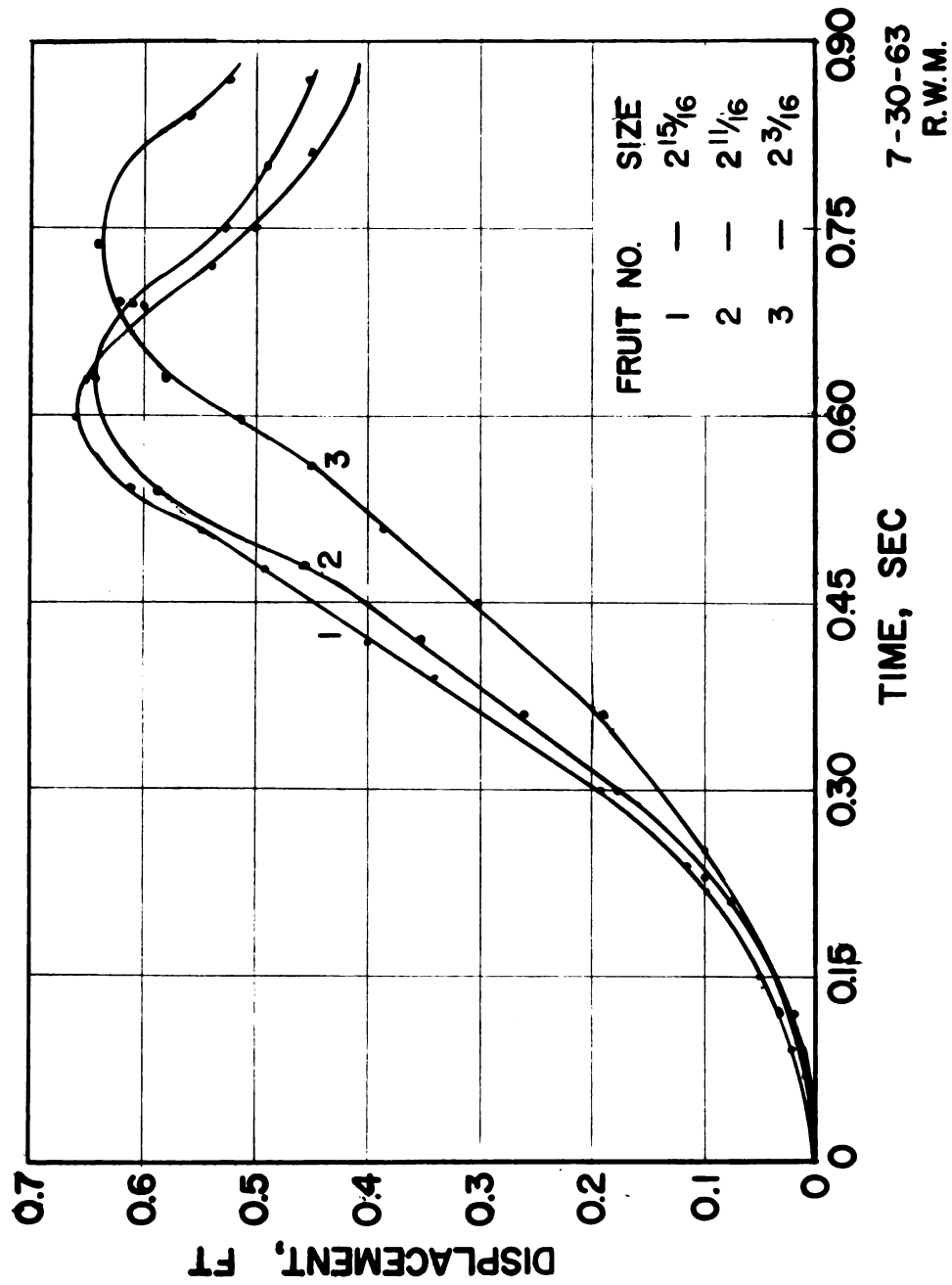


Fig 8 Buoyant velocity (indicated by slope) for three sizes of McIntosh fruits.

were released from rest with their stems up, and would therefore develop a higher drag coefficient than a sphere. The F_2 values were the correction factors necessary to cause theoretical and experimental results to agree. The drag coefficient for apples moving through fluids with stem pointing in the direction of motion can be developed from this correction factor F_2 .

$$V_t(F_2) = V_c \quad (8)$$

where:

V_t = theoretical velocity, fps

V_c = actual velocity in large tank, fps

A reasonable estimate of F_2 for all fruit varieties is 0.8 (Table 4).

Equation 5 relates velocity and drag coefficient.

$$V = \sqrt{\frac{2g W}{C A} \frac{\gamma - \gamma_p}{\gamma_p}} \quad (9)$$

which reduces to

$$V = \sqrt{\frac{K}{C}} \quad (9)$$

where:

K = constant, ft^2/sec^2

C = particle areodynamic drag coefficient, dimensionless

Comparing results for an apple with results for a sphere:

$$\frac{V_a}{V_s} = \frac{\sqrt{\frac{K}{C_a}}}{\sqrt{\frac{K}{C_s}}} = \sqrt{\frac{C_s}{C_a}} \quad (10)$$

where:

C_a = drag coefficient for apple

C_s = drag coefficient for sphere

substituting $V_s(0.8)$ for V_a , Equation 10 becomes

$$\frac{1(0.8)}{1} = \sqrt{\frac{C_s}{C_a}}$$

$$C_a = \left(\frac{1}{.64}\right) C_s = 1.56 C_s$$

Under the turbulent flow conditions in this experiment, $20,000 < Re < 41,000$, one could use $C_s = 0.44$ and find the coefficient of drag for apple fruits equal to $(1.56) (.44) = 0.68$.

This value for drag coefficient was determined from a limited number of tests and should be confirmed by additional tests using a different sized container and large samples of fruits released from several positions.

The curves for displacement versus time in Figures 7 and 8 show that apple fruits reach their terminal velocity after only two to three inches of travel. This surprisingly short distance indicates that, in predicting bruise damage resulting from fruit contact with objects under water in a hydro-handling system, terminal velocity should be assumed.

A hydro-handling system can substantially reduce fruit bruise damage because of the very low buoyant velocity as compared to velocity attained in an air drop. Table 4 shows that the highest velocity attained for a large McIntosh fruit was 1.94 fps. A one-inch drop in air would give an impact velocity of 2.3 fps. Impact in water would be lessened an undetermined amount due to the cushioning effect of fluid. The buoyant velocity of a large McIntosh fruit would appear sufficient to cause bruising upon contact with a solid object in or just above the water surface.

Mohsenin and Goehlich (1962) developed relationships between energy and bruising for apple fruits. Calculations using their results indicated that the minimum bruising energy by impact for McIntosh fruits was 0.126 in-lb which would be developed in a 0.34-inch fall of a large fruit

in air. Gaston and Levin (1951) found that a 2 1/2-inch apple showed a 1/4-inch bruise when dropped from a height of one inch on a rigid surface.

The maximum buoyant velocity of 1.94 fps would produce energy equivalent to a 0.7 inch fall in air, which would produce a slight bruise. Therefore, areas of equipment that fruit contact after floating up more than two inches should be covered with a cushioning material to prevent bruising.

The dropping tests indicated that a considerable depth of water will be needed to completely cushion falling fruits. Fruits sank to an average depth of seven inches when dropped from a height of 2 1/2 inches. As expected, the relation between height of drop and depth of sinkage was not a linear relationship. Fruits dropped from three feet above the surface sank only 18 inches. Cushioning materials should be used in combination with water if the depth of water is not adequate to completely decelerate the fruit.

Coefficient of Friction and Rolling Resistance

One very simple means of transporting apple fruits when they are submerged is to allow the buoyant force to roll them up an inclined plane. Accurate values of the rolling resistance of different varieties of fruits were needed in designing the line components and the transition areas between components, where fruits may be conveyed by rolling along submerged inclined surfaces.

Apparatus

The device shown in Figure 9 was constructed and used in the position shown for the air tests, then inverted for the underwater tests. It provided a means for gradually increasing the angle of incline for the

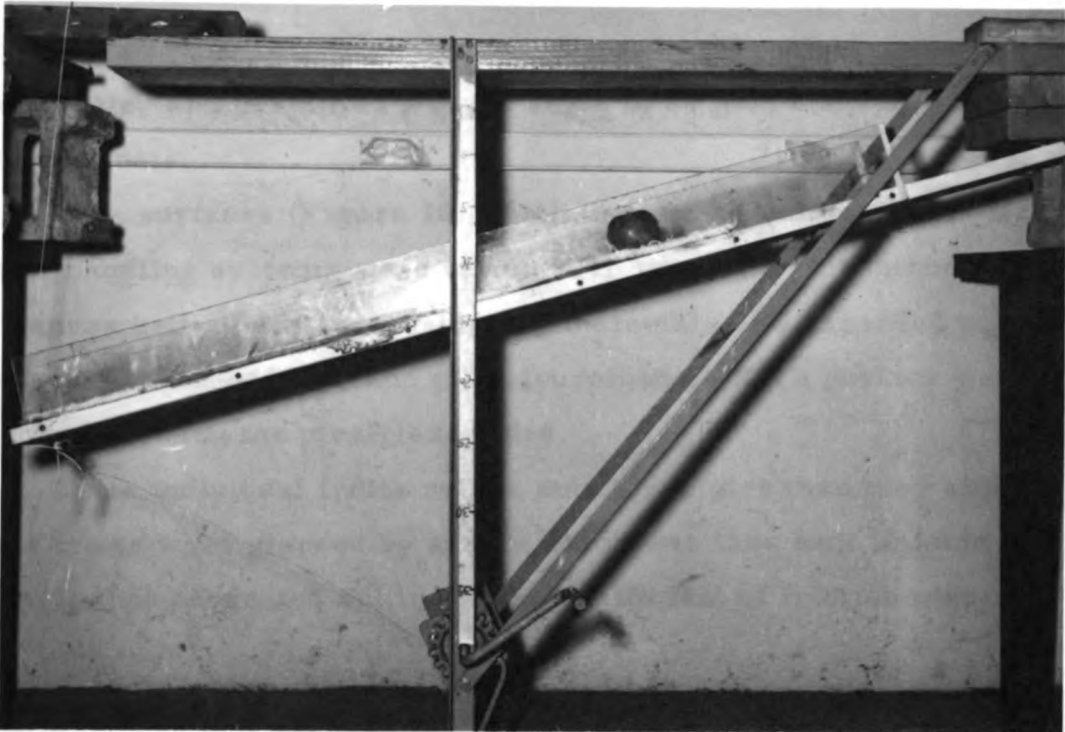


Fig 9. Device used for coefficient of friction and rolling resistance tests (inverted for underwater tests) (631455-2).

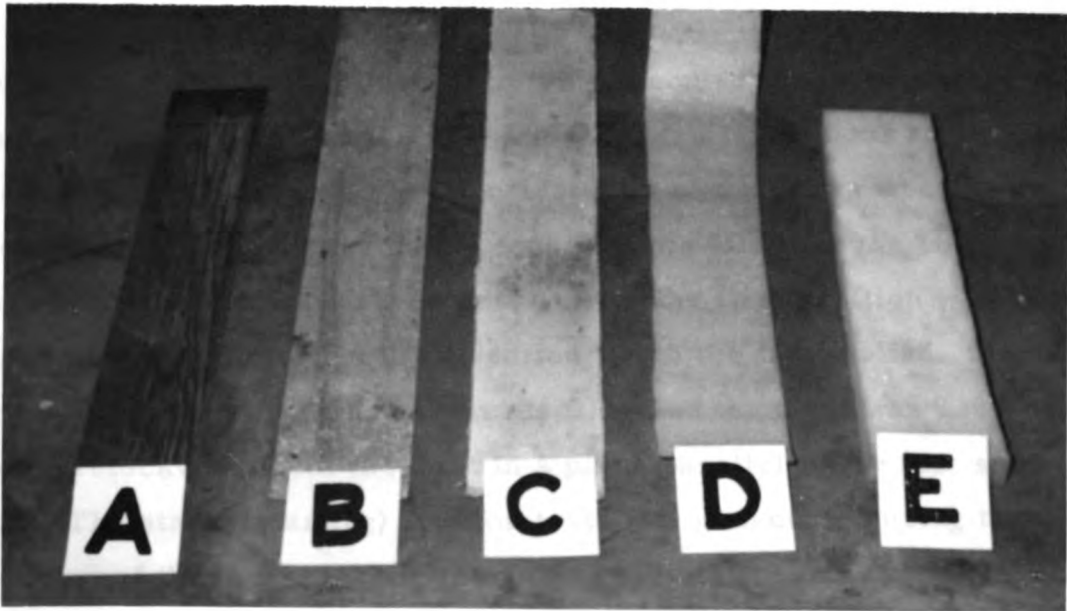


Fig 10. Surfaces used in coefficient of friction and rolling resistance tests: (A) wood, (B) galvanized metal, (C) canvas belting, (D) ethafoam, and (E) polyurethane (631455-1).

static tests, and permitted a given angle to be held constant for the dynamic tests.

Five surfaces (Figure 10) which may be encountered in future hydro-handling systems were tested: (1) wood, (2) galvanized metal, (3) canvas belting and two cushioning materials, (4) expanded polyethylene (Dow Ethafoam) and (5) polyurethane. Each surface was attached between the plexiglass sides.

Since individual fruits roll at smaller angles than they slide, three fruits were pierced by a wire which was then bent to form a triangle that prevented rolling in the coefficient of friction tests.

Procedure

Static tests: Samples of ten fruits of each variety were selected, numbered, and the equilibrium position marked. Each fruit was placed on its equilibrium position and the angle of incline was gradually increased until the fruit rolled. The device was calibrated so that angles of incline could be recorded directly. The equilibrium position was defined as the position which each fruit assumed most frequently after being rolled on a level surface. McIntosh fruits all came to rest on their sides. Because the exact orientation of the fruits when placed on their equilibrium position had a considerable effect on the rolling angle, each fruit was tested in three positions. The first position was chosen with the stem pointing in the direction which the fruit rolled, the second was 120 degrees clockwise from the first and the third was 120 degrees counterclockwise from the first in a plane parallel to the test surface.

The static (starting) friction tests were conducted using three samples of three fruits each from each variety. Each sample of three fruits was placed on the incline and the angle increased until sliding occurred. The sample was then inverted and another reading taken. This procedure was repeated for the three samples of each variety on

four of the five surfaces--polyurethane was omitted because the angle was greater than 35 degrees, which was the maximum angle for the device.

Dynamic tests: The angle of incline was adjusted so that each fruit maintained a constant velocity as it rolled along the incline. These constant velocities were controlled at approximately one fps in air and 1/2 fps in water. These velocities must be specified because rolling resistance varies with velocity. At very slow velocities in both water and air fruits will come to rest on their calyx or stem cavity whereas at slightly higher velocities momentum is sufficient to prevent this occurrence and the fruits roll at considerably smaller angles. In water, however, the velocities must not be great or the fluid drag factor becomes large, and the slope necessary to overcome both rolling resistance and fluid resistance is measured.

Results and Discussion

The results obtained for static and dynamic rolling resistance in air and water are presented in Table 5 and Figures 11 and 12. Results of the static and dynamic coefficient of friction in air and water are shown in Table 5 and Figures 13 and 15.

Unlike spherical and cylindrical objects, a fruit began rolling from its equilibrium position whenever the line of action of the weight advanced beyond the lower (upper in water) contact point. This made the conventional engineering mechanics definition of rolling resistance invalid in its application to the non-spherical shape of fruits. In absence of standards for expressing the rolling resistance of fruits, the average angles of incline were used (Cooper, 1962).

The variation in rolling resistance was very small for all the surfaces tested, but there was a large variation between fruit varieties. McIntosh had much higher static rolling resistance than Delicious and

Table 5. Average rolling resistance and friction of apple fruits.

Variety/Surface	ROLLING RESISTANCE				SLIDING FRICTION			
	Angle, degrees				Angle, degrees			
	AIR		WATER		AIR		WATER	
DELICIOUS	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic
	10.7	2.5	11.7	5.1	19.9	16.1	19.0	19.0
	9.8	2.3	11.6	5.5	19.1	18.8	25.5	25.5
	9.7	2.3	12.4	5.1	19.2	14.1	25.8	25.8
	10.6	2.5	12.8	5.2	24.3	24.3	30.0	30.0
Polyurethane	9.6	3.0	11.9	4.9				
JONATHAN	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic
	7.8	2.0	10.2	4.4	19.3	17.8	21.2	21.2
	8.0	1.7	10.9	4.6	20.8	20.7	27.6	27.6
	8.4	2.1	9.8	5.3	20.5	17.0	25.3	25.3
	8.2	2.0	8.5	4.2	25.8	27.5	30.9	30.9
Polyurethane	7.3	2.7	8.7	5.6				
McINTOSH	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic
	16.0	2.2	16.9	4.0	18.8	17.8	21.1	21.1
	16.2	1.6	15.9	4.9	21.4	22.0	28.0	28.0
	15.9	2.0	16.0	4.7	18.3	16.0	27.0	27.0
	14.9	2.3	15.3	3.9	28.0	29.0	30.7	30.7
Polyurethane	11.9	2.6	15.1	4.8				

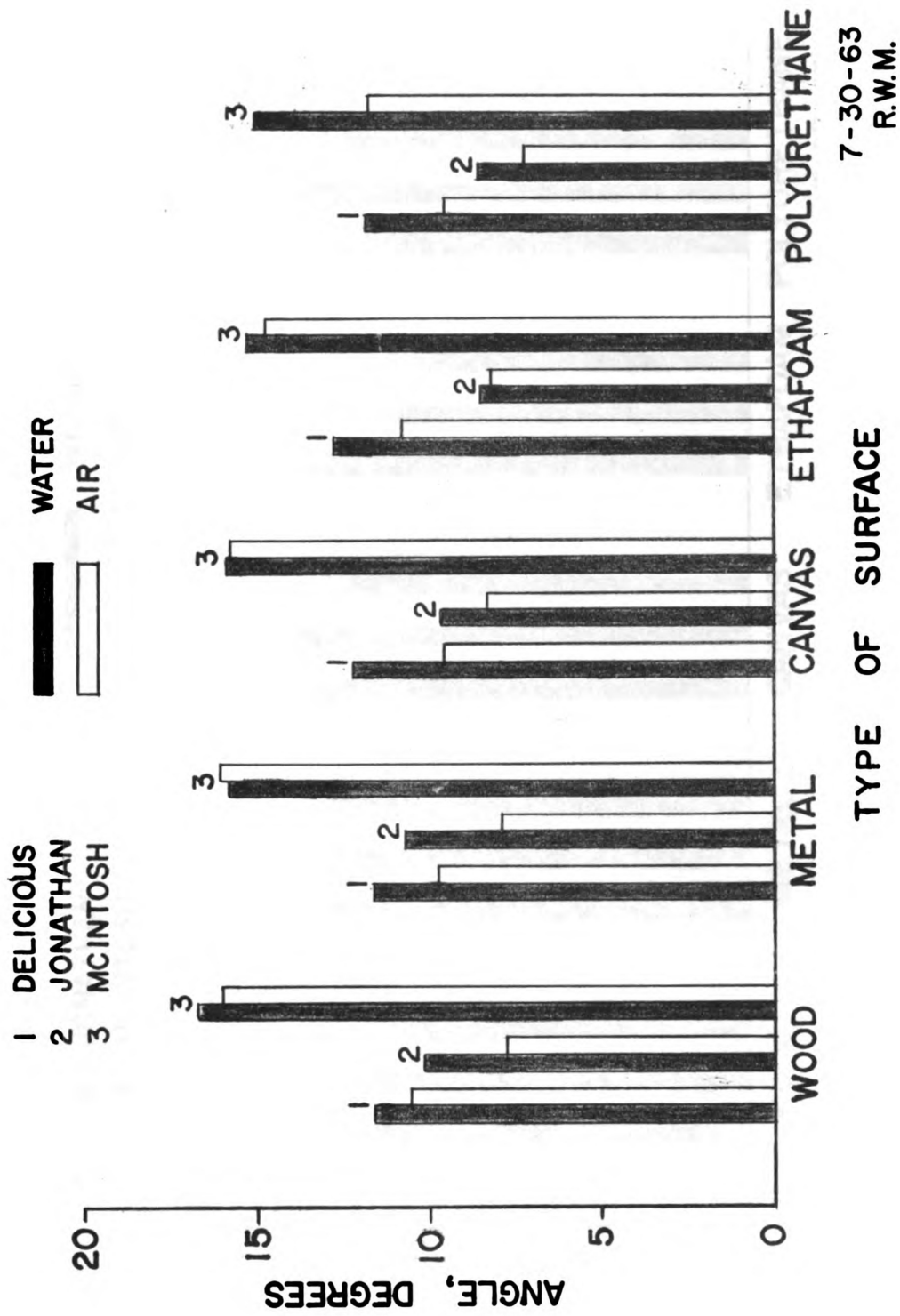


Fig. 11 Static rolling resistance (maximum stability angle) of apple fruits.

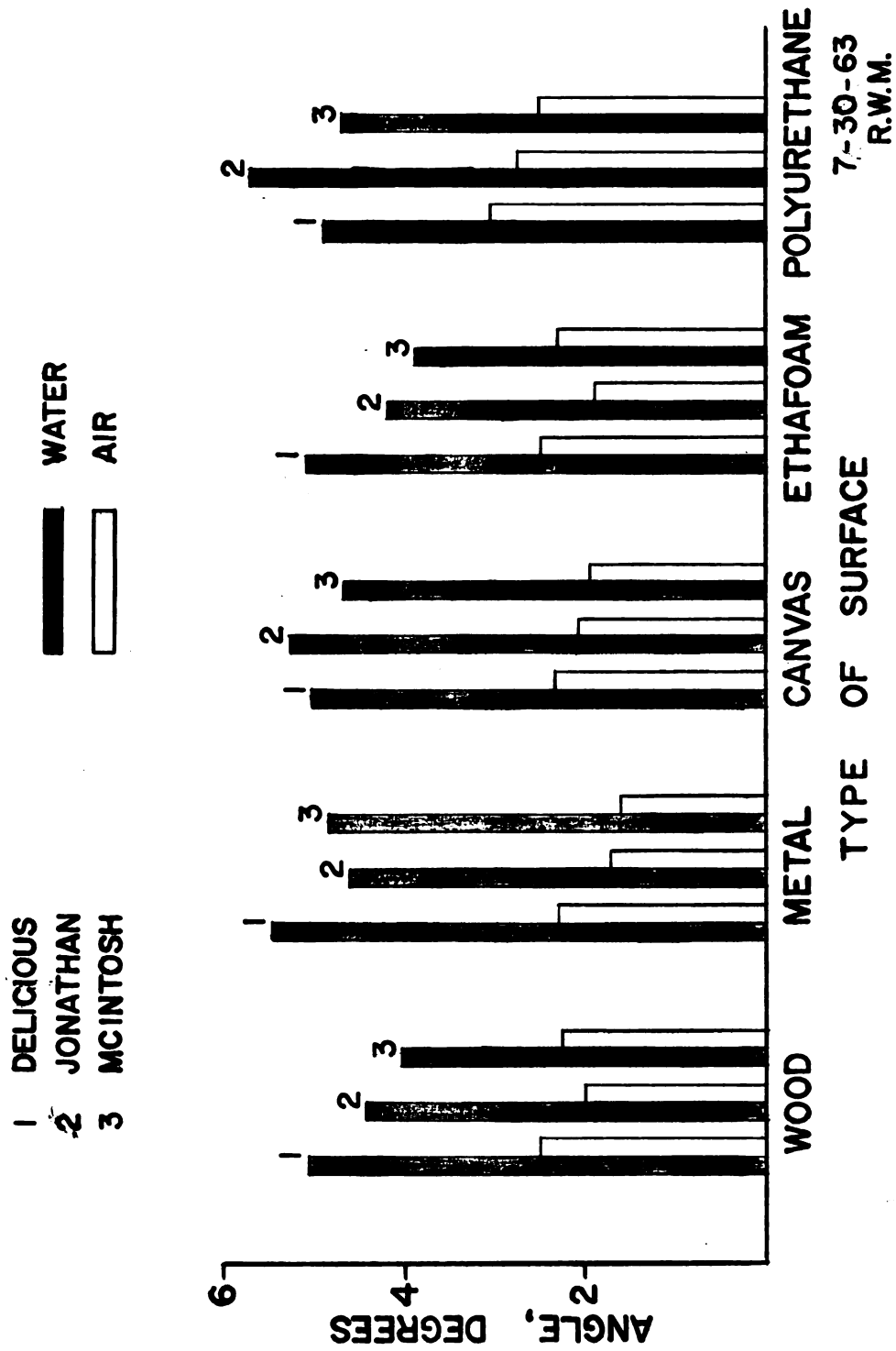


Fig 12 Dynamic rolling resistance of apple fruits.

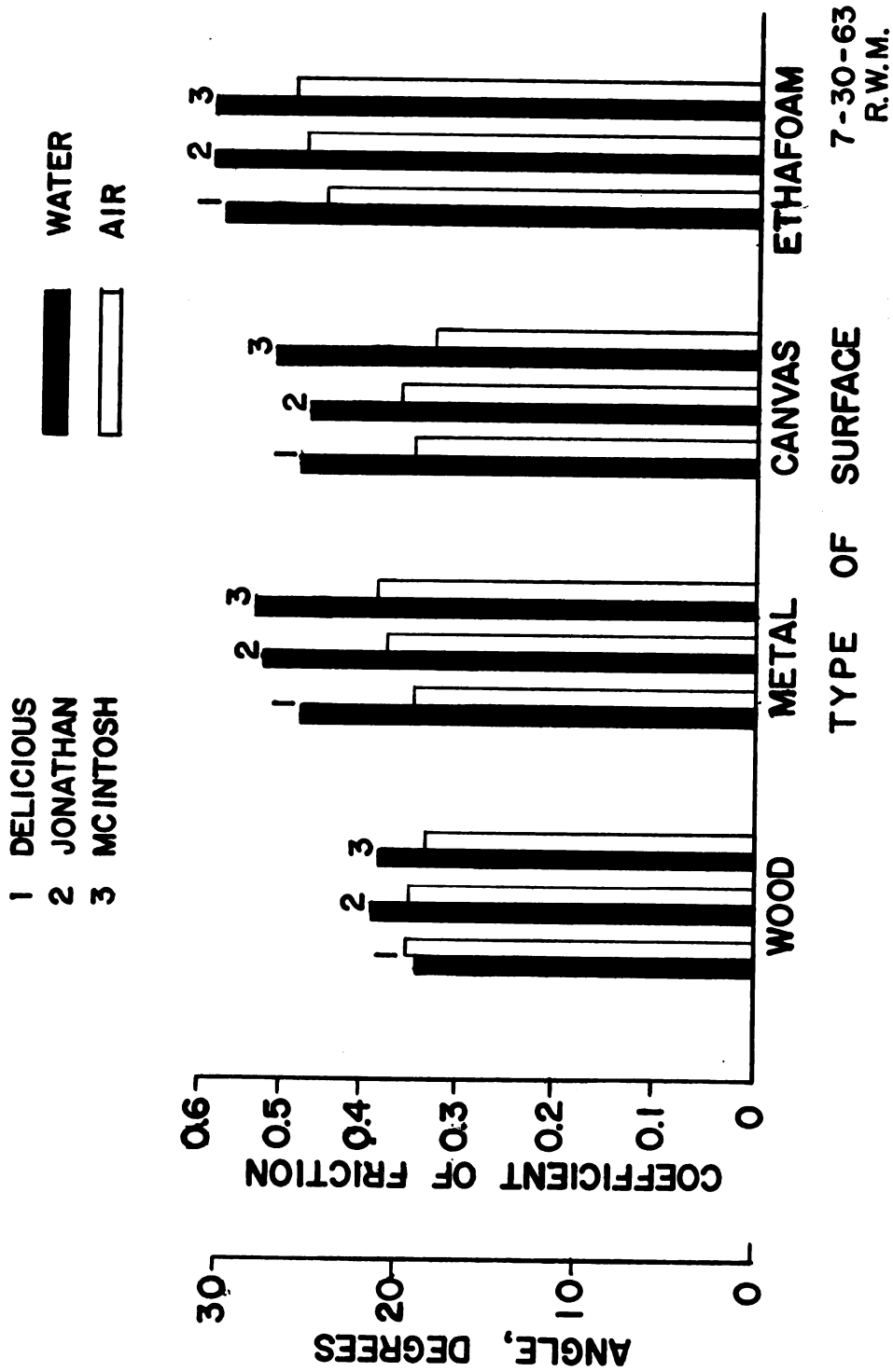


Fig 13 Static coefficient of friction of apple fruits.

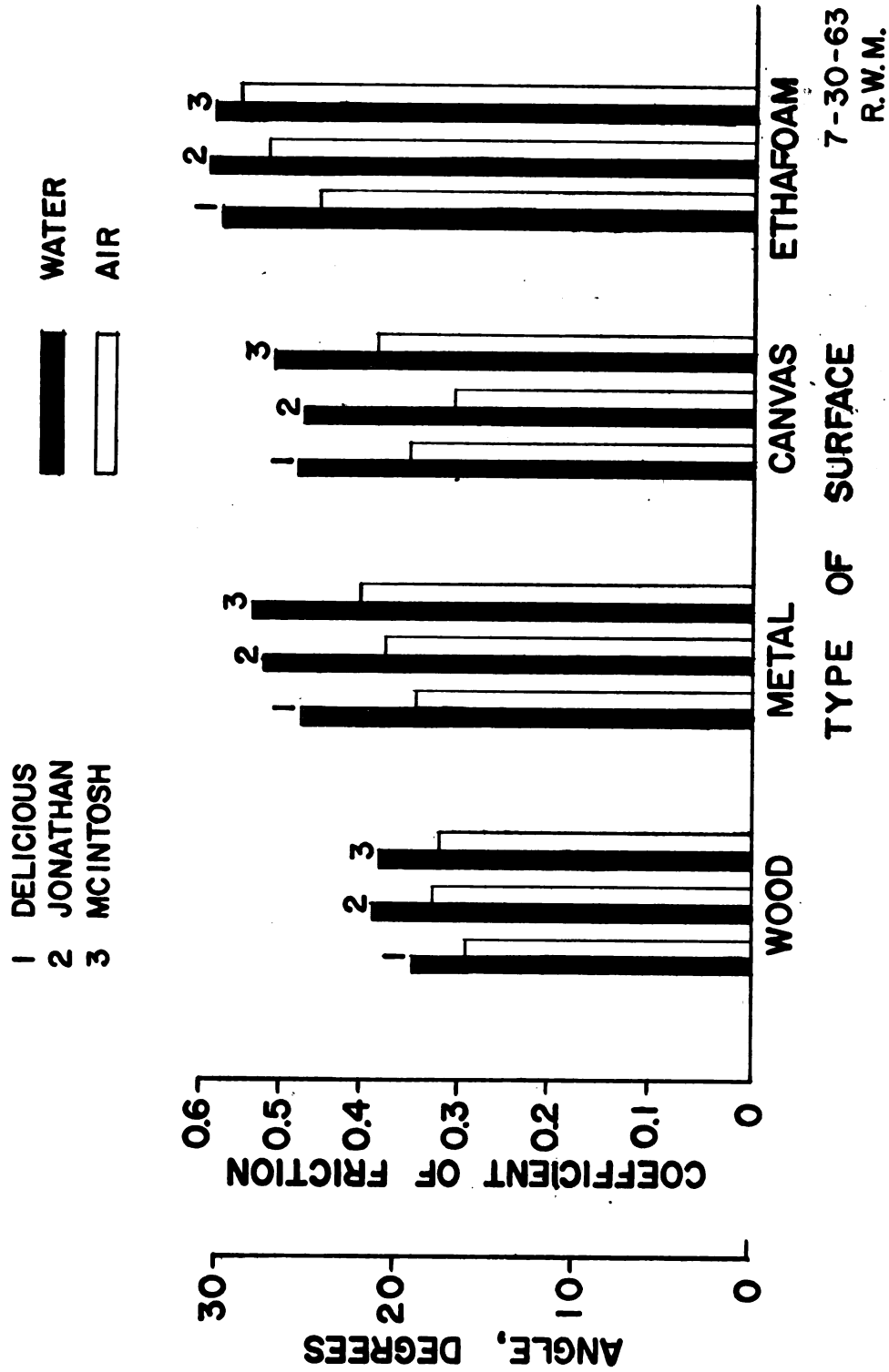


Fig 14 Dynamic coefficient of friction of apple fruits.

Jonathan varieties because of the different equilibrium position. The equilibrium position for all McIntosh fruits was on the calyx, which is a more stable position than an equilibrium position on the side of the fruit, as was the case with the Delicious and Jonathan varieties.

The static rolling resistance in air and water is nearly equal, but dynamic rolling resistance is approximately 2.5 degrees greater under water than in air. This was nearly twice as great an angle as was needed in air. Although fluid resistance probably had some influence on the magnitude of the angle in water, fruits were rolled only fast enough to prevent them from stopping on their calyx or stem cavity.

Sliding friction varied only slightly with fruit variety and with surface. An exception was Ethafoam which had approximately 20 percent greater coefficient of friction than wood, metal, and canvas surfaces.

The coefficient of friction in all cases was approximately 20 percent greater in water than in air.

COMPONENTS FOR A HYDRO-PRESORTING AND PRESIZING SYSTEM

A complete hydro system for the prestorage handling of apples would consist of the following major components: (1) dumper, (2) sorting table, (3) sizers, and (4) bulk box filler. Other minor operations such as leaf and trash removal, utility and cider fruit box fillers, etc. were not investigated but were considered in the overall system planning and layout.

Hydro-dumpers are rather extensively used for apples in Michigan and are manufactured by several companies. Since they are suitable for the needs of this study they were not further investigated.

Sorting Devices

Fruit sorting is an operation which needs considerable study and further development. Present sorting tables using a cull conveyor belt two feet above the center of the sorting table result in poor labor efficiency due to the long motions involved.

Sorting apples in water is limited, however, due to reduced fruit visibility and worker discomfort. Because sorting can best be accomplished in air, as it is presently done, it was not given as much emphasis in this study as the sizing and box filling operations.

Apparatus and Procedure

A wooden-roller sorting table was constructed and tested above a large tank. The sorting area was divided into lanes so that cull fruits could be transferred from the large center lane into four-inch wide cull lanes on the outside. It was designed so that the rolls turned

backwards to roll the fruits in the direction of translation.

Cylindrical nylon brushes of the type presently used in wet brushers were mounted at various spacings in place of wooden rollers for a sorting table. Workers could force the cull fruits between the brushes into the water below for disposal.

Results and Discussion

The roller sorting table with cull lanes at the outside reduced operator arm motion considerably. The major problem limiting its use was the large space requirements for the cull fruit lanes. Two four-inch lanes on a three-foot wide sorting table would reduce its capacity 25 percent, which cannot be tolerated in a large operation.

It would be desirable to avoid grasping the cull fruits by simply pushing them down through the sorting table. This principle was first examined by using a series of parallel three-inch wide belts with a two-inch opening between each pair. Adjacent belts would run at different speeds to cause fruit rotation and workers would force the cull fruits down between the flexible belts. Preliminary studies indicated that when a three-inch fruit was forced between belts adjacent smaller fruit would fall through also.

A second device consisting of cylindrical nylon brushes used in place of rolls on a sorting table gave the same problem. To prevent small fruits from passing down between brushes, the brush spacing had to be reduced so much that three-inch fruit could not be forced through. It is believed this device would be satisfactory if fruit size varied less than one-half inch. Since it is likely more economical to sort before sizing, this sorting method was not developed further.

Sizing Devices

Apparatus

All sizing devices were tested in still water because each device utilized only buoyant force for sizing. The devices tested are shown in Figures 15 to 19.

The slat sizing device consisted of tapered slats so that when submerged and inclined 25 degrees, buoyant force caused the fruits to roll up the incline until the slat spacing became great enough to permit fruits to pass upward. Sizes were separated by placing partitions perpendicular to the slats near the water surface.

The roller sizing device operated on the same principle as the slat device. The slats were replaced by rollers which were rotated at different speeds. The roller which turned downward against the fruit was rotated twice as fast as the roller which turned upward against the fruit. Size partitions were used in the same manner as with the slat device.

The helical sizer (Martin, 1962) was operated in a completely submerged position with size partitions at the water surface perpendicular to the axis of the device. Fruits were introduced inside the eight-inch diameter helix and the helix rotation carried them horizontally until pitch dimension permitted passage between the helix coils.

Chain sizer tests were conducted with the device shown in Figure 18 using the three chains shown in Figure 19. The sizer was mounted in the laboratory test tank on a 15-degree incline so that the chain carried floating fruits below the surface. Buoyant force then caused the small fruits to float upward through the chain links where they were collected after each trial.

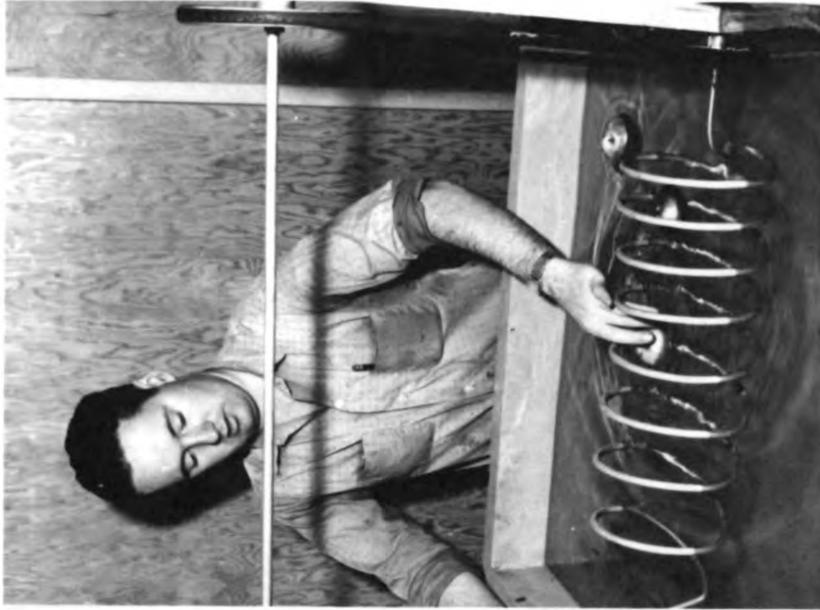


Fig 17 . Helical sizing device raised for photograph. Operating position shown in background, Fig. 16 (622141-6).

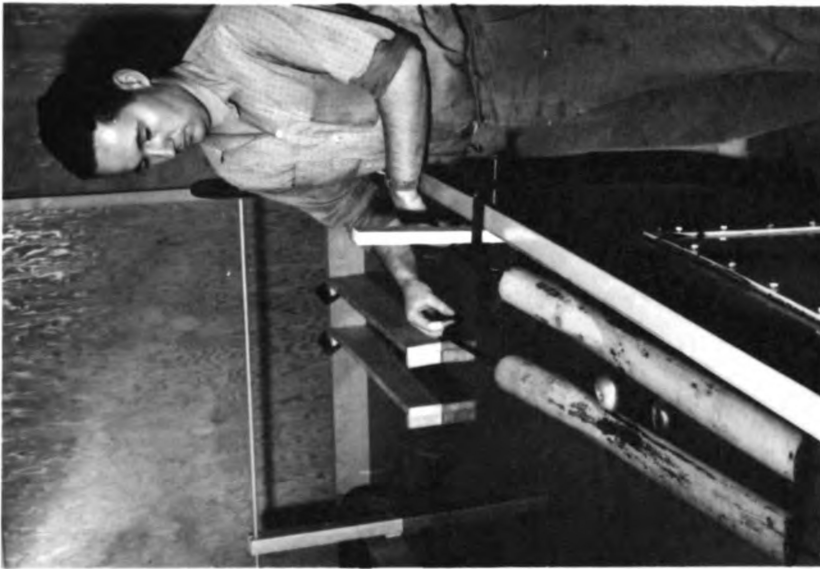


Fig 16 . Roller sizing device during operation (622141-7).

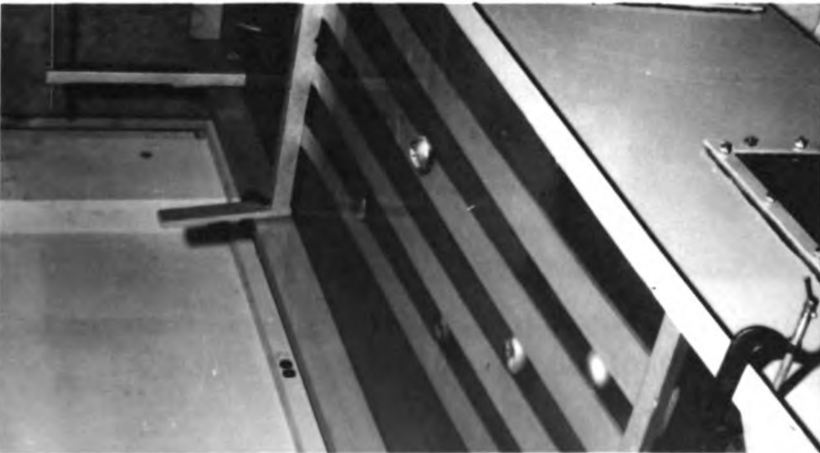


Fig 15 . Slat sizing device in operating position (20 degree angle of incline) (622141-5).

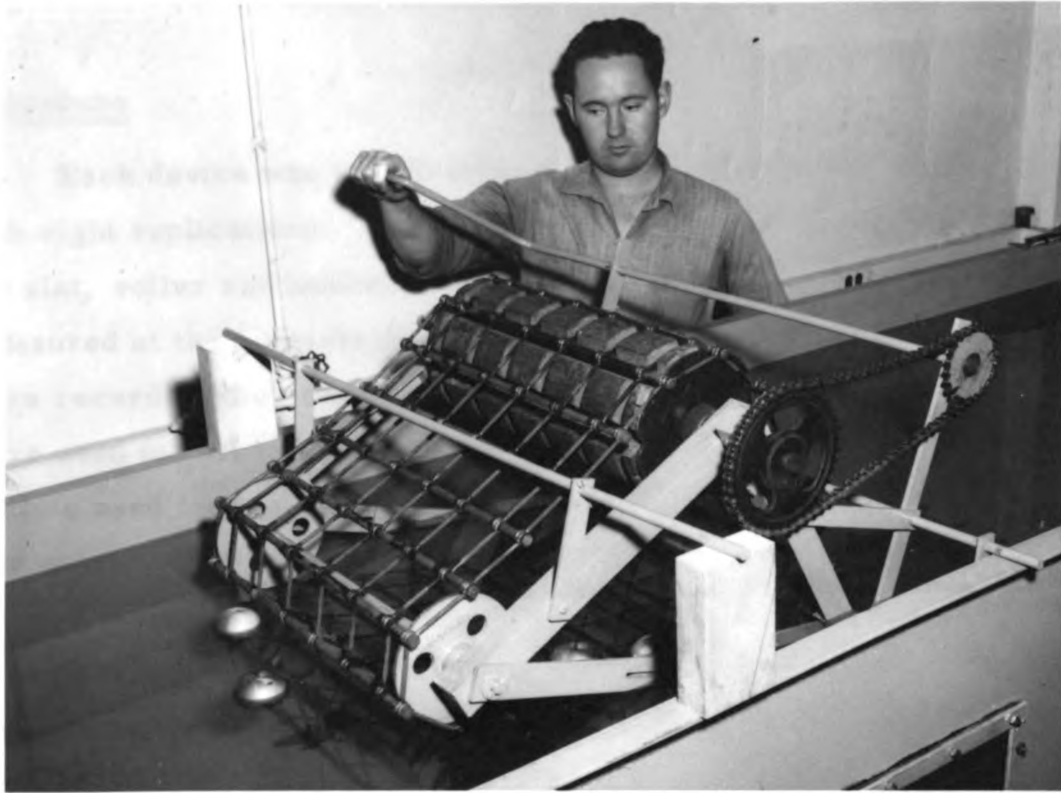


Fig 18 The author operating square link chain sizer (622141-1).

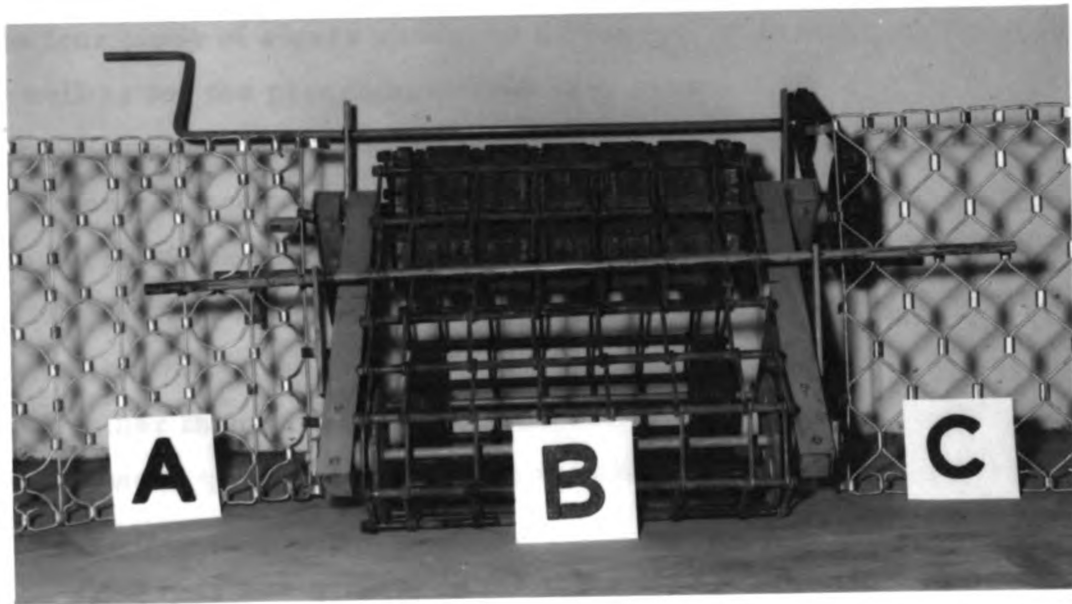


Fig 19 Chain sizing device and the chains tested: (A) round (B) square and (C) hexagonal link (631455-3).

Procedure

Each device was tested using a sample of 20 fruits of each variety with eight replications. The sample was sized into three categories with the slat, roller and helical devices. Before the test each fruit was measured at the greatest diameter and numbered. Only these numbers were recorded after each trial and the same 20 fruits of each variety were used for all tests except those for the chain sizers. The fruit sample used for testing the chain sizers was selected so that fruit size was nearly equal to the chain size. Little would be learned if very small or very large fruits were used. The slat and roller devices were tested at various angles of incline ranging from 14 to 26 degrees. The helical device was operated at 24 rpm. Chain sizers were operated at three speeds: 25 fpm, 35 fpm, and 46 fpm.

Results and Discussion

The results for accuracy of sizing are shown in Figures 20 and 21. The four types of sizers should be compared for the magnitude of error as well as for the percentage error they made.

Sizer evaluation was first made using all three size categories and later reduced to comparison of only the median size for presentation here. Consideration of only the median size allowed the device to make errors in both directions so little data was lost. Chain sizer evaluation was based on the number of fruit passing through the chain links rather than on the number carried under the device. All four devices were quite accurate, with the chain-sizer being superior (Figure 21).

Accuracy was quite good for the slat type sizer in spite of the fact that it inherently sized McIntosh fruit by the smallest rather than the largest dimension. If the ratio of small to large diameter is relatively constant for a given variety, an operator could compensate

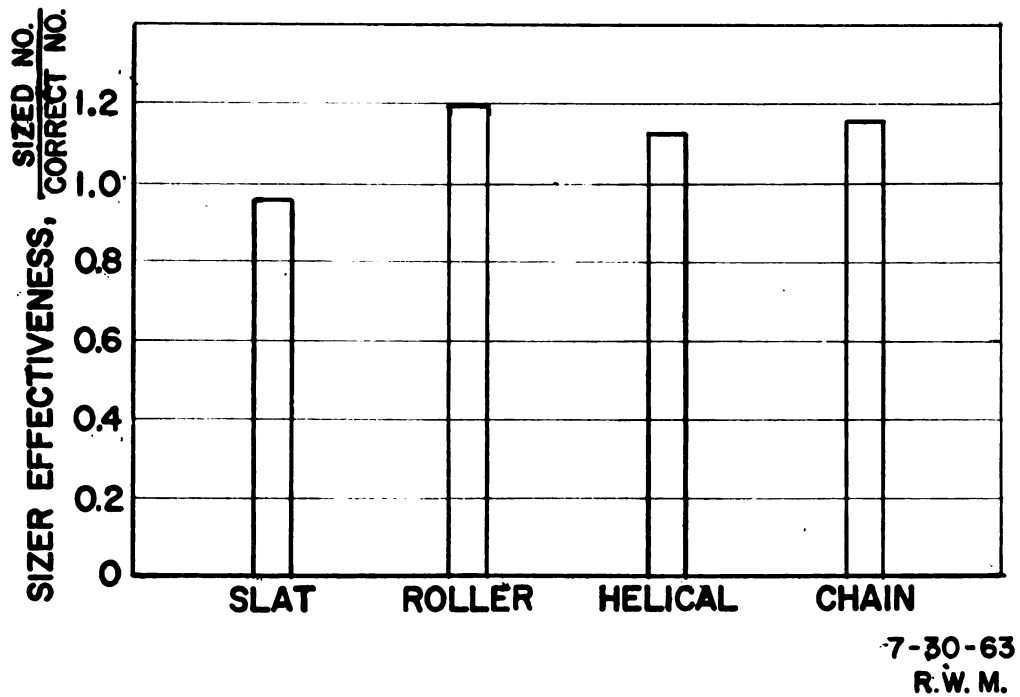


Fig 20 Accuracy of four types of hydro-sizers on McIntosh fruits.

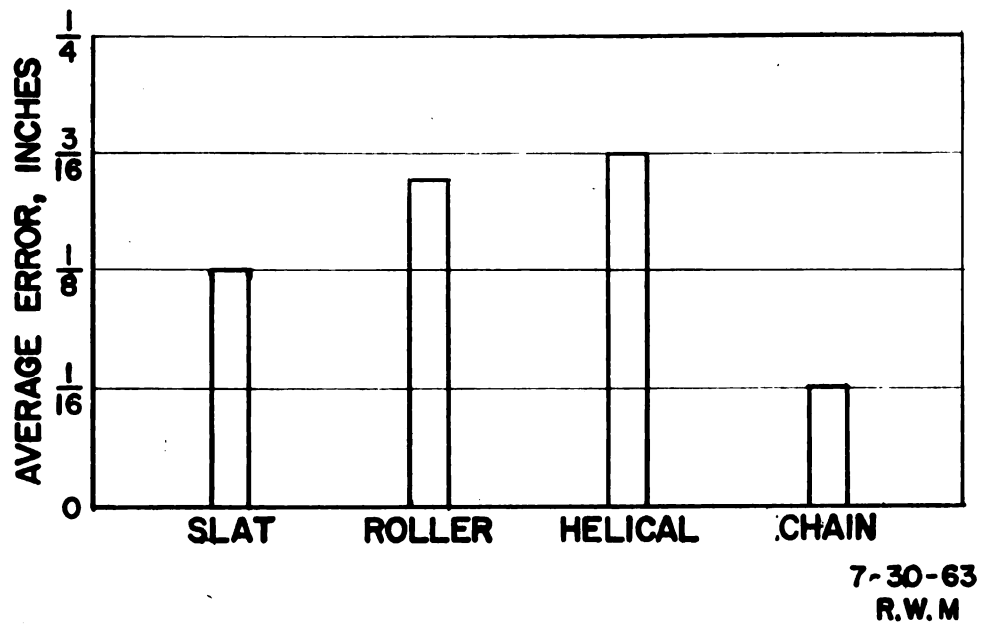


Fig 21 Errors of four types of hydro-sizers on McIntosh fruits.

for this sizing orientation and improve accuracy. The major problem encountered was fruit wedging between the slats; as many as seven of the 20 fruits wedged in several trials. When one fruit wedged it interrupted the entire operation because all other fruit in that slot were blocked. A positive carrying mechanism to prevent stoppage would cause fruit bruising because the fruits would still wedge themselves between slats.

The roller sizer was conceived through efforts to eliminate the wedging problems experienced with the slat sizer. Most wedging was eliminated, except for irregular, angular shaped fruits (especially Delicious) which start to pass between the rollers and then turn to a larger dimension. This caused very severe bruising. The accuracy was fairly good and, unlike the slat device, size was based on the largest dimension of the fruit. The rotation of the rolls caused the McIntosh fruit to rotate with the core parallel to the axis of the roller and the incline of the rollers caused translation so that size was based on large dimension of the fruit.

The helical sizing device had several limitations. Fruit wedging was the most serious fault. This might be expected from results of the slat sizer tests since these devices operate on the same general principle--the helical having a circular rather than linear tapered opening. Like the slat device, the helical sized McIntosh fruits by the small dimension. The magnitude of sizing error was the largest of all devices tested. Its potential capacity is very limited, even if the sizer diameter were increased to 24 inches, which is possible. Multiple units could be used, but this would complicate the fruit submersion-introduction operation.

The square link chain sizer was repeatedly accurate with only minor wedging problems which could be easily solved. McIntosh fruits sometimes passed diagonally through the square links so that 2 3/4-inch

diameter fruits passed through the 2 5/8-inch chain. Because of this sizing error, hexagonal and round link sizing chains were examined for sizing accuracy.

Figure 22 shows that overall performance was not improved by use of round and hexagonal link sizing chains. The problem of large fruit passing diagonally was partially solved by the hexagonal link chain and completely solved by the round link chain. These chains created a new problem which accounted for the lower effectiveness shown in Figure 22. The hexagonal and especially the round link chain had webbed areas between the link openings which caused many small fruits to be carried under the device without contacting a link opening. Also, the round and hexagonal link chains did not submerge the incoming fruits nearly as well as the square link chain so a separate introduction device would be required.

Figure 22 shows that sizer accuracy was not greatly decreased by increased speed of chain movement up to 46 fpm. The square link chain carried all fruits under at 74 fpm. An operating speed of 50 fpm, which is nearly twice the recommended rate for sizing chains operating in air, should be satisfactory in water.

Of the four sizers tested, the chain type was the only satisfactory device for a high capacity system. The square link chain appeared superior to other shape links for accuracy, introduction-submersion characteristics and potential capacity.

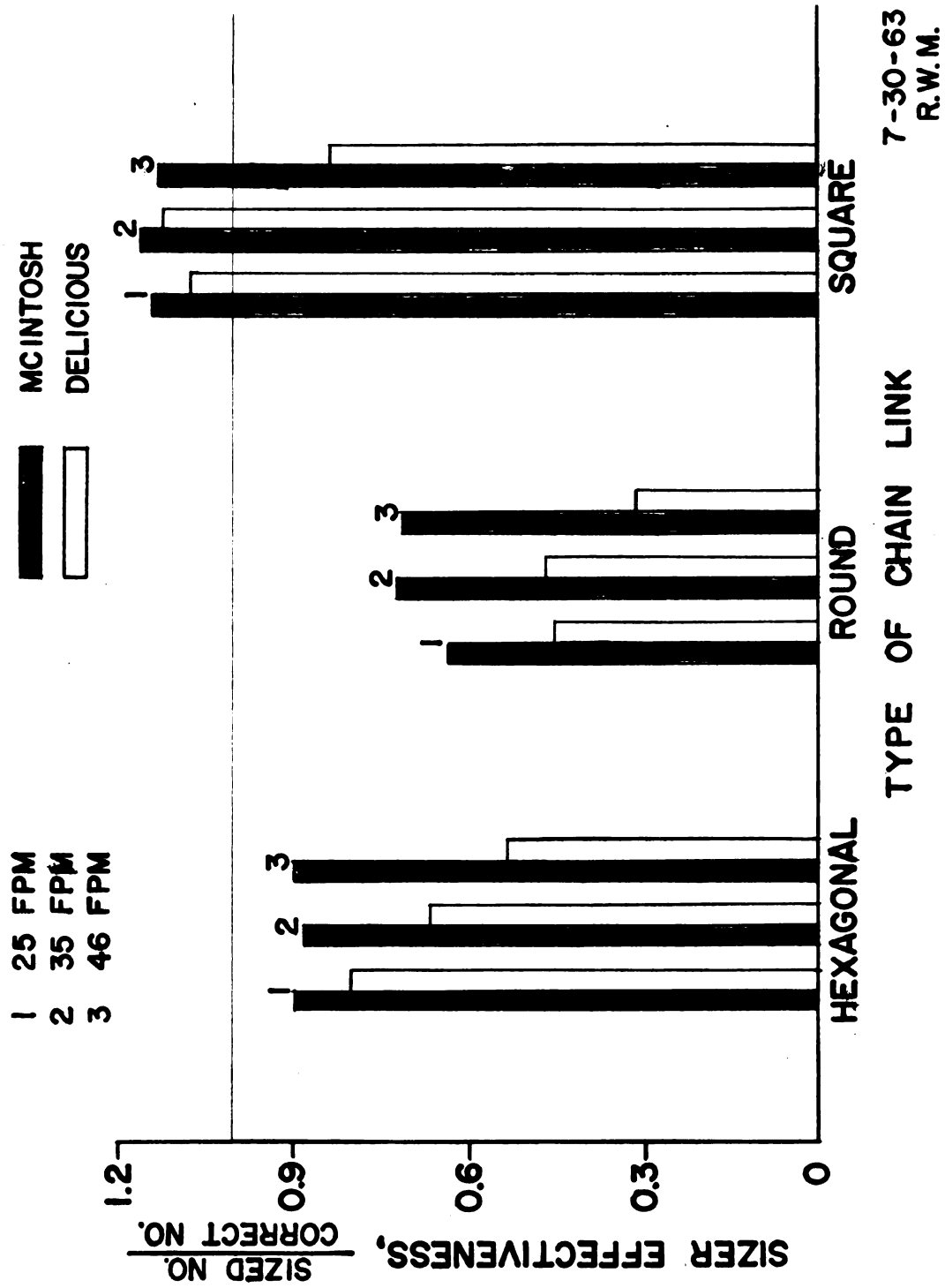


Fig 22 Chain size accuracy and relation of chain speed to accuracy.

Bulk Box Filling Devices

Bruise damage is a problem which has not been completely solved by dry (air-gravity) type box fillers. Several dry fillers have been patented and at least one commercial unit is on the market, but bruise damage on the delicate McIntosh variety has been excessive. Bruising must be minimized in a pre-sorting and presizing system, especially in the box filler, because fruits damaged in this operation will go into long term storage and initiate further spoilage.

A hydro-filling device should solve the problem of bruise damage. Three general types of hydro-fillers were investigated and proposals for a full scale system were made. The three hydro-fillers were (1) flume, (2) direct fill, and (3) accumulator type.

Apparatus

The flume type filler test was conducted using a 10-inch wide plexiglass flume and a one-bushel box in a laboratory sink so that water level could be varied during filling. A hose supplied water which accompanied the fruits down the flume.

Tests of the direct fill device were conducted in the laboratory test tank using a flighted rubber belt submerging conveyor and the box holding and rotating frame shown in Figure 23.

The accumulator type device was tested using a plexiglass-sided container and two wooden boxes (Figure 24). One box was cut down to give 1 1/2 inches smaller lateral dimensions than the other and the slats on both were narrowed to facilitate photography.

Procedure

Each of the three filling devices was tested using one bushel of McIntosh fruits. Bruise evaluations were not made because the

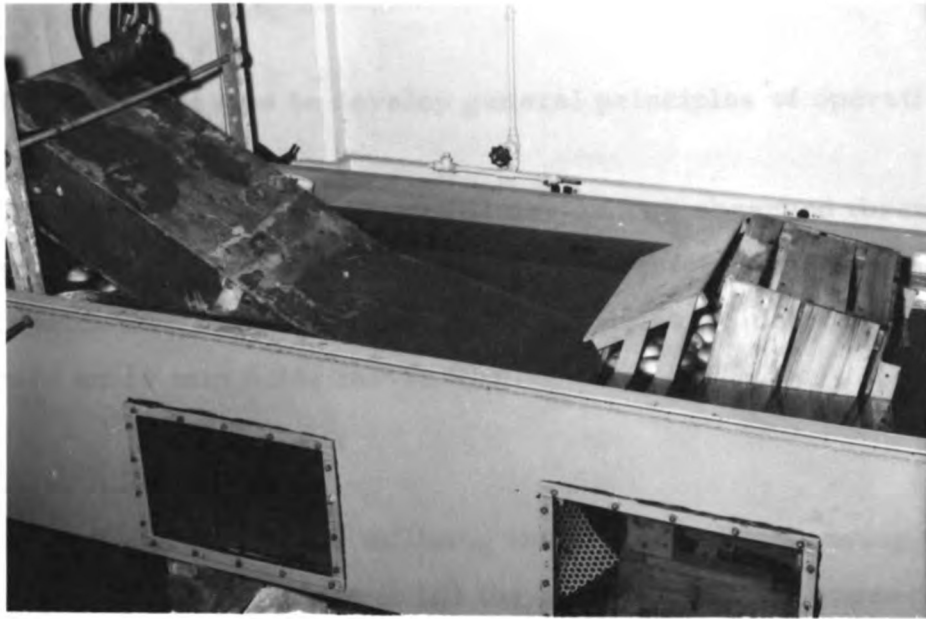


Fig 23 Direct fill type box filler in operation (631445-6).

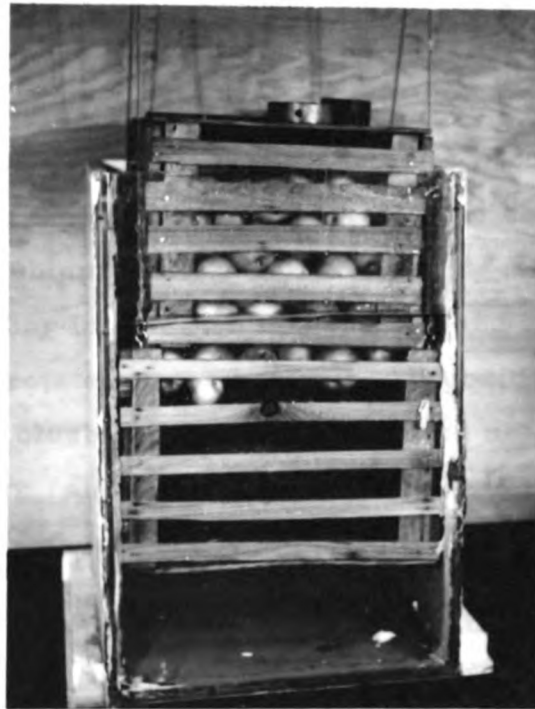


Fig 24 Accumulator type box filler in operation (boxes being raised). Note that friction is holding fruits high above water level (631455-7).

primary objective was to develop general principles of operation for a hydro-box filler.

Performance of the direct fill device was observed through the side and bottom windows of the test tank. Performance of the accumulator device was observed through the plexiglass-sided container and recorded on 16 mm color movie film.

Results and Discussion

The flume type filler utilizing water flow accompanying the fruit down a gently sloping flume to fill the box from the top appeared unsatisfactory because of bruise damage. Even when the water level was carefully controlled in the box, incoming fruit struck stationary fruits in the box which were buoyed up by the 8 to 10 inches of submerged fruit below this top layer. The impact bruising which occurred in this condition seemed nearly as severe as it would have been if there were no water supporting the fruit in the box.

Tests of the direct fill type were quite successful except for one major problem--keeping all of the fruit in the box when it was removed. This problem was partially solved by moving the point of rotation to a higher location so that the box and frame raised out of the water as it was rotated to the box removal position. A mechanically operated gate to close the filling opening was needed to completely solve the problem, and this caused further severe bruise problems for fruits which were caught between the gate and box-holding frame. Further modifications are needed before this box filling method will be satisfactory.

The accumulator method was quite successful when the accumulator box was one to two inches smaller in lateral dimensions than the box being filled. Tests using a stationary accumulator which enclosed the bushel box and contained the fruits floating above the box proved

unsatisfactory because fruits were carried up by the box edges and corner posts and frequently wedged between the accumulator wall and box edges. The tests using a smaller accumulator box which was raised from the water with the bushel box were very satisfactory.

The accumulator method appeared superior to others in all respects except cost and space requirement. A sketch of the proposed full size hydro-filler is shown in Figure 25. This hydro-filler would allow continuous operation of the submerging conveyor, thus providing high potential capacity. Its operation can best be explained by the following list of operations in a cycle.

1. Accumulator box filled by submerging conveyor;
2. Both accumulator boxes roll to put one in hoisting position, the other in filling position;
3. Hoisting mechanism raises both accumulator box and bulk box out of the tank, transferring fruit to the bulk box;
4. Full bulk box rolls off the hoist and an empty box rolls on;
5. Hoist lowers both boxes;
6. Empty accumulator box rolls into filling position and other accumulator box, now filled, rolls into hoisting position on the other hoist.

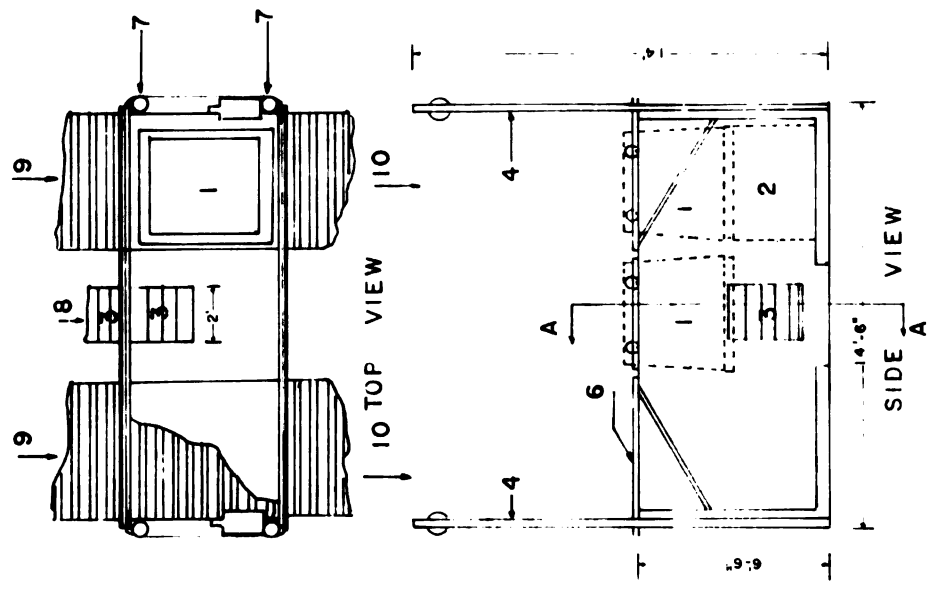
Any type of water filling leaves more cavities and generally gives a poorer fill than air-gravity filling. Attempts to use vibrations and/or turbulent flow through the boxes during fruit transfer proved unsatisfactory in giving a better fill. Further work should be done to solve this problem because, though cavities may increase fruit cooling rate, an estimated 10 percent storage capacity will be lost.

Proposed Hydro-presorting and Presizing System

A plan view of a proposed system for apples is shown in Figure 26. This system could be installed outdoors for apples and in several alternate arrangements to fit the needs of the particular storage plant.

HYDRO-BOX FILLER

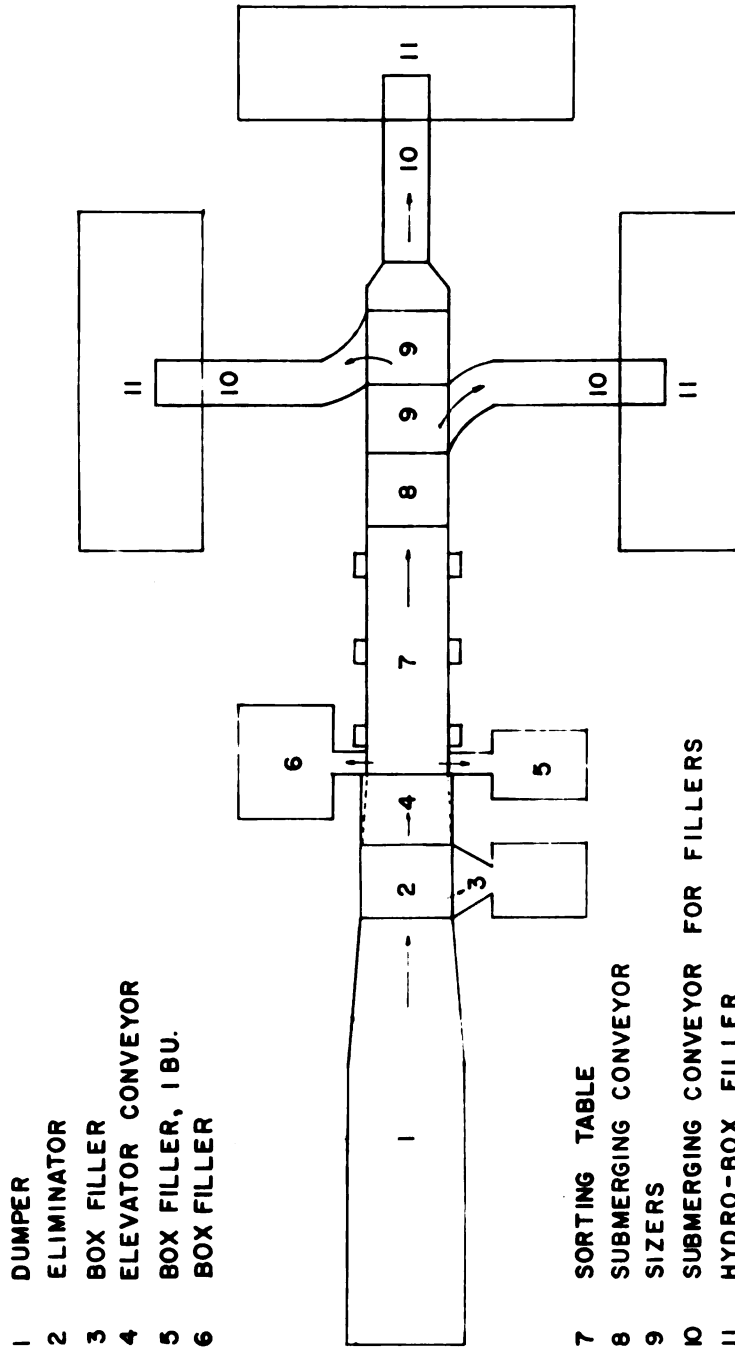
- 1 ACCUMULATOR BOX
- 2 BULK PALLET BOX
- 3 SUBMERGING CONVEYOR
- 4 HOISTING FRAME
- 5 HOISTING MECHANISM
- 6 ACCUMULATOR BOX TRACK
- 7 ACCUMULATOR BOX SHIFTING DEVICE
- 8 FRUIT FLOW PATH
- 9 EMPTY BOX PATH
- 10 FULL BOX PATH



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Fig 25 Continuous flow bulk box filler for the presorting and presizing system shown in Fig 26 (631485-1).

HYDRO-PRESORTING, SIZING SYSTEM



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Fig 26 Plan view of a hydro-presorting and presizing system (631485-2).

A paved area approximately 60 x 90 feet would be required for the system shown allowing a 15-foot perimeter for lift truck operation. This area might be reduced somewhat by careful planning and integration with existing paved areas.

The system would utilize a high capacity commercial hydro-dumper, square link chain type eliminator unit with a simple dry type box filler for the cider apples. A reverse roll sorting table divided into lanes would be used and utility fruit could be automatically packed into either one bushel crates for truckers or bulk pallet boxes for processors. Square link chain sizers operating under water would then separate the fruits into size categories. Each size would be flumed to its respective hydro-filler where bulk boxes would be filled and moved to storage by lift trucks.

The system shown would use 42-inch wide sorting and sizing units and would have a capacity of 600 bushels per hour. A system of this type could be very flexible. Layout, capacity, number of size categories, and type of components could be varied to fit the needs of the individual storage plant.

CONCLUSIONS

The conclusions derived from this study may be stated as follows:

1. Fruit submersion can be accomplished effectively by mechanical methods. The flighted rubber belt was satisfactory and power requirement was low.
2. Angles of repose (under water) varied from 30 to 36 degrees depending on fruit size, the larger fruits having greater angles of repose. The magnitude of these angles indicated that a distributing device may be needed for filling inverted bulk boxes under water.
3. Water penetration into apple fruits under hydrostatic pressure will be no problem at the low (less than six feet) pressure heads normally encountered in hydro-handling.
4. Buoyant velocity of fruits varies with fruit size, specific gravity and shape and ranges from 1.3 to 1.9 fps. The larger McIntosh fruits had velocities near 1.9 fps, developing energy equivalent to a 0.7-inch drop in air which was sufficient to cause slight bruising. Most other varieties, which have much higher critical bruising energy, would not be damaged upon impact at buoyant terminal velocity.

Apple fruits reach buoyant terminal velocity in the first two to three inches of travel after being released from rest. The drag coefficient for apple fruits under turbulent flow conditions ($20,000 < Re < 40,000$) was found to be approximately 0.68, compared to 0.44 for a sphere.

5. Static rather than dynamic rolling resistance and sliding friction should be used in design calculations. Submerged surfaces used for conveying fruits by buoyant force should be inclined at least 18 degrees and if fruit rolling is restricted, a 30-degree incline should be allowed for the sliding condition.
6. The chain sizer had the best accuracy and overall performance of all sizing devices tested. Square link chain gave better sizing accuracy than round or hexagonal link chain.
7. The accumulator type box filler performed best and the direct fill type showed promise for further development.

RECOMMENDATIONS FOR FUTURE STUDY

1. Continue investigation of water penetration into apple fruits to determine the variation between varieties and the flow path of the water. Consider using pressures to detect small bruises on apple fruits in bruise evaluation studies.
2. Evaluate present sorting methods and develop more efficient sorting devices, possibly utilizing the "dunking" principle.
3. Investigate the direct fill type box filler more extensively. If the fruit loss problem could be solved, this type of filler would be more compact and lower in cost than the accumulator type.
4. Conduct bruise evaluation studies using models of the components for the proposed presorting and presizing system.
5. Develop a full scale hydro-presorting and presizing system and, under commercial conditions, conduct extensive system, fruit and economic evaluation during the first year of operation.

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