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Packingline Machinery for Florida Citrus Packinghouses[1]

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Extensive literature is available on individual packinghouse processes, such as degreening and fungicide applications, but little information is available on the individual components of the citrus packinghouse line and even less on assembling them into an efficient system.

Every packinghouse owner and every equipment supplier has his own ideas of what a packinghouse system should accomplish. The purpose of this bulletin is to enunciate basic principles that apply to virtually any citrus packinghouse line, regardless of the particular layout. Errors in proper choice and matching of packingline components are extraordinarily costly in money, labor inefficiency, reduced capacity, increased fruit losses and decay claims. Moreover, many errors occur repeatedly, and many can be avoided if the principles given here are considered *before* installing or remodeling packinghouse equipment.

Principles

Width of Equipment

Whatever the function of the individual component, a packingline is basically so many square feet of conveying surface. The necessary number of square feet needed can be calculated. Within reason, *the wider and shorter the line, the less the initial cost* for the following reasons:

A. The length of the line largely determines the size of the building while width makes very little difference to the building size.

B. There is more initial cost in the sides of the line (framing, bearings, chains, drives, etc.) than in the span.

C. Electrical and plumbing costs relate more closely to the length than to the width of the line.

Capacity of the line depends on the area of conveying surface multiplied by linear speed of forward travel. The wider a line, the slower the linear speed required for a given capacity. If the initial

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linear speed is high, extra capacity can only be obtained by running the line faster or the fruit deeper, with consequent damage and more abusive handling, or else by building an additional line. If the initial speed is low due to an initial design of wide equipment, capacity can be increased by merely speeding up operations where fruit treatment time is not a factor. When fruit treatment time is critical, the line can be redesigned with extra sections added at a minimal cost. *Plan* for *increased capacity and start with the widest available equipment. Design for maximum conditions, not average conditions.*

Logical Order for Packinghouse Processes

The conventional order of fruit treatments along the packingline goes back to the days when fresh fruit was paramount, several grades were packed, processed fruit was a small consideration, and residues of pesticides, etc. were usually not considered. Today, it is common to pack just one grade, though provision for an occasional second grade may be an advantage. Large amounts of fruit, >50% in the case of export grapefruit, may be graded out and sent to the processor where unnecessary chemical residues and fruit labels are to be avoided.

With these considerations in mind, it is apparent that every fruit not shipped as fresh fruit should be removed as soon as possible (Figure 1). Immediately after dumping and trash elimination, over- and under-sizes can be removed mechanically with a pre-sizer. Removal of fruit with exterior blemishes is often not possible until after washing, but provision should be made prior to the washer for removing rotten or split fruit before they contaminate the rest of the fruit handling equipment. Washing should be followed by a water eliminator to remove excess water and grading should follow immediately. There is no reason to put fungicides, waxes, labels, and possibly color-add, on fruit that are processed. This costs the packinghouse money and may create residue problems at the processing plant (7).

Grading immediately after the washer considerably reduces the amount of machinery necessary between the washer and the final sizer. Size and horsepower requirements of the remainder of the line can be decreased proportionately to the amount of fruit removed by grading. Alternatively, if

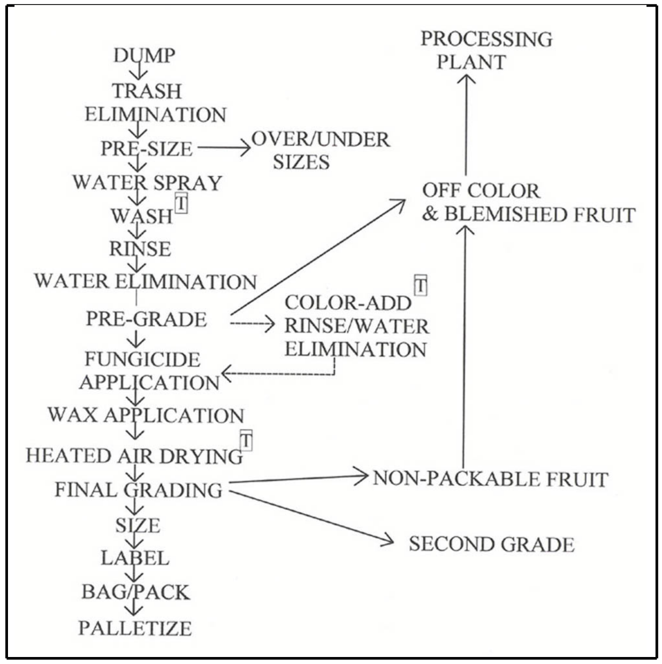

Figure 1. Logical order for a packingline when only one grade is packed most of the time. Degreening and frozen fruit separation are not included here, being covered in separate publications (25, 26). T denotes time-dependent operation.

the width of the line is not reduced, more packable fruit can be handled on it. In either case, machinery cost per box is decreased by grading immediately after washing.

The order in which the other operations are done depends, in part, on the types of fungicide and wax being applied. When SOPP (sodium ortho-phenylphenate) is used (24), it may be combined with the wash soap, but *any excess must be rinsed off to avoid fruit peel injury.* Other fungicides have to be applied to clean fruit and allowed to dry. The color-add process is best accomplished prior to fungicide applications, except for SOPP at the washer, as other fungicides are removed in the color-add emulsion.

Packing a Second Grade

In citrus-producing areas such as Florida, where a second grade is of very minor importance, it is not logical to have a complete line of sizing and packing equipment for the second grade fruit. The fluctuation in volume between first and second grades precludes advantageous use of equipment and labor. Instead, the second grade should be accumulated in pallet boxes (Figure 2) and run on the same equipment after the No. 1 grade fruit is packed. With correctly sized equipment, this will not mean working a longer day.

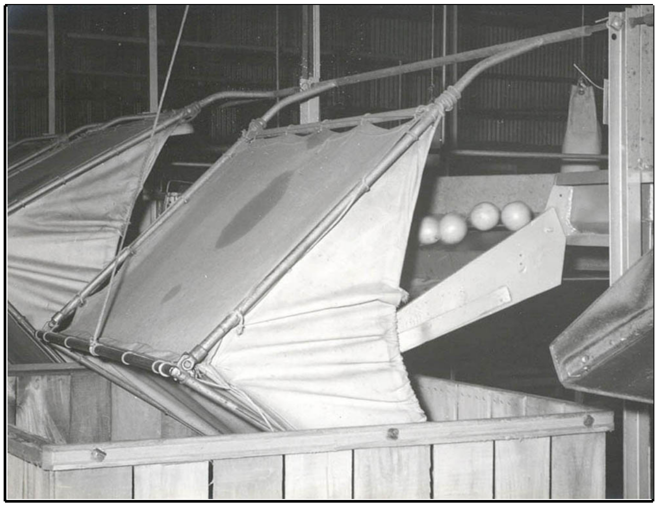

Figure 2. Deceleration pallet box filler for citrus in Florida. Counter-weighted devices begin low in the pallet box and are gradually raised manually as the box fills. There are two pallet boxes per fruit size to allow ample time to remove a full box and replace it with an empty box without interrupting the fruit flow.

Inventory-to-Inventory Packing

A logical approach for ultimate mechanization of packing and palletizing is to use an inventory-to-inventory system accumulating an inventory of sized, prepared fruit from which packing equipment draws one size at a time, and accumulating an inventory of packed, refrigerated fruit. Such broad considerations for a packinghouse layout are not considered in this bulletin. Such a design change also involves changes in fruit harvesting schedules, inclusion of refrigeration, and other matters not discussed here. It should be noted, however, that an inventory-to-inventory system that packs one size at a time can utilize a standard single channel palletizer. Conventional packinghouses handling several sizes simultaneously can only use a mechanical palletizer by first investing in an extremely expensive accumulation system. Robotic palletizers may provide a versatile, less expensive palletizing system without a separate accumulation system.

The Basic Packinghouse Line

Figure 1 shows various packinghouse operations in logical order for a packinghouse in which only one grade is packed most of the time, or in which a second grade is a small proportion of the fruit packed regularly. Operations are indicated as being either time dependent or independent. That is, operations such as dumping, trash elimination, and pre-sizing do not involve retaining the fruit for a given length of time. Time dependent processes, on the other hand, take a certain length of time which must be taken into consideration in calculations to determine the necessary area of conveying surface, e.g. fruit drying.

Dumping

Dry dumping is highly recommended. If the machinery is well designed with unimpeded fruit flow, the fruit will suffer no appreciable damage. Dumping into water inevitably subjects the fruit to an inoculum of fungus diseases, some of which may be resistant to fungicides. Indexing of the bin to fixed positions during dumping assists in creating a uniform flow of fruit. Overhead canvas or belting can reduce the fruit's velocity, minimizing the chance for damage. Fruit-to-fruit contact is preferred over fruit-to-metal. The dumping sequence and fruit flow control are critical for uniform throughput and an efficient operation.

Trash Elimination

Few packinghouses have adequate provision for coping with the trash commonly included in deliveries of fruit from hand picking. Spaced metal rods parallel to the fruit flow are commonplace. A sloping belt trash eliminator (6) will remove most loose trash and deliver it to a conveyor or container. A vacuum brusher (6) can be used to remove loose sand, which is otherwise extremely injurious to the packingline equipment and fruit. Roller conveyors should always be self-cleaning, i.e., with angled supports that wipe the whole length of each roller with openings to shed trash (Figure 3). Several pre-graders with clippers may be required to remove any adhering stems, and provision needs to be made for removing any rots and splits. Rots should be minimal if the grove has been chopped or disked immediately prior to picking.

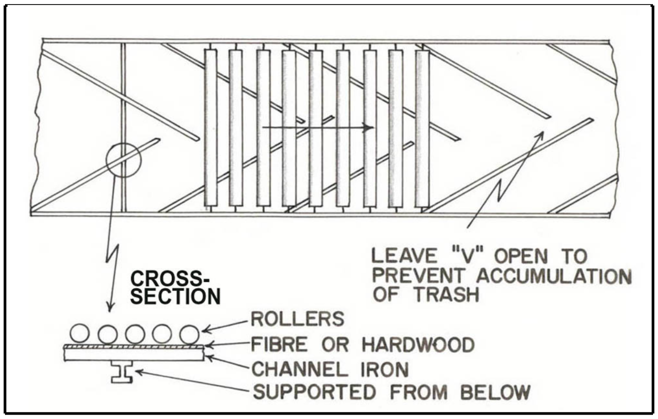

Figure 3. Angled supports under roller conveyors. Spacing is such that every roller is supported by at least two supports at all times, wear is distributed evenly over whole length of each roller, and the rollers are partially self-cleaning.

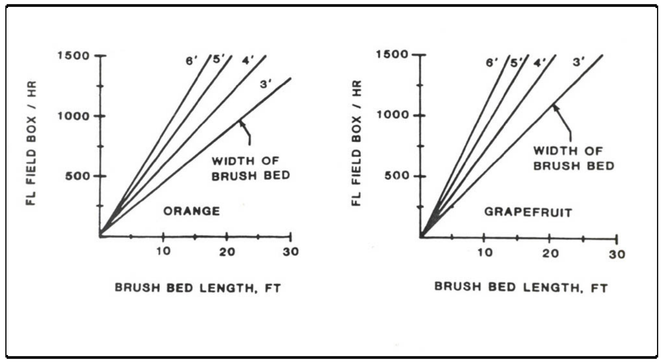

Figure 4. Brush bed capacities for oranges and grapefruit (30 second wash time).

Wetting

The fruit needs to be wet before it reaches the washer. Dip or soak tanks are not recommended for the same reasons mentioned above for water dumps. After removal of rots and splits, a chlorinated water spray over rollers is satisfactory. In handling fruit from canker quarantine areas, fruit treatment with SOPP or sodium hypochlorite is required (3).

Washing

Many packinghouses have increased packingline throughput without a proportional increase in either the length or width of their washer brush bed. In some cases, this change has led to ineffective cleaning of the fruit. Work in Australia (12) has indicated a minimal 30-second time interval for proper cleaning. In all cases, the washing time should remain above 20 seconds. These times are established for fruit in a single layer with all fruit in contact with the brushes. The relationship between packingline capacity and length of the brush bed for a 30-second wash time (Figure 4). Problems such as sooty mold may necessitate even longer cleaning times. Curves were generated for grapefruit and oranges assuming a 75% full brush bed. For conservative design, the curve for a 48-inch (1.22 m) wide unit would be used for 52-inch (1.32 m) wide washers commonly encountered. This slight overdesign incorporates a safety margin for peak fruit throughput conditions.

Use of transverse rotating brushes is virtually universal, as is some form of controlled foam or drip application of soap. The applicator should be located immediately above the space between the first and second brushes, not immediately over a brush, because each row of fruit pauses between the brushes. Tumbler (wavy-pattern) or spiral wound brush designs are effective *when fruit volume is not excessive*. Also, more rigid brush fibers result in more effective cleaning but they may cause damage to sensitive-skinned fruit. Pre-wetting of the fruit is advisable. For all washers, a wipe-out, either manual or motor-driven, should be incorporated to remove fruit before abrasive damage occurs. Excessive brush speeds can also cause damage to the fruit. A roller-spreader conveyor prior to the washer is essential to provide uniform fruit delivery across the width of the brush bed. Having separate drives for alternate brushes allows for different rotational speeds to facilitate the brushing action. The bed should be level so fruit does not migrate to one side. If new brushes are installed, a mid-season change is suggested when the fruit's peel is more mature and resistant to abrasive damage.

A study of washer efficiency in some Florida concentrate plants (22) revealed two other very pertinent factors which are assumed to be similar for fresh fruit packinghouses. First, the postwash rinse was of critical importance. A 52-inch (132 cm) washer with ten sprayheads, each of 2 gallons/minute, was considered necessary for adequate cleaning. Second, washing efficiency was not affected by the amount of soil on the fruit.

To clean fruit more effectively, high-pressure washers (HPW) have been developed (23). Positive displacement pumps are used to generate system pressures from 100 to 850 psi (689 to 5860 kPa). High flow rates of 50 to 500 gpm (0.23 m^3/min to 2.27 m^3/min) necessitated water recycling. Petracek et al. (20) found that HPW does not commonly disrupt the peel integrity of sound fruit. However, rotted or physically damaged fruit rupture during washing due to the lack of peel integrity, the force of high pressure water, and the tearing action of the brushes. Secondly, HPW strips away many of the epicuticular wax platelets, but apparently does not abrade the peel surface. Thirdly, HPW stimulated an apparent ethylene wound response when fruit were washed under higher pressures and prolonged periods.

Rinsing

Thorough rinsing with potable water is required after washing and is best accomplished over the last of the washer brushes or over a roller conveyor. Each fruit should pass under at least two nozzles.

Water Elimination

With increased fuel costs, it is far more economical to remove excess water mechanically rather than by heat and air movement. The common form of eliminator consists of sponge rubber rollers (usually made up of sections of foam rubber or foam plastic known as "donuts"). The effectiveness of these foam rollers depends on the water being "wrung out" by spring-loaded wringer rolls on the underside. For more efficient and economic operation, the wringer rolls are themselves wiped dry by neoprene blades held rigid between metal straps (Figure 5). A less complicated but efficient water eliminator can be made from soft plastic brushes. Metal "flick bars" are placed on the underside to barely touch the rotating bristles, throw off much of the water (Figure 5). Another possible technique eliminates water through the aerodynamic force of a high pressure blower (16). *Remember that it is much less expensive to remove water mechanically than by the use of heated air.*

Grading

The usual situation is that blemished fruit are removed and "in-grade" fruit are left on the line. In Florida, it is normal to manually grade on a simple

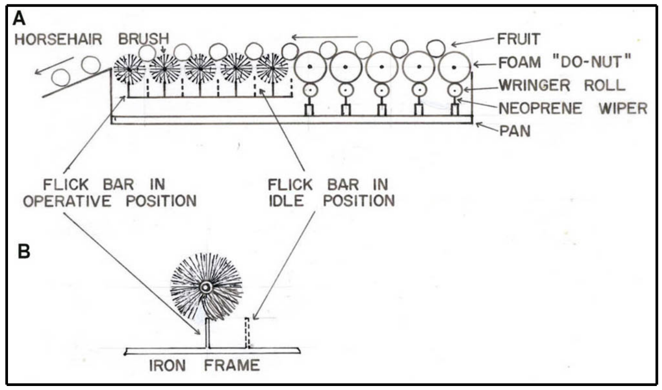

Figure 5. Combined water-eliminator and fungicide-wax applicator. A. Major components of the unit: sponge rubber rolls with wringer rolls wiped by neoprene wipers constitute the water-eliminator section; horsehair brushes with flick bars follow as a brushbed for application of water-emulsion wax or fungicide. Note that flick bars are moved manually and only in contact position when rinsing the brushes. B. Flick bar detail.

roller conveyor, although various improved grading stations have been configured (1, 11, 14). The common arrangement is for culls (unwholesome fruit) and eliminations (processing fruit) to be graded into chutes beside the grader, with a second grade going to a conveyor down the center of the grade table. Points to observe in designing and operating a grade table are as follows:

A. Good lighting is essential. An extensive study of lighting for apple graders (10) resulted in a recommendation for 178 foot-candles at the fruit surface using high output, cool white fluorescent lamps. This should be very suitable for citrus grading. Minimizing glare and providing a better contrast can be accomplished through grey PVC rollers as opposed to the conventional white PVC.

B. *A minimum of lifting should be required.* Cull elimination chutes are normally at the same height as the edge of the grade table. When a center belt is used, a lift of no more than 2 inches should be necessary to cross the separator between the rollers and the center belt. It is most undesirable to position one or more belts above the grading surface. The graders may be required to remove an orange every two seconds to a belt above the grading surface, equating to over 3 tons lifted in the course of a working day. If grapefruit are run all day, lifting more than 10 tons in the course of an 8-hour day may result.

C. The number of grade positions is determined by the number of individual fruit per unit of time (Table 1), which also determines the number of decisions to be made and consequent actions. For a 200 box per hour capacity, the inspection rate would vary from 16,000 fruit per hour for grapefruit to 47,000 for tangerines. Presuming a 60% packout with the 200 box per hour rate, approximately 6,400 grapefruit, 13,760 oranges or 18,800 tangerines would need to be physically removed. Ideally, the number of graders should vary with the type of fruit. However, the usual tendency in a packinghouse running the three types of fruit is to set the number of graders for oranges, which then means that tangerines are under-graded and grapefruit are over-graded.

D. There is a tendency for graders to reject a given number of fruit per minute, regardless of the fruit quality. Either rate of fruit flow or number of graders should be varied according to the proportion of fruit to be graded out.

E. With high packout fruit, a limitation is how many fruit the graders can *observe* per unit of time. With low packout fruit, the limitation is how many fruit the graders can pick up per unit of time. A study in apple packinghouses showed that with good fruit and well designed grade tables, each worker could cope with over 7,000 fruit per hour. With poorly designed grade tables and low packout fruit, this value could drop to little more than 2,000 (11). In Florida citrus packinghouses, each grader inspects more fruit per hour than in a typical apple packinghouse, so obviously they should be given as much consideration through proper design as possible.

F. An inexperienced grader should not check the grading of an experienced grader. When there is much difference in experience or skill, graders working on the same stream of fruit should be positioned with the least experienced upstream and the most experienced downstream. It is common, but highly inefficient, for 7 or 8 graders to observe the same stream of fruit. Fruit flow should be broken into several groups with no more than 3 or 4 graders per stream of fruit (Figure 6). Not only is less fruit being re-inspected, but each time the stream of fruit is divided, the rate of forward travel can be reduced. For example, with four short grading lines instead of two long ones, the fruit passes before the workers at half the linear speed.

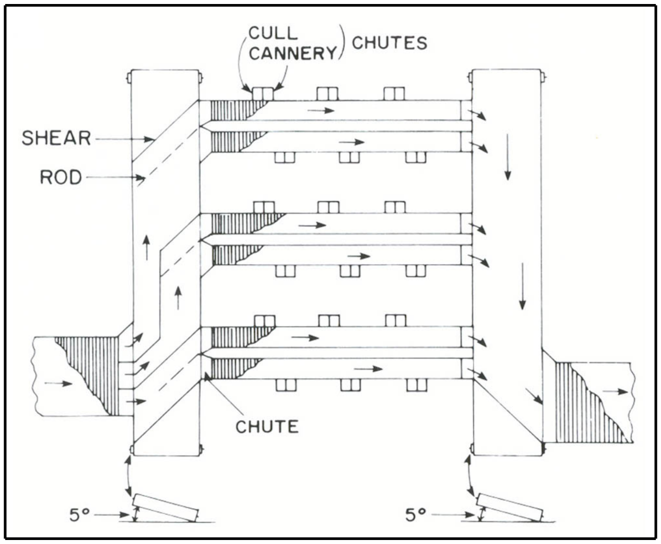

Figure 6. Multiple grade tables. By contrast with a single long grading table, the stream of fruit divides into three standard width graders, speed of forward travel is slowed to one-third and each fruit is examined by one-third as many graders as diagramed for an installation with three two-sided grading tables.

G. A very reasonable provision is to enclose the grading table area in an air-conditioned space to provide better conditions for grading. However, with the eliminations (off grade fruit) being tossed onto metal chutes, noise in such an enclosed area can be excessive. This is distracting for the graders and can reach illegal limits under OSHA regulations (19). A very simple and effective approach to reduce noise is to pad the *undersides* of the chutes with foam rubber. So used, foam rubber never wears out and the sound deadening results are just as effective as putting the foam rubber on the surface of the metal contacted by the fruit.

H. A sharp limitation on the efficiency of the customary roller grader is that rate of forward travel and speed of rotation of the fruit cannot be varied independently. This problem has been solved with various types of "reverse-roll" grade tables developed for the apple industry (11) and are now commonly used in Florida citrus houses. When properly used, they definitely increase the capacity of the workers as well as improving the grade. They must, however, be adjusted for the type and volume of fruit being run.

I. Automatic grading is now feasible for pre-grading of Florida citrus and a substantial number of packers have implemented this technology. The equipment should be sized for the maximum number of fruit handled. Since the fruit takes up one pocket, the number of lanes and the linear speed become the key design specifications. As with fruit washers, a roller-spreader to even the incoming fruit flow is recommended. A section to allow doubled fruit in a pocket to be brushed off is needed especially in handling mandarin varieties and small oranges. Typically these units are based on a peak throughput such as 10 fruit per sec. However, a fill rate of 80% would be exceptional and should be taken into account in capacity determinations. A well-trained operator is critical to automatic grading implementation. The control room should be located so an operator can view both the incoming fruit and the exiting product streams. A maintenance schedule in cleaning camera lens, checking for broken conveyor parts, etc. should be established. Automatic grading can be of great benefit when packout levels are low and the packingline throughput is constrained by the grading task. Weight measurements can be incorporated to calculate fruit density. This criterion is important for separating fruit having natural internal drying or freeze-damage. It has been suggested that the best prospects for economic use of automatic grading equipment in Florida (5) might well be in a highly mechanized, combined fresh fruit and cannery operation (8).

Color-Adding

Color-adding is an optional treatment since it is only used on oranges, Temples, and tangelos–and then only on crops which do not have a distinctive varietal color due to climatic conditions (13). A logical arrangement is to have the color-add tank as a by-pass to the main line. The color-add tank is always a wide piece of equipment in which fruit are several layers deep and therefore advance very slowly. When fruit is not being color-added, it moves forward very quickly on a belt, and it is logical to have the belt in a straight line with no diversions, reducing the possibility of fruit damage.

Color-adding is a time-dependent operation. For a given color-add emulsion, the intensity of color and the amount of residue is determined by the temperature of the emulsion and the fruit exposure time. Maximum conditions for both temperature and time are set by the rules of the Florida Department of Citrus (4).

The color-add process must always be followed by a thorough rinse. Apart from the problem of excess color "bleeding" through the wax, there is a legal necessity for a good rinse as the Food and Drug Administration (FDA) maximum residue is 2 parts per million (ppm) of Citrus Red No. 2. Such rinsing is best done over washer-brushes or moving rollers rather than on a mesh belt or a slat conveyor where the fruit does not rotate.

Waxing

As water waxes are predominantly used for citrus, the water eliminator can be combined with a bed of horsehair brushes to also serve as a fungicide applicator (Figure 5). With solvent wax application, water elimination was the first step in achieving the complete dryness necessary prior to solvent wax application. The more water removed by mechanical means at the water eliminator, the less that has to be removed with more expensive hot air drying.

Water wax applications, now used exclusively, consist of a water emulsion that is applied as a dip, foam, drip, or spray (9). Shellac, polyethylene and carnauba waxes are utilized. Either drip or spray applications are utilized in Florida, the emulsion typically being applied over a bed of slowly rotating (not over 100 rpm) brushes. For this application, either horsehair or 50% horsehair/50% poly is superior to poly bristle, as the horsehair texture tends to hold the emulsion and wipe wax on the fruit rather than throw it off by centrifugal force. The application of the emulsion can be by a bank of fixed or spinning nozzles, drippers, or a traveling nozzle system. In the spinning nozzle system, centrifugal force disperses the wax into a fine fog of emulsion. It is preferable to have two small nozzles on a traveling system rather than one large one so some wax coverage remains if one nozzle is blocked. Also, more uniform coverage results with multiple nozzles. Some waxing units have a flowrate controller which can be set for various types of citrus as the fruit surface area per box decreases with larger sized fruit. Another innovation incorporates finger sensors with switch closures mounted above a conveyor leading to the waxer. The fruit flow is monitored by this device regulating a pump or valve to provide proportional wax flow.

A convenient system for cleaning out wax applicator lines is to have a hot water line connected to the emulsion delivery line with shut-off valves so that the emulsion can be shut off and the lines purged. Special precautions must be taken when packing for an export market with different regulations on waxes and, or fungicides from those of the domestic market (27). A brushbed used for application of wax, fungicide, or both, can contaminate fruit being run over it long after the changeover has been made. Efficient cleaning of the brushbed can be obtained by the use of flick bars under the brushes (Figure 5). These bars are on a sliding rack under the horsehair brushes of the applicator. Except when rinsing, they are in an inoperative position with the flick bars between the brushes.

To clean a brushbed or change wax formulations:

1. *First* rinse out the wax lines and nozzles thoroughly. There is no point in cleaning the brushbed and then flushing out the nozzles onto the brushes.

2. Move the flick bar to its noncontact position and start the brushes.

3. Engage the flick bars so each will contact its corresponding brush.

4. Hose down for at least a minute with the flick bars in place and the brushes revolving.

5. After rinsing, leave flick bars in place for 20 seconds or more to remove excess water which would dilute the wax.

6. Reposition flick bars into the noncontact position.

Fungicide Application

Details of fungicide application are found in Extension Circular 359A (24). It should be noted, however, that fungicides applied on the packingline fall into two classes, depending on whether they are used on unwashed or washed fruit. Sodium o-phenylphenate, as prepared for use on fruit, is an excellent detergent which penetrates into minor wounds on the surface of the fruit. It is usually applied at the washer followed by a water rinse. Other fungicides are best applied (usually over a brushbed) after pre-grading and before drying. Some fungicides may be incorporated in fruit waxes, however, the efficacy may decrease (2). It is important that fungicide application equipment be regularly checked and well maintained to assure the best possible decay control.

Drying

The surface moisture drying rate of fresh citrus is influenced by three factors: surface area, humidity ratio difference, and mass transfer coefficient of water into the airstream. Surface area is determined by fruit variety and packingline capacity. Humidity ratio differences can be determined from psychrometric conditions of the heated air and surface water temperature, which will approach the wet-bulb temperature of the dryer air as evaporation occurs. After evaporation, peel temperatures will approach the heated air dry-bulb temperature. The mass transfer coefficient is affected by the air velocity and geometric considerations such as fruit sphericity, layers of fruit, and type of conveyor, slat or roller (15). Maintaining a full conveyor is essential to eliminate airflow by-passing the fruit.

The dryer moisture load varies with type of fruit. Tangerines with concave ends and a high fruit surface area per box have the greatest unit moisture load. With 0.002 lb water (0.9 g water) per fruit and 300 tangerines per Florida field box, evaporation load is 0.60 lb water (270 g water) per Florida field box. In contrast, grapefruit at 0.004 lb (1.8 g) per fruit and 90 fruit per field box has a calculated load of 0.36 lb (162 g) per Florida field box.

In water wax applications, other chemicals are vaporized which have latent heats of vaporization different than that of water. Furthermore, water may be chemically bound or may require additional drying to overcome tackiness of the wax. Dryers after wax treatments should always be in two sections, a short initial section and a longer final section. This design largely confines excess wax accumulation on the equipment to the first short section. Waxed fruit should not roll continuously while drying. This is usually achieved by using either a slat conveyor or dead rollers which are only supported by the pin chain at the sides so that they do not turn. Contact points between multilayered fruit are difficult to dry, and the fruit requires periodic rotation to expose contact areas as they progress through the dryer. *The combination of hot air and brushing can be a source of damage to tender fruit and is strongly discouraged.*

Some general procedures that are followed in Florida packinghouses include the following: minimum drying time of 2.5 minutes and a maximum air temperature of 140°F (60°C). In cases where modular fan-heater units are utilized, the first dryer section can be set at higher temperatures since the constant evaporation retards excessive temperature increase of the fruit (15). The temperature of the hot air that can be used without damaging fruit depends on several factors. The first of these is obviously the frailty of the fruit. Tender specialty fruit, such as degreened Robinson tangerines, should be heated as little as possible and never brushed. In contrast, mid-season grapefruit seldom suffer damage during drying.

Air recycling is an important energy conservation feature in dryer design. In most cases, heated air is not saturated after passing over the fruit. The air can be further utilized in a multipass dryer, in an air-to-air heat exchanger, or by proportionally mixing with ambient air for recycling. The latter is the most straightforward and requires the least capital investment. A major advantage in a heat exchanger is that only sensible heat is transferred to the inlet air stream and latent heat, associated with moisture, is exhausted. Such exhaust air should be expelled to reduce humidity buildup in the packinghouse. This arrangement has the added advantages of reducing heat and humidity for the benefit of nearby workers. Insulation of the dryers also will save energy and reduce noise levels.

The optimum proportion of recycled air is governed by reduced energy losses via recycling and a reduction in drying potential as dryer air becomes more saturated. The driving force (humidity ratio difference) can be established for the heated air by knowing two of the following properties: dry-bulb temperature, wet-bulb temperature, dew point, or relative humidity.

Infrared drying may have significant potential for initial drying but is energy intensive also. The entire fruit surface must be exposed to the infrared radiation for complete drying. Hence, natural rotation of fruit on rollers and multilayering of fruit make entire drying from an infrared source difficult. However, partial initial drying by infrared has been used on citrus and other crops. Care should be exercised in fruit handling so that there is no contact between fruit and radiant-heated metal surfaces.

Sizing

Most Florida packinghouses now have optical sizing units using either line or area scan cameras. Capacity of these units should be based on a maximum unit count for a crop of high packout. These units size fruit in cups or between rollers providing finer resolution and less abrasive injury to fruit than mechanical sizers. Operators also are able to easily adjust the size categories to maximize the output of desired sizes and to switch between types of fruit such as grapefruit and oranges. Fruit count to an individual drop can be controlled for loose-fill carton filling. Also, electronic weight sizing has been implemented and can be used to control packed carton weight. With a combination of these features, density separation of naturally internal drying and freeze-damaged fruit is possible.

For belt-and-roll sizers, efficiency depends on the relationship between the fruit contact speeds of the belt and roller. For example, on a Florida belt and roll sizer widely used, the belts move at 225 linear ft/min (1.1 m/s) and the 3-inch (7.6 cm) diameter rollers turn at 102 rpm, giving a linear roller surface speed of 80 ft/min (0.4 m/s). This relationship of 2.8:1 must be maintained to size the many types and shapes of citrus fruit likely to be sized in one day in Florida.

Fruit Labeling

Stamping of fresh produce has been supplanted by labeling technologies. The major impetus of this change has been the Universal Product Code (UPC) label requirements imposed by large grocery chains. Detailed information is available on the coding designations (21) for citrus and other fresh produce items.

The labeling is now done after sizing as the price look up (PLU) codes are different for small and large produce items of the same variety. Direct interfacing with electro-optical sizers has been employed but multiple banks of stamping heads are required for each label designation. If brand identifying labels are placed on the fruit also, 3 banks of labeling heads would be required. With mechanical sizing, fruit is conveyed to a roller grommet section with labeling units overhead to facilitate the label application. Bar code systems may someday replace the current UPC identification.

Fruit Packing

Details of fruit packing methods are not dealt with here. However, in any new equipment being set up, provision should be made for ultimate mechanization; the trend is sharply away from individual place packing to mechanized packing with an operator running one or several machines. The system should always allow for maximum flow to every machine, which is not possible when packing machines are merely substituted for people in a traditional packinghouse layout (7).

One common practice which damages citrus fruit is overfilling cartons. When cartons are filled higher than the carton top, the fruit rather than the carton bears the weight of the stacked cartons. For loose-fill as opposed to place packing, a larger carton is necessary. Operations using such mechanical volume-fill sytems may fill cartons upside down. Then when opened from the top, the “pack” looks surprisingly uniform. Although citrus fruit are approximately spherical when packed, they occasionally arrive in the markets severely flattened due to overfilling. It is better to have cartons appear less than full than to have them contain damaged fruit. Volume filling can be done on a fruit count or weight basis. This method takes advantage of mechanization, but makes for a less tailored appearing pack. The ultimate consumers rarely, if ever, see cartons of citrus fruit as they are opened, so the advantages of place packing are only useful to impress people in the wholesale markets and the back rooms of grocery stores. Volume or weight filling, common in bagging operations, may increase for carton operations as the cost and availability of packing labor become more prohibitive.

Palletizing

Cartons of packed fruit are palletized by stacking on wooden pallets, or on fiberboard slip sheets. The pallet can then be moved by lift trucks. Traditionally in Florida, the least reliable labor in a citrus packinghouse is the "set-off crew" who stack fruit cartons on pallets. The work is quite arduous and monotonous.

Mechanical palletizers are commonly used in Florida citrus packinghouses. They are expensive and require even more expensive accumulation systems to group and align enough cartons of one variety, grade, size and type of package (bagged vs. loose) to fill a pallet. Mechanical palletizers eliminate a set-off work force but require several other employees with specific training, namely the palletizer operator(s) and people to direct cartons to the proper lanes in the accumulation system. Some form of simple robot may accomplish the palletizing task in the future. Such robots would not require precision accuracy and should compete economically with mechanical palletizer accumulation systems. Standardization in package size is beneficial for palletization but a diverse range of carton types has evolved in recent years.

Minimizing Fruit Damage on the Packinghouse Line

Damage to fruit on the packinghouse line can take several forms. One of these is inoculation with decay organisms. This is very common when water dumps or soak tanks are used, even when a fungicide is put into the water. This is because there are several decay organisms, such as anthracnose *(Colletotrichum)*, sour rot *(Geotrichum)*, and various resistant strains of mold *(Penicillium)* which are not controlled by approved fungicides. A particularly subtle type of damage occurs due to excessive polishing. Fruit that has been through a hot polisher-dryer may appear beautiful when packed, but the peel can become crisp and brown a few days later. Therefore, *polisher-dryers are not recommended.* The third, and probably most common, type of damage is mechanical injury such as cuts and abrasions. Citrus fruits are comparatively resistant to bruising, but are very susceptible to decay after being scratched or scraped enough to cause small, often invisible, breaks in the peel.

Mechanical damage to fruit most commonly occurs at the transfer point between pieces of equipment or at corners. The most common locations for damage are discussed below. Studies have been undertaken to quantify impact damage with Instrumental Sphere technology (18). Impact damage is more prevalent at transfer drops, mechanical sizers and pallet bin dumpers.

Brushing

Abrasive damage occurs to fruit due to excessive brush speeds and excessive brushing time, especially with washer brushes having very stiff bristles. Although a stiff bristle may be needed for thorough cleaning, the brushing time should not be extended. To control brushing time, a continuous wipeout or one activated by lack of fruit flow should be installed. Brushing time can be significantly altered by dump rate, pre-sizing and pre-grading in some cases. Since these factors vary, some wipeout mechanism is critical to prohibit excessive brushing action. Another helpful practice is to condition new brushes at the beginning of the season when the fruit peel is tender, and especially when sensitive fruit such as tangerines are packed. A plywood sheet lightly touching the rotating brushes for 1 to 2 hours is effective to condition new brushes. Also, the installation of new brushes may be delayed until a midseason break when the fruit peel is more mature.

Damage from brushes can be minimized by pre-wetting the fruit so that dry fruit is never on dry brushes. With this in mind, it is not advisable to use polisher dryers (soft brushes in dryers). Brush speeds over 120 rpm for washers and 100 rpm for fungicide and wax applicators should be reviewed carefully for benefit vs. damage to the fruit peel. Fruit with brush damage (tiny scratches in the cuticle and possibly the outer layer of cells) is more subject to damage from contact with caustic chemicals or excess heat and will dehydrate during marketing. Fruit with damage from brushes will normally show an injury several hours or days after the damage occurs.

Dumping

Today most dumping is from pallet boxes that empty approximately 900 pounds (400 kg) of oranges at once. Cushioning material and overhead deceleration curtains can reduce the high impact levels of the first fruit discharged. It is imperative that this large mass of fruit be leveled out as rapidly as possible, both to avoid squeezing and scraping of the fruit and to make it possible to get the trash out. Some form of anti-surge device, such as 2 belt sections running at different speeds, is recommended.

Deliveries from Roller and Slat Conveyors

All deliveries from roller conveyors should be equipped with ejector slats on the drive shafts (Figure 7). The deliveries from slat conveyors should be equipped with spinner rolls (Figure 8). Chutes (transfer plates) from roller and slat conveyors should be aligned as an extension of a radius from the head shaft (Figures 7 and 8). The slight drop from the roller to the chute will not damage the fruit, but a chute with too little slope on which flat or irregular shaped fruit can back up can be very damaging. A minimum angle of 20° is suggested but the coefficient of friction is dependent upon the material selected (17).

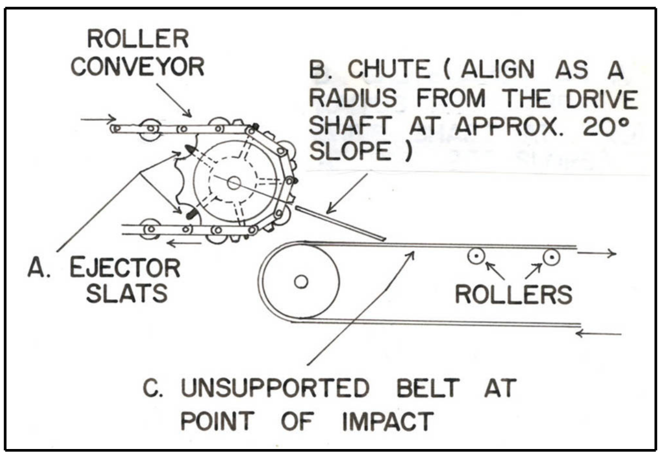

Figure 7. Delivery from roller conveyor to a belt. A. Ejector slats. B. Chute aligned as the radius of the head shaft. C. Delivery onto unsupported belt where one roller has been removed.

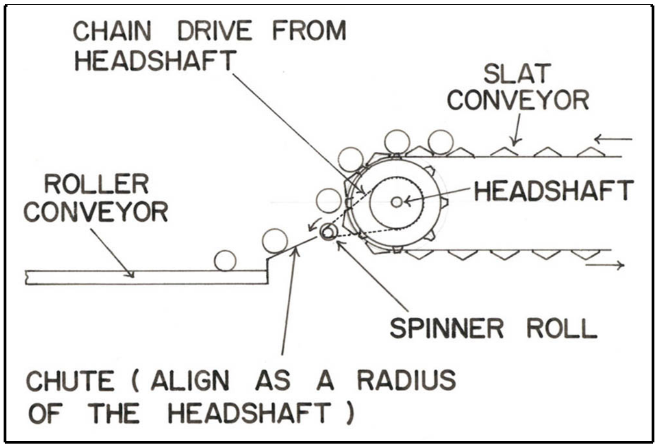

Figure 8. Spinner roll on a slat conveyor delivery.

Points of Impact

One common point of impact is when fruit drop onto a belt. Drops of several inches can be allowed onto a belt *if it is not supported underneath at the point of impact* (Figures 7 and 9). Where the belt is carried on rollers, the rollers are removed at the point of impact; where the belt is carried on a pan, the pan should be cut away under the impact area. Rollers rather than pans for supporting the belts are always recommended, as dragging the belts over a metal pan can increase the horsepower requirements by as much as 30%.

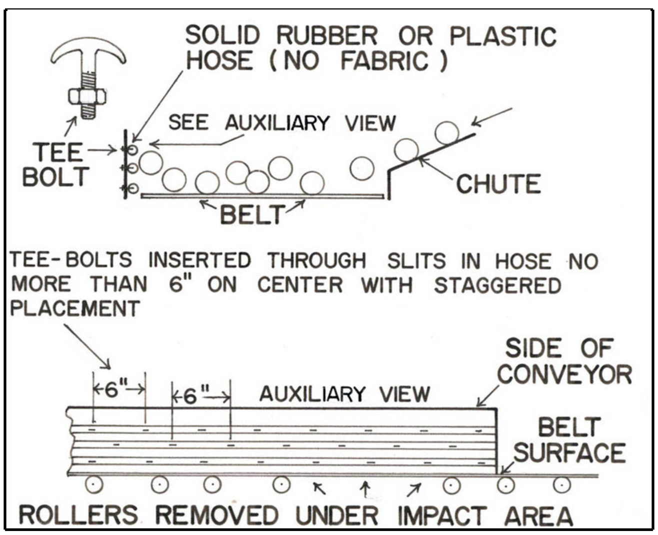

Figure 9. Solid rubber or plastic hose (no incorporated fabric) used as a bumper opposite a right-angle delivery.

Another typical point of impact is where fruit is delivered at right angles onto a belt, as from a dumper. A second point of impact is the side of the machinery. Most forms of padding wear away rapidly or build up with wax which catches debris and becomes abrasive. An excellent form of bumper is made from plastic hose attached with Tee-bolts such as are used for attaching slats in a slat conveyor (Figure 9). The bumper hose should be continued along the conveyor until the point at which the fruit is no longer rolling. The bumper can then be discontinued, and the fruit will continue on the belt without scraping against the sides, materially reducing the wear and tear on both the fruit and the equipment.

Turns

More damage is done to fruit at turns of various kinds than anywhere else in a normal packinghouse. Most turns are at right angles and many involve delivery from one type of conveyor onto another. In general, over-the-end delivery from one conveyor to the other (Figure 10) is preferable to the use of a shear (Figure 11). When two belts intercept at right angles, the belt pulling the fruit out of the corner should be on the top (Figure 12).

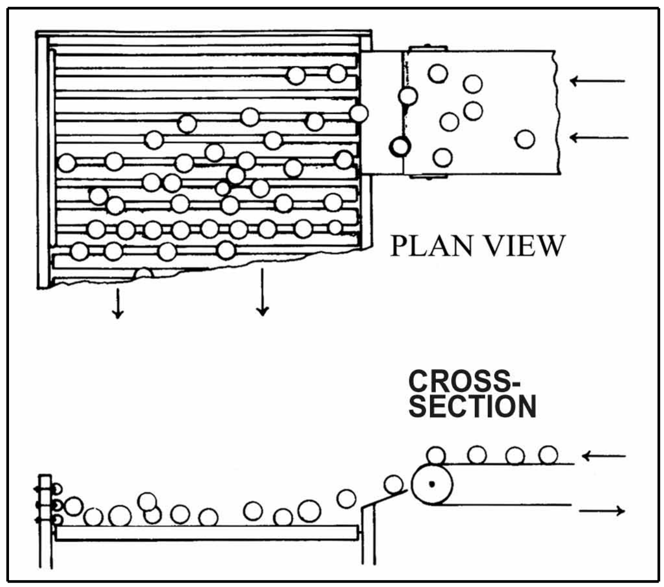

Figure 10. Over-the-end delivery for a right-angle turn onto a belt, roller conveyor, or slat conveyor. This method is preferable to the use of a shear. Triangular delivery chute is necessary when delivering onto a slat conveyor but not essential for either a belt or roller conveyor.

Where the fruit is to turn at right angles, a shear is most commonly used. Most fruit damage occurs at such turns, largely due to the almost inevitable error of not cutting back the inside corner of the turn, thereby restricting the fruit flow and forcing it against what is usually a sharp edge at the inside corner

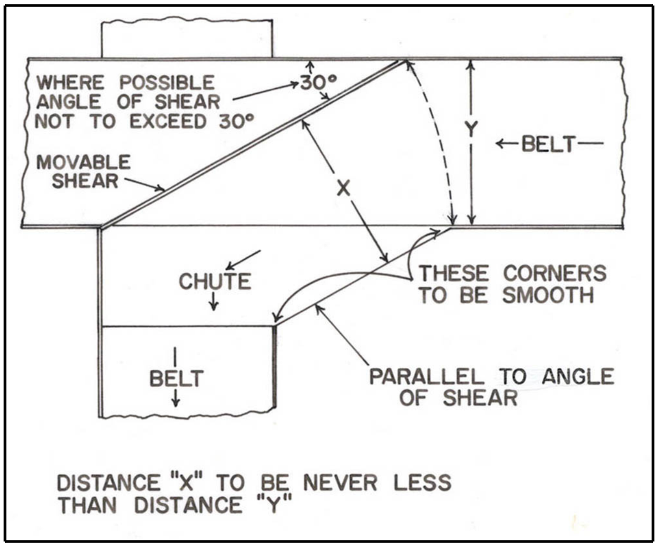

Figure 11. Cutting back the inside corner of a sheared turn. A shear angle of 30° is optimum, but 40° can be used. A supporting plate that prevents the belt from sagging under the shear helps to minimize the change of fruit injury.

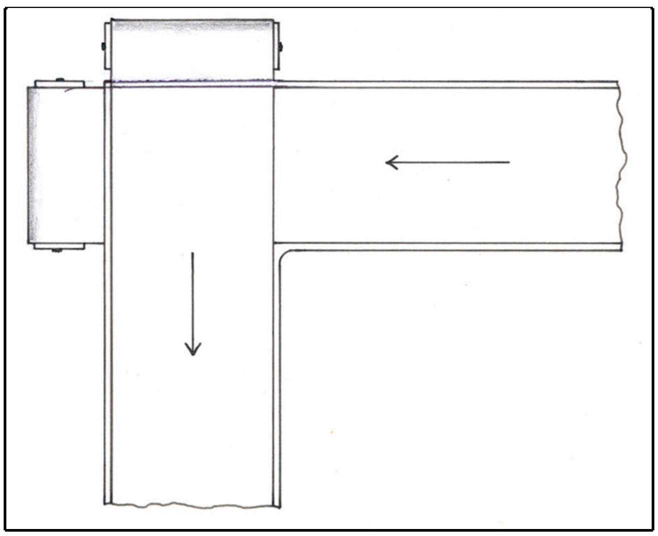

Figure 12. When conveying fruit on two belts at the same elevation, the second belt should be on top. Over-the-end delivery (Fig. 10) is preferred.

(Figure11). It is preferable to keep the angle of a shear no more than 30 degrees. However, there are many cases where this is not possible, particularly when shearing from a narrow belt onto a wider conveyor (Figure 13). In such cases, rods should be used parallel to the shear and riding on the delivery belt. In most instances, a 1/4 inch steel rod is adequate. Where several successive rods are used, they should increase in diameter. When fruit rapidly changes directions, as in bypass belts into and out of a color-add tank, the fruit flow can be aided, and damage minimized by sloping belts 5 degrees in the direction of fruit exit.

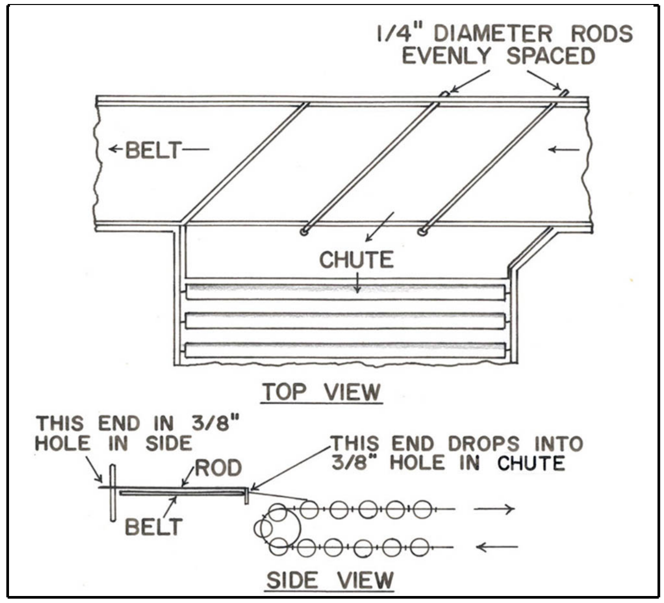

Figure 13. Use of diversion rods with a fixed shear. The rods are NOT fixed in place. They are inserted through holes in the chute and the side of the conveyor and ride on the surface of the belt.

The surface material of the shear contacting the fruit should be slick and resist fruit wax accumulation. Metal shears should not be painted, and wooden shears are best covered with laminated plastic. At the beginning of the fruit line, where there may be twigs and leaves in the fruit stream, shears should be made self-cleaning by cutting out the downstream corner so twigs caught under the shear will be released (Figure 14).

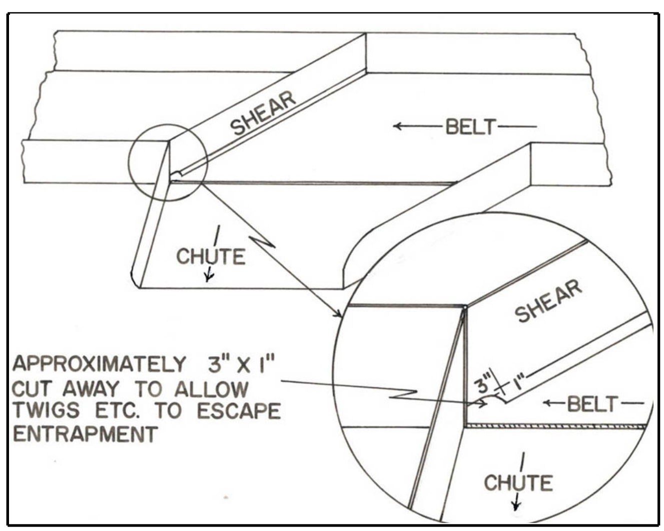

Figure 14. Self-cleaning shear.

Calculating Packingline Capacity

The capacity of a given item of equipment or the size of equipment necessary to handle a given volume of fruit can be calculated. For this, it is necessary to know certain characteristics of both the fruit (Table 1) and of the equipment (Table 2). Note that all conveyor capacities in Table 2 are based on 100% utilization. Here 100% utilization is considered as the case where fruit is a single layer deep and at full capacity (i.e., no empty spots). When these conditions do not exist, an efficiency factor should be incorporated into the capacity equations. In most instances, the actual utilization will be somewhat less than 100%, but will vary according to the machine and the matching of capacities for various machines. Maximum usage may be associated with either low or high packouts. For example, number of graders and belts for rejects should be based on low packout numbers. Packing stations and capacity of the fruit sizer should be based on anticipated high packout levels.

Fruit Characteristics

The capacity of a packinghouse line is governed by certain characteristics of the fruit, particularly fruit size, although weight and shape can also be limiting factors in certain circumstances. On belts, capacity is determined by the speed of the belt (Table 2) and by the area occupied by a box or other unit of fruit (Table 1). On slat and roller conveyors, capacity is determined by the number of linear feet when that same unit of fruit is lined up in a row. This ranges from 27 linear feet for a Florida field box of grapefruit to about 55 linear feet for a box of tangerines. Because of these factors, a belt that can carry 10 boxes of grapefruit at a given speed can carry only 8.7 boxes of oranges and less than 7.0 of tangerines. A slat or roller conveyor that can carry 10 boxes of grapefruit can carry only 6.3 boxes of oranges or 5.0 of tangerines.

It is in manual grading that the size of fruit becomes most critical. Not only is the fruit normally lined up in rows on rollers, which limits the capacity of a conveyor, but, more critically, each grader can make only a limited number of decisions and motions per minute. There is also a human element, as has been noted previously, in that graders tend to throw out a given number of fruit per minute regardless of the condition of the fruit.

Equipment should never run at speeds to cause appreciable damage to fruit along the packingline. However, lines are often operated above design capacity. In such situations the point at which damage first occurs when the line is speeded up or overcrowded becomes the limiting factor. This factor is compounded when handling varieties susceptible to mechanical injury such as tangerines or lemons which require greater conveying surface area per box (Table 1). Electric, hydraulic or mechanical variable speed drives are available to change the linear speed of conveyors or the rotation speed of rollers or brushes.

Equipment Characteristics

Packinghouse machinery in Florida, and to a certain extent elsewhere, has standardized certain components. Such standardization is most helpful in equipment maintenance and in calculating equipment capacities. The amount of fruit per row will vary with the fruit characteristics and the width of the line, but once known, volume or weight of fruit per row or revolution of the machine can be computed.

Equipment characteristics of the machinery components most commonly used in Florida citrus packinghouses are compiled in Table 3. Deviation from such standard specifications, particularly in width of conveyor, can be expected to entail extra costs.

Standard Sizes and Components

Numerous sizes of belts, rollers, and slats are utilized throughout the citrus industry. Roller and slat conveyors are typically found in 6-inch width increments from 12 to 84 inches. Standard drum diameters for belt conveyors range from 6 to 18 inches. Normal belt widths are 14, 18 and 24 inches for small capacities with belts in 1-foot increments above 2 feet for larger fruit volume. Typical belt drive configurations include single and multiple wraps (Figure 15). Double-pitched roller chain is used for most roller and slat conveyor applications. Rollers are typically driven through D5 attachment pins. Chain size and number of sprocket teeth will depend upon design capacity of the system. With double pitch roller chain, sprockets with an odd number of teeth are preferred to reduce the wear factor by 0.5 as contact teeth alternate with each revolution. Sprockets for conveyor and elevator applications usually have the same diameter at both ends. Sprockets with more teeth will minimize wear and provide smoother operation. With this arrangement, only the carrying portion of the conveyor chain is under a high load. A list of typical components has been assembled in Table 3.

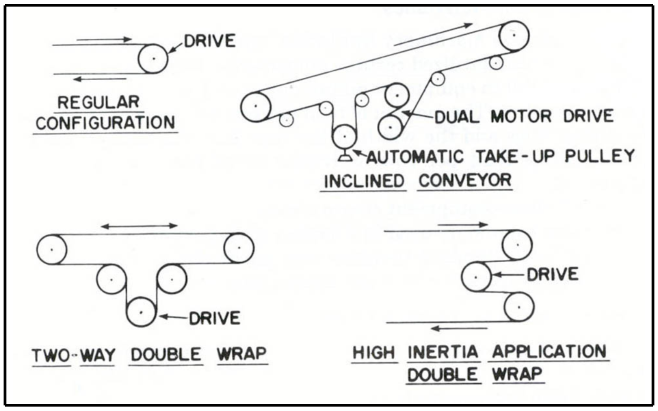

Figure 15. Various belt drive configurations.

Safety Considerations

Safety is very important for the efficient operation of a packinghouse. Federal and state regulations frequently require certain safety precautions, such as guards on chains and bright paint, to highlight certain dangers. In the United States, the Occupational Safety and Health Administration (OSHA) regulates safety in the workplace. Insurance companies may require that safety be taught and practiced. Astute managers will encourage their employees to be safety conscious, keep their machinery and equipment in good repair and do everything possible to avoid accidents. An accident not only interrupts production, but also can be very expensive in terms of personal injury and workman's compensation settlements.

A safety checklist can be helpful to evaluate efforts to improve safety in the workplace. Such a list might include the following:

- Prepare a checklist of safety and ergonomic practices for your particular plant
- Make sure that federal, state and local codes are followed
- Assign one employee to be responsible for safety
- Keep a record of accidents and work-related injuries
- Inspect for tripping hazards
- Properly mark areas of low overhead clearances and take precautionary measures
- Inspect usefulness of guardrails and note absence of needed guardrails
- Inspect for and eliminate sharp edges and burrs
- Provide guards over all chains and rotating assemblies
- Assure face and eye protection for bright flashes and sparks, e.g., welding equipment
- Implement a safety awareness program and post hazard warnings where appropriate
- Be sure that controls are readily accessible and that emergency "Stop" buttons are easily accessible, clearly marked and always painted red
- Guard critical controls to prevent inadvertent operation
- Train employees to respond to emergencies
- Take precautions to avoid electric shocks
- Provide lift trucks and other vehicles with governors or other speed controls
- Reduce noise levels to meet standards and to prevent fatigue and interference with hearing
- Provide adequate lighting, especially for critical locations such as grading
- Protect workers from exposure to dryer heat, volatiles and chemical spills

- Provide comfortable handles when lifting is required
- Avoid unassisted lifting of heavy objects
- Provide safe handling procedures for pesticides and any other potentially toxic substances
- Design equipment to avoid fires and explosions
- Continually train employees to work safely
- Display prominently a notice board, "Days Since Accident Involving Time Off"

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Table 1. Physical characteristics of citrus fruit relevant to conveyor design.

Symbol[z]	Abbreviation	Characteristic	Grapefruit	Oranges	Tangerines
	lb/box	Pounds per Florida field box [y]	85[x]	90[x]	95[x]
	no./box	Average number of fruit per box	80	172	235
	U. S. Measures				
	in.	Average diameter	4.1	3.0	2.8
a	ft^2/box	Area (ft^2) per field box*	7.9	9.1	11.3
	boxes/ft^2	Field boxes per ft^2	.126	.109	.088
	lb/ft^2	Pounds (lb) per ft^2	10.7	9.8	8.4
	no./ft^2	Average number of fruit per ft^2	10.1	18.7	20.7
ul	ft/box	Linear feet per field box	27.3	43.0	54.8
	lb/ft	Pounds (lb) per linear foot	3.1	2.1	1.7
	Metric Measures				
	cm	Average diameter	10.4	7.6	7.1
A	m^2/10 kg	Area (m^2) per 10 kilograms of fruit	.19	.21	.24
	kg/m^2	Kilograms per m^2 of fruit	52.1	47.7	40.9
	no./m^2	Average number of fruit per m^2	108.7	201.2	222.7
UL	m/10 kg	Linear meters per 10 kilograms of fruit	2.16	3.21	3.88
	kg/m	Kilograms per linear meter of fruit	4.02	3.11	2.58

Table 1. Physical characteristics of citrus fruit relevant to conveyor design.

[z]See Table 2.
[y]Florida field box = 4,800 in^3 (approx. 2.23 U.S. bushels).
[x]Legal measure.
NOTE: Area per box and linear feet per box have been determined from statewide statistical analysis. Such figures may vary from theoretical values when fruit are not spherical, e.g., oblate for grapefruit, elliptical for lemons, etc.
*Assume nested pattern.

Table 2. Formulas involved in conveyor capacity.

Value Needed	Belt Conveyor	Slat or Roller Conveyor[z]
U.S. measures[z]		
Capacity of a given conveyor (boxes[y]/hr)	$C = \frac{w \times s \times 60}{a}$	$c = \frac{60 \times rpm \times n \times w}{ul}$
Necessary linear speed (ft/min) for a given capacity	$s = \frac{c \times a}{w \times 60}$	$s \ x \ \frac{c \times ul \times r \times 2 \times Pi}{w \times n \times 60}$
Necessary drive shaft rpm for a given linear speed (ft/min)	$rpm = \frac{s}{Pi \times d}$	$rpm = \frac{s}{2 \times Pi \times r}$
Necessary rpm for a given capacity (boxes/hr)	$rpm = \frac{c \times a}{w \times Pi \times d \times 60}$	$rpm = \frac{c \times ul}{60 \times n \times w}$
Metric measures[x]		
Capacity of a given conveyor (tonnes/hr)	$C = \frac{W \times S \times 6}{10 \times A}$	$C = \frac{RPM \times N \times W \times 6}{UL \times 10}$
Necessary linear speed (m/min) for a given capacity	$S = \frac{10 \times A \times C}{6 \times W}$	$S = \frac{C \times UL \times R \times 20 \times Pi}{W \times N \times 6}$
Necessary drive shaft rpm for a given linear speed (m/min)	$RPM = \frac{S}{Pi \times D}$	$RPM = \frac{S}{2 \times Pi \times R}$
Necessary rpm for a given capacity (tonnes/hr)	$RPM = \frac{A \times C \times 10}{6 \times W \times Pi \times D}$	$RPM = \frac{C \times UL \times 10}{6 \times W \times N}$

[z]U.S. measures: c = capacity (boxes/hr); w = width of conveyor (ft); s = linear speed (ft/min); a = area (sq. ft.) of a box spread 1 fruit deep; d = diameter of drum (ft); rpm = revolutions/min; n = number of fruit rows/sprochet revolution; ul = length of 1 box as a single row of fruit (ft); r = pitch radius, ft; Pi = 3.1416.
[y]A Florida box = 90 lbs oranges, 85 lbs grapefruit, or 95 lbs tangerines.
[x]Metric measures: tonne = 1,000 kg = 2,205 lbs.; C = capacity (tonnes/hr); W = width of ocnveyor in meters (m); S = linear speed (m/min); A = area (m^2) of 10 kilograms (kg) of fruit; RPM = revolutions per minute; N = number of fruit rows/sprochet revolution; UL = length of 10 kg fruit in a single row; R = pitch radius, m; D = diameter of drum (m); Pi = 3.1416.

Table 3. Standard equipment dimensions.

Belt Conveyors	*Standard Sizes*
Width in. (cm)	14 (35.6), 18 (45.7), 24 (61.0), 36 (91.4), 48 (121.9), 60 (152.4)
Drum size in. (cm)	6 (15.2), 8 (20.3), 10 (25.4), 12 (30.5), 14 (35.6), 18 (45.7)
Roller and Slat Conveyors	
Width in. (cm)	12 (30.5), 18 (45.7), 24 (61.0), 30 (76.2), 36 (91.4), 48 (121.9), 60 (152.4), 72 (182.9), 84 (213.4)
Chain	RC2060 with D5 attachment (roller)
	RC2060 with A3 attachment (slat)
Rollers*	2 in. Aluminum tubing
	2 in. Sch. 40 steel pipe
	2 in. Sch. 40 PVC pipe
Washers and Water Eliminators	
Brush length	(As required)
Brush diameter in. (cm)	Less than 6 (15.2)
Moisture eliminators in. (cm)	4 to 6.25 (10.2 to 15.9) (various sizes)

*Pipe diameters are nominal. Sch. 40 2-inch-pipe is 2.375 inches O.D. (6.0 cm O.D.)