Conical Scan Air Shaker for Removing Citrus Fruit

G. E. Coppock, J. R. Donhaiser
MEMBER
ASAE

ABSTRACT

A small machine approach led to the development of a conical scan air shaker for removing citrus fruit. At or below 22.2 N fruit removal force, the shaker in conjunction with an abscission chemical removed fruit from trees at a rate of 170 trees/h with an average removal efficiency of 97 percent.

INTRODUCTION

The Florida citrus industry produced approximately 9.2 million t (10.1 million tons) of citrus on 310,030 ha (766,100 acres) during the 1978-79 season (Florida Agricultural Statistics - Citrus Summary, 1979). About 83 percent of this production was processed with oranges and grapefruit the principal cultivars.

Citrus harvesting is seasonal and labor intensive, employing 35,000 workers at peak periods. The fruit is still picked almost entirely by hand. Handpicking is a strenuous, hazardous, and unpleasant task. Workers prefer other employment when available; thus causing periodic shortages of pickers during the citrus harvesting season. Mechanization of the harvest is expected to improve working conditions and lower peak labor requirements.

Shakers for citrus fruit removal have been developed and demonstrated for processing oranges (Whitney and Sumner, 1977). Air shakers have a significant advantage over other shakers by not having to physically attach to the trees. This advantage contributes to the high volume fruit removal characteristics of air shakers. However, their effectiveness is largely dependent on having the fruit uniformly loosened with an abscission chemical (Wilson et al., 1977).

In the early development of air shaker technology, two approaches were considered. One was to develop a large machine capable of removing the fruit in one pass along each side of the tree. Whitney and Patterson (1972) reported developments on this approach. The other approach was to develop a smaller machine with considerable leeway in directing the air, although more than one pass along each side of the tree might be necessary.

Article was submitted for publication in December 1980; reviewed and approved for publication by the Power and Machinery Division of ASAE in February 1981. Presented as ASAE Paper No. 80-1527.

Cooperative research by Florida Department of Citrus, University of Florida and USDA-SEA-AR.

Florida Agricultural Experiment Station Journal Series No. 2772.

Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the Florida Department of Citrus or an endorsement over other products not mentioned.

The authors are: G. E. COPPOCK, Agricultural Engineer and J. R. DONHAISER, Engineer, Florida Department of Citrus IFAS, Agricultural Research and Education Center, Lake Alfred, FL.

FIG. 1 Oscillating air shaker using two centrifugal fans to produce high velocity air streams for fruit removal. Vanes in air outlets direct the air streams to converge at 2.4 m.

A small machine was developed using a conical scan shaking principle. The purpose of this paper is to discuss the work leading to this development, present machine specifications and give test results.

EARLY DEVELOPMENT WORK

Work was initiated in 1965 on the small machine approach but was discontinued because of low fruit removal efficiency and the poor prospects of finding an abscission chemical to adequately loosen the fruit. However, interest in this approach was renewed in 1970 when the prospects for the development of a successful abscission chemical had improved.

A fruit removal study using an FMC Rotomist sprayer equipped with an air outlet nozzle to produce a single air stream showed that a large initial force was still required for fruit removal, even though it was loosened with an abscission chemical (University of Florida Annual Report, 1970). However, once fruit movement occurred, removal was rapid. The magnitude of the force was dependent on the load of fruit and the stiffness of the limb. Also, this study showed that fruit removal could be accomplished by the impingement force of a high velocity air stream with only a minimal movement of the large limbs.

An air shaker was built in 1973 to test the high velocity air stream fruit removal concept (Fig. 1). Two 66-cm (26-in.) dia centrifugal fans, spaced in line horizontally 61-cm (24-in.) apart, were constructed so that the housing would oscillate 90 deg about the fan shaft. Each fan housing was oscillated by a separate crank drive mounted on a common shaft and the cranks were adjustable so that the phase angles between fan housings could be varied. The fans and drive engine were mounted on a trailer with a pantograph for positioning at various

  0001-2351/81/2406-1456$02.00

FIG. 2 Rotating boom air shaker using aircraft propellers to produce cyclic pulses of air on trees for fruit removal.

heights. The peak outlet air velocity of the fans was 76 m/s (170 mph).

Several changes were made on the machine during a period of operation. As originally designed, the fan housings were oscillated in phase at 60 cpm (cycles per min). However, because of the high inertial force generated in the housings, only 30 cpm was obtained safely without causing the machine to become unstable. To improve stability and increase the oscillation rate, the fan housings were placed 90 deg out-of-phase and oscillated at 60 cpm. This arrangement exposed a point on the tree to 120 air pulses per min with varying time spans between pulses as the housings swept through the 90 deg cycle. The short time span between pulses near the end of the sweep as the housings reversed direction did not allow the limbs to fully swing back from the pulses, thus contributing to poor shaking action. When the phase angle was decreased to 45 deg, the limb response was greatly improved. Vanes were placed in the air outlet of each fan and focused to direct the air streams to converge at a point 2.4 m (8 ft) from the outlets giving a horizontal component to the air pulses. This later arrangement was very effective in removing fruit by exposing it to (a) the impingement force of the air stream, (b) the vertical limb oscillations produced by the 90 deg sweep of the air streams, and the horizontal oscillations produced by the converging air streams.

An air shaker was built by a private individual using 1.5 m (5 ft) wooden aircraft propellers mounted on each end of a 4.7 cm (15.5 ft) boom to produce 2 air streams (Fig. 2). The boom rotated about its center to produce a cyclic air pulse on the trees as it was drawn past a row of trees. Outlet air velocity at the center of the propeller with the boom stationary was 53.6 m/s (120 mph) and averaged 40.2 m/s (90 mph), 2.4 m (8 ft) away. The propellers were powered by a 313.2 kW (420 hp) diesel engine through a V-belt arrangement about the rotational boom pivot. The boom was rotated at 40 rpm (rev. per min) as the machine was drawn along a row of trees with the propellers operating at 2600 rpm.

The shaker was effective in removing fruit when it had been uniformly loosened; however, the machine was dangerous to operate and produced an irritating noise. Fruit was removed more by cyclic movement of the limbs rather than by air impingement on the fruit.

FIG. 3 Conical scan air shaker using a vane-axial fan and rotatable air director assembly to produce a cyclic pulse of high velocity air for fruit removal.

CONICAL SCAN AIR SHAKER

A project was initiated in 1975 to develop an air shaker incorporating the air impingement fruit removal feature of the centrifugal fan shaker and the cyclic scan feature of the propeller shaker. A vane-axial fan with rotatable air directing vanes attached to the air outlet was selected as the machine concept because of its simplicity and ease of positioning to different heights on the tree. The machine in Fig. 3 was constructed to test the concept. It consisted of a 106.7-cm (42-in.) vane-axial fan and a power unit mounted on a high-lift trailer. The peak outlet air velocity of the shaker was 71.5 m/s (150 mph).

Fruit was removed by scanning the tree with an air stream from the vane-axial fan. As the air directing assembly was rotated about the fan outlet, the path of the air stream generated a conical shape with the apex at the fan shaft. With the trailer stationary, the air stream traced a circular path on a plane perpendicular to the fan shaft. As the trailer was drawn forward, the air streams traced a spiraling path along the side of the tree imparting a cyclic pulse of air to different parts of the tree causing it to shake. This method of shaking the tree opened the foliage rather than packing it together, which was a common occurrence with other methods (Whitney, Patterson, 1972), especially near the tree tops.

Operation of the test machine showed that maximum fruit removal was obtained at a scan rate of 90 to 110 rpm and ground speed of 0.81 k/h (0.5 mph). It was concluded that the conical scan concept could be successfully applied to the design of a small and adaptable air shaker.

A prototype air shaker employing the conical scan concept was built in 1977 to meet the following general design parameters:

1 Adjustable to accommodate trees up to 6.1 m (20 ft).

2 Weigh less than 4535.9 kg (10,000 lb).

3 Constructed for minimum cost and reproductibility by local machine shop.

4 Maneuverable over either sandy or sod covered soil.

5 Tractor-drawn for ease of attachment and detachment to a tractor.

6 Narrow enough to operate within the 2.4 m (8 ft) space between trees.

FIG. 4 Prototype air shaker using conical scan concept with fan at lowest position. The rotatable air director assembly with fixed vanes that direct the air is shown.

The general design specifications are given in Table 1 and the completed machine is shown in Figs. 4 and 5. A 137.2-cm (54-in.) dia vane-axial fan was used to produce a 56 m/s (125 mph) air stream. A rotatable air outlet assembly consisting of vanes positioned to direct the air 45 deg from line of air flow as used to direct the air. The air outlet assembly was driven by a spring loaded rubber tired fiction wheel. The general fan arrangement was selected because it was simple, compact and lightweight. The fan was cantilevered from a pivot located 3.1 m (10 ft) above the ground and adjusted for height by 2 hydraulic cylinders. A 111.9 kW (150 hp) continuous duty 3208 Caterpillar industrial diesel engine was selected for its compactness and short length. The engine was mounted crosswise on the machine to facilitate power transmission to the fan through multiple V-belts centered over the fan cantilever pivot. Sweeps were provided in front of the wheels to keep fruit from being crushed in the path of the transport unit during operation.

In operation, air was directed into the tree by rotating the air outlet as the machine was moved along each side of a tree row. In short trees (3.1 to 4.6 m) one pass was made on each side but in tall trees (4.6 to 6.1 m), a low and a high elevation pass were necessary to reach the top fruit.

In one harvesting operation (Wilson et al., 1979) with trees spaced 4.6 × 7.6 cm (15 × 25 ft) and 4.6 m (15 ft) tall and the fruit loosened to below 22.2 N (5 lb) fruit

TABLE 1. DESIGN SPECIFICATIONS

Overall length	4.6 m (15 ft)
width	
Wheel assembly	2.4 m (8 ft)
Structural	1.8 m (6 ft)
Height	
Transport	3.7 m (12 ft)
Maximum extension	6.1 m (20 ft)
Weight	3855.5 kg (8,500 lb)
Tires	40.6 × 49.5 cm (16.5 × 19.5 in.), 14 ply
Engine	Caterpillar 3208 industrial diesel V8 engine. 10.42 L (636 cu. in.), 111.0 kW (150 hp) continuous duty.
Air fan	Joy Manufacturing Co., axivane, series 2000, 137.2 cm (54 in.) diameter blade with 66 cm (26 in.) hub, 2538.5 m^3 /m (90,000 cfm).
Power transmission	Multiple V-belts
Scanning speed	50 to 100 rpm
Air directing vanes	45 deg to air stream

FIG. 5 Conical scan air shaker with fan in elevated position for reaching tops of tall trees. The shielded air inlet to fan is shown.

removal force (FRF), the shaker was operated at a forward speed of 1.6 km/h (1 mph). Fan speed was adjusted to 1500 rpm and outlet assembly was rotated at 70 rpm. These settings were determined for this harvest situation by tree size, foliage density, fruit load and FRF. Fruit was removed at the rate of 26,535 kg/h (58,500 lb/h) or a harvest rate of 170 trees per h. Fruit removal efficiency from the combined effect of the air shaker and abscission chemical averaged 97 percent. Diesel fuel was consumed at 3 gal/h. This performance was under optimum tree and fruit conditions which is not always obtainable.

CONCLUSIONS

An efficient, reliable and adaptable air shaker was developed for removing citrus fruit using a conical scan principle. Generally, all the design parameters were met in building a prototype. The shaker was proven effective in the removal of oranges where the fruit removal force had been uniformly loosened to 22.2 N (5 lb) or below with an abscission chemical.

References

1 Annual Progress Report. 1970. University of Florida, Agricultural Research and Education Center, Lake Alfred, FL.

2 Florida Agricultural Statistics — Citrus Summary. 1979. Florida Crop and Livestock Reporting Service, Orlando, FL.

3 Whitney, J. D. and J. M. Patterson. 1972. Development of citrus removal device using oscillating forced air. TRANSACTIONS of the ASAE 15(5):849-855, 860.

4 Whitney, J. D. and H. R. Sumner. 1977. Mechanical removal of fruit from citrus trees. Proc. Int. Soc. Citriculture 2:407-412.

5 Wilson, W. C., R. C. Holm, and R. K. Clark. 1977. Abscission chemicals — aid to citrus fruit removal. Proc. Int. Soc. Citriculture.

6 Wilson, W. C., J. R. Donhaiser, and G. E. Coppock. 1979. Chemical and air shaker orange removal in South Florida (LABELLE). Proc. Fla. State Hort. Soc. 92:56-58.