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ENERGY CONTENT OF WASTE MATERIALS IN FLORIDA CITRUS PACKINGHOUSES[1]

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Abstract. **Waste products from Florida citrus packinghouses were quantified and evaluated for potential utilization as an energy source. For the solid products, samples were analyzed for ash, fuel carbon, gross heating value, moisture content, sulfur and volatile material. In addition, pruned citrus wood from freeze-damaged trees was analyzed. Since reduced moisture content enhances recoverable energy, samples were solar dried in flat plate collectors to determine expected minimum moisture content levels and the efficiencies of such direct solar drying. For a medium size packinghouse (10^6 cartons per year), recoverable energy estimates were: 4.4 x 10^8 kJ from fiberboard, 5.2 x 10^8 kJ from field debris and 5.7 x 10^8 kJ from combustible volatiles in solvent wax.**

An interest in becoming energy self-sufficient has evolved in the United States since the oil shortages of the 1970's. This theme is not only expressed at a national level but also holds for various industries. Fresh fruit packinghouses are one example, as many plants have prime seasonal markets and limited storage capabilities. Hence, economic losses would be extensive with interruptions of fossil fuel or electrical service.

One potential source of energy at packinghouses is in the waste materials associated with fresh fruit packing. Consolidating and combusting field debris, mutilated cartons, etc. would appear to be a straightforward approach as opposed to more complex gas or liquid fuel conversion processes. Although direct combustion would provide only process heat, typically through an on-site boiler, this technology (3, 4) is well-established and would allow limited portable fuels to be used in mobile equipment. In the future, a more extensive energy generation facility could incorporate cogeneration (12). A cogeneration topping cycle would provide heat and steam or both with secondary production of electricity. Such utilization of these waste materials would also be more socio-economically acceptable than consuming edible products or foodstuffs to sustain plant operations.

Drying of these waste materials enhances potential energy available via combustion. Dixit, et al. (3) reported difficulty with sustained combustion with greater than a 55% moisture content in wood. Burnett (2) cites boundary limits for self burning at $\leq$50% water, $\leq$55% non-combustibles and $\geq$25% combustibles. Solar energy has compatibility with such drying when scheduling is not critical. The waste materials could be dried and stored throughout the packing season and used only during fuel interruptions or at the end of a season.

Other researchers have investigated the direct energy in various crop residues: corn husks and stalks (10), apple and grape pomace (7, 13) and ginning wastes (5). Also, Vetter, et al. (15) classified and established the quantities of processing plant waste for the snack food industry. Research on citrus peel combustion for on-site energy utilization was reported by Kesterson, et al. (6).

Specific objectives of the research reported herein are to: 1) characterize the quantity, energy content and storage properties of citrus packinghouse waste products. 2) Analyze solar drying of such waste materials to increase recoverable energy.

Materials and Methods

The following waste materials were identified in Florida citrus packinghouses: fiberboard material, field debris and the solvent constituent in some wax formulations. An additional grove related waste material is the wood from pruning trees, especially after freeze damage. Of these materials, all but the solvent vapor were analyzed for their heating value.

Samples of fiberboard cartons and citrus debris, primarily leaves and twigs, were obtained from local packinghouses and at the Lake Alfred Citrus Research and Education Center (LA-CREC). For comparative purposes, field debris sampling was also undertaken at a citrus processing plant. For the LA-CREC samples, the mass of debris per pallet box was measured. Debris samples were shredded in a Fitzpatrick hammermill with a 1.75 cm screen. The material was then dried under vacuum at 60°C. Water additions were made to achieve various moisture contents. The samples were thoroughly mixed and allowed to equilibrate overnight before combustion pellets were formed.

Citrus wood from freeze-damaged trees was chipped to approximately 5 cm x 5 cm x 0.3 cm sized-pieces in the field with a Morbark 45 kw tree chipper. Fiberboard was hand cut into similar sized 5.0 cm square pieces. Moisture content for these materials was established by convective oven drying at 105°C for 48 hr.

To establish various combustion related properties of these solid waste materials, samples were analyzed by an independent laboratory (Thornton Laboratories, Tampa, FL). Their fuel analysis included percent ash, fixed carbon, sulfur and volatile matter plus gross heating value and moisture content.

Solar drying tests were conducted with a single flat-plate collector with a tray insert (14). The initial loading rate for citrus debris was 1.1 kg/m^2 and, for the wood chips, 9.3 kg/m^2. Forced air flow across the tray was 0.15 m^3/m^2-min based on the fan's performance curve. Direct and diffuse radiation incident to the collector was monitored with a black and white pyranometer. The biomass material in the tray was weighed after each test day. With useful energy estimated from the product of moisture loss and latent heat of water vaporization, a solar energy utilization efficiency was calculated. Solar drying was performed only on field debris and wood chips as the fiberboard was already in a low-moisture condition.

Results and Discussion

Quantitative. For the citrus field debris samples at LA-CREC, the quantity of material per pallet box averaged 1.2 x 10^{-3} kg-debris/kg-fruit. The range was from 0.8 x 10^{-3} to 1.5 x 10^{-3} kg-debris/kg-fruit. Niemann found 2.3 x 10^{-3} to 4.2 x 10^{-3} kg-debris/kg-fruit in citrus processing loads picked via hand or machine, respectively (G. Niemann, Production Systems, Winter Haven, Florida, personal communication). All the above figures would represent debris in a relatively high-moisture condition.

Fiberboard wastage was calculated from a commercial packinghouse which sent their fiberboard to a recycling center. A seasonal average was 1.9 x 10^{-3} kg fiberboard/kg fruit. Wood material available for chipping is a function of grove conditions and resultant freeze damage. The estimated collectable material after the 1981 freeze ranged from 238 to 685 kg wood/tree (D. Churchill, U. S. Dept. Agr., personal communication). Economic viability of transporting this wood residue would be a function of grove to packing plant distances and empty trailer availability. In most instances, size reduction would be accomplished in the field and the wood chips then transported either in pallet boxes or as a bulk load. From commercial literature (9), chipping energy requirements are approximately 28.6 kJ/kg material. Truck energy requirements are a function of vehicle size. Barton (1) cites 1.84 kJ/kg-km for large trucks of 20.0 x 10^3 kg capacity and 3.37 kJ/kg-km for 6.6 x 10^3 kg capacity trucks.

Qualitative. Properties data for storage and combustion of the solid packinghouse waste materials were compiled in Tables 1 and 2. The initial high moisture content of both the citrus debris and wood chips indicated the advantage of drying to enhance energy recovery and to reduce storage volumes. Bulk densities reported are for an uncompacted condition where the density could be increased if storage volume were a constraint.

The gross heating values were greater than 18000 kJ/kg dry material for all solid waste products. Higher ash content and less volatile material reduced the energy content of the citrus debris. Gross heating values reported in Table 1 were obtained by the independent test lab. We obtained slightly lower values in analyzing the effect of moisture content (Fig. 1).

The effect of moisture content on utilizable energy was substantial with greater than 10% moisture, dry basis. This reduction was slightly offset by a greater energy content observed with moisture increases. This trend of higher energy content with greater moisture was reported also by Kesterson et al. (6) for citrus pulp. In Fig. 1, water vaporization refers to pre-combustion moisture in the fuel source. Water vapor as a product of combustion and in the combustion air would further reduce utilizable energy content.

Two pollutant parameters, sulfur and ash content, were of typical levels to those reported by others (7, 11) for biomass fuel sources. They reported the following for ash content: 4.0% (apple pomace), 2.7% (grape pomace), 1.6% (corn cobs) and 6.0% (paper) and for sulfur: 0.1% (apple pomace), 0.2% (grape pomace), 0.1% (corn cobs) and 0.2% (paper). A higher ash content was found in field debris, most probably a result of silica transferred from the grove. In a separate analysis from various packinghouses and one processing plant (Table 3), reduced heating values were found in the processing plant sample. In that specific sample, a higher sand content was observed. Such sand contamination might be reduced by a vibratory sieve operation before combustion.

Table 1. Moisture content and bulk density of citrus packinghouse solid waste materials.

Waste material	Moisture (dry basis %)	Bulk density (kg/m^3)
Debris[z], initial	55.3 ± 14.1	39.8 (loose) 106.2 (chopped)
Debris[z], solar dried	6.4 ± 3.9	63.9 (chopped)
Fiberboard	10.8 ± 0.5	88.2 (loose) 106.2 (chopped)
Wood chips, initial	33.3 ± 2.3	262.9 (loose)
Wood chips, solar dried	8.4 ± 0.3	231.5 (loose)

[z]Principally leaves and twigs.

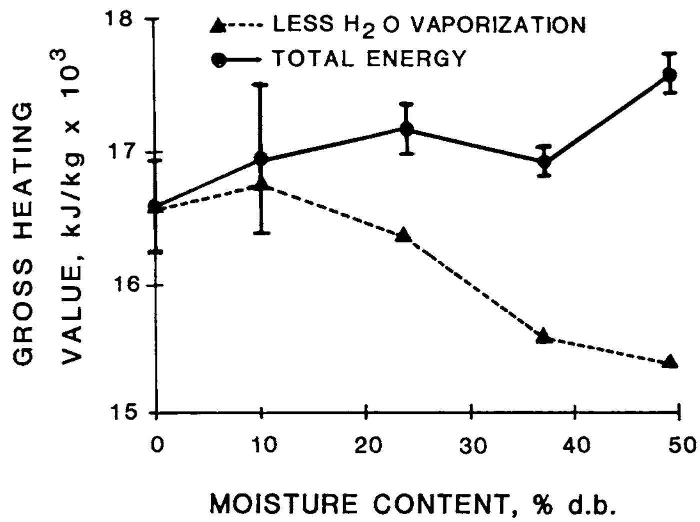

Fig. 1. Heating values for citrus debris with and without water vapor considered.

Table 2. Combustion analyses of citrus packinghouse solid waste materials ($\overline{X}$ ± SD).

Waste Material	Moisture dry basis (%)	Volatile material (%)	Ash (%)	Fuel carbon (%)	Sulfur (%)	Gross heating value (kJ/kg)
Fiber board	7.4 ± 1.8	86.8 ± 0.1	1.1 ± 0.1	12.2 ± 0.1	0.21 ± 0.02	20079 ± 2226
Debris	7.3 ± 2.6	77.5 ± 4.1	8.5 ± 2.3	14.0 ± 1.8	0.31 ± 0.01	18121 ± 360
Wood chips	7.9 ± 0.8	84.6 ± 1.1	1.2 ± 0.8	14.2 ± 0.2	0.50 ± 0.13	18296 ± 33

Table 3. Gross heating value of field debris from various sources.

Source/variety	Gross heating value (kJ/kg) $\bar{X}^{z}$	SD
Lake Alfred CREC/tangerine	17051^{b}	377
Packinghouse A/tangerine	17778^{a}	19
Packinghouse B/tangelo	17060^{b}	107
Packinghouse C/grapefruit	17018^{b}	172
Processing plant/Hamlin orange	12925^{c}	445

[z]Mean separation by Duncan's multiple range test, 5% level.

Solvent waxes were not analyzed experimentally for their energy. However, the solvent readily vaporizes and a certain portion of such vapor may be recoverable. The calculated gross heating value in this waste stream was 34.9 kJ/kg fruit based on: 90% recovery, 0.75 x 10^{-3} kg-solvent/kg fruit and a 46753 kJ/kg gross heating value for C_6H_{12}. This vapor would be handled differently than the solids. One approach would be to pre-mix with ambient air to create the combustion airstream. Presently, packinghouses applying solvent waxes vent the vapor through a stack dispersing it into the atmosphere.

Using the gross heating values reported herein and the quantitative analysis of the waste materials, a mid-size packinghouse (10^6 cartons) would have available: 4.4 x 10^8 kJ from fiberboard, 5.2 x 10^8 kJ from field debris and 5.7 x 10^8kJ from combustible volatiles in solvent wax. The debris figure was estimated assuming a 70% packout. Wood chips were not included due to a questionable seasonable supply. An energy survey conducted for 2 packing seasons (8) indicated that fuel oil and natural gas for boilers averaged 57.1 x 10^8 kJ for a 10^6 carton packinghouse. Therefore, these waste materials have the potential for producing ca. 27% of the energy for packinghouse steam usage.

Solar drying. Solar drying of field debris and citrus wood chips yielded the moisture content reductions of Table 1. Solar energy utilization (SEU) was based on the water loss where:

$$SEU = \frac{\Delta m \cdot h}{Q_{in}}$$

with Δm-moisture (kg), h-latent heat of H_2O vaporization (kJ/kg) and Q_{in}-incident solar energy on the collector surface (kJ). These SEU levels averaged 8.4% for drying field debris and 14.5% for wood chips. This disparity relates to the unit area moisture load in the collector. Initial moisture load was 0.39 kg/m^2 for field debris compared to 2.33 kg/m^2 for wood chips. Average moisture contents are included in Table 1. These results represent 2 tests of 2-day duration conducted in October 1982 for wood chips and for debris, in February and April 1981. Such efficiency vs. moisture load was also evident in individual tests. For example, in a 3-day solar drying period of wood chips, daily efficiencies were 26.3, 11.5 and 5.7% as the test progressed. Another difference between the wood chips and field debris was sample thickness. Falling-rate drying, where moisture migration to the evaporating surface is the limiting factor, would be more pronounced for the chipped wood.

Although solar energy did not completely dry the solid waste materials, moisture contents were reduced to levels of greater energy recovery (Fig. 1). Additional benefits are derived from reduced mass in storage and reduction of mold spoilage which would be more prevalent at high moisture contents.

Summary

The waste matter associated with Florida citrus packing have been identified and evaluated for their potential energy utilization via direct combustion. The available energy from fiberboard, field debris and solvent wax was of comparable magnitude. For a packinghouse with a 1 x 10^6 carton production, total energy from these sources was estimated at 15.9 x 10^8 kJ yearly. An additional energy source is citrus wood, either from regular pruning or after freeze damage. Gross heating value from this wood source was ca. 18300 kJ/kg. Solar drying can complement solid waste material utilization by reducing the moisture content which facilitates bulk storage and enhances recoverable energy.

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