Chipping Citrus Wood for Gasification

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ABSTRACT

CITRUS trees, both green and dead, were chipped to provide a fuel source to make producer gas. Chip moisture content, fuel analysis, drying rate, and data on fuel/t of chips were obtained. The average moisture contents of the green and dead trees when chipped were 32% (w.b.) and 16% (w.b.), respectively. Chips were sized to a minimum of 0.32 cm square by 0.32 cm thick and to a maximum of 5.0 cm square by 0.32 cm thick and normally required four weeks to air dry to 14% (w.b.) moisture content before being used in a gasifier.

INTRODUCTION

Our economy is highly dependent on the use of petroleum-based energy and there is question as to its future availability at any cost. Therefore, research was undertaken to find and develop alternative energy sources. One potential substitute for petroleum-based fuels is forest residues. In 1981, biomass energy supplied over 2 quadrillion kJ's to help power our industries, homes, and provide fuel for our automobiles in the United States (Gavett, 1982).

Riley et al. (1983) reported on some of the problems using green wood chips at different moisture contents for home furnaces. A grinding machine for preparing woody residues for use in a biomass energy conversion system was reported by Arthur et al. (1983). They found that the rate of grinding depended upon the residue being processed and other parameters affecting the machine operation. Massey et al. (1981) did a study on chipping whole-trees for energy, which showed that harvesting systems are economical only as operational downtime approaches zero.

In 1980, 2.6 quadrillion kJ's of energy were consumed in Florida and only 0.42 quadrillion kJ's were produced (Smith, 1983). The largest requirement of energy usage for citrus production in Florida is pumping water for irrigation. A 1977-78 Florida energy survey determined that 32.2% of the citrus production energy went for irrigation pumping requirements which consumed nearly 76 million L of petroleum fuel annually (Stanley et al. 1980).

As a normal practice, non-productive citrus trees are removed and replaced with young tree resets. The removed trees are normally stacked in piles near the grove, with the root system intact, ready for burning.

On a 7.6 x 7.6 m tree spacing, there are 173 trees/ha. The normal reset rate in Florida is 6 trees/ha/year. The tree requirement to produce the necessary chips for operating an irrigation system in Florida is only 1.5 trees/ha (Churchill et al. 1984).

Excluding years of major freezes, approximately 0.54 million t of citrus wood are removed from Florida groves annually because they were non-productive (Commercial Citrus Tree Survey, 1980). Major freezes, three in the last four years, have increased considerably the amount of citrus wood that goes to waste. If petroleum fuel for operating irrigation pumps were to become too expensive or its availability reduced, producer gas from citrus wood that now goes to waste could possibly be used as a substitute.

With the abundant supply of wood available in the Florida citrus industry, it appears that technology to fuel engines with producer gas for irrigating groves could reduce petroleum consumption for irrigation and utilize this biomass source during periods of critical fuel shortages.

Shaw et al. (1983) reported on the design of a gasifier using citrus wood for dual-fuel operation of a diesel irrigation pump engine. The operation of an irrigation power unit using citrus wood chips to produce producer gas for use in a downdraft gasifier was reported by Churchill et al. (1984).

Studies have shown that when a dual-fuel system of diesel fuel and producer gas are used, 67% less diesel is consumed when operating an irrigation system in citrus (Churchill et al. 1984).

The objective of this research was to determine the requirements for chipping and preparing citrus trees for use in a downdraft gasifier as mentioned above. No cost for material handling of the citrus trees and chips or labor and equipment were considered in this study.

PROCEDURE

For this study, total weight of removed trees, including the root system on most of the trees were obtained using a load cell scale mechanism attached to the lift boom of a fruit handling truck. The root system was cut off and discarded because of entrained soil and the difficulty of feeding individual short root pieces into the chipper. After the root system was separated from the tree trunk, the limbs were cut into lengths as long and straight as

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possible with a chain saw. The wood chipper used in this study was limited to a maximum log diameter of 25 cm. Limbs under 2.5 cm in diameter were not used because of poor chip quality. Some of the larger diameter logs were split to reduce them to a size that the chipper would handle.

To determine the average moisture content of each tree, three samples were taken before the chipping operation started. One sample was taken from the trunk, one from a main limb, and the other from one of the branches. Chip moisture content was determined by standard OAC procedure (Organization of Agricultural Chemists). Several trees were prepared for the chipping operation at one time. Records were kept on each tree to determine the percentage of the total tree weight which was made into usable chips which were 0.32 cm thick and between 0.32 cm and 5 cm square.

Several wood chippers were tested for chip size and uniformity. The chipper selected that produced the desired chip size was a Morbark "EEGER BEEVER" powered by a 45 kW engine. It was portable and produced nominal 5 x 5 x 0.32 cm chips. The flywheel, 95 cm in diameter and 2.5 cm thick, had two knives mounted on it which rotated at 1000 r/min. The chipper had hydraulically powered top and bottom feed rollers with the top roller being spring loaded to allow for different diameter logs.

During the chipping operation, conventional citrus fruit handling baskets constructed of expanded metal were placed on a drop cloth. The chipper delivered the chips directly into the basket and the drop cloth caught any chips that missed or passed through the expanded metal basket. The same baskets were used for air drying and storage of the chips. They had an approximate volume of 0.79 m^3. The dimensions of a citrus basket are 74 cm high, 133 cm square at the top and 90 cm square at the bottom. The chips were weighed and three 100 g samples were taken from different locations in the basket for moisture determination. Samples were taken from two sides, 5 cm in from the edge of the basket, and one from the center, all approximately 30.5 cm down from the top surface. The baskets were stored 4 cm off the ground and 4 cm apart in an open shed to allow air movement around the baskets and to keep the chips dry. After two weeks, the chips were sorted into three sizes with only the usable chips as mentioned above being dumped into another basket to aerate them and aid in the drying process. They were weighed again and moisture samples were taken weekly until the moisture content of the chips had reached equilibrium. The baskets of chips were then emptied into a fruit loading high-lift truck for storage. The high-lift truck held the equivalent volume of ten baskets and could be raised and dumped when the chips were needed.

Sizing of the chips was done with two screen sizes to remove very small and very large chips which cause a bridging problem in the gasifier. The small screen had a square opening of 0.3 cm square and the large screen was 5 cm square. The sizing operation was accomplished by dumping the chips onto the respective screens and raking them back and forth by hand. A few of the longer chips oriented vertically and fell through the 5 cm screen during the sizing operation but were not removed from the usable chips.

Chipper engine fuel consumption was recorded for the chipping of each tree along with the weights and percent by weight of usable chips after sizing. Tests of chipping citrus trees were conducted at two different dates.

TABLE 1. CHIPPING DATA (w.b.)

Tests	No. of trees	Average tree wt with roots kg Mean	SD†	Average tree wt without roots kg Mean	SD	Average usable chips kg Mean	SD	Average % of wt as usable chips,* % Mean	SD
Test 1									
Live trees	3	---	---	575	124	221	110	---	---
Dead trees	3	---	---	326	120	133	53	---	---
Test 2									
Live trees	16	765	214	495	126	355	133	47	9
Diseased trees	2	---	---	426	265	331	204	---	---

*Total wt of tree including roots
†SD - Standard deviation

Test 1

The first test consisted of six trees, three of which were dead; the other three were live trees until being removed on April 15, 1982, two weeks before chipping. The initial weights of all six trees were without their root systems.

Test 2

The second test consisted of 18 trees, of which 16 were live trees before being removed on August 16, 1982, three weeks before chipping; the other two were diseased trees. The initial weight of the 16 live trees included their root systems while the initial weight of the two diseased trees was without their root systems.

RESULTS AND DISCUSSION

Table 1 gives the overall chipping data on number of trees, weights, and usable chips, for Tests 1 and 2. Table 2 shows the fuel used for chipping, average quantity of chips produced, and the average ratio of fuel/kg of chips for both tests. Drying data for Tests 1 and 2 are given in Table 3.

Test 1

The chipping operation on the green trees started two weeks after they were removed. Their average moisture content decreased 4 percentage points (from 36% to 32% w.b.) after being removed. The average dead tree moisture content increased 8 percentage points (from 8% to 16% w.b.). The increase in moisture content of the dead trees before the chipping started in early May, was probably caused by the high relative humidity in Florida. The mean high temperatures in 1982 for the months of April-July was 88.7 °F. After four weeks of air drying (May 4, 1982 to June 1, 1982) in the baskets, the average moisture content of the chips from the green and dead trees were 10% (w.b.) and 14% (w.b.), respectively.

Test 2

The average moisture content four weeks after chipping had decreased 7 percentage points (from 32% to 25% w.b.). Four weeks after air drying (October 5,

TABLE 2. FUEL USED FOR CHIPPING AND TOTAL CHIPS PRODUCED

	No. of trees	Average gasoline fuel used, L Mean	SD*	Average chip quantity, kg (w.b.) Mean	SD	Ratio of gasoline per wt. of chips, (w.b.) L/kg Mean	SD	Energy ratio chips out to fuel used†
Test 1								
Live trees	3	3.5	2.3	256	127	0.0129	0.0027	37.6
Dead trees	3	2.8	1.5	143	57	0.0224	0.0164	26.3
Test 2								
Live trees	16	3.7	1.4	386	168	0.0091	0.0022	44.3
Diseased trees	2	3.3	2.2	358	208	0.0088	0.0010	55.8

*SD - Standard deviation.
†Ratio used high heat value of 18.3 MJ/kg of chips w.b. (Table 4) and 35.6 MJ/L of gasoline (Marks', 1955).

1982 to November 2, 1982) the average moisture content had decreased 11 percentage points (from 25% to 14% w.b.).

Eight and one-half liters of gasoline were required to chip 1 t of citrus wood at 25% (w.b.) moisture content in 0.6 h. On a weight basis, an average of 6.8% of the chips were too large to pass through a 5 cm square mesh screen and 1.86% were too small and passed through a 0.32 cm square mesh screen. This left an average of 91.3% of the chips usable for gasification.

Table 4 shows an analysis of citrus wood samples at 6.83% (w.b.) moisture content and another at 21.45% (w.b.) moisture content. Open air drying of citrus chips under a shed reduced the moisture content satisfactorily for use in a downdraft gasifier (10-15% moisture content w.b.). There was little evidence of mildew or mold on any of the chips. By weight the root system represented an average of 36% of the total weight of the tree.

TABLE 3. DRYING DATA (w.b.)

Date	Average moisture content, % Mean	SD	Chip weight loss, kg Mean	SD
Test I				
Live trees — Initial mean chip weight = 361 kg				
4-15	35	1.15	—	—
4-27	32	0.60	15.85	10.11
5-12	10	2.10	74.20	27.50
6-4	11	1.00	1.73	6.29
7-1	11	0.00	0.00	0.00
Dead trees — Initial mean chip weight = 326 kg				
4-15	8	0.00	—	—
4-27	16	2.31	-57.81	16.39
5-12	14	4.16	8.47	10.27
6-4	11	0.58	10.30	13.44
7-1	11	0.00	0.00	0.00
Test II				
Live trees — Initial mean chip weight = 381 kg				
9-3	31.81	3.77	—	—
10-1	24.90	1.96	28.44	20.54
10-18	17.43	4.15	28.24	15.56
11-2	13.67	1.74	12.63	13.69
12-1	13.70	0.00	0.00	0.00
Diseased trees — Initial mean chip weight = 358 kg				
9-3	30.50	0.00	—	—
10-1	24.50	1.84	23.41	19.06
10-18	19.75	5.73	19.58	21.99
11-2	14.65	2.05	13.02	3.09
12-1	14.60	0.00	0.00	0.00

TABLE 4. FUEL ANALYSIS OF CITRUS WOOD*

	Sample A	Sample B
Moisture content, w.b.	6.83	21.45
Density (chips), w.b. kg/m^3	240.30	331.61
High heat value, MJ/kg (w.b.)	18.3	18.3
Sulfur, %	0.03	0.4
Volatile matter, %	85.36	83.77
Ash, %	0.59	1.81
Fixed carbon, %	14.05	14.42

*Analysis performed by Thornton Laboratories, Inc., Tampa, FL.

CONCLUSIONS

The results of these tests demonstrated citrus trees "removed" near an irrigation site could be cut up with a chain saw, chipped, sized, air dried, and stored for subsequent use in a gasifier. With the root system and small limbs removed, 72% by weight of the tree was made into usable chips for a gasifier. The chipper used 10.4 L of gasoline to convert citrus limbs to 1 t of chips.

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