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PRODUCER GAS FROM CITRUS WOOD FUELS IRRIGATION POWER UNIT[1,2,3]

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Abstract. **A 90-hp diesel engine power unit operating a citrus irrigation system was converted to run on a dual-fuel mixture utilizing producer gas from citrus wood chips as the main fuel source. A chip feeder mechanism, gasifier, filter system, and control unit were designed to meet typical irrigation power requirements. Both green and dead citrus trees removed near the irrigation site were used for chipping. Chip moisture content, fuel analysis, drying rate, and fuel per tree weight data were obtained.**

The United States is the highest per capita energy user of all nations. The energy crisis of 1973 brought on energy problems that included supply uncertainty, shortages caused by embargoes, and rapid price escalation in fuel cost. Our economy is highly dependent on the use of petroleum-based energy and there is question of its future availability at any cost. One potential alternative energy source for currently used fossil fuels may be forest residues. Analysis of woody feedstocks have been evaluated to determine their biogassification potential (3). Through gasification of wood, internal combustion engines can be operated without requiring major modifications.

In Florida the largest requirement of energy usage in citrus production is irrigation. According to a 1977-78 Florida energy survey, 32.2% of the citrus input production energy went for irrigation (12). Approximately 20 million gallons of petroleum fuel are used annually for pumping water (12). Under normal rainfall distribution in Central Florida, approximately 336 hp-hr of energy are required to pump 12 inches of water on 1 acre. On a 25 ft x 25 ft spacing there are 70 trees per acre. The reset rate in Florida is approximately 2.43 trees per acre per year or 3.5%. Therefore, approximately 0.6 million tons of citrus wood are pushed out annually (1). Major freezes, 3 in the last 4 years, have added considerably more citrus wood that goes to waste.

In 1878, Dawson in England found that gasification of a solid fuel would produce a fuel which could be used in an internal combustion engine (13). During World War I, thousands of vehicles were operated on producer gas and charcoal fuel as the principal source of motor fuel (5). Researchers have demonstrated the performance characteristics of a dual-fueled, compression ignition engine operating on producer gas and pilot injection of diesel fuel (2, 14).

Several universities and private companies are conducting research on gasification for use in grain drying (4, 6, 7, 8, 10, 11). Three main types of gasifiers have potential for agricultural applications. They are the updraft, downdraft, and the crossdraft gasifiers.

The objective of this research was to demonstrate the conversion of a 90-hp diesel engine power unit to a dual-fueled engine which utilizes producer gas from citrus wood chips as the main source of fuel for 100 hr of operation in a citrus irrigation system.

Methods and Materials

An experimental site was selected where a 700-800 gal/min irrigation pump was already in operation. A Perkins Model 6.354 diesel 6 cylinder engine with a 354 cubic inch displacement, rated at 90-hp at 2250 rpm was modified for dual-fuel operation and installed at the pump site. This engine model has been widely used for a number of years to power agricultural irrigation pumps. Citrus wood was readily available at the pump site and no materials handling of the fuel source to the site was considered.

An Energy Model GPT 2-10-E hydraulic pump and tank assembly was mounted on the engine and belt driven to supply power for operating the agitators, elevator and feed ram for the gasifier. A 250 watt inverter connected to the engine provided 110 volt electric power for the operation of a start-up fan on the gasifier and the 2 commercially available "Bindicators" used as fuel level sensors.

Chipping. Fuel for the test was citrus wood obtained from trees pushed out because they had blight, were nonproductive, or were dead. The trees were weighed and stacked with the root system intact. Later the root system was cut off and the limbs were cut into lengths as long and straight as possible with a chain saw. The root system represented an average of 36% of the total weight of the tree. The chipper would accept a maximum diameter of 10 inches. Wood under 1-inch diameter was not used because of poor chip quality. Records were kept for each tree to determine the per cent of the total tree wood which could be made into usable chips. Moisture samples were taken from different sections of the tree before the chipping operation started.

A portable, flywheel-type chipper (Morbark "EEGER BEEVER") powered by a 60-hp self contained engine was used (Fig. 1). It produced chips 2 x 2 x 0.125 inches in size. Chipper fuel consumption of the chipper engine was measured to determine energy requirements for chipping.

Expanded metal 10-box citrus baskets were used for drying the chips. They emptied from the bottom which facilitated bulk loading of the chips into larger containers for storage after drying.

Gasifier. The Swedish style downdraft gasifier system (Fig. 2) was designed by the Agricultural Engineering Department, University of Florida, at Gainesville, Florida and built at Lake Alfred (9). The gasifier was designed with two agitation systems to prevent bridging. One vibrated the grate and the other stirred the chips in the upper stack.

A ram-type chip-feeder cylinder and hopper was designed and constructed to make the operation continuous for refueling the gasifier while in operation. Chips were

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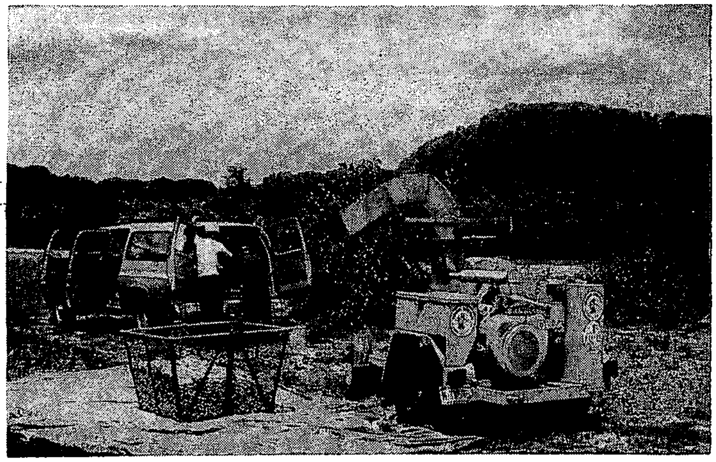

Fig. 1. Flywheel type chipper and collecting system.

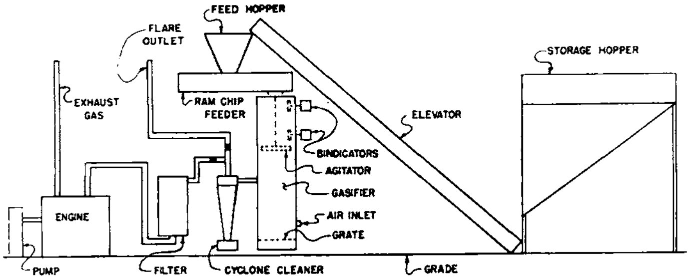

Fig. 2. Downdraft gasifier system.

stored in a large hopper and fed into an elevator leading to the feed hopper mounted on top of the gasifier. Wood chips were weighed before going to the feeder during refueling. The hopper held approximately 0.4 cubic feet of chips. Seals were installed on either side of the feed hopper and a knife was mounted on the feeder housing to cut off the fuel charge in the ram compartment to prevent jamming. The ram was hydraulically operated with a double acting cylinder. The engine was started on diesel and was then switched to the dual-fuel mixture.

The producer gas flowed from the gasifier through a cyclone cleaner, sized to remove small particulates for this gasifier, and then passed through a glass fiber filter specifically designed to remove tars and fine particles. The glass fiber filter contained two elements installed in parallel and sealed in a mild steel housing. These elements were a pleated cartridge type rated by the manufacture at 279 cubic feet of gas flow per minute per element. The filter was rated at 98% efficiency and removed particles of 3 μm in size and larger (a grain of table salt is the size of 100 μm).

To make use of producer gas in a compression ignition engine, a small amount of diesel fuel was injected by the injector pump to ignite the mixture in the compression chamber while an air producer gas mixture was fed into the intake manifold. Modifications were made to restrict the amount of fuel injected and a special producer gas carburetor was installed on the intake manifold. Restricting the output of the diesel injector pump caused the built-in governor to be ineffective so that an externally-mounted governor was required. A butterfly valve was used to adjust the air producer gas mixture. These were the only modifications necessary to operate the engine with the dual-fuel of producer gas and diesel oil. The engine could easily be switched to operate on straight diesel fuel when necessary.

Diesel fuel consumption was determined by timing the consumption of a known volume of fuel in a calibrated cylinder. Thermometers and manometers were installed in the producer gas distribution system to measure temperatures and pressure drops from the gasifier to the engine.

Results and Discussion

Chipping. Two tests of chipping citrus trees were conducted. The first used 6 trees, 3 of which were dead and had an average moisture content of 8% wet basis; the other 3 were alive trees until being pushed out on April 15, 1982, 2 weeks before chipping. The initial average moisture content of the live trees was 36% wet basis. At the time of chipping the moisture content had dropped to 32% wet basis. In the second test 16 of the trees used were alive and 2 were diseased. The trees were pushed out on August 16, 1982 and 2 weeks later the average moisture content was 32% wet basis. Before the chipping operation the root systems were removed and the limbs cut up into lengths that the chipper could handle. Average moisture of the wood at chipping time was 25% wet basis.

The chips were stored in wire baskets under an open shed. After 4 weeks in storage, June 4, 1982 for Test 1 and November 2, 1982 for Test 2, the average moisture content for all the chips was 14% wet basis. There was no evidence of mold or mildew on the chips. Table 1 gives the chipping data. By weight an average of 6.8% of the chips were too large to pass through a 2-inch square mesh screen and 1.86% were too small and passed through a 0.125 inch square mesh screen. Table 2 shows the analysis of two citrus wood samples. Analyses were made of wood chips at two moisture contents (6.83% and 21.45% wet basis).

Gasifier. Operating with the combination of producer-gas and diesel, the engine produced about 80% of the power developed on full diesel when operating at 2000 rpm. The average power-output was 60 hp.

Table 3 shows engine fuel consumption under different operating conditions. A savings of approximately 67% in

Table 1. Weight and moisture in chips produced for use in the gasifier.

	No. of trees	Avg. tree wt with roots (lb.)		Avg. tree wt without roots (lb.)		Avg. useable chips (lb.)		Avg. wt as useable chips[z] (%)		Avg. moisture content at chipping time (%)		Avg. moisture after 3 months of drying (%)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Test 1													
Live trees	3	—	—	1267	274	488	243	—	—	32	0.6	11	1.0
Dead trees	3	—	—	718	265	293	117	—	—	16	2.3	11	0.6
Test 2													
Live trees	16	1687	472	1090	277	782	250	47	9	32	4	13.7	1.7
Diseased trees	2	—	—	939	503	729	450	—	—	31	0	14.7	2.0

[z]Total wt of tree including roots.

Table 2. Fuel analysis of citrus wood used in the gasifier.

	Test 1	Test 2
Moisture content (%, wet basis)	6.83	21.45
Density (chips) (lb./ft³, wet basis)	15.00	20.70
High heat value (Btu/lb.)	7868.00	7868.00
Sulfur (%)	0.03	0.04
Volatile matter (%)	85.36	83.77
Ash (%)	0.59	1.81
Fixed carbon (%)	14.05	14.42

Table 3. Diesel fuel consumption (Perkins Model 6.354, 90-hp engine).

Engine (rpm)	No load	Load	Without wood gas	With wood gas	Diesel used (gal/hr)
1000	X	—	X	—	0.59
2000	X	—	X	—	1.41
2000	X	—	—	X	0.65
2000	—	X	X	—	2.47
2000	—	X	—	X	0.81

diesel fuel consumption was obtained when operating with the dual-fuel system under load at 2000 engine rpm as compared with straight diesel alone. The gasifier performance is shown in Table 4. With a pressure of 40 psi at the pump and the engine running 2000 rpm, the pumping rate was 750 gal/min. The pressure drop across the clean gasifier filter was 3 to 5 inches of water. When the pressure drop reached 16 inches of water the engine would not deliver its power and had to be shut down to install a clean set of glass fiber filters and then started up again. Cleaning of the filters involved 1) 0.5 hr of rinsing with a water hose, 2) placing the filters in a solution of detergent and agitating for 2 hours, 3) rinsing again for 1 hr with a water hose and 4) air drying for 24 hr.

Table 4. Measured factors of gasifier performance.

Chip charge	57 lb/hr
Frequency of filter change	5.9 hr
Ash	2.87 lb/hr
Producer gas temperature before filter	246°C
Producer gas temperature after filter	150°C
Condensate	0.28 gal/hr
Pump rate	750 gal/min
Total time of operation	100 hr
Moisture content of chips	12.3% wet basis

The cyclone cleaner removed an average of 0.4 lb. of ash per hour. The grate functioned satisfactorily and most of the ash was removed from below the grate through a clean out port. Constant power in the engine was maintained by operating the agitators for 4 sec every 15 min. The ram chip feeder worked satisfactorily, and did not cause a decrease in engine power due to gas leakage during refueling of the gasifier.

When operating a standard overhead irrigation system to apply 12 inches of water per year on 40 acres of grove using a dual-fuel mixture of diesel and producer gas from citrus wood chips, it would require 9.6 tons of air dried chips or the equivalent of 24 citrus trees per year. The requirement of 24 trees for 40 acres is only 0.85% *trees per* acre.

Two and one-half gallons of gasoline were required to chip 1 ton of citrus wood at 25% wet basis moisture content. Using the flywheel type of chipper with a 60-hp engine, 1.8 tons of chips could be produced per hour. Therefore, it would take 5.3 hr per year of actual chipping time to chip the necessary wood for operating a 40 acre irrigation system. No measure was made of the labor and equipment cost factor for this particular study.

The results of this test demonstrated that a typical diesel engine can be converted to dual-fuel operation using producer gas made from air dried citrus chips. An operator was required during the entire irrigation period. The gasifier required agitating and refilling every hour and the filter needed changing at least every 16 hr. Cleaning the filters was the biggest problem in the operation of the system. Additional work is being done in this area and will be evaluated in the near future.

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