PN-AAY-357
ISN 50417

CONVERTING AGRICULTURAL WASTE INTO INDUSTRIAL ENERGY: COFFEE PULP AS A FUEL FOR DRYING COFFEE IN CENTRAL AMERICAN BENEFICIOS

FINAL REPORT

INSTITUTO CENTROAMERICANO DE INVESTIGACION Y TECNOLOGIA INDUSTRIAL

GUATEMALA, 1983

PN-AAY-357

INSTITUTO CENTROAMERICANO DE INVESTIGACION Y TECNOLOGIA INDUSTRIAL
(ICAITI)

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FINAL REPORT

CONVERTING AGRICULTURAL WASTE INTO INDUSTRIAL ENERGY: COFFEE PULP AS A FUEL FOR DRYING COFFEE IN CENTRAL AMERICAN BENEFICIOS

Presentado por el ICAITI a

AID Regional Office for Central America and Panama (ROCAP)
(Bioenergy Systems and Technology (BST) Project of AID/W
Office of Energy, Bureau of Science and Technology (ST/EY))

Guatemala, November, 1983

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1. INTRODUCTION

The coffee agroindustry, the most important in the Central American region, confronts a severe energy crisis. Diesel burners were adopted by many "beneficios" as a source of energy for drying their product when oil prices were low and now are no longer economic. Firewood universally used earlier, is increasingly scarce in many regions specially those where a dense rural population lives. This is the case in the small coffee farmers areas.

On the other hand, the building of new coffee "beneficios" for the organized cooperatives in Central America has developed contamination problems mainly due to the pulp or skin of the fruit, a voluminous byproduct. The large waste piles of wet pulp (see Figure 1) serve as breeding sites for flies, mosquitos and other pests; liquid drainage from the decaying pulp carries organic compounds into nearby water streams with disastrous effects on humans, aquatic plants and animals.

There are then very important economic and environmental reasons why coffee pulp should be treated in a new and more economical way. Within this perspective, this project is aimed to:

a) Design and test a mechanical press specifically adapted to coffee pulp, capable of yielding a residual bagasse of lowest practical moisture content, while handling an adequate amount of material per hour;

b) Design and test a burning system capable of handling the dry solid pulp, for further use in coffee drying;

c) Continue studies leading to the obtention of design parameters for an anaerobic digestor producing practical amounts of biogas from the juice obtained during the pressing operation.

The Guatemalan Federation of Coffee Cooperatives (FEDECOCAGUA) has a collaborative agreement with ICAITI and some areas of their "central beneficio" in Palin, Escuintla, were given for the project for the drying yards (patios) and to install the screw presses, the digestors for the juice and the burner for the dried bagasse.

The traditional way to process the coffee fruit is shown in Figure 2 and the possible new way incorporating the technology to be developed in Figure 3. Note that in the new technology the dried pulp will be burned in the coffee dryer. The biogas produced by the anaerobic digestion of the pulp will also be burned in this dryer. Drying of the pressed pulp can be accomplished either in drying patios (if available) or in a silo-dryer combination. In the latter the fuel gases from the coffee dryer, which usually are at around 250°C will be employed as energy source to dry the pulp. Fresh pulp is obtained in the traditional way and pressed continously to generate the two main streams: The pressed pulp and the coffee pulp juice. The sludge and effluent from the anaerobic digestor would be used as a carrier for fertilizers (P-N). Potassium will be recycled as the ashes from the coffee dryer (rich in potassium) will be employed to neutralize the acid stage effluent in the anaerobic digestion. The biogas effluent could also be treated in a high rate algae pond followed by fish ponds.

The activities in this project have been complemented with two concurrent research projects carried out by the Applied Research Division at ICAITI. One is sponsored by IDRC (Canada), in this a heat exchanger unit to heat air for drying has been developed. The other sponsored by OAS is intended to develop high rate digestors for biogas production. Very promisory results were obtained through this short time (one year) project. A low cost, locally constructed, screw press was developed, this is a key piece equipment in the future integrated utilization of the coffee fruit. Assays of biogas production, utilizing both low rate and high rate digestors were compared. The substrate (coffee pulp juice) seems adequate for both. Additionally

a high energy efficiency combustion chamber was designed capable of burning dry pulp to generate heat for coffee drying.

We strongly recommended the continuation of the research and development efforts in this area, to take advantage of the results obtained.

Some of the new concepts that have evolved from this work may, in time, generate dramatic changes in the wet processing of coffee.

2. CONCLUSIONS

1. The results of this work show an example of the need for a systems approach in trying to solve the energy problem in an agro-industrial rural operation carried out in a tropical region.

2. With this methodology the adaptation and development of specific technologies (like the direct combustion of moist solids or the anaerobic biogass operation of effluents) is dictated by the requirements of the analysis, which frequently high lights the necessity of conditioning and pretreatments of wastes. This implies the development, design and testing of prototypes which are simple enough to operate within the cost restrictions of these rural industries.

3. A low cost mechanical press prototype capable of dewatering coffee pulp has been developed. It can be built locally and it is simple to operate.

4. Coffee pulp juice has shown to be a good substrate for biogasification. Traditional reactor geometries gave low productivies. Two high rate reactors have been tested at various capacities; within and complemented by other projects one of them was developed by ICAITI (the sponge packed bed) Both yielded high volumetric methane rates.

5. It was shown that there is a 22% increase in sun drying capacity of patios when processing previously pressed coffee pulp as compared to non-pressed pulp.

6. The pulp drying in a static bed with direct combustion gases had a low thermal efficiency. Due to this lack of solids movement on the bed the buttom layer overheated and charred itself.

7. The combustion chamber design for pressed-dried-coffee pulp showed a high thermal efficiency.

3. MECHANICAL PRESSING OF COFFEE PULP

Pressing is a standard unit operation used in the fruit processing industry for the extraction of the juice from the fruit tissue (Coffelt & Giannini, 1973; Duckworth, 1966; Schwartzberg et al, 1977). It has been often used directly or indirectly to reduce the amount of heat requiered in a final drying operation.

Fresh coffee pulp has a moisture that ranges from 85 to 88% so part of it can be removed by expression before further utilization. Preliminary experiments (Rolz et al, 1980) have shown that juice yields close to 60% of the initial fresh weight of pulp can be obtained when a combination of enzymes and temperature are used as a pretreatment in experiments carried out with a batch hydraulic press. When the fresh pulp was pressed without pretreatment the juice was about 35% of the initial weight of pulp.

Costs of pressing equipment may prove to be one of the greatest obstacles to the widespread use of presses in coffee by-products processing. However, some recent works (Bagnall, 1980) have shown promissory results in developing intermediate technology screw presses for dewatering aquatic plants. Materials tested included water hyacinth and hidrilla both pest aquatic plants in Florida.

The objective of the subproject was to design and test a low-cost mechanical press capable of producing a bagasse-like material from wet coffee pulp, for further use as fuel.

3.1 Experimental Work:

Three different continous screw presses were evaluated for their capacity in handling fresh coffee pulp and the amounts of bagasse and juice obtained for a given power input into the system.

The first unit was a six inch diameter, one-cylinder screw press manufactured by the industrial firm Vincent Processes Inc. (Tampa, Florida). See Figure 4. Its estimated cost in 1983 would be in the order of US$17,000.00

The second press used in these studies was a unit formed by a two-cylinder conveyor that squeezed the pulp against a dead weight. See Figure 5. It was manufactured under the name FASO in Italy. Since this was an old unit, obtained as a loan from a local coffee grower (Mr. Norman Lind) the price was not available but it was estimated that for equivalent capacities, it would be similar to the previous case.

The third unit used as reference was a nine-inch diameter, one cylinder screw press, handmade by Prof. Larry O. Bagnall and his students at the University of Florida (Gainsville, Florida) (see Figure 6). A series of preliminary assays were made during a visit to the University of Florida by José Francisco Calzada and this press was obtined as a loan for one crop season, in order to be evaluated in Guatemala. This design, more economical, was used as basis for the unit that was built locally.

Following evaluations of the above mentioned units, two local mechanical shops were contracted to build and modify (if necessary) a screw press similar to the Bagnall model. A first prototype was prepared by TALLERES MEZA (see Figure 7 and 8). Total cost was US$4,350.00. Further modifications were requiered and these were contracted with TALLERES REA. This final version (see Figures 9 to 12) was evaluated at the beginning of the 1983-1984 crop season. Fresh coffee pulp obtained from a beneficio of the Guatemalan Federation of Coffee Cooperatives (FEDECOCAGUA - Palin) was used as material for the tests. Pre-determined amounts of pulp were passed through the press. Results obtained included: Handling capacity (kg of fresh pulp per hour), yields of pressed bagasse and juice (determined in weight basis). Initial and final moisture of the pulp were also determined (Anon, 1975). The proposed prototype is presented in the Figure 13.

3.2 Results and Discussion:

Pressing tests using the first three units (Vincent, FASO and Bagnall models) were carried out during the 1982-1983 crop season (early January to mid-March, 1983). The results are presented in Table 1, along with those of the proposed prototype. This last one was evaluated in the first days of the 1983-1984 crop season.

It can be observed that the proposed unit is adequate for the dewatering task. The reduction in water content is in the same range as the one obtained with the Vincent press, which also has similar capacity.

The efficiency of energy utilization is closer to the Vincent unit and higher than the FASO and Bagnall prototypes.

Due to the above considerations, the prototype proposed by ICAITI is considered technically and economical adequate for the pressing of fresh coffee pulp previous to its utilization as fuel feed or fertilizer. It must be stressed that two local mechanical shops have now the know-how to build other similar units. The press presenting is working for demonstration purposes at the FEDECOCAGUA-Palin beneficio, during the present crop (1983-1984) and, of course it can be copied by other local manufacturers. This will insure the dissemination of the technology.

4. BIOGAS PRODUCTION FROM COFFEE PULP

As described earlier in this report, coffee pulp juice is a byproduct resulting from the partial dewatering of the fresh coffee pulp. It represents approximately 40-45% of the initial weight of pulp. This is a sugar rich substrate (2.8-4.9% total sugars) that has been used for the production of biogas (gaseous mixture of methane and carbon dioxide). These experiments have been done in two-phase laboratory units (Calzada, 1982; Calzada et al, 1983).

The main objective of this subproject was to extend studies on the production of biogas from the coffee pulp juice, specially aiming to scale up the operations and to improve the productivity of the system.

4.1 Experimental Work:

Two-phase anaerobic systems were assayed, where the first stage was an acidogenic tank and the second one, the methanogenic digestor. The basic unit was similar in all cases and it has been described in detail elsewhere (de León, 1980). Figures 14 and 15 show the tank. The acidogenic reaction was performed in tanks filled with five-centimeter diameter PVC vertical tubes, in order to promote the retention of biomass with in the reactor. The effluent was used as feed for the methanogenic units, following pH correction (to pH 7 approximately), with sodium, calcium and magnesium carbonates.

For the methanogenic phase, two configurations were tested: The basic tank and the tank with vertical tubes similar to that described for the acidogenic phase.

Experiments ran from February to April 1983, when the crop finished. Ambient temperature (20-25°C) was used in all cases.

4.2 Results and Discussion:

From Table 2 can be observed that the packed configuration did not represents an improvement in terms of conversion of volatile fatty acids and reduction of chemical oxygen demand. Some sedimentation effects were present. This conclusion was reinforce by the values of gas production in the methanogenic stage. For the empty chamber digestor, the average value was 0.317 volumes of biogas per volume of digestor per day, while for the packed digestor, the corresponding value was 0.250 v/v day, with 10 days hydraulic retention time.

These results led to the conclusion that improved digestors should be used to increase the gas production rates. Some laboratory experiences with a two-phase conventional column digestor were carried out at ICAITI with the support of the International Foundation for Science (IFS-Sweden). High rate digestors were later applied to (Calzada et al, 1983) this same coffee substrate, with support of the Scientific Department of the Organization of American States. Two specific models were evaluated: The up-flow anaerobic sludge blanket (UASB) developed by Lettinga and co-workers (1980) and the sponge reactor, developed at ICAITI. This last one features the use of polyurethane sponges as packing materials, serving as support materials for the microbial growth (ICAITI, 1983). See Figures 16 to 18.

Results from the different systems are presented in Table 3. The improvement in gas productivity along with the reduced hydraulic retention times, made the high rate reactors very attractive for further development.

For this reason, colaboration with the OAS work was established within the last months of the project, in order to build a mobile pilot unit (1 m^3) featuring the two-phase anaerobic digestion of coffee pulp juice with the proposed methanogenic reactor: The sponge model, working under controlled temperature (35°C), (see Figure 19).

This unit will be tested in a local beneficio, during the 1983-1984 crop season, unfortunately outside of the time span of this project. Although this step was not included in the original scope of work, it was considered that the technology should be developed beyond the laboratory level.

5. DRYING OF COFFEE PULP

After pressing, coffee pulp still has a high water content and with this level of moisture is not attractive as a fuel. It is necessary to dry this pulp by natural or mechanical means in order to obtain a material that burns easily.

The experimental design has contemplated sun drying of pulp in a concrete floor constructed for this purpose, with the following dimensions: Lenght 13.5 m and width 8.5 m. Also a mechanical method of drying was included. It consisted of a vertical silo packed with the wet coffee pulp in which combustion gases coming from the generating unit will pass through the material.

5.1 Experimental Work:

5.1.1 Sun Drying:

Experiments of sun drying of the coffee pulp (with and without pressing) were carried out during the first semester. The pulp was spreaded in a concrete floor in a 5 cm thick layer. See photograph in Figure 20. During the drying tests, and only during the day, the coffee pulp was turned over by hand every two hours in order to prevent the overdrying of the top layer.

The atmospheric conditions were recorded using a hygrotermograph to monitor the ambient temperature and the relative humidity. Linear velocity of the air was measured with an anemometer and the solar radiation was recorded with a mechanical pyranograph.

During the day, samples were taken every two hours for moisture analysis, after turning over the coffee pulp. The samples were randomly taken from all over the drying concrete area. The moisture content of these samples by drying the coffee pulp in

laboratory oven at 105°C, until constant weight was obtained. The time to dry the coffee pulp under the sun was also recorded.

The procedure described above was utilized for drying test of fresh and pressed coffee pulp.

5.1.2 Drying Silo:

A vertical drying silo was constructed in order to test the behaviour of a static bed of pressed pulp when a flow of combustion gases was passed through it.

For this purpose a vertical silo made of galvanized metal was equipped with an induced draft created by a extractor driven by a 0.19 kw electric motor, with a extraction capacity of 0.13 kg air/s. The combustion gases were generated in a combustion chamber, burning dry pressed coffee pulp. Figure 21 shows the vertical drying silo connected with the combustion chamber. The photograph in Figure 22 shows both units. Drying tests were carried out and moisture samples were drawn off from the silo at intervals of 1-3 hours, the moisture content of the coffee pulp samples was determined through the drying of the sample in a laboratory oven at 105°C until constant weight was reached. The dry pressed coffee pulp used as fuel was weighted in a scale (0-500 kg, Fairbanks Morse). The drying silo had a perforated bottom that held the wet coffee pulp layer. A stream of combustion gases was passed through the layer at a temperature between 600-650°C The inlet and outlet temperatures in the silo were recorded with a multipoint temperature recorder (Texas Instrument Tigraph 100 Graphic Display Unit).

5.2 Results and Discussion:

5.2.1 Sun Drying:

The results obtained in the drying tests of fresh and pressed coffee pulp are shown in the Tables 4 to 12. The pressed pulp required an average drying time of 67½ hours to reach a moisture content between 10-12%. The fresh pulp required 75 hours to get to the same moisture level. One square meter of drying area can handle an average of 14.67 kg of pressed wet pulp and 16.8 kg of wet fresh pulp and yield an average of 3.07 kg and 2.76 kg of dry pulp respectively. The increase in yield per unit area and the reduction in drying time give a 22% increase in drying capacity of pressed coffee pulp over non-pressed coffee pulp. However, this figure is preliminary as drying conditions changed during the experiments. We believe a representative increase in drying capacity would be around 40%.

5.2.2 Vertical Drying Silo:

Preliminary results were obtained when wet pressed coffee pulp was dried in a static layer utilizing direct combustion gases (Table 13). A initial charge of 720 kg of wet pressed pulp required 12.15 h to reduce the moisture content from 86.55% to 79.09%, consumming 203.4 kg of dry pressed pulp as fuel. Approximately 257 kg of water were eliminated during the test, requiring 10.4 MJ of energy per kg of water evaporated. This energy demand is relatively high if it is compared with the energy necessary to eliminate the same amount of water during the coffee drying in static bed dryers using heat exchangers to heat the drying air: Between 6.5-16.9 MJ/kg water. Additionally, the high temperature of the drying gases (between 600-650°C), combined with the difficulty of turning over the coffee pulp in the silo, promoted the burning of the pulp layer that is in contact with the bottom screen. Continuation of tests for drying pressed coffee pulp using combustion gases, without heat exchanger and with modified silos is suggested. Improvement of mechanical movement within the silo is also required. Continuous dryers should be included in

the experiments, either for total drying of the pulp or as pre-dryers, associated with the sun drying.

6. BURNING OF COFFEE PULP

At the present, new sources of energy for drying of coffee and the efficient used of them have a very high priority for research in the coffee processing industry. In the past, many beneficios used fossil fuels as source of energy to dry their coffee, but since the large increase in prices of these fuels, most of them had to switch to another non-conventional fuels like coffee hulls and firewood and very recently to a mixture of coffee hulls and pulp.

The coffee processed by the "wet method", adds the pollution problem created by the by-products like coffee pulp, mucilage and washing waters. In most cases these materials are discharged into the rivers or other water bodies thus limiting the sources of potable water, and destroying life. Other coffee industries store the coffee pulp in piles near the processing sites, generating grounds for insect growing and as consecuence a health hazzard to the surrounding population.

The alternative value of the pulp as a renewable fuel source must then be considered. This aspect is explored in this section.

6.1 Experimental Work:

Dry coffee pulp without a preliminary treatment such as pressing is very difficult to burn due to the high content of ashes and the poor contact area of the material. During the pulp pressing, significant quantities of juice are eliminated, lowering the soluble inorganic matter of the pulp and breaking the original structures of it. In spite of the previous treatment of the pulp, the behaviour of this material in the traditional combustion chambers is not adequated to obtain continuous operation and good combustion results. ICAITI designed a combustion chamber to test the different parameters involved

in the combustion. This pilot plant combustion chamber is showed in the Figures 23 y 24. The equipment was designed with different fuel inlets to find an adecuated feeding point of the pulp. Four fuel inlets were tested (see Figure 25) two of them were located 0.8 m above the grit, at the center and tangential to the cylindrical chamber, other at the center, at the same level of the grit and the last one 0.3 m above the grit and tangential to the camber. The dry pressed pulp was fed through inlets by a pneumatic conveyor at a rate ranging between 23.04-25.2 kg of pulp per hour.

Secondary air inlets were also tested. The first one was a forced air stream (created by a 0.19 kw fan) entering tangentially to the chamber wall and at the same level of the grit, opposite to the tangential fuel inlet (located 0.3 m above the grit). See Figure 26. The second alternative tested was an induced draft created by the extractor coupled to the drying silo thus entering the air through the grit and the ash pit gate.

The dry coffee pulp burned in the combustion chamber, was weighted in a scale, (0-500 kg, Fairbanks Morse). The pulp moisture was also determined in each test by taking a representative sample and placed in a laboratory oven at a temperature of 105 $\pm$ 5°C until constant weight. The combustion gases and ambient air temperatures were recorded by a multipoint temperature recorder (Texas Instruments Tigraph 100 Graphic display unit).

The extractors volumetric flow was measured at ambient temperature and corrected to the operation conditions. The air velocity was measured with hot wire anemometer (model W-141-A Measure Corp.). This data, in conjuntion with the duct geometric characteristics, were used to calculate the volumetric flow.

The pressed pulp calorific value was calculated according with the equation:

$$\text{Calorific value} = 15\,882 \left(\frac{100-H}{100}\right) - 2\,589 \left(\frac{H}{100}\right) \left(\frac{kJ}{kg}\right)$$

where:

15 882 = dry basis calorific value of pressed pulp determined by calorimetric bomb (kJ/kg)

2 589 = Sensible and latent calorific value of water ($\frac{kJ}{kg}$)

H = pulp moisture (%)

It is necessary to clarify the fact that the calorific value of pressed pulp was obtained from a sample of pressed pulp obtained with the Vincent press. Although there would be different among samples obtained with other equipment it is felt that their would be small less than 10%.

6.2 Results and Discussions:

The results obtained in the burning test of dry pressed coffee pulp are shown in Table 14. It can be observed that the coffee pulp pressed with the Vincent press burns more easily than the pulp pressed with the FASO press. This is due to fact that the Vincent press extracts more juice from the pulp and it also destroys more of the original configuration of the coffee pulp. It is showed in the Figure 27, that there are differences among the bagasses when pressed with the various presses.

Higher temperatures were obtained in the combustion chamber with the pulp pressed in the Vincent unit, and it is more easily fed by the pneumatic conveyor. To the extent that the pressing action is better, the pulp burns more efficiently and the ashes generated during the combustion, drains in better way through the grit. Ash coming from coffee pulp without pressing or submitted to a mild pressing action, keeps the original configuration of the pulp and it has to be drained by hand from the combustion chamber; the pulp also burns with difficulty.

As can be seen in Table 14 very good burning efficiencies (between 91-96%) were obtained during the combustion tests. The high efficiency data obtained while burning pulp, pressed with the FASO press, could be due to a lower heat losses in the combustion chamber, as a consecuence of a lower combustion temperature. In addition, on a lesser scale, such differences in burning efficiency could be caused by a small difference in the calorific value of both fuels obtained with the two presses.

During the burning tests, the FASO pressed coffee pulp was accumulated in the combustion chamber and had to be turned over to obtain adequate burning. Ashes were removed by hand, as they had difficulty passing though the grit.

As for the secondary air inlets, the induced draft was the most promissing way to feed air to the combustion chamber. This air flow could be also forced under the grit to improve the combustion and to help the mixing of the fuel in the chamber. The other option, when the air was introduced in a tangential way at the same level of the grit, did not improve the combustion of the pulr. On the contrary, in some cases, it extinguished the flame and the combustion process had to be started again.

7. MODELLING AND OPTIMIZATION OF COFFEE PROCESSING OPERATION:

Figure 28 represents an outline of the coffee process in a beneficio, showing some of the possible alternatives both in processing and in by-products utilization. Selection of alternatives is not easy because of the complexity of the operation. Processing capacities range from hundreds of kg/day to thousands of tons/day. The lenght of the annual coffee harvesting season varies according to the climatic conditions of the region, ranging from 3 to 6 months. The raw material (coffee fruit) reaches the beneficios in small quantities at the beginning of the season, increasing continuously towards a maximum peak and then decreasing in the same way at the end of the season.

A mathematical model of a coffee beneficio, with enough flexibility to simulate most of the possible alternatives, will permit selection of processing methods and by-product utilization options which optimize operational cost for different plant sizes and geographical locations.

7.1 Experimental Work:

An IBM PC microcomputer with 320 k of CPU memory, two flexible disc drives, one CRT and one EPSON printer, was purchased. The order was placed in April 1983 and the equipment was received in September of the same year.

A mathematical model for each step of the process should be established. These individual models will then be assembled as subroutines of the main program for modeling the whole operations.

The first individual operation to be modeled will be coffee drying. This is because it is the most expensive step in the process and also because experimental data is already available, consisting in

coffee bean moisture vrs time; moisture content and temperature vrs time for the air leaving the dryer; obtained from a commercial size batch bed dryer built and tested by ICAITI in a coffee beneficio. Besides, data on drying efficiencies for different fuels and air-heating systems and on cost of operation is also available.

Experimental data will be used to calculate overall mass transfer coefficients in the dryer. Since these coefficients are not very sensitive to air flowrates in static bed dryers, and the temperature of the drying air has little variation during the coffee drying cycle, it can be assummed that the mass transfer coefficients will remain constant and thus used to predict drying times. Drying cost can be calculated as a function of drying time as the objective function to be optimized. An algorithm for restricted non-linear optimization should be used to calculate optimum air flowrates and temperatures. As experimental data become available, other process operations will be modeled and incorporated to the coffee beneficio model.

7.2 Results and Discussions:

At the time of writing this report, the coffee drying model was being programmed.

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9. FINANCIAL REPORT

INSTITUTO CENTROAMERICANO DE INVESTIGACION Y TECNOLOGIA INDUSTRIAL

PROJECT: COFFEE PULP FUEL
CONTRACT NO.: 53-319R-3-2 WORKPLAN: 392 6100400015
ICAITI NO. 82/4.6.1733

PERIOD: 7 OCTOBER 1982 THROUGH 6 OCTOBER 1983 (FINAL STATEMENT)

CATEGORY	TOTAL BUDGET	EXPENDITURES DISBURSED	ACCRUALS	TOTAL	BALANCE
1. PROFESSIONAL PERSONEL	15,920.00	17,326.65	0.00	17,326.65	1,406.65-
2. TECHNICIANS	2,250.00	2,570.63	0.00	2,570.63	320.63-
3. CONSULTANTS	2,700.00	0.00	0.00	0.00	2,700.00
4. EQUIPMENT AND INSTRUMENTATION	22,000.00	23,535.55	1,702.00	25,237.55	3,237.55-
5. EXPENDABLE SUPPLIES	2,000.00	1,549.02	404.30	1,953.32	46.68
6. TRAVEL AND PERDIEM	2,200.00	1,509.29	655.86	2,165.15	34.85
7. BIBLIOGRAPHY AND SUBSCRIPTIONS	2,000.00	1,095.28	480.92	1,576.20	423.80
8. OTHER (COMMUNICATIONS)	390.00	215.47	77.19	292.67	97.33
9. CONTINGENCY	3,000.00	0.00	0.00	0.00	3,000.00
10. OVERHEAD (90% OF 1+2)	14,540.00	15,917.82	0.00	15,917.82	1,377.82-
TOTAL >>>>	67,000.00	63,709.74	3,290.26	67,000.00	0.00

THE UNDERSIGNED HEREBY CERTIFIES: (1) THAT PAYMENT OF THE SUM CLAIMED ON THE VOUCHER IS PROPER AND DUE UNDER THE TERMS OF THE AGREEMENT; AND (2) THAT THE INFORMATION ON THE DISBURSEMENT REPORT IS CORRECT AND SUCH DETAILED SUPPORTING INFORMATION AS MAY REQUIRE WILL BE FURNISHED ON REQUEST.

USDA

MARIO A. [illegible], CHIEF
BUDGET & COST CONTROL DIVISION

INSTITUTO CENTROAMERICANO DE INVESTIGACION Y TECNOLOGIA INDUTRIAL

PROJECT: COFFEE PULP FUEL
CONTRACT NO.: 53-319R-3-2 WORKPLAN: 302 610040015
ICAITI NO. 82/4.6.1783

PERIOD: 7 OCTOBER 1982 THROUGH 6 OCTOBER 1983 (FINAL STATEMENT)

CATEGORY	TOTAL BUDGET	EXPENDITURES DISBURSED	ACCRUALS	TOTAL	BALANCE
1. PROFESSIONAL PERSONEL	15,920.00	17,326.66	0.00	17,326.66	1,406.66-
2. TECHNICIANS	2,250.00	2,570.63	0.00	2,570.63	320.63-
3. CONSULTANTS	2,700.00	0.00	0.00	0.00	2,700.00
4. EQUIPMENT AND INSTRUMENTATION	22,000.00	23,535.55	1,702.00	25,237.55	3,237.55-
5. EXPENDABLE SUPPLIES	2,000.00	1,549.02	404.30	1,953.32	46.68
6. TRAVEL AND PERDIEM	2,200.00	1,509.29	655.86	2,165.15	34.85
7. BIBLIOGRAPHY AND SUSCRIPTIONS	2,000.00	1,085.23	450.92	1,536.20	463.80
8. OTHER (COMMUNICATIONS)	370.00	215.49	77.18	292.67	97.33
9. CONTINGENCY	3,000.00	0.00	0.00	0.00	3,000.00
10. OVERHEAD (80% OF 1+2)	14,540.00	15,917.92	0.00	15,917.92	1,377.92-
TOTAL >>>>	67,000.00	63,709.74	3,290.26	67,000.00	0.00

THE UNDERSIGNED HEREBY CERTIFIES: (1) THAT PAYMENT OF THE SUM CLAIMED ON THE VOUCHER IS PROPER AND DUE UNDER THE TERMS OF THE AGREEMENT; AND (2) THAT THE INFORMATION ON THE DISBURSEMENT REPORT IS CORRECT AND SUCH DETAILED SUPPORTING INFORMATION AS USDA MAY REQUIRE WILL BE FURNISHED ON REQUEST.

MARIO A. SANTOS, CHIEF
BUDGET & COST CONTROL DIVISION

INSTITUTO CENTROAMERICANO DE INVESTIGACION Y TECNOLOGIA INDUTRIAL

PROJECT: COFFEE PULP FUEL
CONTRACT NO.: 53-319R-3-3 WORKPLAN: 002 610040015
ICAITI NO. 82/4.6.1763

PERIOD: 7 OCTOBER 1982 THROUGH 6 OCTOBER 1983 (FINAL STATEMENT)

CATEGORY	TOTAL BUDGET	EXPENDITURES DISBURSED	ACCRUALS	TOTAL	BALANCE
1. PROFESSIONAL PERSONEL	15,920.00	17,326.66	0.00	17,326.66	1,406.66-
2. TECHNICIANS	2,250.00	2,570.63	0.00	2,570.63	321.63-
3. CONSULTANTS	2,700.00	0.00	0.00	0.00	2,700.00
4. EQUIPMENT AND INSTRUMENTATION	22,000.00	23,535.55	1,702.00	25,237.55	3,237.55-
5. EXPENDABLE SUPPLIES	2,000.00	1,547.62	404.70	1,953.32	46.68
6. TRAVEL AND PERDIEM	2,200.00	1,509.29	655.86	2,165.15	34.85
7. BIBLIOGRAPHY AND SUBSCRIPTIONS	2,000.00	1,085.29	450.92	1,536.20	463.80
8. OTHER (COMMUNICATIONS)	350.00	215.49	77.18	292.67	57.33
9. CONTINGENCY	3,000.00	0.00	0.00	0.00	3,000.00
10. OVERHEAD (90% OF 1+2)	14,540.00	15,917.82	0.00	15,917.82	1,377.82-
TOTAL >>>>	67,000.00	63,709.74	3,290.26	67,000.00	0.00

THE UNDERSIGNED HEREBY CERTIFIES: (1) THAT PAYMENT OF THE SUM CLAIMED ON THE VOUCHER IS PROPER AND DUE UNDER THE TERMS OF THE AGREEMENT; AND (2) THAT THE INFORMATION ON THE DISBURSEMENT REPORT IS CORRECT AND SUCH DETAILED SUPPORTING INFORMATION AS USDA MAY REQUIRE WILL BE FURNISHED ON REQUEST.

MARIO A. SANTOS, CHIEF
BUDGET & COST CONTROL DIVISION

10. TABLES AND FIGURES

TABLE 1

PRESSING OF FRESH COFFEE PULP

Press	Power kW	Capacity[a]	Bagasse yield[b]	Initial water content in pulp, %	Final water content in bagasse, %	Productivity[c]
Vincent (6 in)	1.5	1 023.0	609.2	87.0	82.0	112.2
Bagnall	6.0?	655.0	509.2	86.3	83.0	65.7
FASO	5.6	550.4	569.2	86.0	80.7	60.4
ICAITI	2.25	1 022.2	707.7	87.3	83.7	112.1[d]

a kg of fresh pulp fed per hour
b kg per ton of pulp fed on wet basis
c kg of dried bagasse produced per hour
d data calculated from the moisture found in the samples after and before pressing

TABLE 2

ACIDOGENIC AND METHANOGENIC BIOREACTORS USING COFFEE PULP JUICE

Material	Total solids (%)	Volatile solids (%)	pH	Volatile fatty acids (%)	C.O.D. (mg/l)
Fresh coffee pulp	4.30	2.87	4.0 - 4.5	very small amounts	51 690
Effluent from acidogenic phase	2.43	1.80	3.0 - 3.5	0.398	33 650
Effluent from methanogenic phase (packed chamber)	2.33	1.22	6.8 - 7.2	very small amounts	7 320
Effluent from methanogenic phase (empty chamber)	1.49	0.78	6.8 - 7.2	0.128	13 170

TABLE 3

METHANOGENIC REACTORS USING COFFEE PULP JUICE

REACTOR	Temp. (°C)	Hydraulic Retention time (days)	Volatile Solids load (g/l day)	Gas Productivity v/v day	% CH_4
Tank	20-25	10	1.50	0.32	-
Tank with tubes	20-25	10	1.50	0.25	-
Column (up-flow)	35	10	1.51	1.00	69
	35	8	1.84	1.30	73
	35	6	2.42	1.00	51
UASB	35	5	8.8	2.18	92
	35	4	11.0	2.98	95
	35	3	14.7	1.87	67
	35	2	22.0	4.58	77
Sponge	35	5	8.8	1.87	90
	35	4	11.0	2.51	93
	35	3	14.7	2.73	87
	35	2	22.0	3.18	90

TABLE 4

SUN DRYING OF PRESSED PULP

Type of press: Twin screw (FASO)
Experiment No.: 1

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-01-19	8:00	0	4.30
	10:00	2	3.87
	12:00	4	3.57
	14:00	6	3.03
	16:00	8	3.13
1983-01-20	8:00	24	2.98
	10:00	26	2.45
	12:00	28	1.81
	14:00	30	1.31
	16:00	32	1.39
1983-01-21	8:00	48	1.33
	10:00	50	0.95
	12:00	52	0.54
	14:00	54	0.31
	16:00	56	0.23
1983-01-22	8:00	72	0.38
	10:00	74	0.19
	12:00	76	0.15

Average atmospheric conditions during the test:
- wind velocity (m/s): 0.99
- ambient temperature (°C): 26.5
- relative humidity (%): 55.0
- solar radiation (J/m^2/seg): 620.0

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 13.01
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 2.55
- initial weight (kg wet pressed pulp): 1 458
- final weight (kg dry pressed pulp): 286
- drying area (m2): 122.2

TABLE 5

SUN DRYING OF PRESSED PULP

Type of press: Twin screw (FASO)
Experiment No.: 2

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-01-26	8:00	0	3.92
	10:00	2	3.77
	12:00	4	3.21
	14:00	6	2.81
	16:00	8	2.72
1983-01-27	8:00	24	2.32
	10:00	26	2.04
	12:00	28	2.03
	14:00	30	1.97
	16:00	32	1.81
1983-01-28	8:00	48	1.49
	10:00	50	1.40
	12:00	52	0.84
	14:00	54	0.52
	16:00	56	0.35
1983-01-29	8:00	72	0.41
	10:00	74	0.22
	12:00	76	0.08

Average atmospheric conditions during the test:
- wind velocity (m/s): 0.85
- ambient temperature (°C): 22.0
- relative humidity (%): 70.0
- solar radiation (J/m^2/seg): 375.3

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 12.90
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 2.63
- initial weight (kg wet pressed pulp): 723
- final weight (kg dry pressed pulp): 148
- drying area (m^2): 56.1

TABLE 6

SUN DRYING OF PRESSED PULP

Type of press: Twin screw (FASO)
Experiment No.: 3

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-01-02	10:00	0	4.39
	12:00	2	3.26
	14:00	4	2.97
	16:00	6	2.67
1983-02-03	8:00	22	2.19
	10:00	24	2.08
	12:00	26	1.38
	14:00	28	1.05
	16:00	30	0.77
1983-02-04	8:00	46	0.75
	10:00	48	0.49
	12:00	50	0.34
	14:00	52	0.19
	16:00	54	0.13

Average atmospheric conditions during the test:
- wind velocity (m/s): 1.82
- ambient temperature (°C): 25.5
- relative humidity (%): 58.1
- solar radiation (J/m^2/seg): 571.1

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 14.89
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 3.32
- initial weight (kg wet pressed pulp): 822
- final weight (kg dry pressed pulp): 183
- drying area (m^2): 55.3

TABLE 7

SUN DRYING OF PRESSED PULP

Type of press: Single screw (VINCENT)
Experiment No.: 4

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-02-08	10:00	0	4.57
	12:00	2	4.40
	14:00	4	3.11
	16:00	6	2.88
1983-02-09	8:00	22	2.88
	10:00	24	2.70
	12:00	26	2.01
	14:00	28	1.58
	16:00	30	1.64
1983-02-10	8:00	46	1.82
	10:00	48	1.67
	12:00	50	0.95
	14:00	52	0.56
	16:00	54	0.37
1983-02-11	8:00	70	0.44
	10:00	72	0.28
	12:00	74	0.14
	14:00	76	0.10

Average atmospheric conditions during the test:
- wind velocity (m/s): 1.17
- ambient temperature (°C): 25.0
- relative humidity (%): 69.0
- solar radiation (J/m^2/seg): 398.2

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 14.05
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 2.30
- initial weight (kg wet pressed pulp): 474
- final weight (kg dry pressed pulp): 80
- drying area (m^2): 33.8

TABLE 8

SUN DRYING OF PRESSED PULP

Type of press: Single screw (VINCENT)
Experiment No.: 5

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-02-15	15:00	0	4.56
1983-02-16	8:00	17	4.25
	10:00	19	3.82
	12:00	21	3.04
	14:00	23	3.68
	16:00	25	2.28
1983-02-17	8:00	41	2.09
	10:00	43	1.59
	12:00	45	1.18
	14:00	47	0.98
	16:00	49	1.18
1983-02-18	8:00	65	0.51
	10:00	67	0.52
	12:00	69	0.37
	14:00	71	0.15

Average atmospheric conditions during the test:
- wind velocity (m/s): 1.52
- ambient temperature (°C): 23.0
- relative humidity (%): 65.4
- solar radiation (J/m^2/seg): 522.2

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 13.07
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 2.55
- initial weight (kg wet pressed pulp): 732
- final weight (kg dry pressed pulp): 143
- drying area (m^2): 56.1

TABLE 9.

SUN DRYING OF FRESH PULP

Experiment No.: 6

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-02-23	10:00	0	6.33
	12:00	2	5.72
	14:00	4	5.29
	16:00	6	4.70
1983-02-24	8:00	22	3.45
	10:00	24	3.09
	12:00	26	2.80
	14:00	28	2.41
	16:00	30	2.02
1983-02-25	8:00	46	1.21
	10:00	48	0.82
	12:00	50	0.91
	14:00	52	0.61
	16:00	54	0.57
1983-02-26	8:00	70	0.42
	10:00	72	0.34
	12:00	74	0.18
	14:00	76	0.14

Average atmospheric conditions during the test:
- wind velocity (m/s): 1.52
- ambient temperature (°C): 25.0
- relative humidity (%): 61.5
- solar radiation (J/m^2/seg): 470.0

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 21.85
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 3.35
- initial weight (kg wet pressed pulp): 864
- final weight (kg dry pressed pulp): 133
- drying area (m^2): 39.6

TABLE 10

SUN DRYING OF FRESH PULP

Experiment No.: 7

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-03-01	8:00	0	7.89
	10:00	2	6.44
	12:00	4	6.21
	14:00	6	5.58
	16:00	8	5.58
1983-03-02	8:00	24	5.43
	10:00	26	4.97
	12:00	28	3.88
	14:00	30	3.53
	16:00	32	3.25
1983-03-03	8:00	48	3.03
	10:00	50	2.01
	12:00	52	2.02
	14:00	54	1.87
	16:00	56	1.63
1983-03-04	8:00	72	1.30
	10:00	74	1.19
	12:00	76	0.82
	14:00	78	0.79
	16:00	80	0.48
1983-03-05	8:00	96	0.26
	10:00	98	0.10

Average atmospheric conditions during the test:

- wind velocity (m/s): 1.43
- ambient temperature (°C): 28.00
- relative humidity (%): 66.00
- solar radiation (J/m^2/seg): -

Sun drying of pulp in patios:

- wet pulp per unit area (kg wet pressed pulp/m^2): 16.44
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 2.55
- initial weight (kg wet pressed pulp): 1 239
- final weight (kg dry pressed pulp): 193
- drying area (m^2): 75.5

TABLE 11

SUN DRYING OF FRESH PULP

Experiment No.: 8

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-03-09	10:00	0	6.16
	12:00	2	6.39
	14:00	4	4.47
	16:00	6	3.91
1983-03-10	8:00	22	3.15
	10:00	24	3.03
	12:00	26	1.48
	14:00	28	0.63
	16:00	30	-
1983-03-11	8:00	46	0.33
	10:00	48	0.14
	12:00	50	0.13
	14:00	52	0.10

Average atmospheric conditions during the test:
- wind velocity (m/s): 3.06
- ambient temperature (°C): 25.00
- relative humidity (%): 55.00
- solar radiation ($J/m^2/seg$): 460.20

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 12.11
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 2.37
- initial weight (kg wet pressed pulp): 720
- final weight (kg dry pressed pulp): 141
- drying area (m^2): 59.5

TABLE 12

SUN DRYING OF PRESSED PULP

Type of press: Single screw (BAGNALL)
Experiment No.: 9

Date	Time	Drying time (h)	Moisture content (kg water/kg solid)
1983-03-27	12:00	0	3.64
	14:00	2	3.84
	16:00	4	3.47
1983-03-28	8:00	20	2.31
	10:00	22	2.57
	12:00	24	2.11
	14:00	26	2.66
	16:00	28	2.19
1983-03-29	8:00	44	1.39
	10:00	46	1.02
	12:00	48	0.91
	14:00	50	0.26
	16:00	52	0.17

Average atmospheric conditions during the test:
- wind velocity (m/s): 2.74
- ambient temperature (°C): 22.5
- relative humidity (%): 65.7
- solar radiation (J/m^2/seg): 492.8

Sun drying of pulp in patios:
- wet pulp per unit area (kg wet pressed pulp/m^2): 20.12
- dry pulp yield per unit area (kg dry pressed pulp/m^2): 4.98
- initial weight (kg wet pressed pulp): 2 263
- final weight (kg dry pressed pulp): 572
- drying area (m^2): 112.6

TABLE 13

PRESSED COFFEE PULP DRYING
IN A VERTICAL SILO

DRYING TIME (h)	MOISTURE CONTENT (%)
0.0	86.55
3.5	85.97
4.5	85.70
5.5	78.57
7.0	83.15
8.0	81.66
9.0	82.47
11.0	83.24
13.0	79.09

Pressed coffee pulp burned: 203.4 kg
Moisture content: 13.93%
Wet coffee pulp charged to the drying silo: 720 kg

TABLE 14

COMBUSTION CHAMBER BURNING EFFICIENCY

TYPE OF FUEL	Fuel Humidity (%)	Caloric Value MJ/kg	Fuel Comsuption (kg/S)	Combustion Gases Temperature (°C)	Ambient Temperature (°C)	Combustion Gases Masic Flow (kg/S)	Burning Efficiency (%)
Dry pressed coffee pulp (Vincent Press)	13.93	13.309	0.0070	23.0	640	0.120	91.43
Dry pressed coffee pulp (FASO Press)	15.12	13.089	0.0064	23.0	605	0.120	95.72

FIGURE 1 Wet coffee pulp pile.

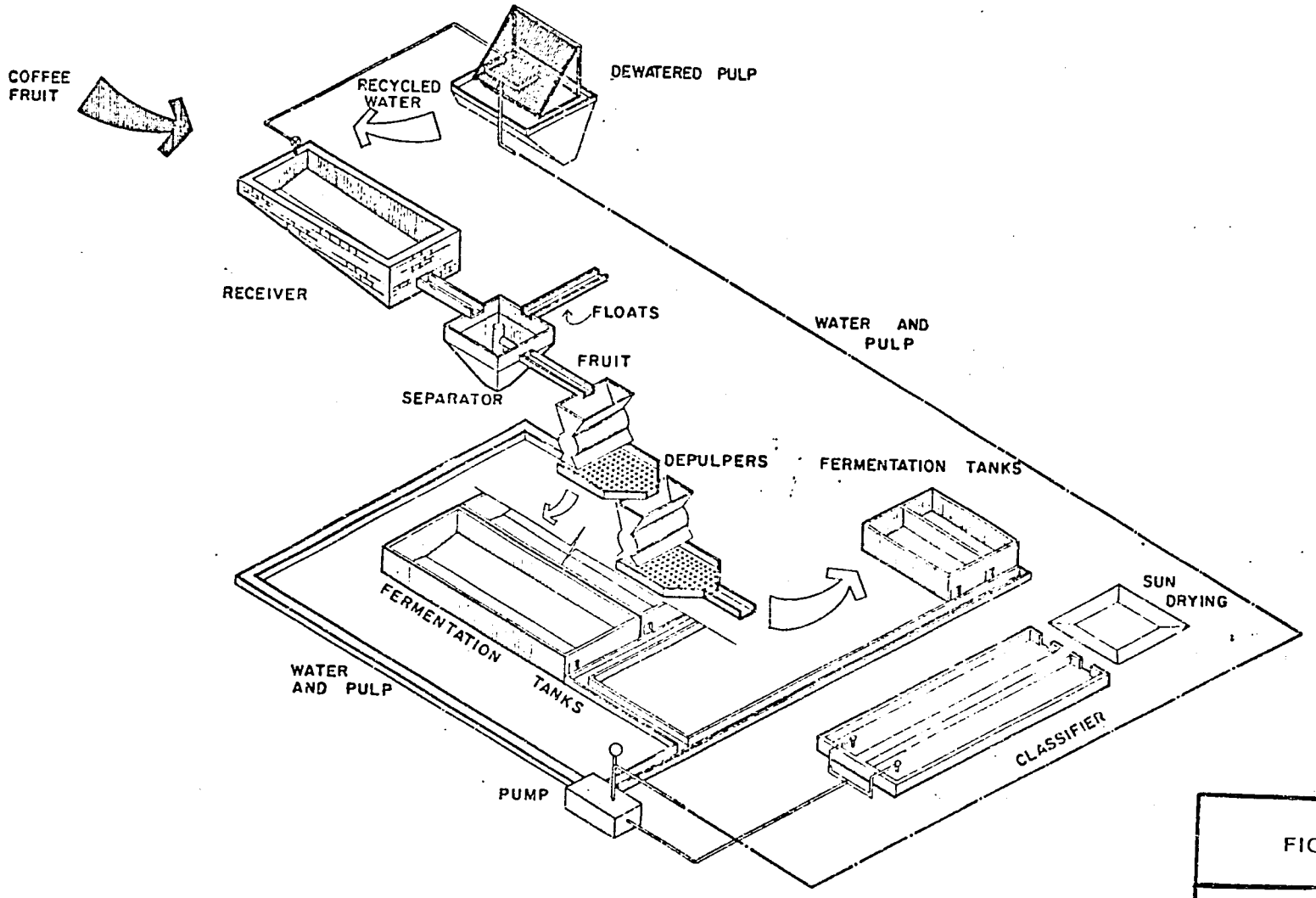


FIGURE 2

CONVENTIONAL PROCESSING PLANT
WATER RECIRCULATION

ENG. JUAN E. MENCHU | JUNE 1983

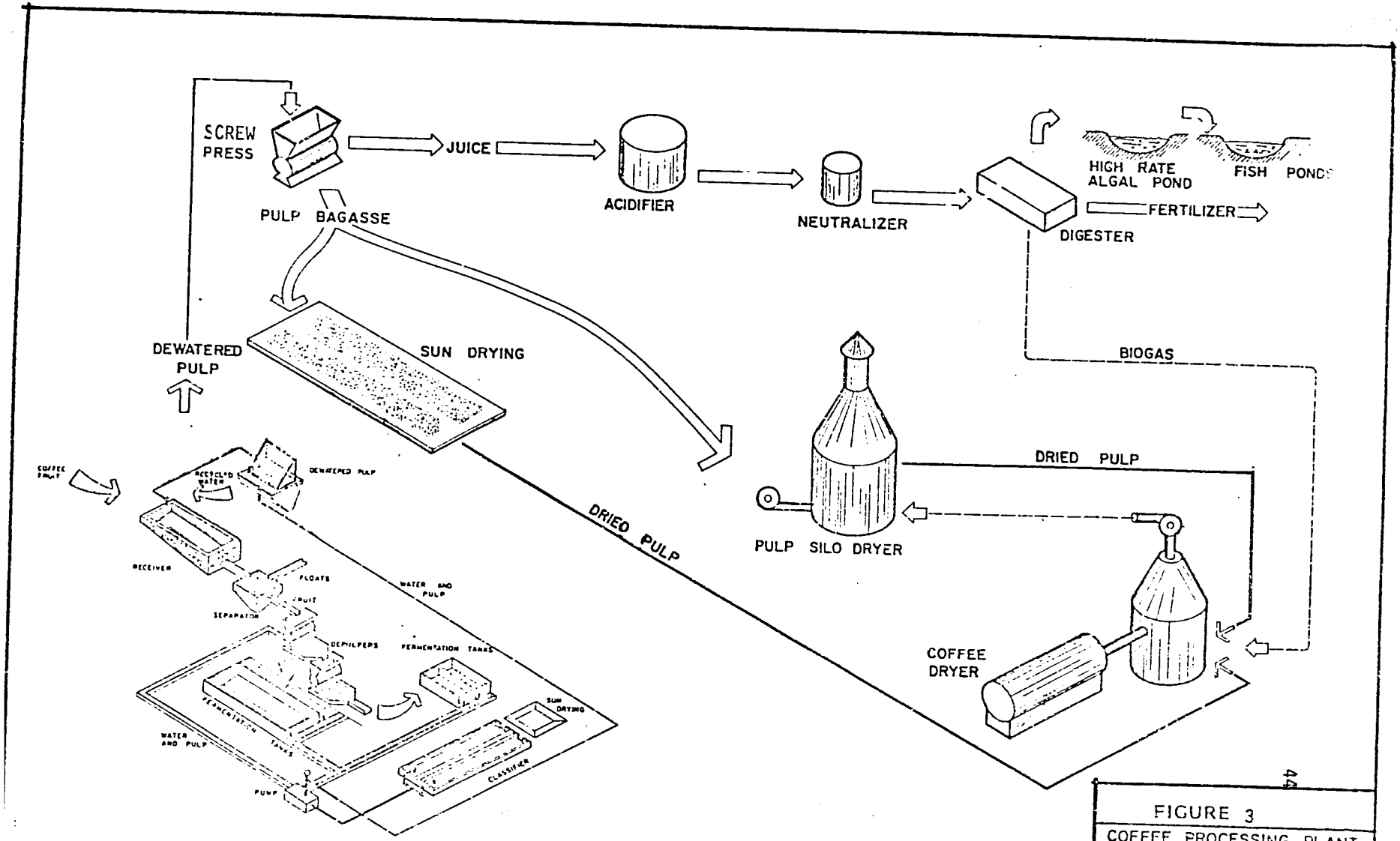


FIGURE 3

COFFEE PROCESSING PLANT INTEGRATED SYSTEM

COFFEE PULP AS ENERGY SOURCE

ENG. JUAN F. MENCHU | JUNE 1981

FIGURE 4 Vincent Screw Press.

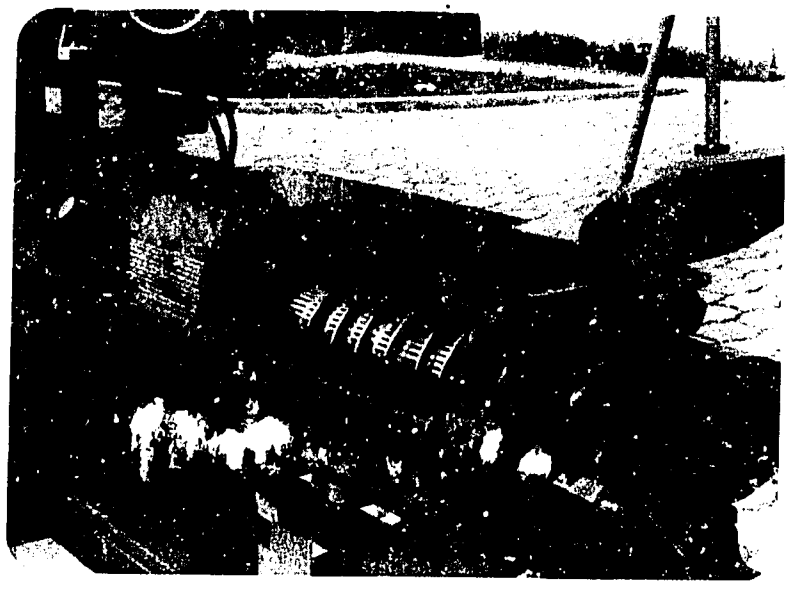


FIGURE 5 FASO twin-screw press.

FIGURE 6 Bagnall screw press (right side).

FIGURE 7 ICAITI screw press. First prototype.

FIGURE 8 Perforated shell of ICAITI screw press.

FIGURE 9 ICAITI screw press. Modified version.

FIGURE 10 Gear system. ICAITI screw press.

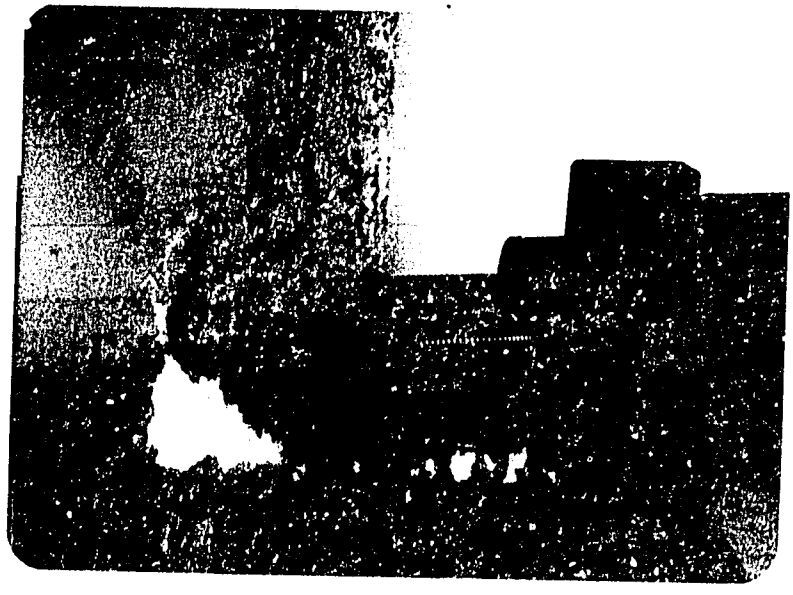


FIGURE 11 Spring pressure discharge system. ICAITI screw press.

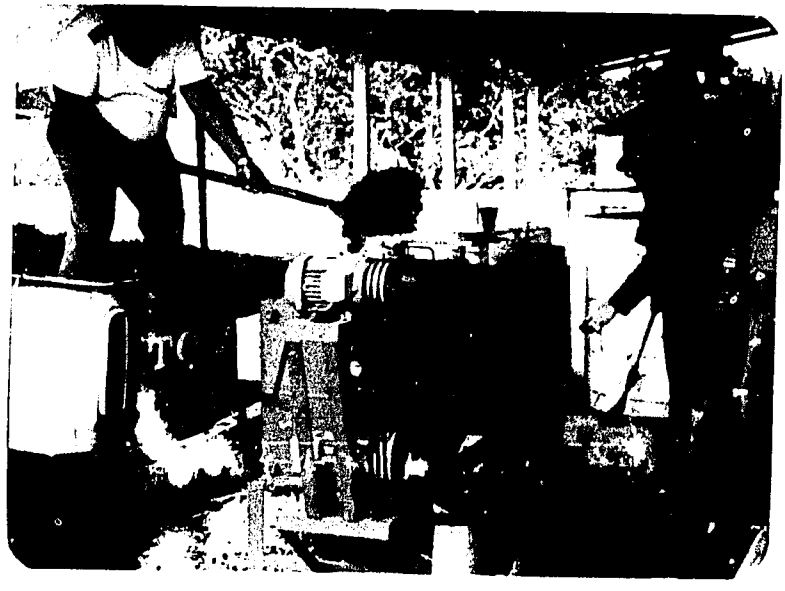


FIGURE 12 Pressing of fresh coffee pulp with ICAITI screw press.

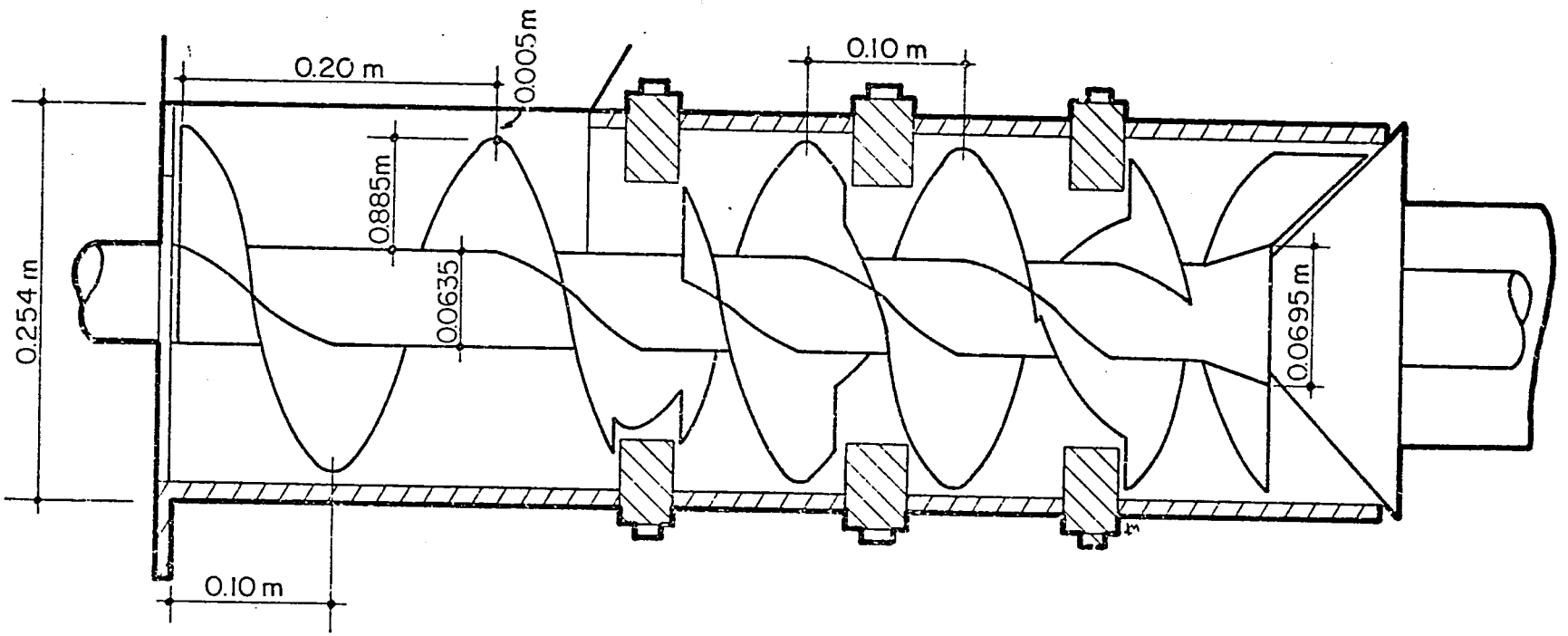


FIGURE 13 ICAITI CONTINOUS SCREW PRESS

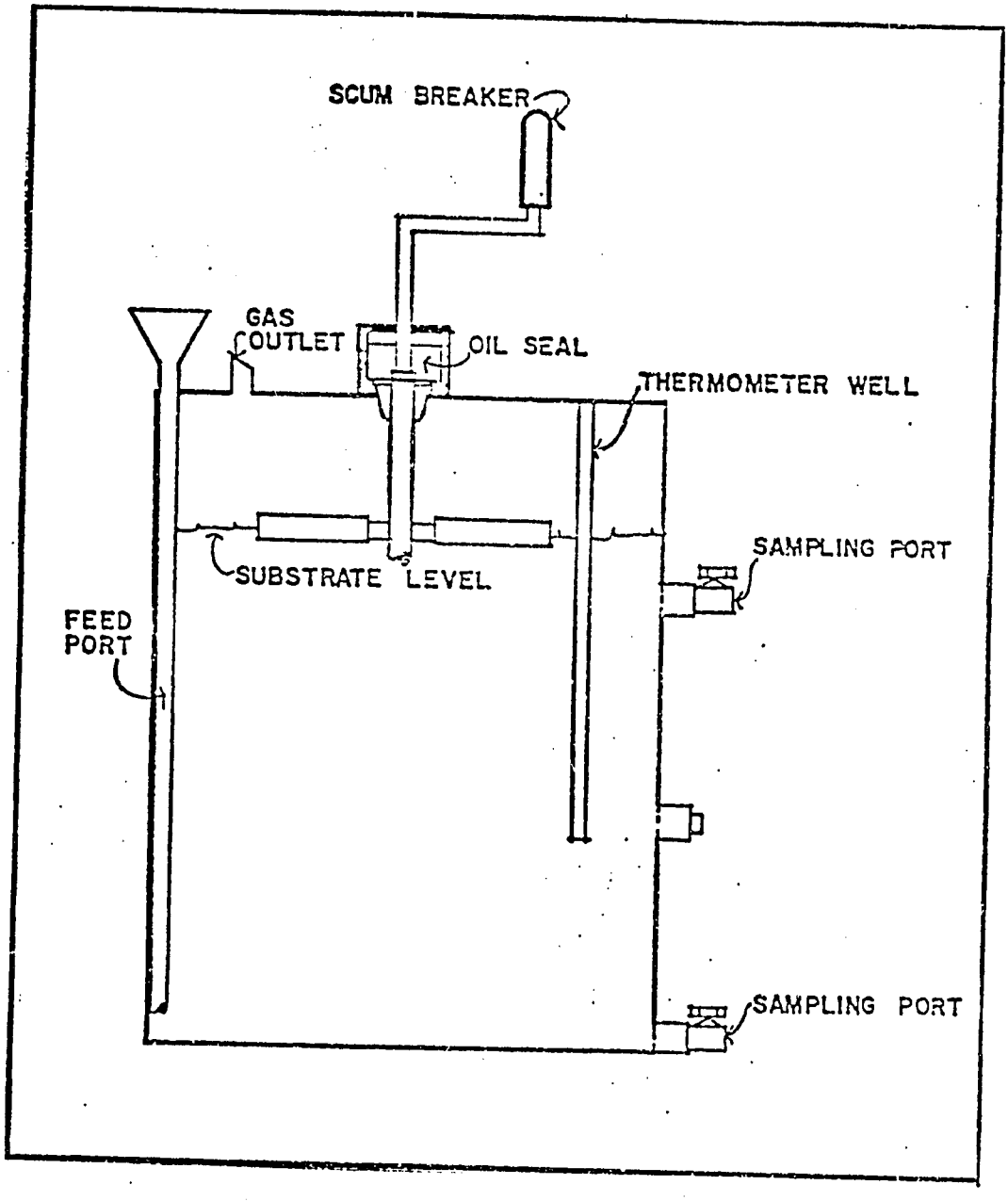


FIGURE 14: PILOT PLANT DIGESTOR

FIGURE 15 Acidogenic tank for biogas production.

FIGURE 16 Up-flow anaerobic sludge blanket laboratory reactor.

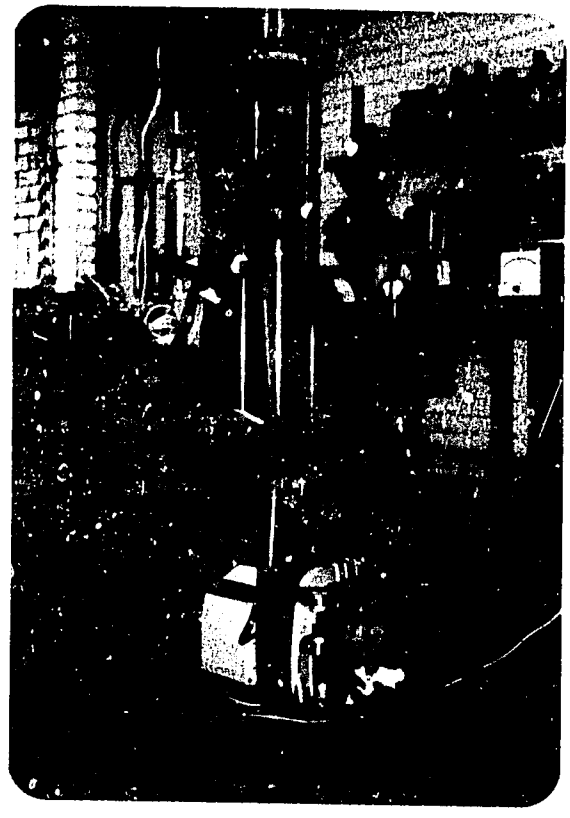


FIGURE 17 Sponge reactor for biogas production. Laboratory unit.

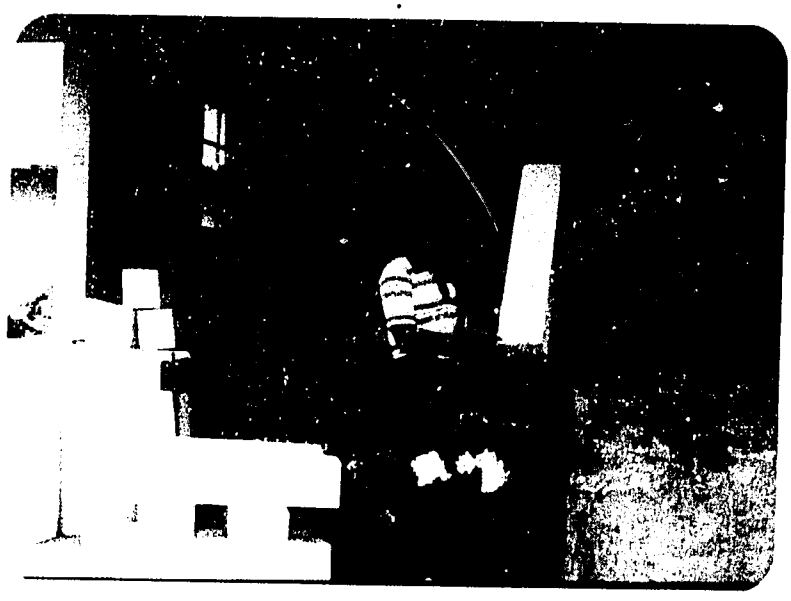


FIGURE 18 Polyurethane sponges as packing material. Sponge reactor pilot plant unit.

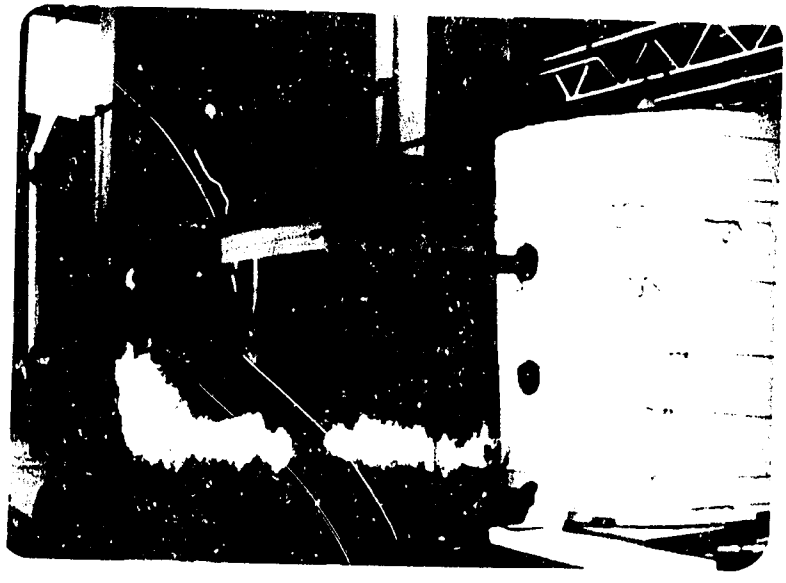
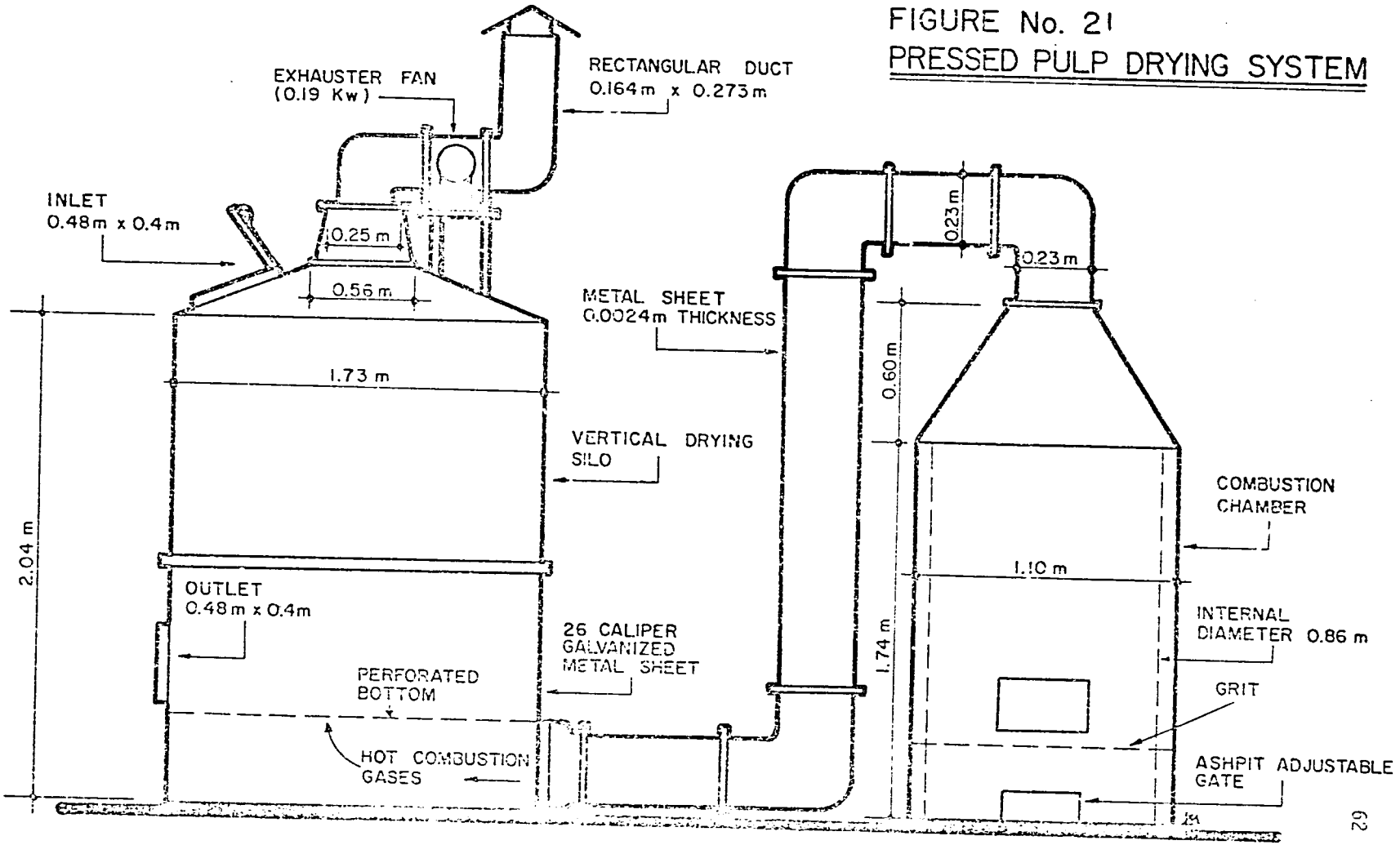


FIGURE 19 Sponge reactor pilot plant mobile unit for biogas production.

FIGURE 20 Pressed coffee pulp controled solar drying assay.

FIGURE No. 21
PRESSED PULP DRYING SYSTEM



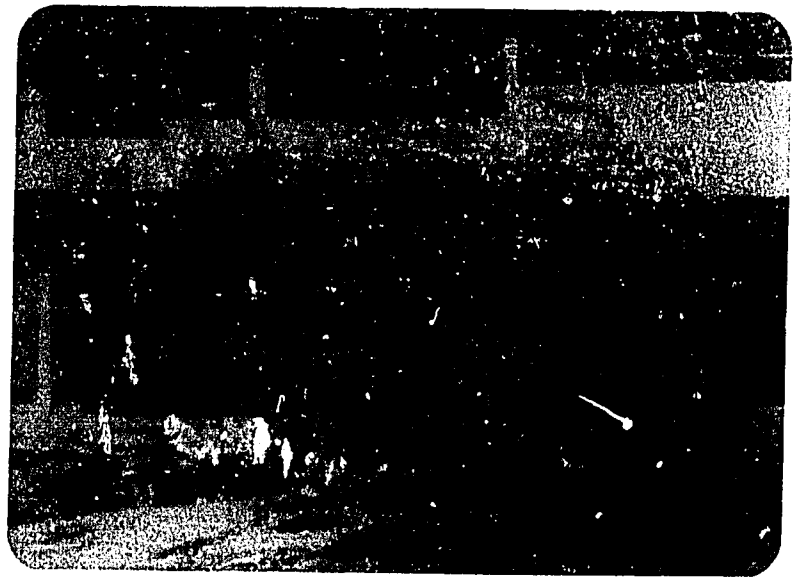
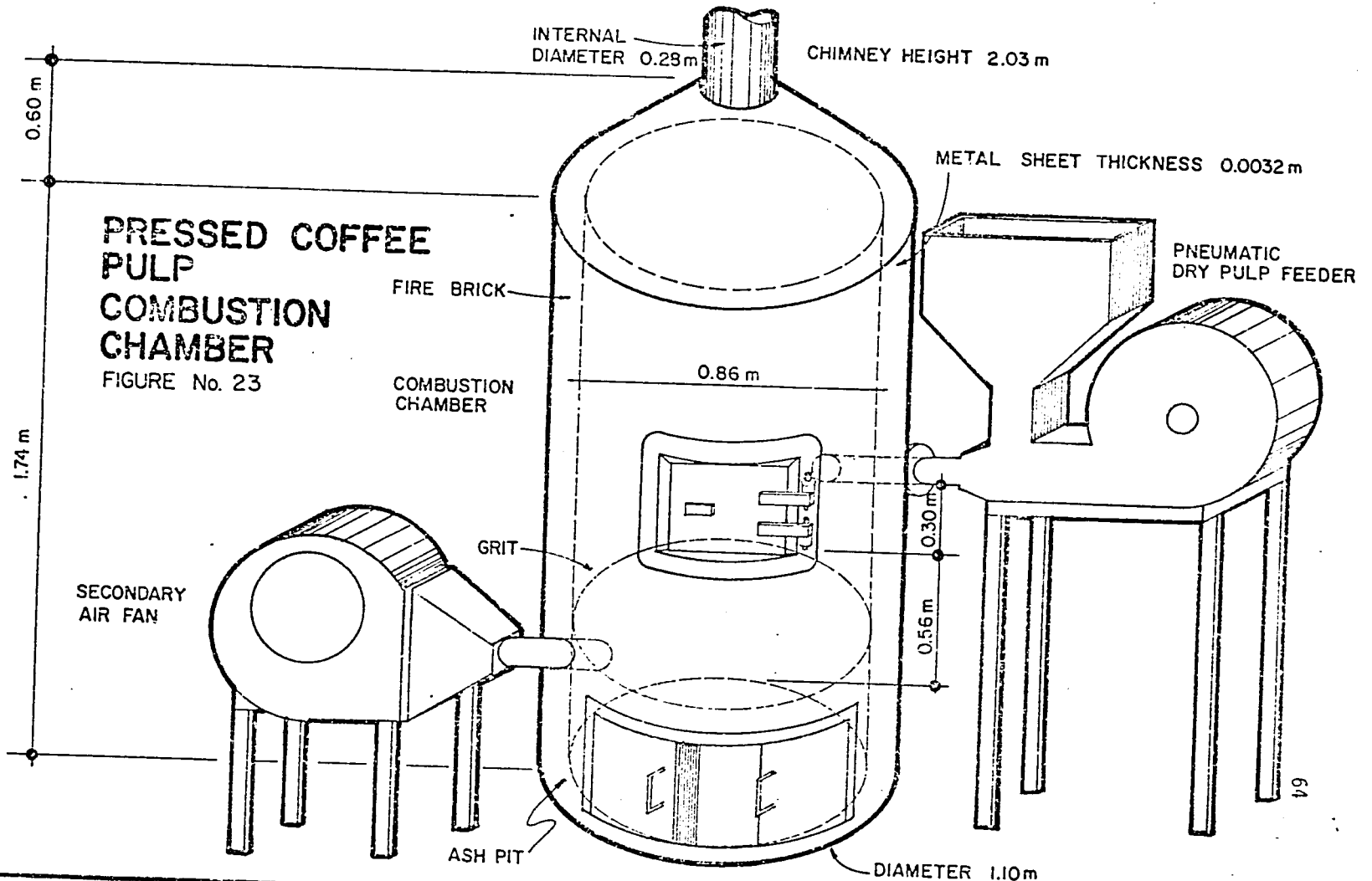


FIGURE 22 Vertical drying silo and combustion chamber.



PRESSED COFFEE PULP COMBUSTION CHAMBER

FIGURE No. 23

FIGURE 24 Combustion chamber for dry coffee pulp.

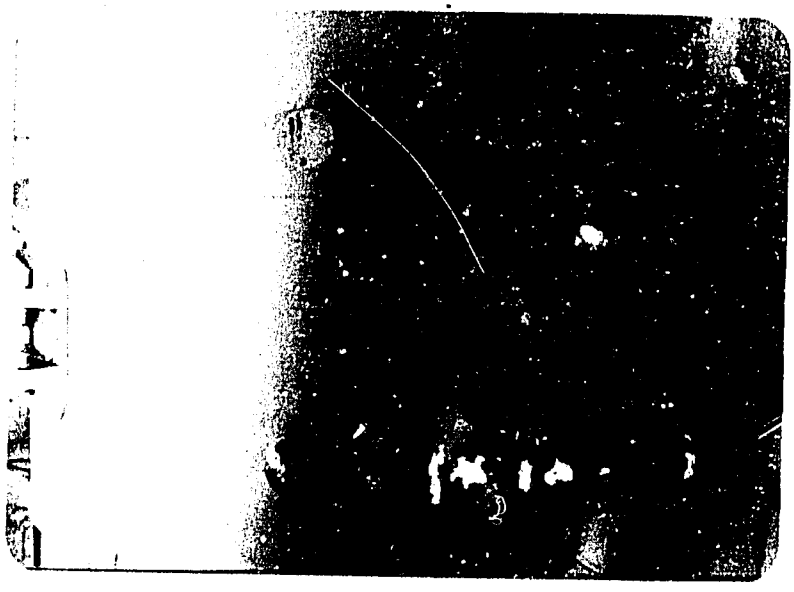


FIGURE 25 Dry coffee pulp feeding points.

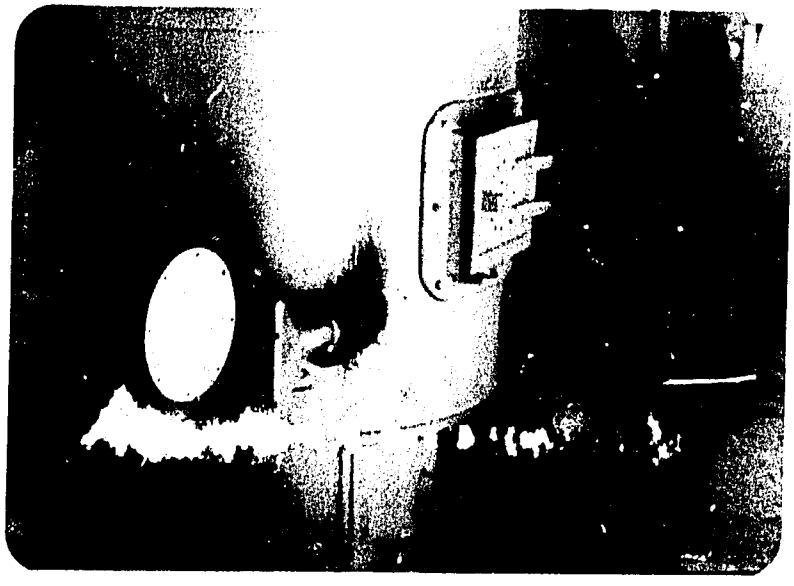


FIGURE 26 Secondary air inlets.

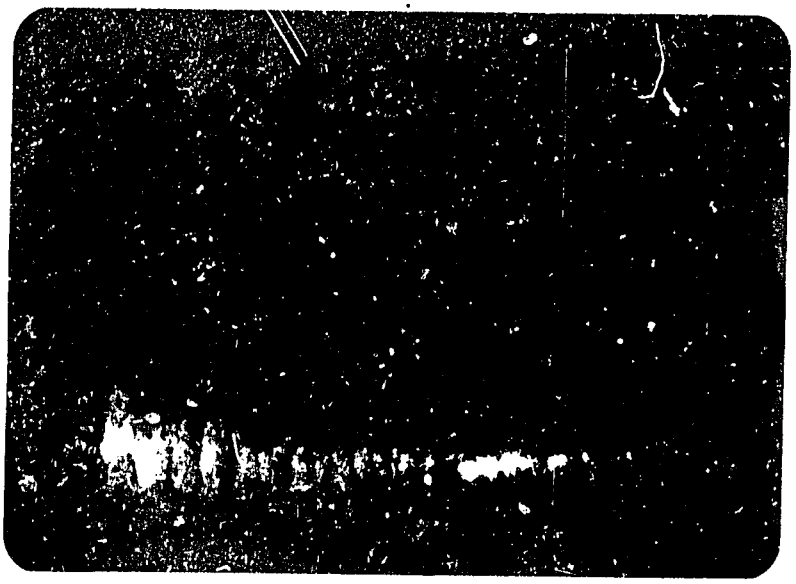
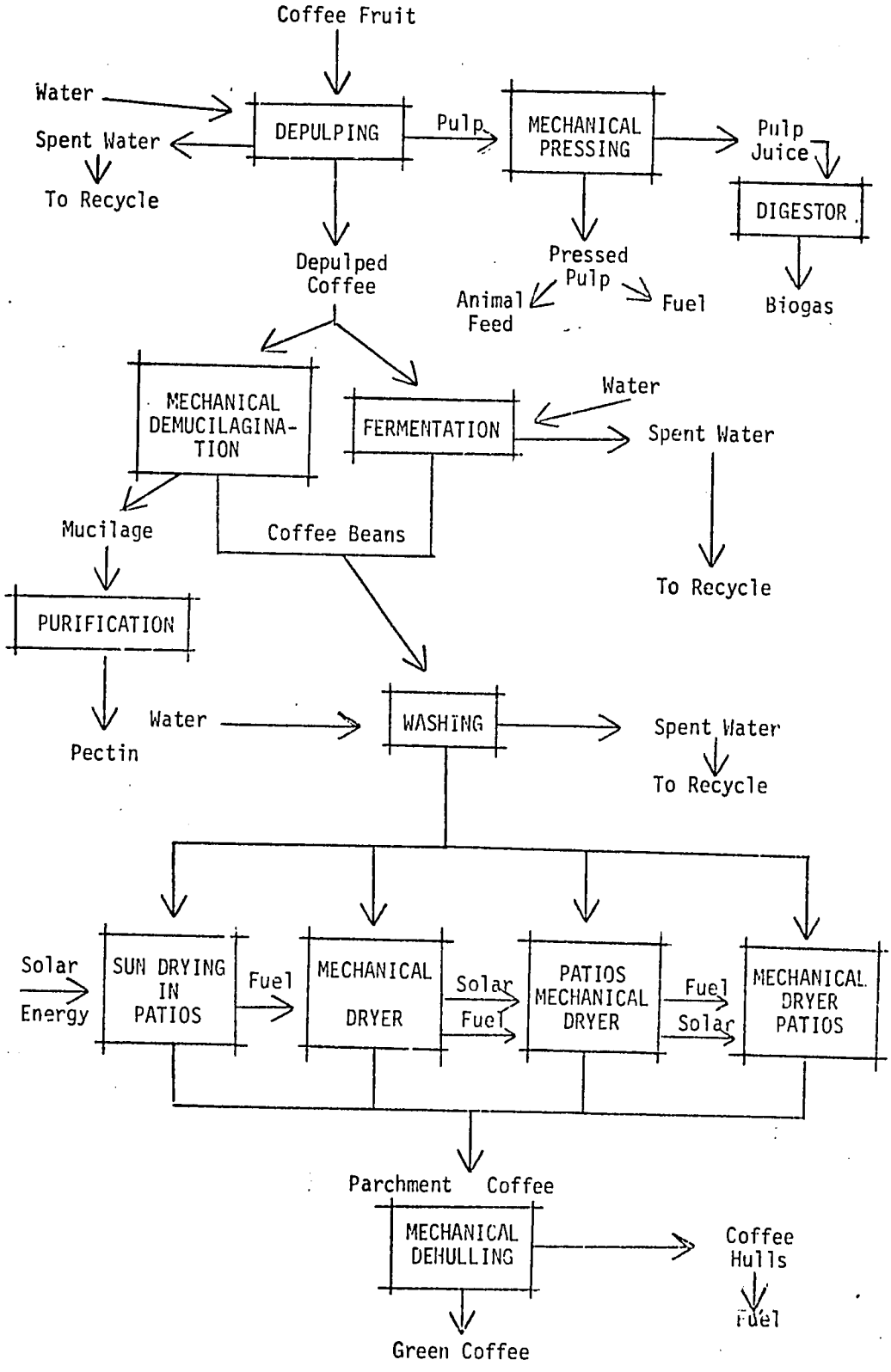


FIGURE 27 Two different types of dry pressed coffee pulp.

FIGURE 28

OUTLINE OF COFFEE PROCESSING OPERATION



11. APPENDIX

BURNING EFFICIENCY CALCULATIONS:

The burning efficiency of the combustion chamber was calculated according to the equations:

$$\text{Burning efficiency} = \frac{\text{Heat content of combustion gases}}{\text{Calorific value of the fuel}} \times 100$$

$$\text{Heat content of combustion gases} = W \times C_p \times (T_2 - T_1)$$

Were:

W = mass flow of combustion gases, calculated from the volumetric flow $(\frac{kg}{h})$

C_p = specific heat at constant pressure of combustion gases $(\frac{kJ}{kg\text{-}°C})$

T_1 = ambient temperature (°C)

T_2 = combustion gases temperature (°C)

See section 6.1 for calculations of calorific value of the dry pulp.

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