PROJECT NO. RS-1

COMPREHENSIVE RESEARCH ON RICE

ANNUAL REPORT

January 1, 1983 - December 31, 1983

PROJECT TITLE: Thermo-chemical Conversion and Utilization of Energy and Chemical Feedstocks from Rice Straw

PROJECT LEADER AND PRINCIPAL UC INVESTIGATORS:

John R. Goss, Project Leader
G.E. Miller, Jr., Co-investigator
J.J. Mehlschau, Senior Development Engineer
Three Research Assistants (Total time paid equivalent of 0.34 R.A. positions)
Technical Assistants (4.2 Man months)

LEVEL OF 1983 FUNDING: $24,567 (carryover)

OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

Introduction:

The revised long-term objectives for the Project are:

1) Development and performance testing of thermochemical processes, such as fluidized bed gasification, direct combustion, and pyrolysis to convert rice straw to low-Btu gas, heat, char, pyrolytic oils and chemical feed stocks.

2) Development and performance testing of systems and processes to utilize low-Btu gas, char, pyrolytic oils and chemical feed stocks produced by the thermochemical conversion of rice straw.

Objectives:

The work proposed for the budget period of January 1, 1983 to December 31, 1983 for the above long-term objectives were:

1. Obtain the performance data for the fluidized bed gasifier converting rice straw to low-Btu gas.

2. Design, construct, and test producer gas conditioning systems for engine and heated air operation.

3. Obtain the performance and stack emission data for the combustion of producer gas from the fluidized bed gas producer when burned in a fire box that approximates steam boiler operation.

4. Construction and testing of a 100 kW portable farm power plant for dual-fuel operation with conditioned producer gas and diesel fuel. A fluidized bed gas producer fueled with rice straw will generate the producer gas. Major components of the J. Deere farm power plant will be part of the portable farm power plant.

5. Set-up and test the system in 4. above at a on-farm site in a rice production district to pump irrigation water. Five hundred hours of pumping are the target test period.

6. Determine wear of diesel engine in portable farm power plant after on-farm test period.

7. Obtain the performance and heated air quality data for the combustion of producer gas from the fluidized bed gas producer when burned in a low-Btu burner system for producing heated air to dry rice or other crop drying application.

8. Continue updating of annotated reference listing for gasification with the aid of developed programs for automatic data processing.

9. Prepare and present technical and semi-technical reports on completed phases of the foregoing objectives.

To accomplish the objectives for 1983, a budget of $120,587 was requested ($96,020 in new funds and $24,567 in residual funds). No new funds were provided. The residual funds were "to be retained by the Project Leader to essentially wind down the project". Thus, work was limited to objectives 1, 2, 3, 8 and 9.

Progress on the Selected Objectives:

All work on the selected objectives was done at the Agricultural Engineering Department on the Davis Campus.

Objective 1. Between the period of January 21 and April 26, 8 test runs were conducted with a mixture of chopped and cubed rice straw. The mixture ranged from 40 to 80 percent soft cubes for these tests. Gas was satisfactorily produced and combusted during the runs for a total of 20 hours. Rice straw feed rates ranged from 485 to 940 pounds per hour. A total of 16,600 pounds of rice straw was gasified with char separated by the cyclones ranging from 10 to 26 percent by weight of the fuel. The hot gas contained from 60 to 65 percent of the energy in the fuel and the cold gas contained 40 to 46 percent of the fuel energy. The 940 pound per hour feed rate with the higher heating value of rice straw of 6375 Btu/lb and a 65% overall efficiency provides a hot gas energy rate of 3.9 million Btu/hr. Satisfactory minimum feed rate is about 600 pounds per hour.

The low gasification efficiencies are the result of the large amounts of char separated by the hot cyclones and the fly ash carried by the hot gas exiting the final cleaning cyclones. An example of the computer summary of the data analysis for one test is attached (Appendix A). The summary extensively characterizes the process and product to provide design information to commercialize the process. Mass and energy analyses have been compiled for five of the rice straw test runs. In addition to rice straw, satisfactory hot gas production has been achieved with almond shell screenings, course hammer-milled wheat straw and alfalfa seed straw. These investigations were supported by other contract research funds. One copy of the final report for the almond shell screenings will be forwarded to Mr. Mel Androus, Manager, Rice Research Board.

An iso-kinetic sampling system was designed and installed to determine the condensable and solid particulate fractions in the hot gas. These data are needed for the mass and energy balance calculations which are shown in the attached summary sheet and design gas cleaning equipment to condition the gas for internal combustion engine fuel. Summary data for 3 of the 8 tests are:

Avg. Hot Gas Temp °C	Rice Straw Moisture % W.B.	Feed Rate lb/hr	Condensables % gas volume	Solid Particulates gm/Std. m^3
637	29	940	29	153
489	25	840	25	104
488	20	840	21	115

Objective 2. A producer gas conditioning system for engine operation was assembled and tested with gas generated in the fluidized bed from a mixture of cubed and chopped rice straw. The system consisted of a prototype hot gas, solid particulate filter and the cooler-condenser from the J. Deere farm power plant. The prototype filter was based on hot gas filters developed for cleaning hot producer gas generated from coal to condition it as the feed stock for the production of synthetic petroleum products. It was provided without cost by the cooperating designer-manufacturer of the fluidized bed gas producer. The gas was sampled for solid particulate content after the gas from the cooler-condenser has passed through one of the following three filters: a column of demisters, a coalescing filter and a column of dust-free, aluminum silicate (Kitty Litter) granules. The solid particulate content of the cool clean gas for each of these filters was: 2, 0 and 0.08 grams/cubic meter of gas at 1 atmosphere and 66°F. A safe level of solid particulates for engine operation is from 1 to 3 grams/cubic meter of gas at 32°F and 1 atmosphere. The gas was cooled to 140°F with ambient air at 78°F. The performance of this conditioning system is satisfactory for sustained engine operation.

Objective 3. The California Air Resources Board, SSCD, Engineering Evaluation Branch, conducted a particulate emissions test on the stack of a small (2 million Btu/hr) horizontal furnace fueled with hot producer gas generated from a mixture of cubed and chopped rice straw by the fluidized bed gas producer. The furnace effluent was reported to contain: 100 ppm SO_2, 75 ppm CO, 150 ppm hydrocarbons, 100 ppm NO_x and 0.7 grains/ft^3 of particulates (one pound contains 7000 grains).

During this test the fuel feed to the furnace was cycling from practically nothing to a maximum value. After the test was conducted, the particulate discharge of the coarse particulate cyclone was found to be blocked thus overloading the fine particulate cyclones. These two factors, which can be corrected, contributed to the high emissions level measured in the effluent of the combusted hot producer gas.

The solid particulate load in the hot gas from the above table ranges from 45 to 67 grains/standard cubic foot. Since the combustion effluent from the hot gas contained only 0.7 grain/standard cubic foot, the large reduction is attributed to the major fraction being carbon which was burned in the furnace.

The gaseous components of the effluent are at a low enough level to satisfy air pollution standards for probably all situations. The standard for solid particulates is 0.3 grains per standard cubic foot of effluent. Thus, to meet this standard the cleaning efficiency of the cyclone system must be considerably improved. If this cannot be achieved, additional equipment would be needed to reduce the solid particulate level in the hot gas fuel or the combustion effluent from burning the hot gas.

Fluidized Bed Operational Performance. Several minor modifications and repairs as well as two major modifications were required for sustained operation. The major modifications were made in the char removal system and the fluidizing air distributor.

Frequent blockage of the ash removal system was eliminated by providing separate vertical discharge ducts for the 2 cyclone systems and remounting the char auger in a horizontal position.

The main manifold duct of the air distributor, after 357 hours of operation which included 80.7 hours in the gasification mode, was no longer horizontal. Its unrestrained end had been elevated from thermal elongation in the static part of the sand bed and the pipe nipple risers were found to be structurally weak at the base of the threads. The mild steel distributor was replaced with one of the same design but made from stainless steel. The free end of the main manifold was restrained from vertical movement but free to move horizontally to accommodate thermal dimensional changes. The main manifold duct must be restrained to maintain the horizontal position for proper orientation of the fluidizing air jets and minimize sand leakage into the manifold when the sand bed is static.

An attempt was made to conduct a test after April 26 with a load of cubed and chopped rice straw which contained a very small amount of very hard cubes. These cubes jammed the injection auger so testing with rice straw was discontinued. The search for a reliable, commercial cube disintegrator for rice straw cubes having a capacity of about 1000 pounds/hour has been unsuccessful.

The normal processing of long rice straw for fluidized bed gasification would be chopping or hammer-milling to a particle length of 2 to 4 inches. Cubing of the rice straw is not required or desirable. The salvage operation to store the rice straw that was provided in 3-wire bales, required partially cubing of the straw after course chopping or hammer-milling to reduce the volume of the salvaged straw to meet the available temporary storage space with full protection from rain.

With contract support from other agencies, the development of a fluidized-bed gas producer-engine generator system has been continued. This support has been provided to use a 95 kW generator directly connected to a Caterpillar Model G333A LP gas engine. The system performance will be determined for six biomass fuels, namely the remainder of the processed rice straw on hand, corn stalks, cotton stalks, wheat straw, alfalfa seed straw and seed alfalfa screenings. Performance testing with these fuels will begin in January, 1984 and should be completed in about three months. Technical engineering reports, fully documenting the performance for each of the six crop residues should be available by October, 1984. The Rice Board will be requested to cooperate, if it so desires, in arranging for selected audiences to attend operational demonstrations of the system producing electric power from producer gas that is generated from rice straw or any of the other crop residues.

Objective 8. The annotated reference listing for gasification was updated from 572 items to 710 items.

SUMMARY OF 1983 RESEARCH (MAJOR ACCOMPLISHMENTS) BY OBJECTIVE:

Objective 1. Extensive modification of the fluidized bed gas producer and fuel feed system have resulted in satisfactory gasification of a mixture of soft cubed and chopped rice straw. System performance has been determined and documented with the aid of a dedicated computer system for data collection and mass and energy balance analyses to provide design information for commercial development of the process. Performance of the system has been extensively determined when fueled with almond shell screenings. It has also been satisfactorialy operated with coarse hammer-milled wheat straw and alfalfa seed straw.

Objective 2. A producer gas conditioning system for fueling internal combustion engines has been assembled and tested. The system contained a prototype hot gas filter and full-scale cooler-condenser. The quality of the cool-clean gas from this system was within the established range of temperature and solid particulate content for sustained engine operation. With contract support from other agencies, the development of a fluidized-bed gas producer-engine system has been continued to produce electrical power from high ash crop residue. Performances testing of the system will begin in January, 1984. About three months will be required to obain the data for six different crop residues including rice straw. The test work will be done at the Agricultural Engineering Department on the Davis Campus.

Objective 3. The pollution constituents have been determined for the stack effluent from a small horizontal furnace fueled with hot producer gas generated from a mixture of soft cubed and chopped rice straw by the fluidized-bed gas producer. This determination was made by the Engineering Evaluation Branch of the California Air Resources Board. The constituents which are subject to air pollution regulations were reported as follows: 100 ppm SO_2, 75 ppm CO_2, 150 ppm hydrocarbons, 100 ppm NO_X and 0.7 grains/ft^3 of particulates. The gaseous emmission levels are most likely less than the allowable amounts for most installations. The allowable solid particulate content is 0.3 grains/ft^3. The high level of this pollutent in the stack effluent was attributed to malfunctioning of the hot gas cyclones during the test which was discovered after the test had been conducted. Iso-kinetic sampling of the hot gas before combustion indicates that proper functioning of the hot gas cyclones may not be adequate to meet the solid particulate stack effluent standard. During 1984, the Air Resources Board will be requested to make a second determination of the furnace stack effluent when combusting hot produce gas generated from rice straw.

Objective 8. The annotated reference listing for gasification was updated to contain 710 references from the previous listing of 572. During 1983 one Master of Science thesis was completed on the isokinetic sampling of the hot gas and two technical papers presented on the chemical composition, deformation and fusion temperatures of crop residue ash. Several samples of rice straw were included in the analyses. The deformation temperature of the ash of any fuel to be gasified in a fluidized-bed gas producer must be known to avoid fouling of the refractory sand bed.

PUBLICATIONS OR REPORTS:

Sachs, Kerry Michael. 1983. Particulate and Moisture Content of Producer Gas Generated by a Fluidized Bed Gasifier. M.S. Thesis. University of California, Davis.

Osman, Elzamzami A. and John R. Goss. 1983. Ash Chemical Composition, Deformation and Fusion Temperatures for Wood and Agricultural Residues. ASAE Paper No. 83-3549.

Osman, Elzamzami A. and John R. Goss. 1983. Ash Deformation and Fusion Temperature Models for Wood and Agricultural Residues. ASAE Paper No. 83-3550.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

Extensive modification of the fluidized bed gas producer and fuel feed system have resulted in satisfactory gasification of a mixture of soft cubed and chopped rice straw. System performance has been determined and documented with the aid of a dedicated computer system for data collection and mass and energy balance analyses to provide design information for commercial development of the process. Performance of the system has been extensively determined when fueled with almond shell screenings. It has also been satisfactorialy operated with coarse hammer-milled wheat straw and alfalfa seed straw.

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FLUIDIZED BED GASIFIER ON RICESTRAW 22-FEB-83

INPUT DATA:

TEMPERATURE FOR FLOW RATES	298.20	K
SAT VAPOR PRESSURE AT THIS T	31.69	MILLIBARS
AIR VOLUME FLOW RATE	4.68	M3/MIN

COMPOSITION(% DRY WT):		FUEL	CHAR	FLY ASH
	C	35.580	24.160	24.160
	H	4.720	0.670	0.670
	O	39.320	0.000	0.000
ENTHALPY HHV(MJ/KG)		14.850	7.710	7.710
MASS FLOWRATE(WET KG/HR)		241.500	41.710	42.846

FUEL MOISTURE CONTENT 13.30 % DRY BASIS

DRY GAS COMPOSITION (% VOL):

CO	10.26
CO2	15.16
CH4	4.40
C2H	1.10
H2	6.78
N2	62.21
O2	0.09

GAS MOISTURE CONTENT	0.00	% DRY BASIS
GAS TEMPERATURE	1014.70	K
HOT GAS SAT VAPOR ENTHALPY	4.020	MJ/KG

OUTPUT DATA:

MASS BALANCE(KG/HR):	C	H	O	N	OVERALL
AIR			77.09	255.27	332.25
DRY FUEL	74.50	9.88	82.33		209.38
FUEL MOISTURE		3.09	24.76		32.12
DRY GAS	54.07	5.00	91.36	246.51	397.48
GAS MOISTURE		7.69	92.82		86.82
CHAR	10.08	0.28	0.00		41.71
FLY ASH	10.35	0.29	0.00		42.85
CLOSURE(%)	0.00	-2.21	0.00	3.43	0.85

DRY GAS VOLUME FLOWRATE		5.74 M3/MIN	
MOLEC. WT.-DRY GAS		28.247	
DENSITY- DRY GAS		1.154 KG/M3	
GAS WATER VAPOR MASS FRACTION		21.84 % DRY BASIS	
STOICH AIR	MASS BASIS	4.04 KG/KG FUEL	
	VOLUME BASIS	11.90 M3/MIN	39.33 %
AIR/FUEL RATIO		1.38	

ENERGY BALANCE:

GAS HHV AT 298 K		4.215 MJ/M3	113.13 BTU/FT3
GAS LHV AT 298 K		3.895 MJ/M3	104.55 BTU/FT3
DRY FUEL ENERGY-HHV		3109.62 MJ/HR	
LHV		2836.38 MJ/HR	
ENERGY IN CHAR		321.58 MJ/HR	10.34 %
ENERGY IN FLY ASH		330.34 MJ/HR	10.62 %
SENSIBLE ENERGY IN GAS		670.00 MJ/HR	21.55 %
CHEMICAL ENERGY IN GAS		1451.81 MJ/HR	46.69 %
ENERGY LOSSES		335.89 MJ/HR	10.80 %
EFFICIENCY	HOT GAS	64.69 %	
	COLD GAS	43.15 %	