Conversion of Rice Husks to Pyrolytic Gas for Rice Mill Application in Thailand

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ABSTRACT

From January 1982 to September 1984, a project on the pyrolysis of rice husk was carried out by the Thailand Institute of Scientific and Technological Research (TISTR), with support from USAID and the National Energy Administration (NEA). The main objective of the project was to promote the application of pyrolysis technology in rice mills in Thailand, and the study was implemented by dividing it into three phases: a preliminary study, technological development, and promotion of the technology. Preliminary studies began by surveying 158 sample rice mills and 1541 surrounding households throughout Thailand. There were positive changes in the attitudes of the millers and the rural people toward pyrolysis technology and some of its products, such as char, suggesting a good possibility for acceptance of pyrolysis technology in the future. Data on rice production, rice husk supply and the utilization of rice husk was studied, and a feasibility study on the utilization of rice husk as a fuel for rice mills, through the introduction of pyrolysis technology, was carried out. It was found that pyrolysis technology could and should be introduced to medium- and small-sized mills using diesel engines with a power rating of not more than 30 hp, and a daily supply of rice husk of not less than one ton. After completion of the field survey, a prototype pyrolytic conversion system was constructed at the TISTR, and satisfactory conditions for operating the system were found. The pyrolytic products, except for the oil, can be readily and conveniently utilized as fuel with minimal processing. Two demonstration plants were designed and constructed at two rice mills. The installed plants included some modifications of the prototype unit. Concurrently, socio-economic factors were analysed. The economic analysis of the demonstration plant was based on integrating the pyrolysis system with a rice mill and evaluating the financial gain from the earnings in oil saving and selling the char and oil products. The findings indicated that pyrolysis technology could and should be applied and promoted among rice mills. An integrated promotion plan for pyrolysis technology was prepared and would be implemented by the NEA with technical support from the TISTR.

INTRODUCTION

Rice husk is an important agro-industrial residue which can be found in large quantities in Thailand. Only a small percentage of rice husk is presently utilized as industrial and domestic fuel. Consequently, the remaining amount creates a significant disposal problem for the rice milling industries.

In 1980/1981, Thailand produced 4.25 million tons of rice husk. Only 0.7 million tons, or 15% of the total amount produced, was reportedly used as fuel to provide energy for operating rice-mills and for other purposes, such as domestic cooking, brick-making, charcoal production, etc. A significant amount is still left, and this is usually dumped nearby on open ground and disposed of by burning. For off-site use as a fuel, rice husk has a very short radius of economic supply because of its low bulk density. Obviously, the environmental and energy problems can be overcome by on-site pyrolysis of rice husk to produce valuable fuels, such as gas, char and oil for the replacement of the conventional energy used at rice mills and other surrounding communities.

Recognizing the potential of rice husk as fuel, the Thailand Institute of Scientific and Technological Research (TISTR) decided to carry out a project on the pyrolysis of rice husks. The project was divided into three phases, namely a preliminary study, technological development, and promotion of the technology. The aim of the preliminary study was to assess the practical potential of pyrolysis technology in the socio-economic, cultural and environmental settings of Thailand, and to evaluate the suitability of rice husk as feedstock. The information obtained from the preliminary study helped in formulating the objectives for the technological development phase of the project. The technological development phase involved the development of a prototype pyrolytic reactor and an evaluation of its performance, based on the cost and engineering objectives established in the preliminary study. The feasibility of pyrolysis technology had already been confirmed at this stage, and a pragmatic promotion plan was subsequently formulated.

This paper presents in brief the findings of the preliminary study for the potential application of pyrolysis technology in rice mills. The details of a prototype pyrolytic converter constructed at TISTR and demonstration plants at two selected mills are analysed and discussed in the order of project development. The economic aspects of the demonstration plant are analysed on the basis of the earnings from oil saving and from selling the char and oil products of the system.

POTENTIAL APPLICATION OF RICE HUSK PYROLYSIS TECHNOLOGY

A preliminary study of the potential application of rice husk pyrolysis technology has been carried out by TISTR. The study began with a socio-economic survey on rice mills and their surrounding communities, which involved collecting information on rice production and the supply of rice husk and its utilization; the energy base, energy consumption and energy costs; the potential use of pyrolytic products; and the social attitude towards the new technology and new products.

Studies on rice production, rice husk supply and its utilization revealed that during a period covering the years 1975 to 1980 rice production fluctuated between 13.92 to 17.47 million tons, due largely to the variation in agro-climatic conditions. The supply of rice husk depended on the total paddy supply, the operation procedures of the rice mills and the yield of the rice husk, a yield which was found from the survey to be about 260 kg per ton of paddy. From the yield figure, if was calculated that the total amount of rice husk produced during the years 1975-1980 was in the range of 3.62 to 4.54 million tons, as shown in Table 1. The utilization of rice husk at present is minimal due to its low bulk density, which makes it inconvenient and costly for transportation. Its utilization as a fuel, however, which was its main use, accounted for only 15% (0.7 million tons) of the total amount available, and it was used in areas located at or near the original sources. Thus, there would be no problem in supplying rice husk as feedstock for a

Table 1. Number of rice mills, rice production and rice husk supply

Year	Number of Rice Mills	Rice Production (X 10^6 ton)	Rice Husk Supply (X 10^6 ton)
1975	25 868	15.30	3.96
1976	28 424	15.07	3.92
1977	30 410	13.92	3.62
1978	33 166	17.47	4.54
1979	36 212	15.76	4.10
1980	39 470	17.37	4.52

Source: Agricultural Statistics Center, Ministry of Agriculture and Co-operatives.

pyrolysis system.

Subsequent surveys of 158 sample rice mills and 1541 surrounding households throughout the country were conducted. Of the total 158 rice mills surveyed, 116 mills (or 73.42%) used diesel engines, 18 mills (or 11.39%) used steam engines and 24 mills (or 15.19%) used electricity (Table 2). Assuming there was no change in the distribution of rice mills according to their power rating, the number of registered rice mills in 1978 with a power rating lower than 30 hp would account for 92.77% of the total number of rice mills (Table 3). As a result, it can be deduced that at present the majority of mills are of small and medium sizes and use diesel engines of 30 hp or less. Based on the figure obtained from the survey, the diesel oil consumption per ton of paddy ranged from 7.82 L to 10.79 L. Using the average figure of 8.50, and assuming an efficiency of 25% for diesel engines, the energy requirement for rice production would be about 19 913 kcal/tons (the heating value of diesel oil is 9371 kcal/L). The finding indicated that the potential application of pyrolysis technology for diesel oil reduction should be in small and medium-sized rice mills. In the marketing study for pyrolytic products, the possible uses of pyrolytic gas and rice husk char were considered. The gas produced by the pyrolysis system could be used as a

Table 2. Regional distribution of surveyed rice mills according to their energy use patterns

Region	Type of Energy Use		
	Diesel Oil	Rice Husk	Electricity
Northern	30	5	5
North-Eastern	51	5	15
Central	16	7	2
Southern	19	1	2
Total	116	18	24
	(73.42)	(11.39)	(15.19)

Figures in parenthesis are per cents.

Table 3. Number of registered rice mills by region according to their horse power in 1978

Region	Horse Power of Engine		
	0-30	31-60	Over 60
Northern	7 256	388	319
North-Eastern	15 684	360	181
Central	3 499	627	409
Southern	4 329	75	39
Total	30 768	1 450	948
	(92.77)	(4.37)	(2.86)

Figures in parenthesis are per cents.

diesel oil substitute for powering milling machines. The gas could also be utilized in drying paddy, and the profit could be taken into account in an economic analysis – in addition to the oil replacement benefit and the income from selling the char and oil products.

In the present study, owners of the sample rice mills were interviewed concerning their interest in the application of pyrolysis technology. The interview results showed that the majority of the owners of rice mills using diesel engines expressed a strong interest in pyrolysis technology (as high as 89.66% for the small mills and up to 100% for the medium and large mills), while the owners of the rice mills using electric motors and steam engines showed less interest (Table 4). The finding indicated the distinct potential needs of the owners of rice mills using diesel engines who were expected to be the end-users of pyrolysis technology. However, whether or not the need can be converted into a demand will depend mainly on the financial return of the pyrolysis system and on its technical feasibility.

It is intended that the char to be obtained from the pyrolysis system should compete with wood charcoal. Since the rice husk char is slightly lower in heating value than wood charcoal, it could only compete with wood charcoal when its price is lower than the price of wood charcoal.

In the present study, 1541 randomly selected households in the communities surrounding of the sample rice mills were surveyed to gain information on the energy used for cooking and the

Table 4. Attitude of rice mill owner towards pyrolysis technology.

Size of Rice Mill	Diesel Rice Mill		Electric Rice Mill		Steam Rice Mill	
	Interest	No Interest	Interest	No Interest	Interest	No Interest
Large	100	–	16.67	83.33	5.56	94.44
Medium	100	–	42.86	57.14	–	–
Small	89.66	10.34	36.36	63.64	–	–

Unit: per cent

interest of the householders in rice husk char briquets. It was found that wood charcoal was most commonly used as a cooking fuel in all regions (70-87% of the households), followed by firewood (12-25% of the households). Only a small percentage of the housholds surveyed used liquefied petroleum gas and electricity (Table 5). On the average, each household used 52 kg of wood charcoal and 91 kg of firewood monthly at an average price of 2.10 baht*/kg and 1 baht/kg respectively (Table 6). As regards the attitudes towards the new low-cost fuel, most of the people interviewed showed a strong interest once they had seen a sample of rice husk char briquets and the fuel properties of the briquets had been explained to them. It was pointed out that the rice husk char briquets have a shorter combusting period but a higher maximum temperature as compared to wood charcoal, and also that they cost less than wood charcoal.

Table 5. Types of cooking fuel used in surveyed households

Region	Types of Cooking Fuel				
	Wood Charcoal	Firewood	Rice Husk	L.P.G.	Electricity
Northern	71.20	24.69	0.41	2.47	1.23
North-Eastern	87.03	11.98	–	0.98	–
Central	69.71	13.14	8.00	6.86	2.29
Southern	72.13	18.85	–	5.74	3.28
Average	75.02	17.17	–	4.01	2.27

Unit = per cent of households.

Table 6. Average energy consumption per household and cost per unit

Region	Types of Cooking Fuel							
	Wood Charcoal		Firewood		Rice Husk		L.P.G.	
	kg/month	baht/kg	kg/month	baht/kg	kg/month	baht/kg	kg/month	baht/kg
Northern	52.0	2.0	101.26	1.15	30.0	0.05	22.95	11.17
North-Eastern	50.0	1.63	40.0	1.00	60.0	0.04	13.5	11.47
Central	52.0	2.68	–	–	58.31	0.07	9.75	11.13
Southern	53.2	2.08	129.6	0.75	–	–	7.35	13.42
Average	51.8	2.10	90.86	0.97	35.36	0.05	8.65	11.22

*Approximately 23 baht is equal to US$1 (1973).

A final analysis of all the findings indicated that pyrolysis technology could and should be introduced to small- and medium-sized mills with diesel engines which are not larger than 30 hp. Based on the conventional energy consumption of the target rice mills, it is estimated that a pyrolysis system with a capacity of 1 ton/day would be necessary to supply the required energy. In addition, the marketability of rice husk char briquets is becoming a more practical proposition, as firewood and wood charcoal are in short supply at present because the planting of fast-growing trees cannot keep pace with over-deforestation.

THE PROTYPE PYROLYSIS SYSTEM CONSTRUCTED AT TISTR

A prototype pyrolysis system with a capacity of 1 ton/day of rice husk as feed material was constructed at TISTR to investigate the basic design parameters and the cost of the system, and to evaluate the reliability of the system in operation.

Pyrolysis System Design and Process Description

Theoretically, pyrolysis involves the thermo-chemical conversion of organic materials in the presence of a limited amount of air (Knight, 1979) into combustible gases, and into char and oil products. The reaction is self-sustaining and requires no external heat input.

Figure 1 presents a flow diagram of the TISTR rice husk pyrolysis system. It can be seen that the system, which is nominally rated at a 1 ton/day input, comprises a storage bin, a feeding system using an air conveyer coupled with a screw feeder, a vertical bed pyrolytic reactor with a char removal system, an airgitator, a cyclone separator, a dual jet condenser, a water condenser, gas cooling and purifying units, a gas mixing tank, a mixer and a briquetting machine.

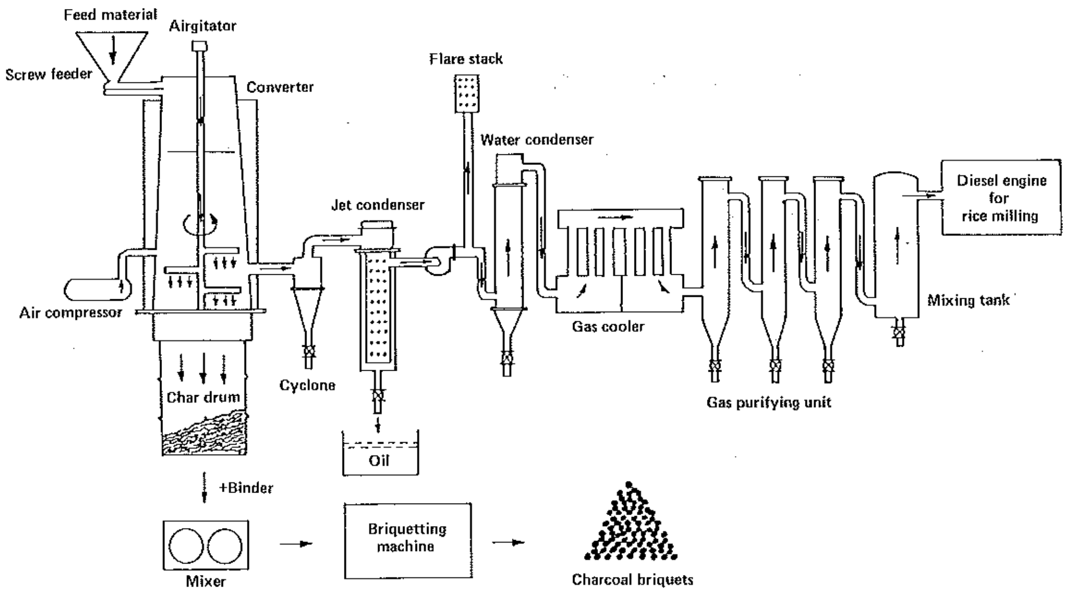

Fig. 1 Flow diagram of rice husk pyrolysis process

The rice husk pyrolytic reactor was built according to the Tatom design, except for the assembling parts which were improved and modified to suit the rice mill conditions (Fig. 2). Initially, dry feed was introduced into the adjacent storage bin which supplied the feed to the system. The dry feed was then conveyed to the reactor by the air conveyer and the screw feeder. The air for the pyrolytic reactor process was introduced via a slowly turning "airgitator," which not only continuously stirs the bed to break up any fissures or bridges that may form, but also, because of its rotating action, helps to avoid the formation of these troublesome cavities which often plague the operation of the packed-bed reactor. As the material moved downwards through the reactor, the temperature increased substantially in the pyrolysis zone, varying from 500°C to 800°C. The temperature in the reactor was controlled by varying the air-to-feed ratio and the char discharge rate.

The rice husk char was periodically discharged into a sealed drum which was attached to the bottom of the reactor by a pneumatic-controlled rotating "star grate." The drum filled with the hot char was removed from the bottom of the reactor and left to cool. After cooling, the char was

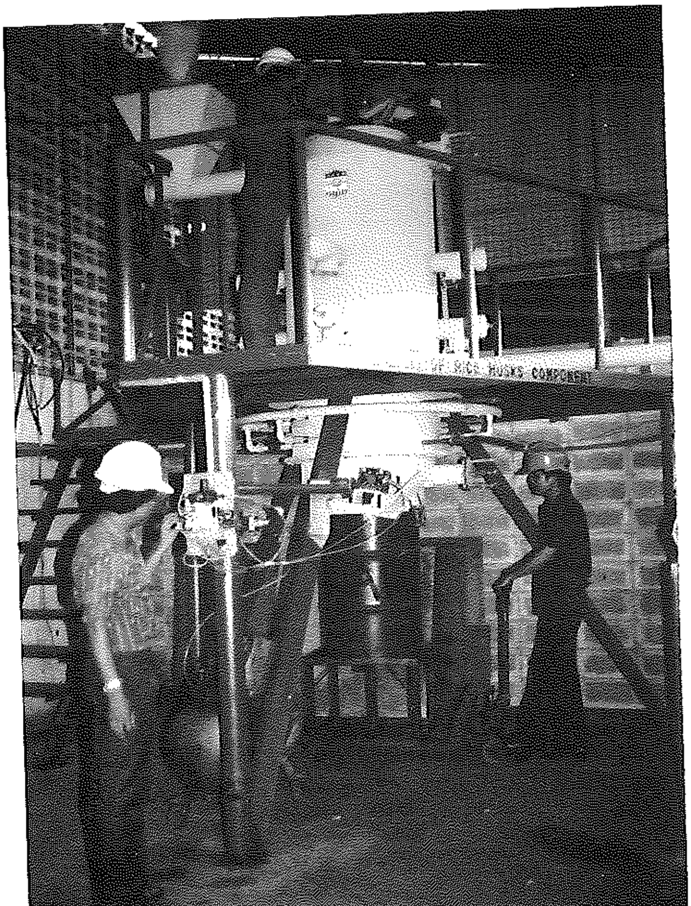

Fig. 2 TISTR pyrolytic reactor

mixed with 10-15% starch by weight and then the mixture was put into a briquetting machine to form char briquets (Fig. 3).

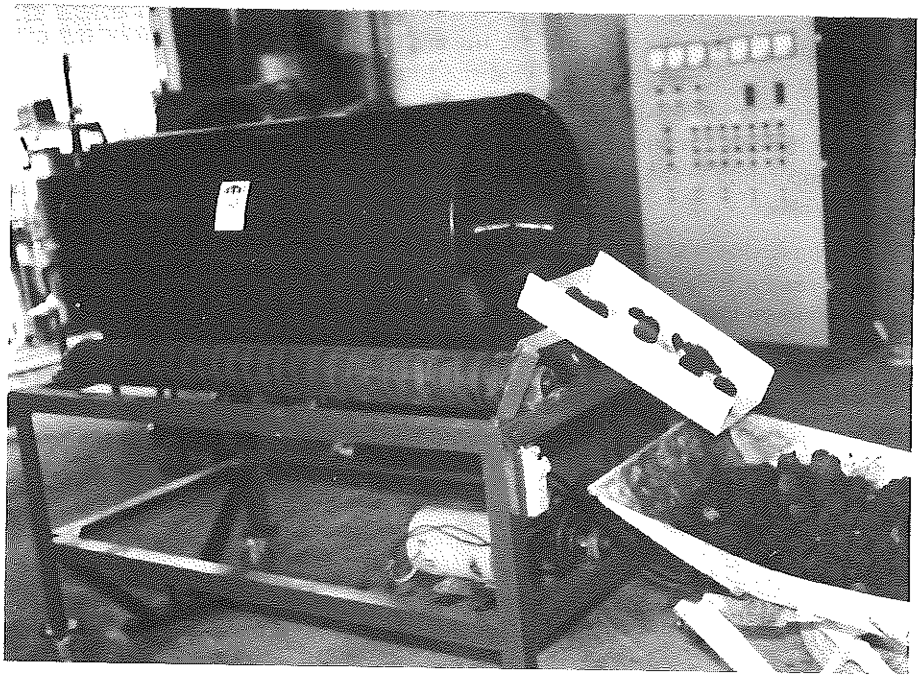

Fig. 3 Charcoal briquetting machine

The pyrolytic gases produced in the reactor left the rice husk bed at the off-gas ports near the bottom of the reactor. The off-gases, which contained noncondensible gases, condensible gas, condensible organics, water vapor and particulates were passed through a filter system to a cyclone separator where the particulates were removed. Then the gases were condensed by the dual-jet condenser and the water condenser, where the pyrolytic oil was separated from the noncondensed gaseous mixture. After cleaning in the purifying unit, the combustible gases, whose major constituents were carbon monoxide, hydrogen, methane, carbon dioxide and water vapour, were tested to determine their effectiveness in driving a 5 kW AC diesel generator (Fig. 4). First an 11 hp Kubota diesel engine was powered with diesel oil as a fuel to drive the generator. After the generator had functioned steadily, the cleaned gas was then allowed to replace the oil, and the maximum limit of the oil substitution was determined. This procedure was reiterated by increasing each step by a 500 W load until it reached 3 kW.

In the tests using tar oil as fuel, the oil produced was first sampled by evaporating 60% of the water content. After that the samples were blended with furnace oil in the ratio of 20:80, 30:70, 40:60 and 50:50 respectively, and they were tested to determine their efficiency as fuels in an open furnace. The combustion of the tar oil/furnace oil substance (at each ratio of the mixture) was observed and the furnace temperatures were measured.

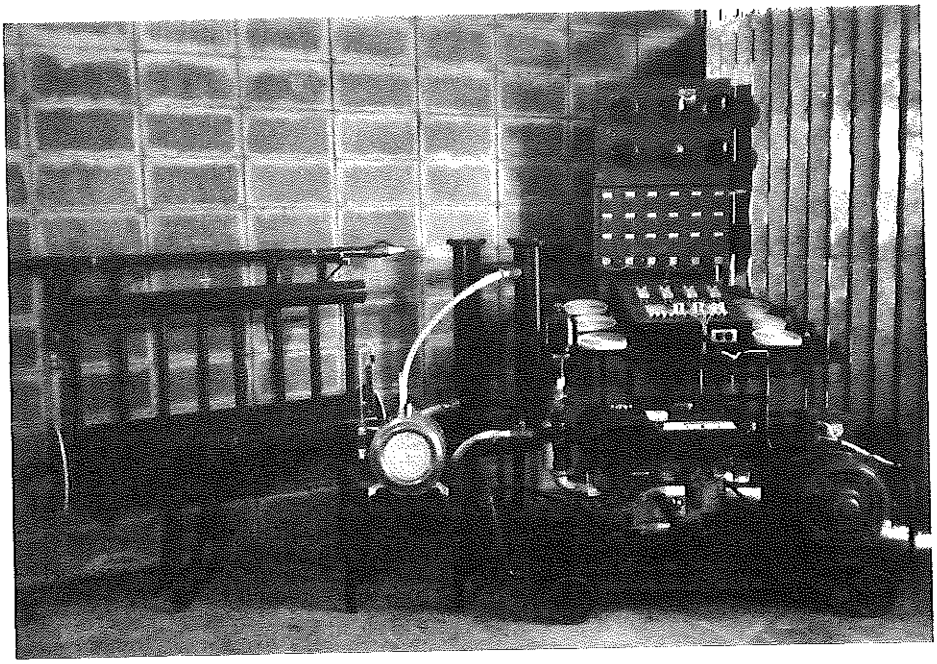

Fig. 4 Off-gas system and electricity generator

Experimental Design and Initial Test Results

In implementing the pyrolysis experiment, the following basic design parameters were investigated to determine their effects on the system operation: the moisture content of the rice husk, the air-to-feed ratio, the operating temperatures, the rate of char discharged, and the off-gas rate. The aim of the investigation was to determine the yields of pyrolytic products (gas, char and oil) and their fuel properties.

Table 7. Fuel properties of rice husks

Properties	Rice husk samples						Average	Range
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6		
Moisture, %	9.6	8.4	8.1	9.4	11.2	10.2	9.5	8.1 – 11.2
Fixed carbon, %	18.2	19.4	19.7	18.0	18.4	18.5	18.7	18.0 – 19.7
Volatile matter, %	61.0	64.9	63.9	62.6	62.6	62.2	62.7	61.0 – 64.9
Ash, %	20.9	16.5	16.4	19.4	19.0	19.3	18.6	16.4 – 20.9
Sulphur, %	0.10	0.15	0.21	0.23	0.15	0.20	0.17	0.10– 0.23
Heating value, kcal/kg	3 770	3 890	3 890	3 760	3 710	3 820	3 800	3 770 –3 890
Density, kg/m³	105	107	106	106	107	105	106	105 – 107

It was found that the optimum conditions for plant operation were as follows:

- The moisture content of the feed material should range between 8-11% by weight. Operating with a moisture content over this range would result in a high tar content in the gas product, a high water content in the oil product and difficulty in controlling the temperature of the reactor.
- The rate of the input can vary from 49.1 to 53.7 kg/h, which requires an air supply at a rate of 33.2-34.6 kg/h.
- The air-to-feed ratio can vary from 0.68 to 0.73 kg/kg, depending on the particular products which were to be maximized. In practice, the lower the air-to-feed ratio the higher the char yield, and the lower the gas and oil yields. On the other hand, the higher the air-to-feed ratio, the lower the char yield, but the higher the gas and oil yields.
- The char discharge rate should be consistent with the input rate. In the steady-state, a discharge lasting two seconds should be made at five-minute intervals.

In practice, the vertical bed pyrolytic conversion system was capable of converting one ton of rice husk per day into combustible char, gas and oil. Using the processing conditions mentioned above, the system yielded 35.5-39.8% char, 41.8-50.9% gas and 13.5-18.4% oil, with overall average yields of 37.3%, 47.1% and 15.6% respectively (Table 8).

Table 8. Product yields of rice husk pyrolysis from pilot plant

Run No.	Operating Time (hr)	Feed (kg)	Moisture (%)	Feed rate (kg/hr)	Air flow rate (kg/hr)	Air/Feed (kg/kg)	Char		Oil		Gas
							kg	%	kg	%	%
1	3.00	155.0	9.6	51.7	33.2–34.6	0.70	58.0	37.4	24.0	15.5	47.1
2	5.19	261.0	10.0	50.3	33.2–34.6	0.72	104.0	39.8	48.0	18.4	41.8
3	6.07	325.8	10.5	53.7	33.2–34.6	0.68	115.8	35.5	56.5	17.3	47.2
4	7.00	360.0	9.8	51.4	33.2–34.6	0.70	135.0	37.5	56.0	15.6	46.9
5	8.21	403.4	8.1	49.1	33.2–34.6	0.73	114.4	35.8	54.5	13.5	50.9
6	9.00	465.0	10.2	51.7	33.2–34.6	0.70	174.0	37.4	72.0	15.5	47.1
7	10.42	552.2	8.4	53.0	33.2–34.6	0.68	210.9	38.2	77.3	14.0	47.0
8	11.00	567.0	9.0	51.5	33.2–34.6	0.70	212.0	37.4	87.0	15.3	47.3
9	12.02	640.8	10.2	53.3	33.2–34.6	0.68	222.0	36.7	94.3	15.6	47.7
10	15.00	775.0	9.3	51.7	33.2–34.6	0.70	290.0	37.4	118.0	15.2	47.4

Table 9 shows the mass and energy yield determined from the results of a number of test runs in the steady-state condition. The energy recoveries of the char and gas products were found to range between 38.7-41.7% and 14.4-16.3% respectively, while the energy recovery of the oil product ranged between 9.7-10.2%. The overall average was 40.6%, 15.6% and 10.0% respectively.

The fuel properties of the char varied in the values of its constituents depending on the conditions of carbonization. On a dry basis, the fixed carbon in the char ranged between 34.7-59.8%;

Table 9. Mass and energy yields from pilot plant operation

Products	Run No. 1		Run No. 4		Run No. 9		Average	
	Mass*	Energy**	Mass*	Energy**	Mass*	Energy**	Mass*	Energy**
Char	0.4015	0.4147	0.4033	0.4166	0.3742	0.3865	0.3930	0.4059
Oil	0.0645	0.1013	0.0649	0.1019	0.0617	0.0969	0.0637	0.1000
Gas	0.5210	0.1604	0.4690	0.1444	0.5312	0.1635	0.5071	0.1561
H_2O	0.1068	–	0.1075	–	0.1023	–	0.1055	–
Total	1.0938	0.6764	1.0447	0.6629	1.0693	0.6469	1.0693	0.6620

*Mass of product per unit mass of dry input feed.
**Ratio of energy content of product to energy content per unit mass of dry input.

the volatile matter between 5.2-9.8%, and the ash between 33.9-58.6%. The overall average was 43.7%, 6.9% and 48.4% respectively. As a result, the calorific value of the char was found to range between 3670-4820 kcal/kg, with an average of 3930 kcal/kg.

The laboratory analysis of the gas produced revealed that, on a dry basis, the gas composition was as follows: carbon monoxide, 11.0-28.5%; carbon dioxide, 6.8-13.5%; oxygen, 0.5-8.2%, hydrogen, 6.0-10.6%; and methane, 1.0-4.7%. The calorific values ranged between 950-1390 kcal/kg, or 1170 kcal/kg on the average.

The laboratory analysis of pyrolytic oil samples revealed that the moisture content in the oil was rather high, ranging between 46.1-68.8% by weight; the specific gravity at 26.6°C ranged between 1.03-1.14; the flash point was 78°C; the boiling point was 86.8°C; and the pH ranged between 3.5-3.8. The calorific values ranged between 5120-6210 kcal/kg, or 5960 kcal/kg on the average.

DEMONSTRATION PLANTS AT THE RICE MILLS

Two pyrolysis demonstration plants were designed so that they would be capable of converting 1-1.5 tons/day of rice husk into combustible char, gas and oil. The plants were installed at rice mills in two provincial areas: one at the Koo Charoen rice mill, Amphur Wihandaeng, Sara Buri Province, and the other at a cooperative rice mill, Amphur Wangsaiphoon, Pichit Province. Each plant was fitted with a gas duct from the gas storage tank of the PT system connected to the mill's engine to supply cleaned pyrolytic gas.

After the plant was installed, a preliminary test run of the pyrolysis system (without connecting it to the mill's engine) was conducted to examine the functioning of the system. This was to prevent any mechanical problems which might occur during plant operation. The method used for operating the demonstration plant was the same as that for operating the pilot plant.

Initially, the mill's engine was powered by diesel oil. After that, the gas produced from the pyrolysis system was cleaned and stored in the gas storage tank. When there was sufficient gas, the gas valve was opened to allow the gas to replace the diesel oil in the mill's engine. The amount of oil left over was measured, then the percentage of oil substitution was calculated.

The field tests at the Koo Charoen demonstration plant revealed that the hourly product yields of the pyrolysis system were as follows: char, 24.3 kg (or 45%); gas, 23.2 kg (or 43%); and oil, 2.6 kg (or 5%). Based on the heating values of char (3930 kcal/kg), gas (1170 kcal/kg) and oil (5960 kcal/kg), and with a moisture content in the char and oil of 3% and 60% by weight respectively, it was found that the energy recoveries from the char, gas and oil were 95 499 kcal/h, 27 144 kcal/h and 15 496 kcal/h respectively – or equivalent to approximately 286 Mkcal, 81 Mkcal and 46 Mkcal respectively on a yearly basis (10 h/day, 300 days/yr). Consequently, it can be calculated that the total energy output of the pyrolysis system would be approximately 413 Mkcal/yr. With an average feed rate of 53.7 kg/h, the ratio of output to feed would be 0.89, with a loss of approximately 11% of the feed.

The energy input required to operate the PT demonstration plant at Sara Buri Province was calculated on the basis of a 10 h/day, 300 days/yr. Thus, the total electricity consumption of all the electric components was approximately 12.75×10^3 kWh/yr (4.25 kWh/h, measured using an integrated kilowatt-hour meter), or equivalent to 10.97 Mkcal/yr, which accounted for only 2.6% of the total energy output.

UTILIZATION OF PYROLYTIC PRODUCTS

a. *Rice Husk Char and Briquets*

The main product of PT, rice husk char briquets, was intended for the cooking fuel market to compete with the wood charcoal or fuelwood used in the surrounding communities. The rice husk char produced, after cooling, was put into a briquetting machine to mix with 10 - 15% starch binder to produce char briquets which had no objectionable odor. The fuel properties of the char briquets were as follows: the moisture content ranged between 4.2 - 5.0% on a dry basis; the fixed carbon ranged between 42.4 - 45.4%; the volatile matter between 14.3 - 16.5%; and the ash between 38.8 - 43.3%. As a result, the calorific value and bulk density of the char briquet samples was found to range between 4120 - 4330 kcal/kg and 460 - 510 kg/m^3 respectively, with averages of 4220 kcal/kg and 490 kg/m^3 respectively.

A number of char briquets were sampled for the survival drop test. It was found that the number of surviving samples depended mainly on the length of sun-drying, followed by the size of the samples. None of the tested samples survived without drying, or even after one-day drying (six hours per day). After two days of drying, balls of 1 - 1.5 inches in diameter survived. These accounted for 40 - 50% of the tested samples and this number increased to 100% after four days of drying. For balls of 2 inches in diameter, there was a survival rate of 20% of the tested samples days of drying, and this increased to 100% after five days of drying.

b. *Pyrolytic Gas*

The tests on using the gas produced to partially replace diesel oil used for driving TISTR's engine (a 5 kW diesel with an AC generator) revealed that, by varying the load beween 1.6 - 2.6 kW, the amount of oil substitution could reach 30 - 60% of the total used to generate power.

The tests on operating the Koo Charoen Rice Mill's engine (280 hp, 8 pistons) with the dual mixing fuel revealed that the amount of oil substitution could reach 23 - 35% of the total used, depending on the rate of gas production.

c. *Pyrolytic Oil*

In tests using pyrolytic oil as a fuel in the open furnace constructed at TISTR, it was found that the mixed fuel (pyrolytic oil and furnace oil in the ratio of 20:80, 30:70, 40:60 by volume) was quite combustible, except for the ratio of 50:50 by volume.

ECONOMIC ANALYSIS

The following analysis was based on coupling one pyrolysis demonstration unit with the Koo Charoen rice mill and evaluating the financial gain for a five-year working life period. The analysis was based on the earnings in oil savings and the earnings from selling the char and oil products of the system. The relative values of the products were derived from the present market prices of diesel oil, wood charcoal and furnace oil, respectively.

A typical rice mill having a nominal milling capacity of 17 tons of paddy per day for a working period of 10 h/day and 300 days/yr was assumed for this case study. Being connected to the mill, the pyrolysis system was capable of converting 1 - 1.5 tons of rice husk per day into combustible char, gas and oil using 264.6 kg, 277.6 kg and 20.83 kg of feed respectively.

The gas produced could replace as much as 35% of the diesel oil used for the milling process. Since the daily oil consumption of the mill was determined to be 142.8 litres, the amount of daily oil saving would thus be 49.98 litres, valued at 344.86 baht (selling price of diesel oil = 6.90 baht/L).

After being briquetted and dried, the daily char yield was 275.6 kg. At a price of 1.50 baht/kg (compared to the price of wood charcoal, i.e. 4.75 baht/kg), the daily income from selling char briquets would be 413.4 baht.

The daily yield figure of pyrolytic oil was 20.83 kg, which was equivalent to 18.8 L (density of pyrolytic oil = 1.108 kg/L). At the pyrolytic oil price of 2 baht/L (compared to the price of furnace oil of 4.31 baht/L), the daily income from selling oil would be 37.60 baht. Consequently, the total daily income from the earnings was estimated to be 795.86 baht.

The initial investment for a 1 - 1.5 tons/day pyrolytic conversion system is approximately 194 600 baht. This cost excludes the cost of land and other kinds of infrastructure (such as buildings, paving, utilities, etc.).

In this analysis, the financial return of the investment was determined by using the Internal Rate of Return (IRR) method. The determination of the IRR value was based on the following assumption:

- The prevailing interest rate was 17.5% yearly;
- The plant operated for 10 h/day, and for 300 days/yr;

On this basis, the IRR value was determined to be 57.36% with a payback period of 2.06 years. This short payback period is considered to be sufficiently attractive to warrant widespread adoption of a pyrolysis system.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were drawn from the foregoing discussion;

1. From the surveys, the majority of rice mills (73.4%) used diesel engines; only 11.4% used steam engines, and 15.2% used electricity.

2. It was found that, in 1978, the registered rice mills with a power rating lower than 30 hp would account for 92.8% of the total number of rice mills.

3. Regarding the potential use of pyrolytic gas for rice mill application, most of the owners of rice mills using diesel engines expressed very strong interest in pyrolysis technology.

4. A study on the rural energy use patterns revealed that 70-87% of the households surveyed used wood charcoal, and 12-25% used firewood as cooking fuels. The social attitudes towards rice husk charcoal are likely to be positive.

5. It was found that the conditions for operating the process satisfactorily at TISTR were as follows:

- The moisture content of the rice husk as feed material should be less than 11%.
- The nominal rate of input should be at about 50 kg/h, and the air to feed weight ratio should range from 0.68 - 0.73.
- The period for discharging the char should last two seconds, and the char should be discharged at five-minute intervals.
- The pilot plant was capable of converting one ton of rice husk per day into combustible char, gas and oil, with yields ranging from 35.5 - 39.8%, 41.8 - 50.9% and 13.5-18.4% of the feed respectively.

6. The Koo Charoen demonstration plant, which was developed from the pilot plant and adapted to suit the mill's conditions, was capable of converting 1 - 1.5 tons of rice husk into combustible char, gas and oil with yields ranging from 43.7 - 47.0%, 40.0 - 45.6% and 3.7 - 6.7% of the feed respectively. The energy input required for the operation was found to be 42.5 kWh/day, and cost about 74.38 baht/day (1.75 baht/kWh) or US$3.23/day (about 8 US¢/kWh).

7. By using pyrolytic gas from the pilot plant at TISTR to drive a diesel engine, 30 - 60% fuel oil reduction was attained.

8. The gas produced from each demonstration plant was used as a diesel oil substitute for powering the mill's engine. After being coupled with a diesel engine of 280 hp and 8 pistons, the pyrolysis system demonstrated a maximum sustained diesel oil reduction of 35%.

9. The char briquets have fuel properties as well as physical characteristics which are competitive with those of wood charcoal.

10. The tests on the utilization of tar oil as a fuel for the open furnace revealed that a mixture of tar oil/furnace oil in the ratios of 20:80, 30:70 and 40:60 by volume achieved good combustibility, but the ratio of 50:50 did not.

11. It was determined that the cost of the demonstration unit could be paid back in 2 years, with a 57.36% annual internal rate of return.

12. For the promotion plan, NEA will play the role of administrative coordinator between the government agencies and the private sectors concerned.

13. For technological support, TISTR will be responsible for the transfer of the developed technology by providing equipment manufacturers with engineering designs and consultancy services.

14. Pyrolysis technology might also be applicable in terms of process heat to other agro-industries, such as the coconut-milk production industry and saw mills, where the industrial wastes are adequate to be utilized as feed for a pyrolysis system. In areas which lack an electric supply but have considerable amounts of waste materials available, the application of pyrolysis technology for generating electricity should be further investigated.

15. Since until now biomass gasification technology has proved feasible only when using wood charcoal as its feed, which is still a costly process, the cost could be reduced by the replacement of wood charcoal with rice husk char briquets produced from a pyrolysis system.

BIBLIOGRAPHY

1. Thailand Institute of Scientific and Technological Research, Ministry of Science Technology and Energy, Thailand (1984), *Feasibility Study on Rice Husk Pyrolysis Technology for Rice Mill Applications in Thailand,* Final Report.
2. Agricultural Statistics Center, Ministry of Agriculture and Co-operatives, Thailand (1979-1981), *Agricultural Statistics of Thailand.* No. 108-110.
3. National Energy Administration, Ministry of Science, Technology and Energy, Thailand, (1982), *Thailand Energy Situation,* Energy Economics Section of the Regulatory Division.
4. Knight, J.A. (1979), *Progress in Biomass Conversion,* Vol. 1, Kyosti V. Sarkanen and David A. Tillman (editors). Academic Press, Inc., New York.