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Report on

FEASIBILITY STUDY ON RICE HUSK PYROLYSIS TECHNOLOGY FOR RICE MILL APPLICATIONS IN THAILAND

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EXECUTIVE SUMMARY

The Thailand Institute of Scientific and Technological Research (TISTR) was commissioned by the National Energy Administration (NEA), under USAID support, to carry out the research and development work on the pyrolysis of rice husks (PRH) component. The work commenced in January 1982 and was completed in September 1984.

The main objective of the PRH component was to promote the application of pyrolysis technology (PT) among rice mills in Thailand. The implementation was divided into three phases:

1. The Preliminary Study;
2. The Technological Development; and
3. The Promotion Plan.

The Preliminary Study

The preliminary study, which covered the period from January 1982 to February 1983, consisted of a review of PT literature and PT design, development and data gathering of a socio-economic survey (for rice mills and their surrounding communities), and the fabrication of hardware.

The review of PT literature and PT development explored experimental work done in a number of developing countries, including Indonesia and the Philippines. Results of these experiments indicated that PT could be successfully developed in developing countries, including Thailand.

The field survey sampled and gathered data on 158 rice mills and 1,541 surrounding households throughout the country. The results revealed that most rice mills were either small or

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medium size and operated with diesel engines. There was a positive change in the attitude of rice mill owners and rural people toward PT and its products, (i.e. char briquets) after the potential benefits of PT and its products were explained to them. This suggested the possibility for positive, future acceptance of PT.

Studies on rice husk production and utilization revealed that the potential availability of rice husk in 1980/1981 (calculated on the basis of total paddy output and the average rice husk production rate per ton of paddy), was estimated to be approximately 4.54 million tons. Utilization of rice husk as fuel, which was the largest potential utilization, accounted for only 15 percent of the total amount of rice husk available.

Final analysis of findings in the preliminary study indicated that PT had its initial potential applications among diesel engine rice mills whose daily supply of rice husk was not lower than one ton.

Technological Development

After completion of the field survey, a prototype pyrolytic conversion system capable of processing one ton of rice husk per day was constructed using a model designed by John W. Tatom (with some modifications in the feeding system, and the char removal, off-gas cooling and cleaning units). The system served as a training facility for the engineering staff and for research and development.

In the technological development phase (which covered the period between February 1983 to September 1984), the study began with operation of the pilot plant to determine optimum design parameters and cost data of a PT system suitable for rice mill operation.

After operating the pilot plant, some modifications on the prototype unit were made to the airgitator, the by-pass of the off-gas system, and the water condenser. These modifications were made to eliminate some problems encountered during operation. After modifications were made, system performance and operational reliability became satisfactory and were finally confirmed.

Two demonstration plants were designed and constructed at two rice mills. The installed plants included some modifications from the prototype unit. The first demonstration plant was installed at Koo Charoen Rice Mill, Amphur Wihandaeng, Sara Buri Province and the second one at the Cooperative rice mill, Amphur Wangsaipoon, Pichit Province.

An operational program was designed based on the actual working hours and days of the mills. However, the field test for each plant required two months to complete. The program covered tests of PT system performance and system reliability in operation when coupled with milling machines. It also included a training program for mill workers in operating and maintaining the system.

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 PT could and should be applied and promoted among rice mills.

The Promotion Plan

An integrated promotion plan for the pyrolysis technology was prepared and was to be implemented by NEA with technical

support from TISTR. The promotion plan covered the following key issues: promotion strategies, financial policy and strategies, infrastructure requirement, institutional arrangement and a detailed promotion program.

CONCLUSIONS

The following conclusions were drawn from the foregoing discussions:

The Preliminary Study

1. A systematic field survey of 158 sample rice mills throughout the country revealed that most of the rice mills were of small and medium sizes with daily milling capacities ranging between less than 5 tons/day to 20 tons/day of paddy. The daily and yearly operating time of the mills depended on the supply of paddy in each region, normally ranging between 3 to 24 hours and 160 to 240 days respectively, with the overall average of 12 hours and 200 days respectively.

2. Study on the energy use patterns of the surveyed rice mills revealed that more than 73.4% of them used diesel engines while the remaining 11.4% and 15.2% used steam engines and electric motors respectively. The number of the diesel engined rice mills, over 92.8% were of small and medium sizes using engines with rating power of 30 hp or less.

3. It was also determined that the small and medium mills used diesel engines as high as 88.8% and 76.8% respectively, while the majority of large mills used steam engines, which accounted for 66.7%. Obviously, the oil

consumption by rice milling industry was mostly shared by the small and medium mills.

4. The diesel oil consumption per ton of paddy for the milling processes was determined to range from 7.8 to 10.8 litres. Using the average figure of 8.5 litres and assuming an efficiency of 25% for a diesel engine, the energy requirement was determined to be 19,913 kcal/ton.

5. Interviews of rice mill owners concerning their attitude towards PT revealed that most of the owners of the diesel engined rice mills showed very strong interest in PT while those of the steam and electric mills showed less interest.

6. Study on the marketability of char briquets revealed that more than 75% of the 1,541 surveyed households used wooden charcoal as their major cooking fuel with the average monthly consumption of 51.8 kg per household. This indicated a good market potential for the rice husk char briquets considering the forecasted trend in a shortage of wooden charcoal in the near future.

Technological Development

1. After modification in the pyrolysis system design and operating with the following field conditions--8 to 11% moisture content of the rice husk feed; varying the rate of input, 49.1-53.7 kg/hr; air-to-feed ratio, 0.68-0.73; and a char discharge rate of every 5 minutes for 2 seconds--the pilot plant was capable of converting one ton of rice husk per day into combustible char, gas and oil with the yields ranging between 35.5-39.8%, 41.8-50.9% and 13.5-18.4% of the feed respectively.

2. 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 the yields ranging between 43.7-47.0%, 40.0-45.6% and 3.7-6.7% of the feed respectively, and with a loss of approximately 11% of the process.

3. Due to the time constraint, there was still no available data from the demonstration plant operation at Pichit Province.

4. The energy input required for the demonstration plant operation, was determined 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 cents/kWh). The total energy output of the pyrolysis system was determined to be approximately 413 Mkcal/yr.

5. The gas produced 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 sustained maximum 35% of diesel oil reduction at the normal milling rate of 2 tons/hr.

6. The test on utilization of char briquets as a cooking fuel in comparison with wooden charcoal revealed that with the mass samples of one kg each, both had nearly the same temperature peaks and combustion periods ranging from 840-880°C and 1.5-2.0 hr respectively but the temperature of the char briquet samples decreased slightly faster than that of the wooden charcoal.

7. The test on utilization of tar oil as fuel of the open furnace revealed that the mixture of tar oil/furnace oil in the ratios of 20:80, 30:70 and 40:60 by volume could be easily combustible, except for the ratio of 50:50 by volume.

8. It was determined that the cost of the demonstration unit could be paid back within 2 years with a 61.8% annual internal rate of return, based on the following field conditions:

- Rice mill operating with diesel engine of 280 hp;
- Capacity : 40 tons/day;
- Working time : 10 hr/day and 300 day/yr;
- No. of workers : 2 persons;
- Capital cost of pyrolysis system : 194,600 baht;
- Working life of the system : 5 yr;
- Income : Char 124,020 baht/yr (1.50 baht/kg);
  Pyrolytic oil 11,280 baht/yr (2.00 baht/l.);
  Saving in oil 103,485 baht/yr (35% oil reduction).

9. After the plant demonstration and training program were completed, the rice mill owners from every part of the country showed much interest in the PT system. Many of them inquired by letter or came to TISTR to observe and to request more information.

The Promotion Plan

During the period of the promotion, NEA will play the role of administrative coordinator between the government agencies and private sectors concerned. NEA, in collaboration with TISTR, low-interest rate finance corporations, and regional rice-mill associations, will be an organizing committee for arranging seminars and workshops on PT. This will introduce the new technology to interested rice mills, as well as assess the potential demand for the applications, which will be very helpful in making financial arrangements for investment in PT.

For technical support, TISTR will be responsible for the transfer of the developed technology through equipment manufacturers by providing them with engineering designs and consultancy. Furthermore, TISTR will also provide engineering and cost data as well as arrange a training program in the operation and maintenance of the pyrolysis system to the rice mills where PT installation is requested.

RECOMMENDATION

Since, at present, there are more than 40,000 rice mills operating throughout the country, and only two demonstration sites of rice husk pyrolysis, the current situation is inadequate to promote the technology; thus, the period for the demonstration should be extended until at least 3 demonstration units are installed in the Northeastern and the Southern regions of the country.

For the financial arrangement, NEA will approach low-interest rate financial sources proposing the investment project with the technical data back-up from TISTR. In case some rice mills could partly afford the investment themselves, NEA might subsidize them by providing the balance. The subsidy might be provided by requesting support from the government or international organization funds. By these means the investors would take part in the responsibility for the investment. In addition, tax incentives should be allowed to encourage more investment.

Since PT can process a wide variety of organic materials, it has an extensive application in other areas of energy sources, such as solid waste disposal, and the production of industrial

feeds. Further investigation on other applications of pyrolytic products, i.e., char, gas and tar oil, is therefore strongly recommended.

In addition to its application among rice mills, PT might be also 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 feeds for PT. In case the areas lack electric supply but considerable amount of wastes as feeds for PT are available, the application of PT for generating electricity should be further investigated, particularly the scale of economy.

Since the biomass gasification technology, at present, has been proved feasible only for using wooden charcoal as its feed, a costly process still, this processing cost could be reduced by the replacement of wooden charcoal with the rice husk char briquets produced from PT.

Eventually, the cost-reduction in the pyrolysis system operation should be further investigated, probably by using the energy recycling method.

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1

INTRODUCTION

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND CONCEPTUAL FRAMEWORK

In August 1979, the United States Agency for International Development (USAID) provided a US $ 5 million grant to the Royal Thai Government for a project entitled "Renewable Nonconventional Energy Development". The project aimed to develop indigenous technological capabilities in the conversion and utilization of renewable energy resources and to promote commercial application of appropriate technologies developed. The project consisted of 14 components: National Energy Information Center, Regional Energy Centers, Energy Master Plan Support, Village Survey, Solar/Wind Assessment, Pyrolysis of Rice Husks, Biomass Gasification, Stove Improvement, Charcoal Improvement, Village Woodlots, Industrial Biogas, Micro Hydro Project, Water Lifting Technology, and Solar Thermal Processes. The project was executed by the National Energy Administration (NEA) in collaboration with various governmental agencies and technical institutes, including Thailand Institute of Scientific and Technological Research (TISTR), and with back-up technical, managerial and administrative supports from a US-based consulting firm, Meta Systems, Inc.* TISTR was assigned the responsibility for implementing the Pyrolysis of Rice Husks (PRH) component. Due to the delay in budget and administrative arrangements, the PRH component actually commenced in January, 1982 and was completed 30 months later.

In implementing the PRH component, TISTR was cognizant of the innovative nature of pyrolysis technology (PT), techno-

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* Available until January 1983.

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economic constraints, and limited successful experience in commercial application of PT in other developing countries. Consequently, TISTR adopted a cautious and pragmatic approach to the PT development and application. The PRH component was divided into 3 phases: namely, preliminary study, technological development, and promotion of pyrolysis technology. The preliminary study aimed to assess the practical potential of PT in socio-economic, cultural and environmental settings of Thailand, and to evaluate the suitability of rice husks as feedstock for PT. The information obtained from the study was integrated to establish the objectives for the technological development phase of the project.

The technological development phase involved the development of a prototype pyrolytic reactor and evaluation of its performance, based on the cost and engineering objectives established in the preliminary study. Once the feasibility of PT had been confirmed, a pragmatic promotion plan was formulated.

During the promotion phase, the promotion plan will be implemented by the NEA with technical support from TISTR. The developed PT will be transferred to equipment manufacturers for commercialization.

1.2 PROJECT OBJECTIVES

The prime objective of the project is to promote the application of pyrolysis technology among rice mills in Thailand. In this context, the project output is an integrated plan for systematic promotion of pyrolysis technology, and the development of indigenous capability in engineering design of the technology. The developed capability and all the facilities built during the course of the project become the major infrastructure for the promotion of the technology. Finally, this project provides a

model for technology transfer between a developed country like the United States and a developing country like Thailand.

The project is also seen to have spin-off benefits. Since pyrolysis technology can process a wide variety of organic materials, it has an extensive application other than energy, such as solid waste disposal, and the production of industrial feeds. The indigenous capability in this technology is, therefore, a basis for environmental and industrial development.

1.3 SIGNIFICANCE OF THE STUDY

In Thailand at present, agro-industries such as rice mills annually generate large quantities of rice husk which are considered as residues. Only small percentages of them are presently utilized as industrial and domestic fuels. Consequently, the remaining amount creates a significant disposal problem for rice milling industries.

In 1980/1981, Thailand produced 4.54 million tons of rice husk. With the calorific value at 3,800 kcal/kg and the average moisture content at 9% by weight, the total amount of rice husk produced had its energy content equivalent to about 15.7×10^{12} kcal. Only 0.7 million tons or 15% of the total production of rice husk was reportedly used as fuel for large size rice mill operation and for other purposes such as domestic cooking, brick-making, charcoal production, etc. A significant amount is still left, and is commonly dumped nearby on open ground and disposed of by burning. For an off-site use as fuel, rice husk has a very short radius of economic supply because of its bulkiness. While considering the small and medium-size rice mills operating with diesel engines which accounted for about 70% of the total number of rice mills in the country, it was found that most have high energy expenses for their operations. The environmental and

energy problems can be overcome by on-site disposal of rice husk to be used as more efficient fuels for large and medium-size rice mill operation and for domestic cooking. Pyrolysis of rice husk is a promising technology which can provide gas used as an oil substitute to drive a milling machine, char used as a domestic cooking fuel, and condensed tar oil used as a wood preservative or as fuel after neutralizing in some solvent and mixing with other fuel oil. The financial gain of PT, therefore, can be accrued through income from diesel or gasoline substitution plus income from the selling of charcoal and oil.

1.4 SCOPE OF THE STUDY

The following tasks were to be undertaken in this feasibility study;

- Literature review on PT to gather basic information on the existing status of PT in other countries and Thailand;

- Construction and operation of a protopype vertical-bed pyrolytic reactor to investigate the design parameters and cost data for further development;

- Socio-economic survey of selected rice mills to determine the forms and the amounts of energy used and evaluate their socio-economic impact. The information obtained would help establish an insight of the rice husk supply situation and the market opportunity of pyrolytic gas;

- Market survey of charcoal and oil products competitive to domestic cooking fuel in selected communities;

- Installation and operation of field demonstration plants to demonstrate technical viability and evaluate performance;

- Arrangement of a training program in operation and maintenance of a PT system for interested rice mill owners and their workers;

- Preparation of an integrated promotion plan for pyrolysis technology.

2

REVIEW OF LITERATURE

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CHAPTER 2

REVIEW OF LITERATURE

2.1 BRIEF HISTORY OF PT DEVELOPMENT

Pyrolysis is the thermo-chemical conversion of organic materials in the presence of a limited amount of air, into combustible gases, char and oil products. The reaction is self-sustaining, requiring no external heat input. The technology was commercially applied on a large scale in the production of methanol from wood in the United States in the late 1800's and early 1900's. However, PT lost its popularity when methanol could be produced at a much lower cost from petroleum oil. In recent times, PT has received considerable attention in two areas: (1) as a conversion method for the disposal of biomass wastes in an environmentally acceptable manner with resource recovery, and (2) as a method for converting biomass to more convenient fuels. Since 1960 much of the work in this field has been pioneered by the Georgia Institute of Technology with the objective of developing a nonpolluting process for the disposal of peanut hulls with recovery of the charcoal for the briquets market (Knight, 1979). In recent years, because of the energy crisis, the focus of the program has been to develop the process as a means to convert forestry and agricultural residues to the more conventional energy forms of char and oil. Small-scale pyrolysis systems have been tested in a number of developing countries such as Papua New Guinea, Costa Rica, Indonesia, and the Philippines.

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2.2 PRINCIPLES OF PYROLYSIS TECHNOLOGY: THE VERTICAL BED PYROLYSIS SYSTEM

Pyrolytic reactions may be induced in various types of reactors including vertical, fluidized-bed, horizontal and inclined reactors with either direct or indirect heat transfer. The vertical-bed reactor is, however, considered to be most appropriate for use with rice husk. The advantage of the vertical bed pyrolysis system lies in its flexibility in varying yields of the pyrolytic products through adjusting the heating rate of the system. By reducing the air-to-feed ratio, yields of char and oil can be increased while gas yield will decrease. Similarly, increasing the air-to-feed ratio will result in increased gas yield but decreased char and oil yields.

The Georgia Tech pyrolysis process utilized a vertical reactor with a moving packed bed. Figure 2.1 presents a simplified flow diagram of the Georgia Tech pyrolysis process.

The wood feedstock is chipped to reduce the particle size to not more than about an inch at the maximum in any dimension (Knight, 1979). The chipped material is conveyed to a dryer so as to dry the waste to approximately 7-10% moisture. The operation of the reactor is more easily controlled by feed material of reasonable consistency and low moisture content. A portion of the gaseous fuel from the process is used to fire the dryer, and in the event that the amount of gaseous fuel is not sufficient, the pyrolytic oil can be used as a back-up fuel. The dried feed which is stored in a bin to provide surge capacity for the pyrolysis reactor, is fed into the top of the reactor through an airlock device and moves down through the reactor under the force of gravity. A bed-height sensing device is used to control the input into the reactor. As the material moves down through the reactor, the temperature increases substantially in the

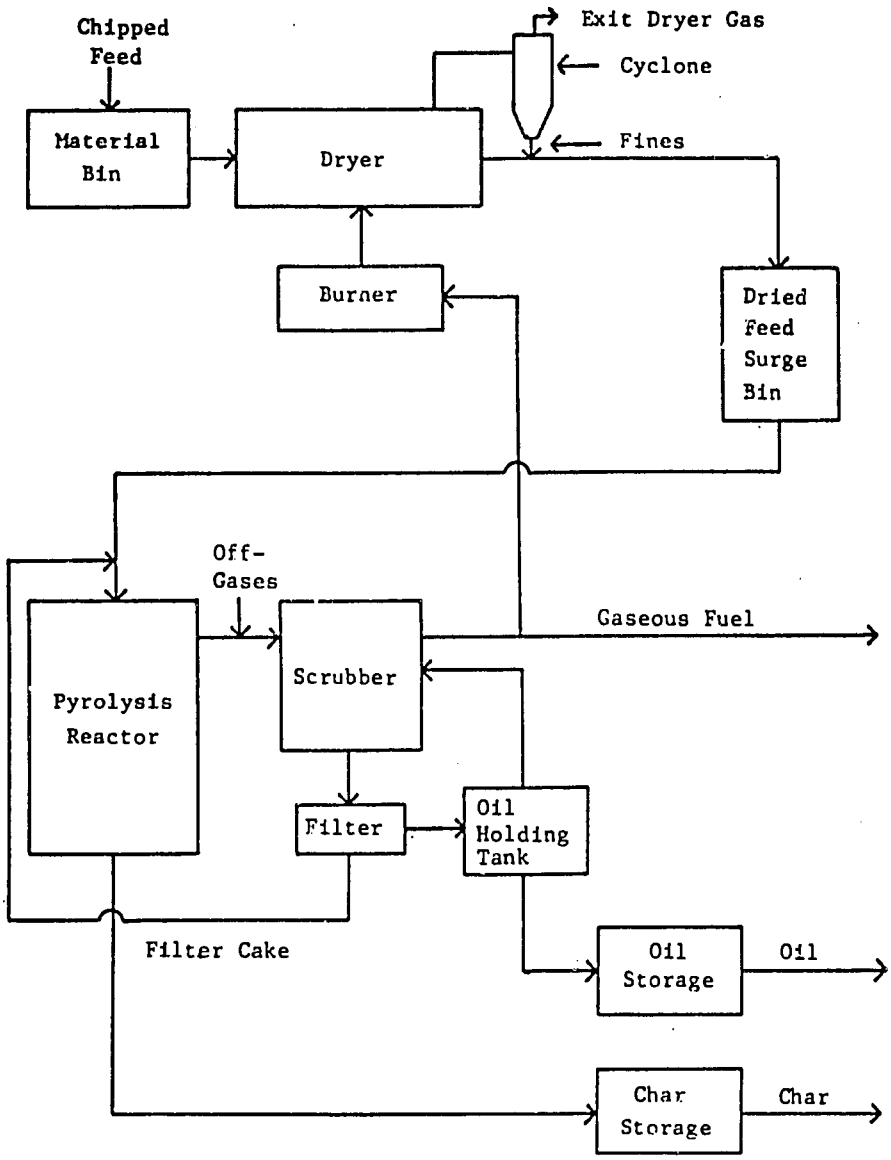

Figure 2.1 Flow Diagram of the Georgia Tech Pyrolysis Process

pyrolysis zone, which varies from 540 °C to 930 °C.

The temperature in the converter is controlled by the air-to-feed ratio. The gases produced in the reactor flow upward through the bed of descending feed material and leave at the top of the pyrolysis zone. The charcoal is discharged through the feedout mechanism at the bottom of the reactor into a sealed chamber, cooled by spraying with water and then conveyed to the charcoal storage bin.

The off-gases from the reactor which contain noncondensible gases, condensible organics, water vapor and entrained particulates are passed into a scrubber, the particulates are removed and the gas stream is cooled. The pyrolytic oil from the scrubber is filtered and pumped into a holding tank.

The noncondensed gaseous mixture from the scrubber condenser is combustible, with the major components being hydrogen, methane, carbon monoxide, carbon dioxide, water vapor, low boiling organics, and nitrogen from the process air. A portion of the gases is utilized as fuel for the dryer to dry the feed material. The remainder of the gases can be used as a fuel for a boiler or some other heat device.

2.3 PYROLYSIS TECHNOLOGY IN DEVELOPING COUNTRIES

Small-scale pyrolysis of rice husk experimentation was conducted in Indonesia, the Philippines, Papua New Guinea, Costa Rica and Thailand. In all cases, the reactors used a vertical-bed system with some slight modification (Knight, 1979). Only the results of the experiments in Indonesia, the Philippines and Thailand are available for review.

2.3.1 Review of PT in Indonesia

There were two phases of the PT development project in Indonesia -- the preliminary study and the development phase. The preliminary study involved the assessment of agricultural and forest wastes for the preparation of PT's raw material and the construction of three types of converters for comparative system design study (Tatom and others, 1977). The work was carried out in 1976 by the Bandung Institute of Technology jointly with the Georgia Institute of Technology, USA, under the USAID/Indonesia Pyrolysis Technology Development Project. The findings identified the appropriate feedstocks and PT models for further study in the development phase.

The development phase involved the construction of two prototype pyrolysis converters - one for research and development and for personnel training, and the other for demonstration at a rice mill (Tatom and others, 1980). Both converters have a similar nominal capacity of one ton per day of rice husk as dry feed material. For the cost-benefit analysis of the system, it was revealed that the return on investment was as high as 73.8% which was sufficiently attractive to warrant widespread adopting of PT application among rice mills.

2.3.2 Review of PT in the Philippines

In 1979, a study on pyrolysis of rice husk was carried out by the University of the Philippines, under the so-called BED-UNIDO supported project (Festin, 1981). A manually-operated pyrolysis system with a capacity of one ton per day of rice husk as dry feed material was constructed to investigate PT's techno-economic feasibility for rice mill application. The calculation on the savings earned by installing a pyrolysis system for rice mill application showed that the PT unit could be paid off within one year.

A survey on marketability of pyrolytic products and a survey on biomass waste production in the Philippines were also conducted by the Philippines National Oil Company (PNOC) to assess the potential demand for PT application and to establish the required plant capacity for each of the three main wastes, i.e. rice husk, coconut shell and saw dust. In brief, the findings indicated that the units of about 100 kg/hr, 400 kg/hr and 1,000 kg/hr were appropriate to the needs of the Philippines for the three types of wastes, respectively (Cruz and Tatom, 1982).

Under the same project, during the period from August 1982 through January 1983, a prototype pyrolysis system with a capacity of 100 kg/hr of rice husk as feed material was constructed at the Energy Research and Development Center. Results of the experiments will not be available until the operation of the prototype plant is completed.

2.3.3 Review of PT in Thailand

In Thailand, pyrolysis technology has been considered by energy technologists as a comprehensive means to convert wastes from biomass into conventional forms of fuel. There are many research institutes as well as universities involved in the R&D activities of this technology. However, in all cases, only laboratory-scale studies have been carried out. TISTR has also gained experience, since 1976, from conducting a series of batch-type pyrolysis experiments with capacities up to 100 kg per batch of biomass (Pitakarnnop, N. and others, 1979).

Representative data on the mass and energy yields of pyrolytic products from rice husk conversion conducted by Occidental Research Corporation, California, USA; Bandung Institute of Technology, Indonesia; University of the

Philippines, the Philippines; and Thailand Institute of Scientific and Technological Research, Thailand; are given in Table 2.1. These data indicated no problem on energy balance of the PT system for operation at rice mills (Tatom and others 1980, Festin 1981, and Anderson and Tillman 1977).

2.4 UTILIZATION OF PRODUCTS

Pyrolysis of rice husk yields combustible char, oil and gas products. Utilization of the products as fuel and for other purposes is summarized as follows;

2.4.1 Char

Char is considered as the main product of the pyrolysis process. It can be briquetted for utilization as both domestic and industrial solid fuel with a heating value of 3,930 kcal/kg on a dry basis (TISTR laboratory analysis). As a smokeless fuel and for ease of transportation, rice husk char has an advantage for replacing firewood or even wooden charcoal. For industrial utilization, it can, with some modification of the furnace, also replace the fuel oil used in a cement kiln. From an environmental point of view, rice husk char has very low sulfur content causing no pollution problem due to sulphur dioxide (Anderson and Tillman 1977).

Besides being a solid fuel, rice husk char can also be utilized as a useful, commercialized material, such as an oil absorbent, a building material component, insulating material, a fertilizer, a filter medium, a carbon source for water purification, or activated carbon, etc.

Table 2.1 Mass and Energy Yields for Rice Husk Pyrolysis

Productions	Indonesia		Philippines		TISTR***		U.S.A.	
	1 ton/day		1 ton/day		100 kg/day		4 ton/day	
	Mass*	Energy**	Mass*	Energy**	Mass*	Energy**	Mass*	Energy**
Char	0.25	0.27	0.30	0.43	0.50	0.63	0.36	0.38
Oil	0.18	0.29	0.09	0.18	0.08	0.12	0.23	0.42
Gas	0.32	0.12	0.30	0.07	0.19	0.07	0.12	0.06
H_2O	0.32	-	0.30	-	0.23	-	0.29	-
Total	1.07	0.68	0.99	0.68	1.00	0.82	1.00	0.86

* 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 feed

*** Batch-type pyrolysis experiment

2.4.2 Pyrolytic Gas

Normally, the main components of the noncondensed gaseous phase from the pyrolysis of rice husk process are carbon monoxide, carbon dioxide, hydrogen, methane, small amounts of low molecular weight hydrocarbons, and water vapor. The pyrolytic gas has a heating value of approximately 1,170 kcal/kg (TISTR laboratory analysis). Because of its relatively low heating value which makes it uneconomical for storage and transportation, pyrolysis off-gas must therefore be utilized on or near the site of production. However, the gas is extremely useful for drying crops, water pumping, and heating a boiler. The dry and clean gas can also be used for powering internal combustion engines (Anderson and Tillman, 1977).

2.4.3 Pyrolytic Oil

The oil produced from the rice husk pyrolysis process is an organic substance with a wide spectrum of organic compounds including oxygen. Although pyrolytic oil has high acidity (pH value about 4) and the unavoidable presence of about 50 to 68 percent water, reducing the heating value to about 5,960 kcal/kg (TISTR laboratory analysis) can, nevertheless, improve its properties through chemical and heat treatment. Pyrolytic oil, when blended with furnace oil, can be used as fuel for powering a boiler. Similar to the char product, pyrolytic oil has very low sulfur content which causes no corrosion nor pollution problems due to sulfur oxide. As a result, pyrolytic oil might be utilized as a diesel oil after neutralizing it in an appropriate solvent, followed by careful filtration. However, further technical improvement is necessary.

Besides being a fuel, pyrolytic oil which contains a

substantial quantity of creosote might also serve as a wood preservative to prevent insect infestation (Anderson and Tillman, 1977).

2.5 PRESENT STATUS OF RICE MILLING INDUSTRY

Rice milling is an important agro-industry in Thailand. At present, there are more than 40,000 mills throughout the country responsible for producing rice and other by-products, including rice husk. Their geographical and size distribution, growth and structure, production and utilization of rice husk, and energy use patterns are presented in this section.

2.5.1 Geographical and Size Distribution

Rice cultivation is the most important component of the agricultural sector of Thailand's economy in terms of planting area and export. The rice planting area in 1980 was 60.1 million rai (24 million acre) and 19,508 million baht* of rice was exported (Agricultural Statistic Center, 1974-1981). Consequently, rice milling is considered to be one of the most important agro-processing industries and is virtually the only industry prevailing in rural areas. In 1980, there were 39,470 rice mills in the country with the total rice output of 17,368,000 tons (see Table 2.2). About 51.8% of the rice mills were in the Northeastern region while those in the Central and the Southern regions accounted for only 12.60% and 11.73%, respectively. The average rice output per mill (see Table 2.3) indicates the average rice milling capacity of each region. It can be stipulated that most rice mills in the Northeastern and the Southern regions would be of small capacity, while medium capacity and large capacity mills would likely be found in the North and the Central regions, respectively. The conclusion was

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* Approximately 23 baht equal to US $ 1

Table 2.2 Number of Rice Mills, Rice Production and Percentage by Region in 1980

Regions	Number of rice mills	Percent	Rice production (x 10^3 ton)	Percent
Northern	9,420	23.87	4,860	27.98
Northeastern	20,444	51.80	5,811	33.46
Central	4,975	12.60	5,543	31.92
Southern	4,630	11.73	1,154	6.64
Total	39,470	100	17,368	100

Source : Agricultural Statistics Center, 1980

Table 2.3 Number of Rice Mills and Rice Output (1974 - 1980)

Particulars	1974	1975	1976	1977	1978	1979	1980
Northern region :							
Number of rice mills	5,628	6,306	6,988	7,369	7,963	8,697	9,420
Rice production*	3,858	4,219	4,112	3,692	5,021	4,385	4,860
Product per mill**	0.685	0.669	0.588	0.501	0.630	0.504	0.516
Northeastern region :							
number of rice mills	10,966	12,098	13,363	14,570	16,225	18,192	20,444
Rice production	3,795	5,326	4,686	3,556	5,325	5,662	5,811
Product per mill	0.346	0.440	0.351	0.244	0.328	0.311	0.284
Central region :							
Number of rice mills	2,960	3,467	3,860	4,195	4,535	4,855	4,975
Rice production	4,843	4,678	5,103	5,351	6,059	4,617	5,543
Product per mill	1.636	1.349	1.322	1.276	1.336	0.951	1.114
Southern region :							
Number of rice mills	3,529	3,997	4,231	4,276	4,443	4,468	4,631
Rice production	890	1,004	1,167	1,322	1,073	1,094	1,154
Product per mill	0.252	0.251	0.276	0.309	0.241	0.245	0.249
Total :							
Number of rice mills	23,029	25,868	28,424	30,410	33,166	36,212	39,470
Rice production	13,386	15,300	15,068	13,921	17,470	15,758	17,368
Product per mill	0.581	0.591	0.530	0.458	0.527	0.435	0.440

* In 1,000 ton

** In 1,000 ton per mill

Source : Agricultural Statistics Center, 1974-1980

supported by the data in Table 2.3.

At the provincial level, the number of rice mills in each province varied significantly - mainly due to the production of paddy (see Appendix 1). In the Northern region, the number of rice mills in Chiang Rai and Lampang were significantly higher than those in the other provinces. In the Southern region, nearly 30% of the rice mills were located in Nakorn Sri Thammarat. However, for the Northeastern and the Central regions, distribution of the rice mills seemed to be more uniform.

2.5.2 Growth and Structure

During the period from 1974 to 1980, the number of rice mills in all four regions steadily increased at an overall rate of 11.90% per annum with the regional growth rates ranging from 6.99% to 12.33% per annum (see Table 2.4 and Fig. 2.2). However, although the annual rice outputs on the average increased at the rate ranging from -9.80% to 25.49% per annum, there was a high fluctuation in paddy production which, in turn, was dependent, to a great extent, on agro-climatic conditions.

Within each region, annual changes in the average outputs would also indicate the change in the structure of the rice-milling industry. For all regions, the average output per mill showed a decreasing trend, indicating that small rice mills increased at rates faster than large rice mills. The increase in transportation cost, paddy price, and interest rate might have been responsible for the change in economy of scale in favour of smaller rice mills.

Table 2.4 Mill Growth Rate and Rice Production (1974-1980)

Particulars	1974	1975	1976	1977	1978	1979	1980
Northern region:							
Number of rice mills	5,628	6,306	6,988	7,369	7,963	8,697	9,420
Growth rate of rice mill(%)	-	12.05	10.82	5.45	8.06	9.22	8.31
Rice production (1,000 ton)	3,858	4,219	4,112	3,692	5,021	4,385	4,860
Growth rate of rice production(%)	-	9.36	-2.54	-10.21	36.00	12.67	10.83
Northeastern region:							
Number of rice mills.	10,966	12,098	13,363	14,570	16,225	18,192	20,444
Growth rate of rice mill(%)	-	10.32	10.46	9.03	11.36	12.12	12.38
Rice production (1,000 ton)	3,795	5,326	4,686	3,556	5,325	5,662	5,811
Growth rate of rice production(%)	-	40.34	-12.02	-24.11	49.75	6.33	2.63
Central region:							
Number of rice mills	2,960	3,467	3,860	4,195	4,535	4,855	4,975
Growth rate of rice mill(%)	-	17.13	11.34	8.68	8.10	7.06	2.47
Rice production (1,000 ton)	4,843	4,678	5,103	5,351	6,059	4,617	5,543
Growth rate of rice production(%)	-	-3.41	9.09	4.86	13.23	-23.80	20.06

Table 2.4 (Continued)

Particulars	1974	1975	1976	1977	1978	1979	1980
Southern region:							
Number of rice mills	3,529	3,997	4,231	4,276	4,443	4,468	4,631
Growth rate of rice mill(%)	-	13.26	5.85	10.64	3.91	4.49	3.65
Rice production (1,000 ton)	890	1,004	1,167	1,322	1,073	1,094	1,154
Growth rate of rice production(%)	-	12.81	16.24	13.28	-18.84	1.96	5.48
Total:							
Number of rice mills	23,029	25,868	28,424	30,410	33,166	36,212	39,470
Growth rate of rice mill(%)	-	12.33	9.88	6.99	9.06	9.18	9.00
Rice production (1,000 ton)	13,386	15,300	15,068	13,921	17,470	15,758	17,368
Growth rate of rice production(%)	-	14.30	-1.52	-7.61	25.49	-9.80	10.22

Source: Agricultural Statistics Center, 1974-1980.

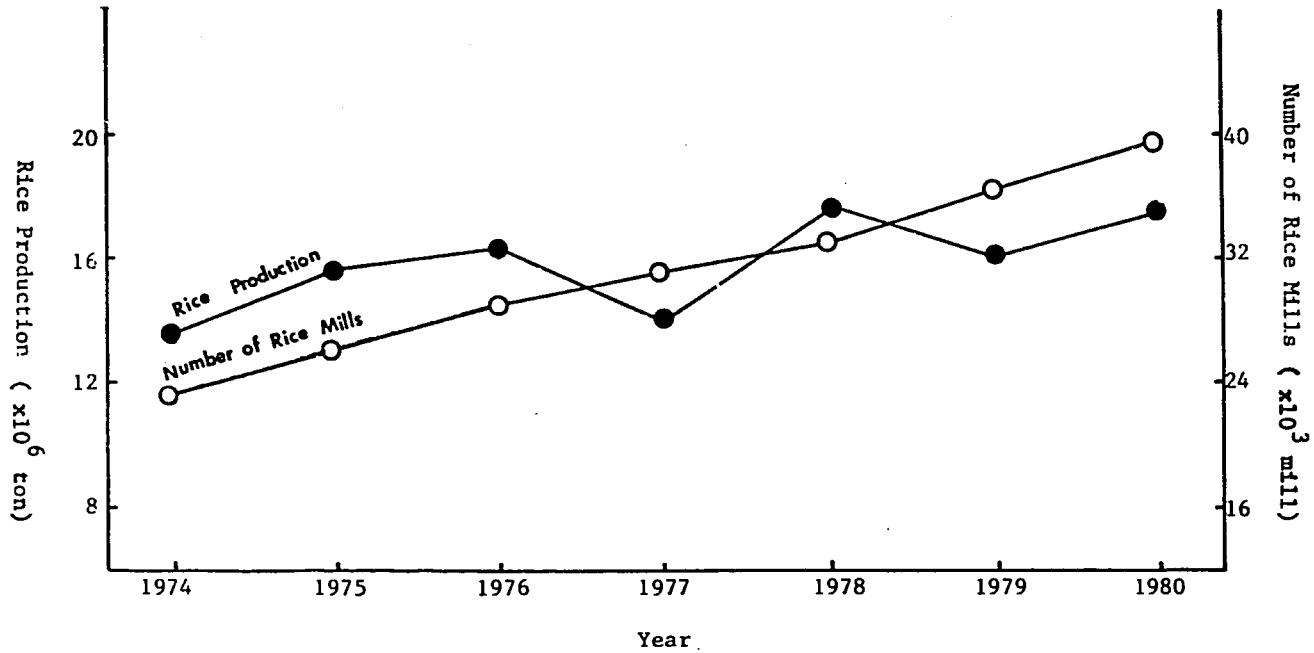

Figure 2.2 Number of Rice Mills and Rice Production by Year

2.5.3 Rice Husk Production

The amount of rice husk per unit weight of paddy would depend on the milling efficiency. The average figure determined by Niyom and others (1976) was 222.20 kg per ton of paddy. However, the survey of 158 rice mills in the present study revealed that the overall average yield of rice husk was 261.36 kg per ton of paddy. The discrepancy between this yield and the yield determined by Niyom and others may be due to the difference in rice varieties.

From the yield figures, the total amount of rice husk produced in 1980 was readily determined to be 4.54 million tons, distributed in various regions as shown in Table 2.5. Based on the average calorific value of 3,800 kcal/kg and an average moisture content of 9% (TISTR 1978), the total energy of 4.54 million tons of rice husk would be equal to 1,707 million litres of crude oil (calorific value of crude oil is 9,193 kcal/lt, NEA 1982). This figure would be equivalent to 20% of the total amount of crude oil imported in the year 1982.

2.5.4 Rice Husk Utilization

For a large rice mill using a steam engine larger than 30 hp, the major use of rice husk is as fuel for its own consumption. Assuming the mechanical conversion efficiency of 30% and a boiler efficiency of 40%, the average milling energy requirement was determined to be 19,000 kcal per ton of paddy. This is equivalent to 15.6% of the rice husk produced that would be consumed in the rice milling operation. Information obtained from the sample rice mills using rice husk for their steam engines showed the figures between 15% and 25%. The variation may be due to discrepancies in the efficiency of steam engines and boilers.

Table 2.5 Regional Distribution of Rice Husk in 1980

Region	Number of rice mills	Rice production ($x\ 10^6$ ton)	Rice husk ($x\ 10^6$ ton)
Northern	9,420	4.86	1.27
Northeastern	20,444	5.81	1.52
Central	4,975	5.54	1.45
Southern	4,631	1.15	0.30
Total	39,470	17.4	4.45

Utilization of rice husk as fuel in other industries would be limited by its bulkiness as indicated by its density of only about 106 kg/m (TISTR, 1978). Uses other than fuel are also constrained by the transportation cost. At present, only a small quantity is used for firing claybricks and for concentrating palm syrup. As packaging material, rice husk is utilized to protect eggs from damage and for handling ice. In brick making, husk is added to decrease the unit weight and make the heating process easier. Utilization of rice husk as a soil conditioner in flower beds and for growing bean sprouts is also known in Thailand but the quantities of rice husk used are relatively small. Other utilizations include rice husk as poultry litter and as a filling material, in the form of husk ashes.

The amount of rice husk used as fuel in 1980 was estimated at about 0.7 million tons which accounted for only 15 % of the total amount produced (NEA, 1982). Quantities used for other purposes would, therefore, appear to be insignificantly small. Consequently, a very large amount of rice husk would still remain unused, and thus, have to be disposed of, marketed and/or discarded. The figures would vary depending on seasonal variation of the supply and demand of rice husk. On some occasions, rice husk could be sold at prices ranging from 25 to 250 baht per ton. Thus it appears that the price of rice husk is relatively low compared to those of other fuels. Therefore, if the PT became viable, the rice mill owners would likely want to keep rice husk for the pyrolysis application instead of selling them.

2.5.5 Energy Used in Rice Milling

The rice milling operation in Thailand uses steam engines, diesel engines, or electric motors. Due to its economy of scale, the steam engine is normally the choice for rice mills with a capacity greater than 20 tons/day. Small and medium size rice mills would prefer electric motors if the public supply of electricity is available. In the absence of electricity supply, a diesel engine is the only option.

For rice mill owners, the choice of energy would depend on economic and other technical considerations. Advantages and disadvantages of the three energy options are summarized as follows:

1. Steam Engine

Advantages:

- no fuel cost (use rice husk)
- dependence on local manufacturer
- fewer possibilities of breakdown
- no problem of rice husk disposal

Disadvantages:

- large capital outlay
- large capacity required
- requirement of skilled labors for operating the furnace and the boiler
- fluctuation in pressure, if unproperly regulated, may adversely affect rice milling operation
- air pollution problem

2. Diesel Engine

Advantages:

- small capital outlay
- easy to operate
- valid in all sizes of rice mill

Disadvantages:

- high fuel cost
- high maintenance cost
- dependence on oil price
- no utilization of rice husk

3. Electric Motor

Advantages:

- easy to operate
- valid in all sizes of rice mill
- power regulation provided

Disadvantages:

- fails to operate due to voltage drop and instantaneous out off electrical supply
- high maintenance cost
- no utilization of rice husk

Most of the rice mills in Thailand are small. They have engines of 30 hp or less and use diesel oil as fuel. There are no available data on the number of rice mills for each energy option and it was not possible in the present study to survey all

existing rice mills. According to the number of registered rice mills in each region in 1978, the rice mills with a power rating lower than 30 hp would account for 92.77% of the total number of rice mills and the remaining of only 4.37% and 2.86% were shared the mills with a power rating 31-60 hp and over 60 hp respectively (see Table 2.6).

Table 2.6 Number of Registered Rice Mills in Each Region According to Their Horse Power in 1978

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

Figures in parenthesis are percent

3

DESIGN OF THE STUDY

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CHAPTER 3

DESIGN OF THE STUDY

In implementing the PRH component, a systematic work plan was designed to serve as a framework for operation of the PRH technological demonstration project.

3.1 STUDY APPROACH

The project team was divided into two groups. The engineering group, consisting of engineers and technicians, was responsible for all engineering aspects of the project. The second group, consisting of economists and sociologists, was responsible for all socio-economic aspects of the project. The two groups concurrently carried out their responsibilities and then their activities were integrated to work on the integrated promotion plan. Fig.3.1 gives the organizational structure of project management. The PRH component leader was responsible for project operations. The component manager served as an official coordinator between TISTR, and the NEA/USAID. He also took responsibility for administrative management of the project and played an active role in giving technical guidance to the project team.

Project activities were grouped into various tasks as diagramatically presented in Fig. 3.2. In the preliminary study phase, the sequence of activities involved orientation of the project team (A1), work preparation (A2), socio-economic survey (A3), fabrication of hardware (A4), and training of the engineering team (A5). In task A1 the project team was briefed on the project concept and the work plan for project implementation by the project manager. Task A2 involved the work

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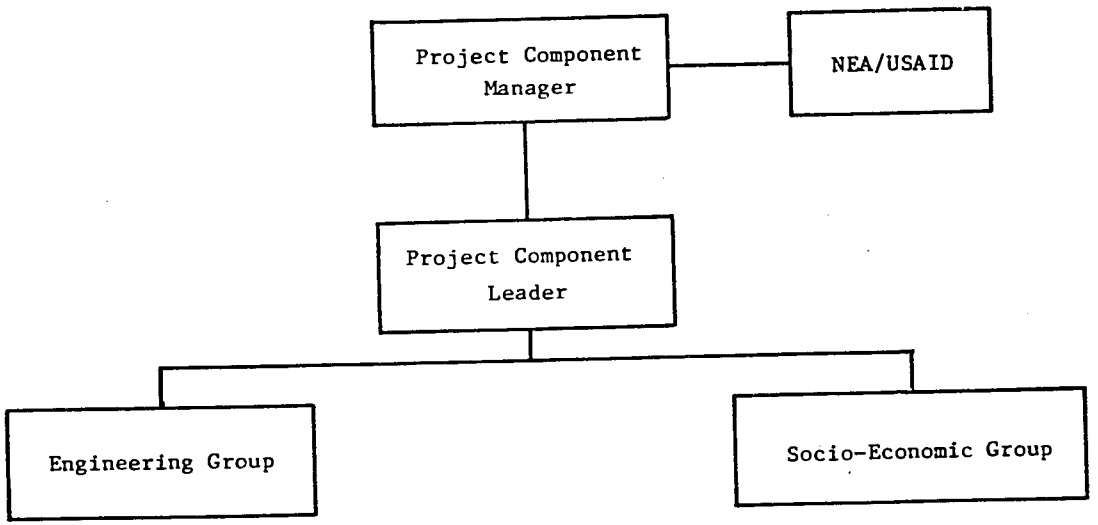

Figure 3.1 Organization of Project Management

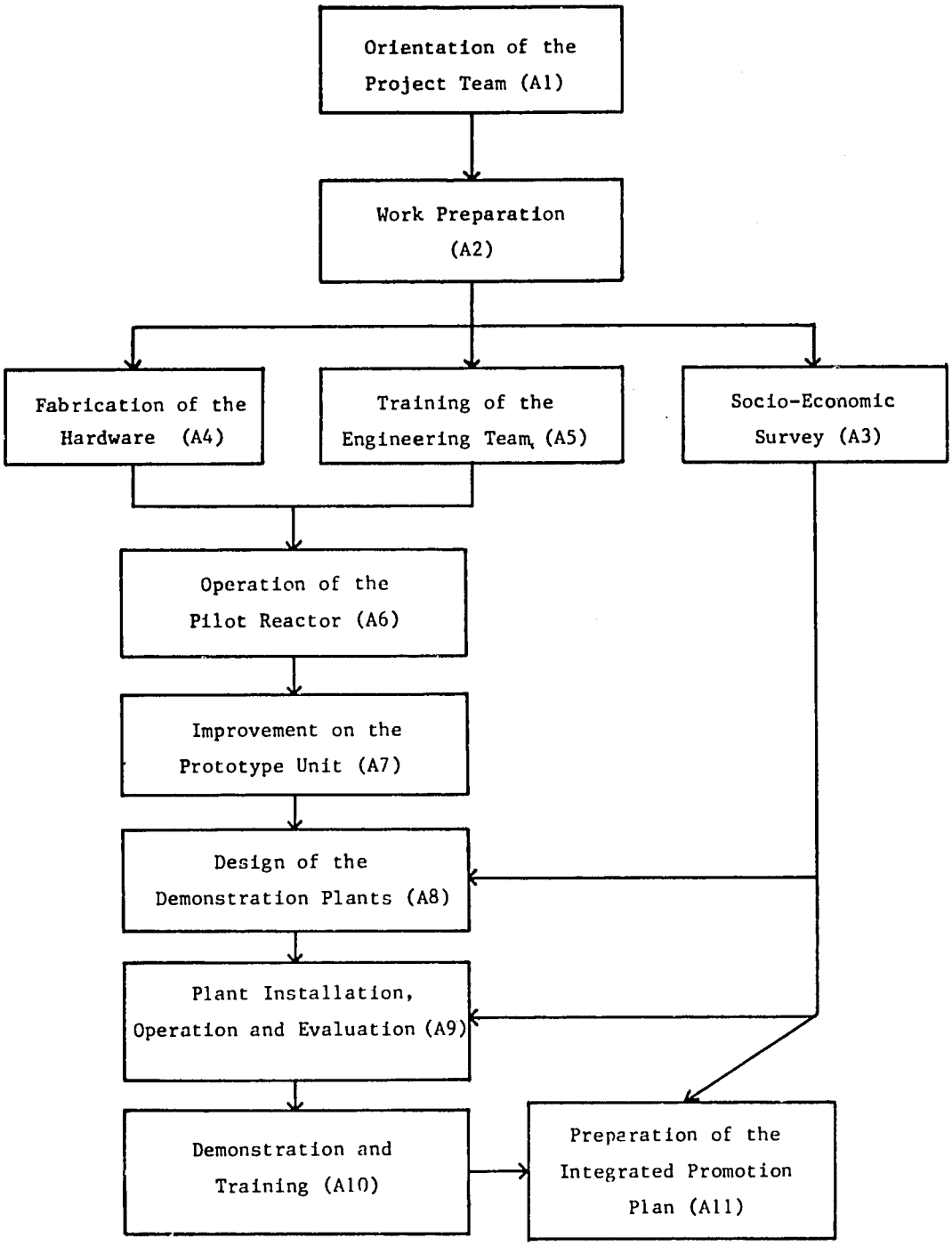

Figure 3.2 Study Approach

preparation for tasks A3, A4 and A5. With the plan for the field survey established in task A2, the socio-economic group carried out its activities of task A3. Concurrently, the engineering group fabricated the hardware (A4) using the engineering data obtained from task A2, and finally was trained (A5) by an expert provided by USAID at TISTR and in the Philippines.

In the technological development phase, the engineering group was involved in the operation of the pilot reactor (A6), improvement on the prototype unit (A7), design of the demonstration plant (A8), plant installation, operation and evaluation (A9), technological demonstration and training (A10) and preparation of the integrated promotion plan (A11). In task A6, the pilot reactor was operated by using experience gained from previous work carried out at TISTR and also from tasks A2, A4 and A5. Concurrently, task A7 was concerned with design modifications of the pyrolysis system that were to be carried out to improve the unit and make it appropriate for field conditions. Task A8 involved designing the demonstration plants using the engineering and cost data determined from tasks A3 and A7. After the completion of task A8, the demonstration plants were to be installed, operated and evaluated on their technical, economic and social viabilities. The evaluation was also to be based on the study output given by task A3. During the plant operation in task A9, the interested rice mill owners from the surrounding demonstration site were invited to investigate and participate in a training program in operation and maintenance of the plant. Eventually, the integrated promotion plan was to be prepared using the information obtained from tasks A1 through A10. The work schedule of all the tasks is shown in Appendix 2.

3.2 DETAILED WORK PLAN

3.2.1 Orientation of the Project Team

In this task, the project team was briefed by the project manager on the project concept the project approach and other relevant details. This was to ensure that the whole team would develop the same concept and work for the same goal. In addition, team discussions generated a crossflow of ideas and experiences. The project leader described all the technical aspects of the PT system. This was to familiarize the team with the technology. Finally, the detailed operation plan was jointly prepared by the team.

3.2.2 Work Preparation

In this task, the technical groundwork for the project was to be prepared by the engineering group. The activities were as follows;

- Review literature on pyrolysis of rice husk;
- Study the theoretical principles and engineering design aspects of pyrolysis technology;
- Design and construct the shelter for the pilot plant facilities; and
- Do test runs on a batch-type pyrolytic system to gain experience in the pyrolysis of rice husk and in the analysis of pyrolytic products.

Concurrently, information on rice mills, utilization of rice husk, and the charcoal market needed to be collected from

secondary sources of data (Agricultural Statistics of Thailand, 1974-1980) by the socio-economic group. The information obtained was to help for the preparation of the plan for field surveys. The socio-economic group also needed to become familiar with the technology.

3.2.3 Socio-Economic Survey

Based on the information obtained from secondary sources of data (Agricultural Statistics of Thailand, 1974-1980) the plan for the field survey was to be established. In the plan, areas to be surveyed including the number of various sizes and types of rice mill samples and their surrounding communities were to be identified. The objectives of the field survey were to collect information on the technical, social and economic aspects of the rice milling industry, and to evaluate the supply of rice husk and the potential application of pyrolysis technology. In addition, the survey also aimed to assess the potential use of pyrolytic products and to identify a suitable rice mill for the field demonstration of the technology.

3.2.4 Fabrication of the Hardware

In this task, drawings of the pyrolysis system, designed by J.W. Tatom, were closely studied for revision and detailed specification by the engineering team. Additional units were designed and modified to suit local equipment and materials. After the completion of the engineering study and design, a prototype pyrolytic conversion system was constructed and installed at TISTR.

3.2.5 Training of Engineering Team

A PT training program was provided by Meta Systems Inc. both at TISTR and in the Philippines. This task aimed to strengthen the technological capability of the engineering team in operating the pyrolysis system.

3.2.6 Operation of the Pilot Plant

After the completion of fabrication of the hardware and training of the engineering team, the pilot plant was to be operated by the engineering group at TISTR for 4-6 months. The four prime objectives for operating the pilot plant were as follows:

1. To determine optimum design parameters and cost data for PT;

2. To determine optimum processing conditions for PT;

3. To identify operating and control problems of the PT system and their solutions; and

4. To gain experience in operation and control of the PT system.

From the operation of the pilot plant, an operational program was to be designed to strengthen the technical capability of the engineering group in the design and operation of the pyrolysis plant. Design modifications of the plant and evaluation of techno-economic feasibility of PT were also included.

3.2.7 Improvement of the Prototype Pyrolytic Reactor

In this task, an appropriate model for field demonstration was to be determined through the process of adaptation which could vary the reaction temperatures to provide different product yields.

The task also included some modifications of hardware resulting from operational problems and the development of pyrolytic products. It was essential that, after this task, the engineering group would be able to design a pyrolytic plant to suit actual field conditions.

3.2.8 Design of the Demonstration Plants

In this task, the field demonstration plants were to be designed and fabricated for installation at two selected rice mills. The design was based on the system modification carried out in operation of the pilot reactor, and also relevant conditions found at the selected rice mills such as capacity, supply of rice husk, power rating of engines, oil consumption, space and utilities for PT installation, etc. In the design, the value engineering technique was to be applied to make the design cost-effective and practical.

3.2.9 Plant Installation, Operation and Evaluation

The field demonstration plants were to be installed at two rice mills and operated for 2 months each to demonstrate technical viability and evaluate performance. Similar to the operation of the pilot plant, an operational program was to be designed according to the actual working hours and days of the mills. In the program, the rice mill workers were to be trained to operate and control the PT system in connection with the

milling machine as well as to maintain the PT system. Concurrently, the socio-economic data were to be systematically collected and compared with the baseline data to evaluate the social and economic viability of PT.

3.2.10 Technological Demonstration and Training

During the plant operation, interested rice mill owners from the surrounding demonstration site were invited to investigate the PT system's performance and gain information on its technical and economic aspects. Some of the rice mill owners were interviewed about their attitudes towards PT. A training program in operation and control of the system was to be arranged in which the interested owners could participate.

3.2.11 Preparation of The Integrated Promotion Plan

This task was to be the synthesis of all the outcomes of tasks A1 to A10, inclusively, to develop an integrated plan for the promotion of PT. The plan covered the following five key issues;

1. Promotion strategies: This involved demonstration of the technology at rice mills, transfer of the technology through equipment manufacturers, training of the mill workers, as well as organization and execution of workshops and seminars for dissemination of the technology.

2. Financial policy and strategies: Plans for financial assistance to the investors were to be discussed. It proposed three possible alternatives for financial arrangement i.e., provision of low-interest rate financial sources, or governmental subsidy, or both, for the investors. In addition, investment incentives through reduction in taxes

and tariffs were also to be discussed.

3. Infrastructure requirements: All the facilities required for promotion of the technology were to be identified. They included a center for transfer of the technology through the equipment manufacturers and the mill workers, as well as the budget required for carrying out such the technology transfer activities, which would be organized and executed by TISTR and NEA.

4. Institutional arrangement: The organization structure of all the institutions concerned for promotion of the technology was to be established and their responsibilities were to be described. In brief, the technology would be promoted by NEA with technical support from TISTR, and the financial arrangement would be made by NEA and some private company.

5. Detailed Promotion Program: This involved details of activities in the promotion phase which were to be carried out by the agencies responsible.

4

EXPERIMENTAL TECHNIQUES AND PROCEDURES

CHAPTER 4

EXPERIMENTAL TECHNIQUES AND PROCEDURES

This chapter presents the methods used for field survey, the technological development, and the technological demonstration and training on pyrolysis technology.

4.1 METHODOLOGY FOR FIELD SURVEY

4.1.1 Collection of Secondary Information

Initially, in implementing the field survey, the information on the rice milling industry was collected from the Department of Factory Control, the Agricultural Statistics Center, the National Statistical Office, the NEA and TISTR (see "Present Status of Rice Milling Industry" in Chapter 2).

Based on the information obtained, areas to be investigated by the survey, and the number of various sizes of existing registered rice mill (including their surrounding households) were randomly selected for investigation. The method used for the selection was known as the Multi-Stages Sampling System.

4.1.2 Design of Questionnaires

After the random sampling of the mills was completed, questionnaires used for the field survey were designed (see Appendix 3). There were questions on;

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- Rice mill operation--investment, capacity, power rating, supply of paddy, actual working period, rice production rate, energy base, energy consumption, energy cost, labor and maintenance costs;

- Supply of rice husk, production and consumption, off-site utilization, market value, excess and disposal;

- Energy use patterns in surrounding communities, energy supply, energy consumption, energy cost; and

- Social attitude towards new technology and new products, attitude of rice mill owners towards PT, attitude of the rural people towards rice husk charcoal and pyrolytic oil.

4.1.3 Survey of the Selected Rice Mills and Surrounding Communities

According to the plan for the field survey, the existing operational status of 158 sample rice mills was investigated. Information on milling capacity, operating conditions, rice husk production and utilization, excess of rice husk, energy base, energy consumption, energy cost etc., was systematically collected by interviewing rice mill owners using the survey questionnaire.

Of the 158 sample rice mills, 40 mills were in the North; 71 mills were in the North-East, 25 mills were in Central Thailand, and 22 mills were in the Southern part of the country. The size distribution of the 158 mills was as follows: 27 large mills, 33 medium mills, 98 small mills, equivalent to 17.09%, 20.89% and 62.02% respectively (see Table 4.1). A large mill produced more than 20 tons/day, a medium mill produced 5-20 tons/day, and a small mill produced less than 5 tons a day.

Table 4.1 Size Distribution of Surveyed Rice Mills by Region

Sizes of rice mill	Number of rice mills in each region				Total
	Northern	Northeastern	Central	Southern	
Large (>20 ton/day)	7	10	9	1	27 (17.09)
Medium (5-20 ton/day)	4	17	9	3	33 (20.89)
Small (<5 ton/day)	29	44	7	18	98 (62.02)

Figures in parenthesis are percent

Concurrently, a survey of 1,541 surrounding households was conducted to gain information on their energy use patterns and attitude towards new low-cost fuels. Their regional and provincial distributions are shown in Appendix 4.

In implementing the field survey, the survey team was divided into two groups, one for interviewing the rice mill owners and the other for interviewing the people in the surrounding communities.

4.1.4 Site Selection for Installation of Demonstration Plants

To ensure the technical, economic and social suitability of rice mills for installation of a demonstration plant, 27 rice mills operating with diesel engines were selected for investigation. Of the 27 mills, 14 mills had a power rating of between 12 to 30 hp, 3 mills had a power rating between 56 to 60 hp, and another 10 mills had a power rating between 65 to 280 hp. Selection of those mills was primarily based on their ownerships; they consisted of those owned by individuals and corporations (14 mills), and cooperatives (13 mills). Each was investigated with the purpose of evaluating their acceptance of and interest in becoming a demonstration plant. However, the technical and economic factors of capacities, amount of rice husk supply, energy consumption, power rating of the engine used, and the economic situation of those mills were also taken into consideration. The techno-economic data of the sample of the 27 rice mills are presented in Appendix 5.

4.2 METHODOLOGY FOR TECHNOLOGICAL DEVELOPMENT

4.2.1 Laboratory Study on PT

A batch-type pyrolysis experiment was carried out at TISTR primarily to investigate the process parameters. First, approximately 30 kg of rice husk was collected from a rice mill located in the provincial area near Bangkok. The rice husk sample (which had a moisture content of 8-10% by weight) was sun dried for 2 days to reduce its moisture content to approximately 4% and then the dried husk was subdivided into samples of one kilogram each. A one-kilogram sample was put into a retort. This was then placed into an electric furnace for pyrolysation with the heating rates of 8-12°C/min until the temperature reached 500°C, 700°C or 900°C depending on the test conditions. The sample was maintained at the testing temperature for 3 hours. Then the hot retort of rice husk char was taken out of the furnace and cooled to room temperature overnight. After cooling, the char was weighed and the tar oil yield was determined. During each experimental run, the pyrolytic gas yield was measured by using a wet test meter.

4.2.2 Design and Construction of the Pilot Plant

Prior to the fabrication of the hardware, the shelter was designed and the detailed drawings of the pilot reactor was studied by the engineering group. The original design was revised and missing parts such as a rice husk storage, feeding system, cyclone separator, off-gas cooling unit, and gas purifying unit were designed into the system. However, the revised model was still based on the original one--known as a vertical bed reactor--with a nominal capacity of 1 ton/day. The subsequent tasks included detailed specifications for each component and procurement of the specified materials and equipment for the fabrications.

In the construction of the pilot plant, most of the components were made and installed by the engineering group. Due to the time limitations of the project, the fabrication of some components was put out for bid, contracted, and made the responsibility of the contractor.

4.2.3 Installation of the Pilot Plant

After completion of construction, the PP systems were fabricated and installed. Presented in Fig. 4.1 is a flow diagram of the pyrolysis system developed at TISTR. The system consisted of a storage bin, a feeding system using an air conveyor coupled with a screw feeder, a vertical bed pyrolytic reactor with a char removal system, an airgitator, a cyclone separator, a dual-jet condensers, a water condenser, gas cooling and purifying units, a gas mixing tank, a mixer and a briquetting machine.

4.2.4 Operation of the Pilot Plant

Twenty experimental runs were conducted. In practice, the operating time for the test runs varied from 3 to 15 hours depending on the availability of the feed material. This operational program included the preparation of the feed material, the operation of the reactor, system modification, data collection, and tests on the utilization of pyrolysis products.

Preparation of Material and Design of Parameters

Before the pilot plant operation, the feed material was prepared, and an amount of rice husk was sampled from the storage bin to measure its moisture content. Laboratory analysis of the rice husk samples were conducted to determine their calorific values as well as their chemical and physical characteristics. Results of the analysis are given in Table 4.2.

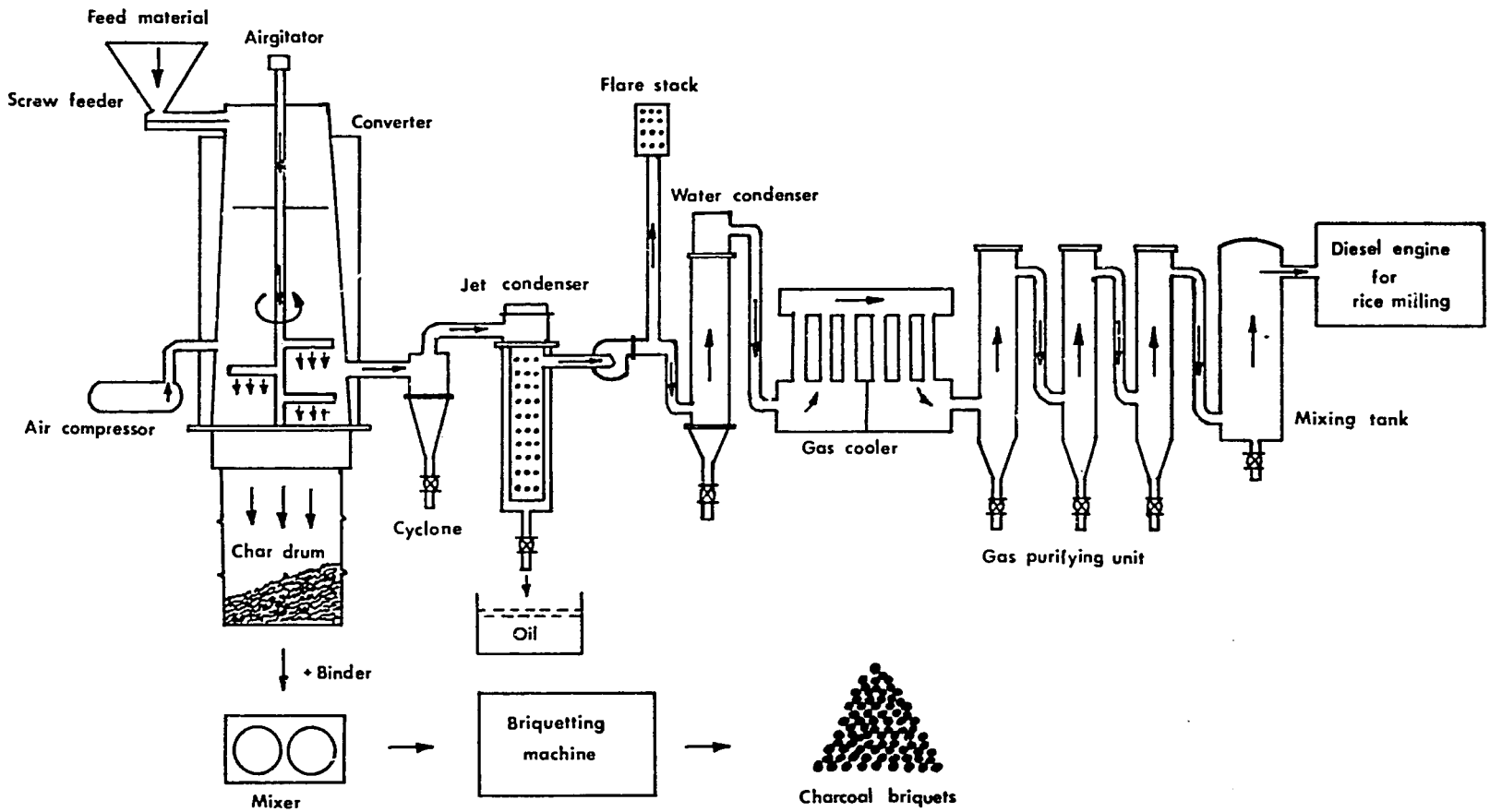

FIGURE 4.1 FLOW DIAGRAM OF RICE HUSK PYROLYSIS PROCESS

Table 4.2 Fuel Properties of Rice Husk

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
Calorific value, kcal/kg	3,770	3,890	3,890	3,760	3,710	3,820	3,800	3,710 - 3,890
Density, kg/m^3	105	107	106	106	107	105	106	105 - 107

Prior to reactor operation, measurement parameters were designed and their measuring instruments were prepared. Basically, the process parameters included: amount of feed material and process air, temperature in the pyrolysis zone, off-gas temperature, and yields of pyrolytic products.

Operation of the Reactor

In the operation of the TISTR pyrolytic reactor (see Fig. 4.2), dry feed was initially placed in the storage bin, ready for feeding into the system. Then, approximately 50 kg of dry feed was put into the bottom of the reactor, followed by 2 kg of hot charcoal. After that, the process air produced by the air compressor was introduced via an "airgitator" (see Fig. 4.3). Meanwhile, the blower of the off-gas system was turned on to allow the air passing through the reactor to help ignite the rice husk. The dry feed was then conveyed by an air blower from the storage bin to the hopper located at the top of the reactor, and proceeded into the reactor through a screw feeder. Concurrently, the airgitator was turned on to stir the bed continuously to break up any fissures of bridges that might form to plague the operation of the packed-bed reactor. As the material moved down 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.

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 for cooling. After cooling, char was mixed with 10-15% starch by weight and then the mixture was put into a briquetting machine to form char briquets (see Fig. 4.4).

The pyrolytic gases produced in the reactor left the rice husk bed at the off-gas ports near the bottom of the reactor by the air suction caused by a blower. The off-gases which contained condensible gases, noncondensible gases, 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 condensers and the water condenser where the pyrolytic oil was separated from the noncondensed gaseous mixture (see Fig. 4.5). From the condensers, the gaseous mixture was passed into gas coooling and purifying units, where the gas stream was cooled, and the water and tar mist were removed.

System Modifications

After completing a few test runs, some parts of the system were redesigned and modified to improve system performance;

- Airgitator performance was improved by adding one more stirring blade;

- A throat was installed above the off-gas ports inside of the reactor to reduce ashes and other small solid particles in the off-gas;

- A by-pass was installed between the top of the reactor and the dual-jet condensers to reduce the moisture emitted by the rice husk feed; and

- A water condenser was placed next to the dual-jet condensers to help reduce the moisture content of the off-gas and tar oil which were still incompletely condensed after passing through the dual-jet condensers.

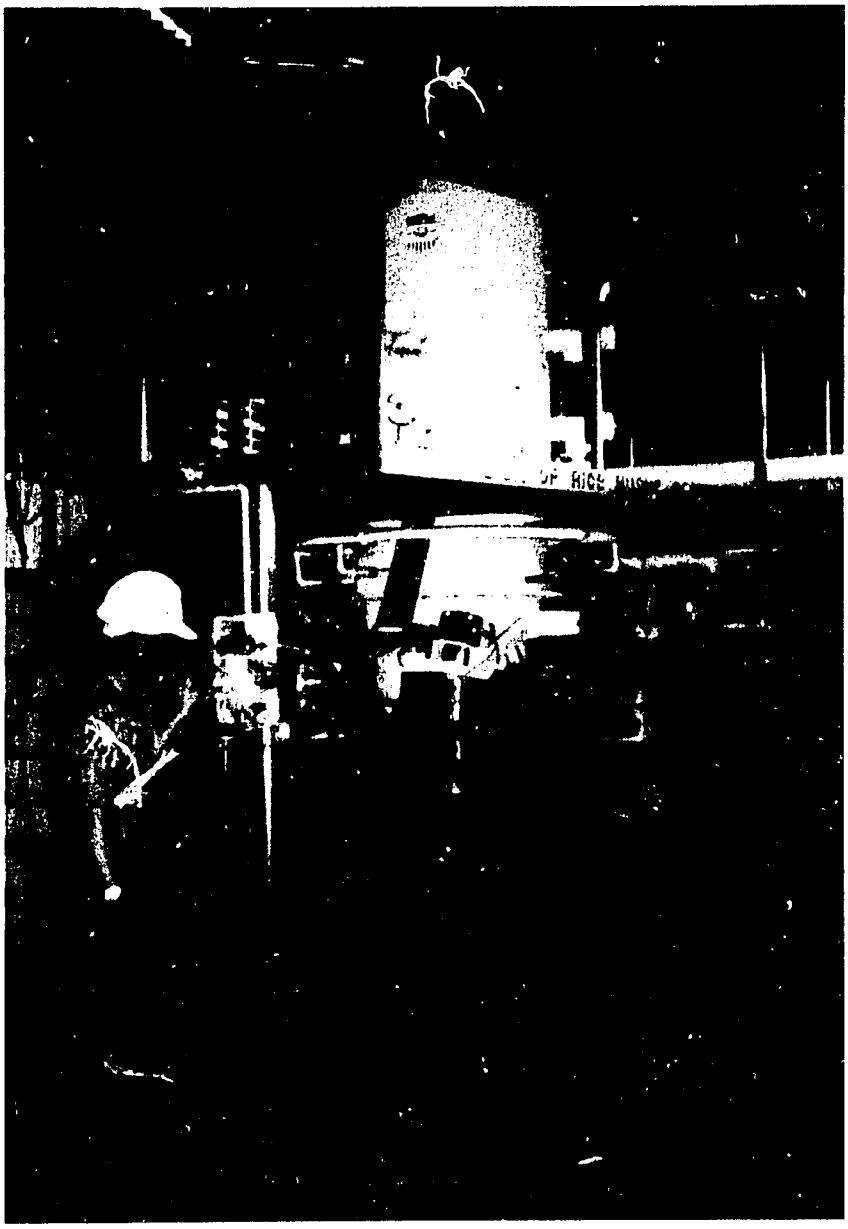

Figure 4.2 TIDTR Pyrolytic Reactor with Char Removal System

Figure 4.3 Airgitator

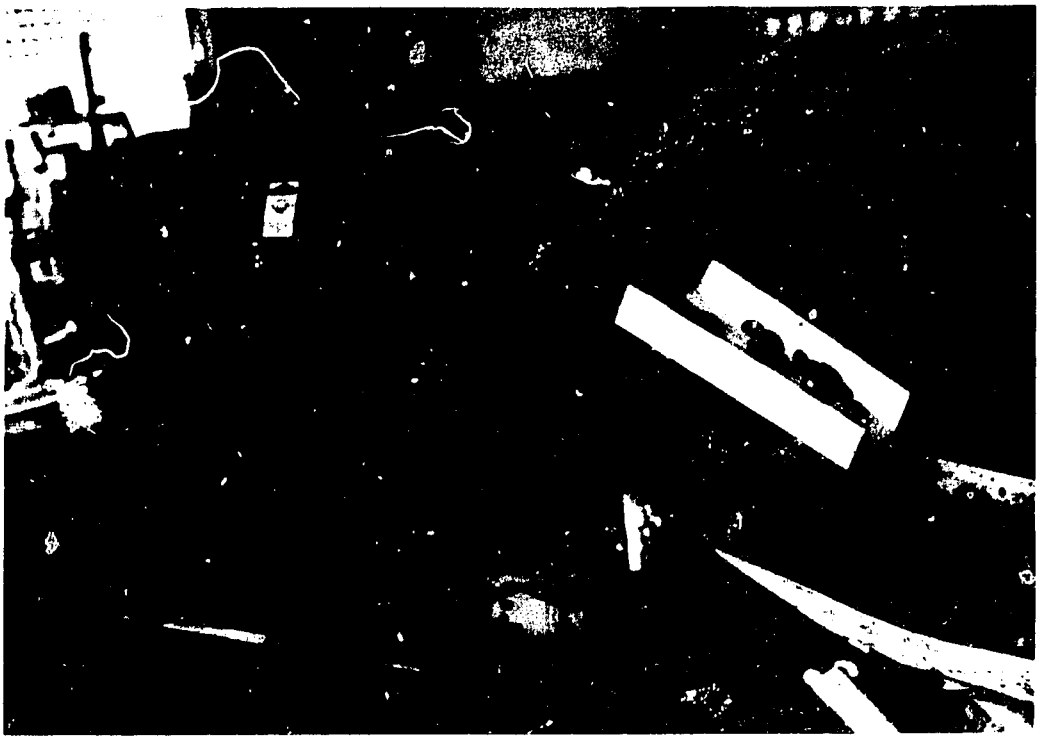

Figure 4.4 Char Briquetting Machine

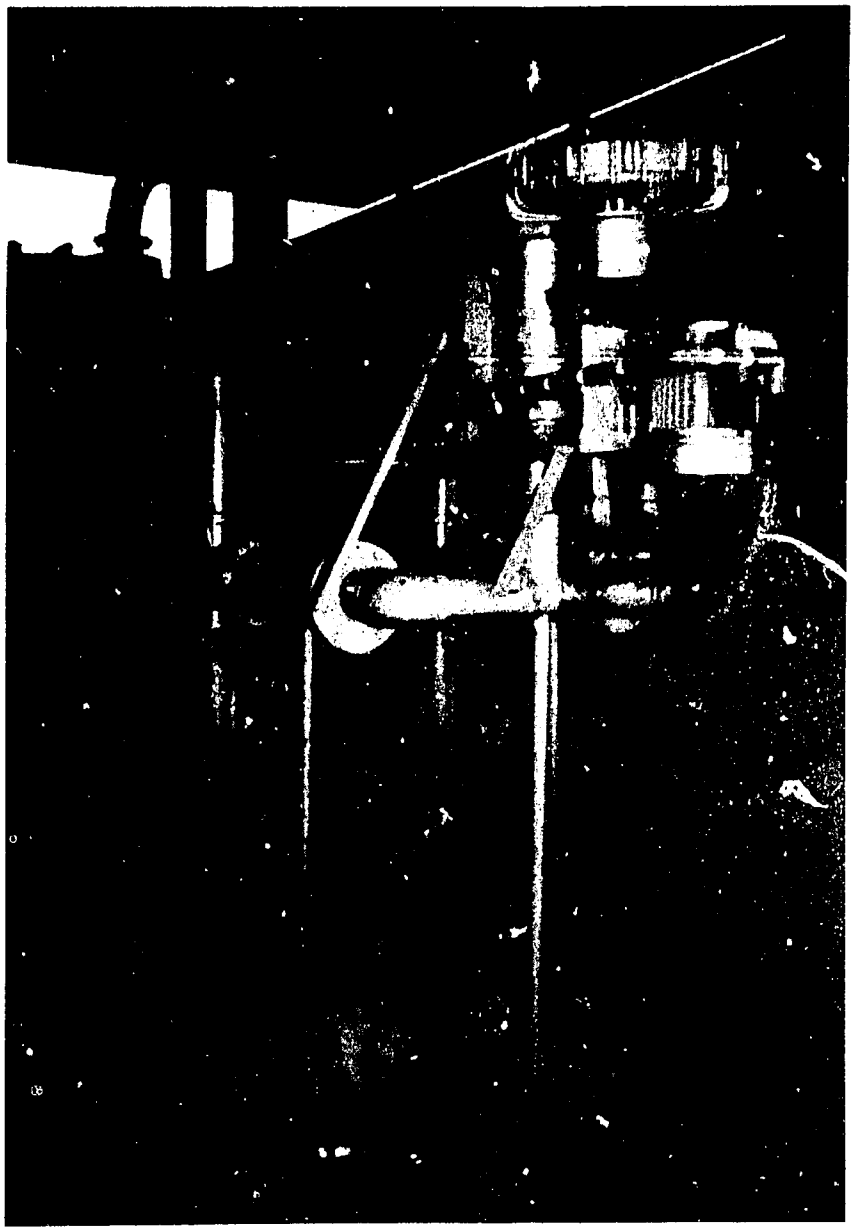

Figure 4.5 Dual-Jet Condensers

Data Collection (Parameters and Measurements)

In operating the reactor, the rice husk was weighed before being fed into the system and the process air was measured by an air flowmeter. The temperature in the pyrolysis zone, normally between 500-800° C, was recorded by a temperature recorder. Concurrently, the off-gas temperatures at the off-gas ports, after the cyclone separator and before the test engine, were all recorded by a multi-channel recorder. The char and oil products were collected and weighed after cooling and a flowmeter was affixed to the off-gas duct to measure the flow of off-gas.

Study on the Utilization of Pyrolytic Products

Since the prime objective of the project was to promote PT application investigating the utilization of pyrolytic products became one of the most important aspects of the project.

The utilization of char briquets was studied. A number of char briquets, after being dried for 3 days, were sampled to investigate their physical and fuel properties. A subsequent series of drop tests on the briquet samples was conducted using a drop distance of 2 meters above a concrete slab. Then, the surviving briquets were counted. Fuel properties of the briquets were tested by performing laboratory analysis to determine bulk density, calorific value, combustion temperature and combustion period.

To determine the combustion period of char briquets by comparison with that of wooden charcoal, 1 kg of each sample was put into identical typical cooking stoves. After being ignited, the temperatures at two points, one at contact and the other at 2 inches above the hot samples, were recorded. During each test, the time was also measured until the temperature of the stove decreased to 100°C.

The gas produced after being cleaned in the purifying units was tested for use, primarily with the diesel engine AC generator. First, an 11 hp Kubota diesel engine was powered by 100 percent diesel oil to drive a 5 kW AC 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 watt load until it reached 3 kW (see Fig. 4.6).

In the test of tar oil to be utilized 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 ratios of 20:80, 30:70, 40:60 and 50:50, respectively, they were then used for testing as fuel 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.

4.3 TECHNOLOGICAL DEMONSTRATION AND TRAINING AT RICE MILLS

4.3.1 Design and Construction of Demonstration Plants

Two PT demonstration plants were designed to be capable of converting 1-1.5 tons/day of rice husk into combustible char, gas and oil. Some redesign and modification of the PT components was necessary to make the equipment suitable for rice mill conditions. The following modifications were made;

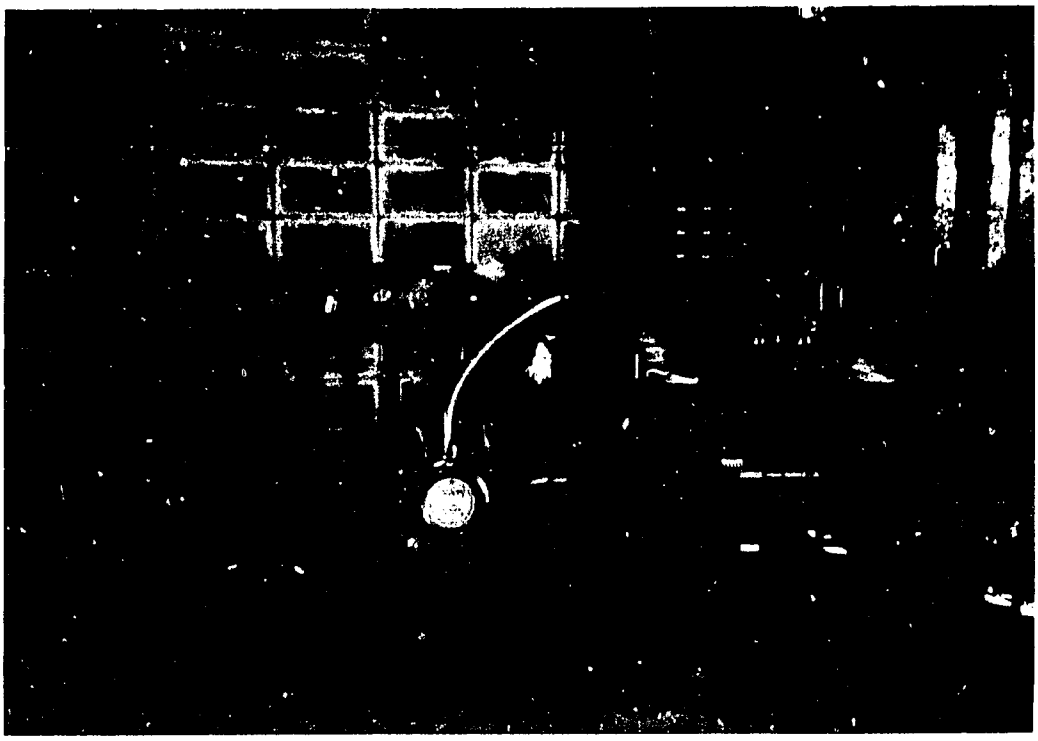

Figure 4.6 Off-gas System and Electricity Generator

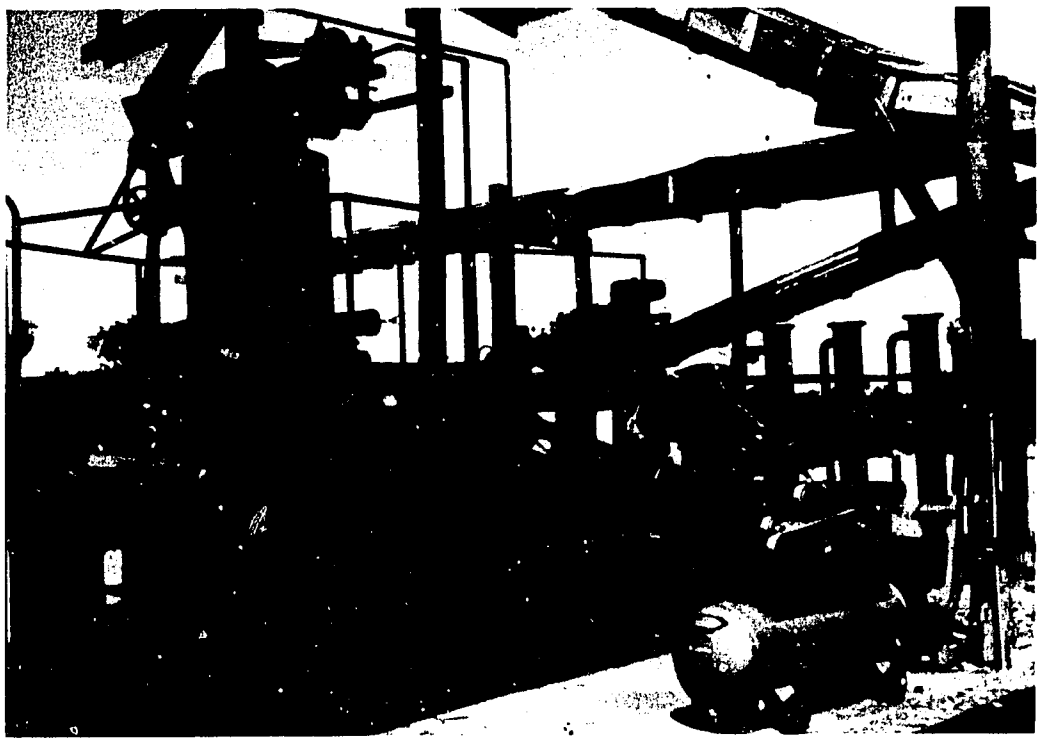

Figure 4.7 Demonstration Plant at Sara Buri Province

- The height of the reactor body was expanded to enlarge its combustion zone;

- The feeding system was changed from functioning with a blower and screw feeder to a gravity force feed. This was to reduce the capital cost;

- The height of the condensing unit was also expanded to increase its efficiency for condensing more tar oil;

- The gas purifying units were expanded to increase their performance; and

- A gas storage tank was made and added to the system to make the system capable of providing a sufficient and continuous flow of pyrolytic gas to the mill's engine.

Two demonstration plants were set up and installed at the rice mills in two provincial areas--one at the Koo Charoen rice mill, Amphur Wihandaeng, Sara Buri Province (see Fig. 4.7) and the other at a cooperative rice mill, Amphur Wangsaiphoon, Pichit Province. The plant was installed with a gas duct from the gas storage tank of the PT system connected to the mill's engine to supply cleaned pyrolytic gas.

4.3.2 Operation of Demonstration Plants

After the plant was installed, a preliminary test run of the PT 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 of operating the pilot plant, except for the utilization of the gas produced.

Initially, the mill's engine was powered by 100% diesel oil. After that, the gas produced from the PT system was cleaned and stored in the gas storage tank. When there was sufficient gas for use, the gas valve was opened to allow the gas to replace diesel oil in the mill's engine. The amount of oil left over was measured, then the percentage of oil substitution was calculated.

In each experimental run, the yields of pyrolytic oil and char were determined and some of them were sampled for laboratory analysis. The results obtained were used to determine the mass and energy yields as well as to provide a basis for economic analysis. The processing conditions used for the demonstration plant operation were similar to the "appropriate" one developed from investigating the pilot plant at TISTR--except for the air-to-feed ratio which was less than that of the pilot plant due to the mill's engine suction. Due to the time constraint only 9 experimental runs were conducted.

4.3.3 Demonstration and Training at Rice Mills

During plant operation, interested rice mill owners in the surrounding areas (such as in Ayutthaya, Lop Buri, Nakorn Nayok and Prathum Thani) were invited to observe system performance at the demonstration plant. In addition, a training program in operation and maintenance of the PT system was arranged for interested rice mill owners and workers.

4.4 METHODOLOGY FOR ECONOMIC STUDY

The study on the economic aspects of the PT demonstration plant was based on coupling a pyrolysis system with a typical rice mill operated by means of a diesel engine of 280 hp, 8 pistons. First, the initial investment, operation cost, depreciation costs, and the earnings in oil saving and from

selling the char and oil products were determined. Based on the findings obtained and the assumptions made for the plant's working conditions, the break-even point, the financial return of the investment and the payback period were obtained. In addition, the relationship of the internal rate of return value to that of selling pyrolytic products was determined and analysed.

5

ANALYSIS DISCUSSION AND EVALUATION OF RESULTS

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CHAPTER 5

ANALYSIS, DISCUSSION AND EVALUATION OF RESULTS

This chapter presents the project findings for the preliminary study and technological development. It contains 4 sections. The first two sections relates to the techno-economic study results of PT and the other two sections relates to the results of the field survey, including results of the social evaluation on the acceptability of PT application.

5.1 TECHNOLOGICAL STUDY RESULTS

Since the study progressed in three development stages (starting from the laboratory, extending to the pilot plant and then to the demonstration plants), the findings are presented, analysed and discussed in this section in the order of project development.

5.1.1 Laboratory Study Results

In the laboratory, the pyrolysis of rice husk of one-kilogram-per-day was conducted at temperatures of 500°C, 700° C and 900° C on a batch type system. The product yield data are presented in Table 5.1. It was found that the char yield at these three temperatures ranged between 44.0-52.0% the highest yield was obtained at 500°C. In addition, the oil and gas yields were found to range between 27.6-33.3% and 20.0-22.7% respectively, and shared the maximum yield at 900°C.

It can be concluded from the results that, as the pyrolysis temperature was reduced, the char yield increased while oil and gas yields decreased. Similary, increasing the pyrolysis

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Table 5.1 Products of Rice Husk Pyrolysis on Laboratory Scale

Run No.	Moisture (%)	Temperature (°C)	Char		Oil		Gas	
			(kg)	(%)	(lt)	(%)	(lt)	(%)
1	4	500	0.520	52.0	0.265	27.6	130	20.4
2	4	500	0.520	52.0	0.270	28.0	132	20.0
3	4	700	0.480	48.0	0.285	29.6	158	22.4
4	4	700	0.485	48.5	0.280	29.1	160	22.4
5	4	900	0.445	44.5	0.315	32.9	200	22.6
6	4	900	0.440	44.0	0.320	33.3	210	22.7

temperature resulted in increasing oil and gas yields while the char yield decreased.

5.1.2 Experimental Results of the Pilot Plant

In the early series of pilot plant test runs the conditions necessary for operational reliability were determined and some redesign and modification took place to obtain good system performance and good yields of pyrolytic products.

It was determined that the improvement of the airgitator resulted in better stirring of the rice husk bed and in a more complete combustion of the feed. The added throat effectively extracted ashes and other solid particles from the off-gas. The by-pass reduced the volatile matter created by the feed moisture and helped control the temperature in the reactor. The water condenser also extracted more water and tar oil from the gas. The optimum conditions for plant operation were found to be:

- Having moisture content of the feed material 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;

- Varying the rate of input from 49.1 to 53.7 kg/hr (to be consistent with the air supply at the rate of 33.2-34.6 kg/hr);

- Varying the air-to-feed ratio from 0.68 to 0.73 kg/kg, depending on what products 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;

- Having char discharge rate consistent with the input rate. In the steady-state, this is every 5 minutes for 2 seconds.

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 the overall average yields being 37.3%, 47.1% and 15.6% respectively (see Table 5.2). The char and oil yields were determined by collecting and weighing these products, while the noncondensed gas yield was determined by the difference.

Table 5.3 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% respectively, while the energy recovery of the oil product ranged between 9.7-10.2%; the overall average was of 40.6%, 15.6% and 10.0% respectively.

5.1.3 Results from the Demonstration Plant Operation

Although two demonstration plants have been installed, due to implementation time limitations, only the test results from the one installed at Koo Charoen Rice Mill, Sara Buri Province are available. The test results represent both the field test conditions and demonstration plant system operational performance, including system energy yields and energy consumption.

In operating the PT demonstration plant (which was coupled with the mill's engine), almost all the processing conditions applied were similar to conditions at the TISTR pilot plant. The exception was the char discharge rate which was

Table 5.2 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	11.0	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 5.3 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

prolonged from every 5 minutes for 2 seconds (at the pilot plant) to occur every 10 minutes for 2 seconds (at the demonstration plant). In addition, the air-to-feed ratio was automatically reduced (from the range between 0.68-0.73 kg/kg to 0.36-0.37 kg/kg). This was due to the effect of external air replacement caused by the gas suction from the mill's engine into the top of the reactor.

Under the conditions mentioned above, it was found that the average char yield increased to 45.2% while the average gas and oil yields decreased to 43.3% and 4.7% respectively, compared to 37.3%, 47.1% and 15.6% obtained from pilot plant operation, respectively (see Tables 5.2 and 5.4). Increases in the char yield resulted from reducing the air-to-feed ratio and extending the period of time for char discharge rate which decreased the heating rate in the pyrolysis zone; therefore, a slow pyrolysis reaction would occur. Variations in the oil yield depended on the off-gas temperature, the lower the off-gas temperature, the lower the oil yeild. In operating the domonstration plant, the off-gas temperature ranged between 56-60°C, compared to 65-100°C measured during pilot plant operation. Consequently, decreasing the gas yield resulted in decreasing the oil yield.

Table 5.5 shows the mass and energy yields of the system under the steady-state condition. On a dry basis, the energy recoveries of the char and gas products were found to range between 49.5-52.2% and 15.1-17.1%, respectively, while the energy recovery of the oil product ranged between 2.5-2.6%, with an overall average of 50.9%, 16.1% and 2.5%, respectively. Comparing the demonstration plant results to those obtained from pilot plant operation, the energy recovery of char increased while that of gas and oil decreased.

Table 5.4 Product Yields of Rice Husk Pyrolysis from the Koo Charoen Demonstration Plant

Run No.	Moisture (%)	Feed rate (kg/hr)	Air flow rate (kg/hr)	Air/Feed (kg/kg)	Char		Oil		Gas	
					(kg/hr)	(%)	(kg/hr)	(%)	(kg/hr)	(%)
1	9.8	56.3	21.0	0.37	26.5	47.0	2.1	3.7	24.9	44.2
2	9.0	47.1	16.8	0.36	21.2	45.0	1.8	3.8	21.5	45.6
3	10.7	57.9	18.9	0.36	25.3	43.7	3.9	6.7	23.2	40.0

Remarks : approximately 11% loss in the process

Talbe 5.5 Mass and Energy Yields from the Koo Charoen Demonstration Plant

Products	Run No. 1		Run No. 2		Average	
	Mass*	Energy**	Mass*	Energy**	Mass*	Energy**
Char	0.5056	0.5220	0.4794	0.4954	0.4925	0.5087
Oil	0.0165	0.0259	0.0160	0.0251	0.0162	0.0255
Gas	0.4909	0.1511	0.5563	0.1713	0.5236	0.1612
H_2O	0.0247	-	0.0240	-	0.0243	-
Total	1.0377	0.6990	1.0757	0.6918	1.0566	0.6954

* Mass of product per unit mass of dry input feed

** Ratio of energy content of product the energy content per unit mass of dry input

5.1.4 Energy Output and Energy Consumption of the Pyrolysis System

The field tests at Koo Charoen demonstration plant revealed the hourly product yields of the pyrolysis system to be as follows; char, 24.3 kg; gas, 23.2 kg and oil, 2.6 kg (as shown in Table 5.4). By using the heating values of char, gas and oil at 3,930 kcal/kg, 1,170 kcal/kg and 5,960 kcal/kg, respectively, and the moisture content in the char and oil of 3% and 60% by weight, respectively, the energy recoveries from the char, gas and oil were determined to be 95,499 kcal/hr, 27,144 kcal/hr and 15,496 kcal/hr, respectively--or equivalent to approximately 286 Mkcal, 81 Mkcal and 46 Mkcal on a yearly basis (10 hr/day, 300 day/yr), respectively. Consequently, the total energy output of the pyrolysis system was determined to be approximately 413 Mkcal/yr. With the average feed rate of 53.7 kg/hr, 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 based on a 10 hr/day, 300 days a year. Thus, the total electricity consumption of all the electric components was approximately 12.75×10^3 kWh/yr (4.25 kWh/hr, measured using an integrated kilowatt-hour meter), or equivalent to 10.97×10^6 kcal/yr. This result was obtained from the cost-reduction process developed after investigating the pilot plant. The process involved reducing the excess power ratings of the electric components.

5.1.5 Test Results on the Utilization of Pyrolytic Products

This section presents the test results on the utilization of rice husk char, pyrolytic gas and oil which were obtained in both the laboratory and in the field.

Rice Husk Char and Briquets

As the main product of PT, rice husk char briquets was aimed at the cooking fuel market to compete with the wooden charcoal or fuelwood used in the surrounding communities.

The proximate analysis of 10 char samples with their moisture content ranging between 1.5-4.2% by weight were shown in Table 5.6. On a dry basis, the fixed carbon in the char ranged between 34.7-59.8%; valatile matter, 5.2-9.8% and ash, 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 3,670-4,820 kcal/kg, with an average of 3,930 kcal/kg.

Tabel 5.7 shows the fuel properties of the char briquets. The moisture content of the briquet samples ranged between 4.2-5.0% on a dry basis, the fixed carbon, in the char briquets ranged between 42.4-45.4%; volatile matter, 14.3-16.5% and ash, 38.8-43.3%. As a result, the calorific value and bulk density of the char briquet samples were found to range between 4,120-4,330 kcal/kg and 460-510 kg/m^3, with averages of 4,220 kcal/kg and 490 kg/m^3, respectively.

Table 5.8 shows the results from the survival drop test of a number of char briquet samples. 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 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. Balls of 2 inches in diameter started surviving after three days of drying, accounted for 20% of the number of tested samples, and increased to 100% after five days of drying.

Table 5.6 Fuel Properties of Rice Husk Char

Properties	Rice husk char samples										Average	Range
	1	2	3	4	5	6	7	8	9	10		
Moisture, %	4.2	1.5	2.4	2.8	3.4	3.6	3.3	2.7	3.8	2.2	3.0	1.5 - 4.2
Fixed carbon, %	34.7	35.5	40.8	41.4	44.1	44.1	44.7	45.1	47.1	59.8	43.7	34.7 - 59.8
Volatile matter, %	6.7	9.8	6.5	7.0	9.0	7.0	5.2	5.8	5.8	6.3	6.9	5.2 - 9.8
Ash, %	58.6	54.7	52.7	48.9	46.9	49.0	50.1	46.5	46.5	33.9	48.8	33.9 - 58.6
Calorific value, kcal/kg	4,090	3,900	3,460	3,670	4,000	3,810	3,960	3,710	3,850	4,820	3,930	3,670 - 4,820

Table 5.7 Fuel Properties of Char Briquets

Properties	Char briquet samples					Average	Range
	No. 1	No. 2	No. 3	No. 4	No. 5		
Moisture, %	4.7	4.7	4.9	5.0	4.2	4.7	4.2 - 5.0
Fixed carbon, %	45.4	45.3	44.7	42.4	42.4	44.0	42.4 -45.4
Volatile matter, %	15.3	15.6	16.5	15.1	14.3	15.4	14.3 -16.5
Ash, %	39.3	39.1	38.8	41.8	43.3	40.5	38.8 -43.3
Calorific value, kcal/kg	4,270	4,250	4,330	4,120	4,140	4,220	4,120-4,330
Bulk density, kg/m^3	460	510	490	490	510	490	460 - 510

Table 5.8 Drop Test Survival of Char Briquets

Time (day)	Briquet diameter (in)	No. of tested sample (ball)	Survived sample		Broken sample	
			(ball)	(%)	(ball)	(%)
0	1.0	100	0	0	100	100
	1.5	80	0	0	80	100
	2.0	80	0	0	80	100
1	1.0	20	0	0	20	100
	1.5	20	0	0	20	100
	2.0	20	0	0	20	100
2	1.0	20	10	50	10	50
	1.5	20	8	40	12	60
	2.0	20	0	0	20	100
3	1.0	20	16	80	4	20
	1.5	20	16	80	4	20
	2.0	20	4	20	16	80
4	1.0	30	30	100	0	0
	1.5	30	30	100	0	0
	2.0	10	6	60	4	40
5	1.0	25	25	100	0	0
	1.5	25	25	100	0	0
	2.0	25	25	100	0	0

Comparison tests on the combustion of the char briquets and wooden charcoal revealed that the maximum temperature during the combustion period of each was determined. At a contacting point of char briquets and wooden charcoal, the temperatures were 880° C and 840°C, respectively. At 2 inches above the contacting point of char briquets and wooden charcoal, the tempertures were 860°C and 600° C, respectively. After the temperature at 2 inches above the contacting point of each decreased to approximately 100°C, the combustion periods of the char briquets and wooden charcoal were then measured to be 1.5 hr and 2.0 hr respectively. It should be noted that the char briquets had a shorter combustion period but had higher maximum temperatures at both points, compared to those of the wooden charcoal.

Pyrolytic Gas

The gas produced was aimed to be utilized on-site as a diesel oil substitute for powering the mill's engine.

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%; with the calorific values ranging between 950-1,390 kcal/kg, or 1,170 kcal/kg on the average.

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

Tests on driving 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.

Pyrolytic Oil

Initially, pyrolytic oil was aimed at being developed to be utilized both as a fuel and as an industrial feed. Due to implementation time limitations only the test results on utilization as a fuel will be discussed.

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; specific gravity at 26.6°C, 1.03-1.14; flash point, 78°C; and boiling point, 86.8°C; pH, 3.5-3.8. The calorific values ranged between 5,120-6,210 kcal/kg, or 5,960 kcal/kg on the average.

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

5.2 ECONOMIC ANALYSIS

Since the pilot plant had no actual application of its gas product, it was rather difficult to carry out its cost-benifit analysis. Thus, 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 saving and 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, wooden charcoal and furnace oil, respectively.

A typical rice mill operating with a diesel engine of 280 hp, 8 pistons and having a nominal milling capacity of 17 tons of paddy per day for a working period of 10 hours and 300 days a year, 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 of 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/lt).

After being briquetted and dried, the daily char yield of 264.6 kg was increased to 275.6 kg. At a price of 1.50 baht /kg (compared to the wooden charcoal's price of 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 lt (density of pyrolytic oil = 1.108 kg/lt). At the pyrolytic oil price of 2 baht/lt (compared to the furnace oil's price of 4.21 baht/lt), the daily income from selling oil would be 37.60 baht.

Consequently, the total daily income from the earnings was 795.86 baht.

5.2.1 Initial Investment

The initial investment for a 1-1.5 tons/day pyrolytic conversion system is approximately 194,600 baht (see Table 5.9). This cost excludes the cost of land and other kinds of infrastructure (such as buildings, paving, utilities, etc.). In this study, it was assumed that PT would be installed at a rice mill with facilities ready for the addition of a PT system. In the case of PT installation at places without existing facilities, these costs must be taken into account. It should be noted that approximately 60% of the capital cost was shared by the cost of all the hardware. These costs could be reduced through mass production, when PT system efficiency is confirmed and equipment is manufactured.

5.2.2 The Break-Even Point

Basically, the break-even point will mostly depend on a mill's operating costs and income derived from selling pyrolytic products.

Let C = income derived from earning in oil saving and from selling pyrolytic products

N = break even point, day/yr

F = fixed cost, baht/yr

V = variable cost, baht/day

A break-even point equation can, thus, be written as:

$$C \times N = F + V \times N \quad \text{.....(1)}$$

Table 5.10 shows details of fixed and variable costs of operation. It should be noted that the labor cost shares more than 46% of the fixed cost. Table 5.11 shows the determination

Table 5.9 Capital Cost for the Koo Charoen Demonstration Plant

Items	Cost (baht)
1. Shelter	20,000
2. Pyrolytic conversion system	100,000
3. Motor for feeding system	2,600
4. Pneumatic system	10,000
5. Air Blower	3,600
6. Briquetting machine	10,000
7. Motor for airgitator	3,200
8. Reducer gear	1,700
9. Blower for off-gas	12,000
10. Gas cooling unit	5,000
11. Oil filter	3,500
12. Gas purification unit	5,000
13. Regulator	5,000
14. Working capital	13,000
Total	194,600

Table 5.10 Operating Cost

Description	Fixed cost (baht/yr)	Variable cost (baht/day)	Remarks
1. Depreciation cost	28,017	-	see Table 5.11
2. Accumulative interest	34,055	-	17.5%, yearly
3. Maintenance cost			
3.1 Shelter	200	-	1%, yearly
3.2 Pyrolysis system	3,232		2%, yearly
4. Labor cost(2workers)	60,000		100 baht/day
5. Electricity (4.25 kWh)	-	74.38	1.75 baht/kWh
6. Binder	-	66.00	6 baht/kg
7. Air filter	-	18.00	
8. Lubricating oil	-	5.00	
9. Rice husk	-	-	
10. Miscelleneous	5,000		
Total	130,504	163.38	

Table 5.11 Determination of Depreciation Cost*

Nomenclature	Working life (year)	Salvage value 10%	Depreciation cost (baht)	Values at the end of five-year (baht)
1. Shelter	10	2,000	1,800	11,000
2. Pyrolysis system	5	-	20,000	-
3. Motor	10	580	522	3,190
4. Air blower	10	360	324	1,980
5. Pneumatic system	8	-	1,250	3,750
6. Briquetting machine	10	-	1,000	5,000
7. Reducer gear	8	170	191	743
8. Blower for off-gas	10	1,200	1,080	6,600
9. Gas cooling and purifying system	10	-	1,850	9,250
Total			28,017	41,513

*Straight line method

of the depreciation cost (which accounted for only 21.5% of the fixed cost).

Using data obtained from calculation, the break-even point equation can be derived and written as:

$$CN = 130,504 + 163.38\ N \ldots\ldots (2)$$

To be financially viable, the plant which normally operates for 300 days a year must have a daily income of at least 598.39 baht. From the equation (2) above, if the daily income of the plant is 795.86 baht, then its operating period or break-even point (N) must be at least 206 days/yr (or equivalent to 68.7% of the normal operating period). In the other case, if the income of the plant could be increased due to the rising demand for char briquets in replace of wooden charcoal as well as the capability in value-adding of the oil to be used as an industrial feed stock, the N value would be lower than the previously calculated one.

5.2.3 Financial Return of the Investment

In this analysis, the financial return of the investment was determined by using the method of Internal Rate of Return (IRR). To be financially feasible, the IRR value must be higher than the financial gain from the opportunity cost of capital. The determination of the IRR value was based on the following assumptions;

- Prevailing interest rate was 17.5% yearly;
- The plant operated for 10 hr a day, 300 days a year; and
- Selling price of char was 1.50 baht/kg; pyrolytic oil, 2.0 baht/lt and diesel oil, 6.90 baht/lt

Table 5.12 shows the determination of IRR value at a total daily income of 795.86 baht. 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 PT.

5.2.4 Sensitivity Analysis

Table 5.13 shows the variation of IRR values as well as the payback period when the price of char briquets were changed, while the prices of pyrolytic oil and diesel oil substituted were fixed at 2 baht/lt and 6.90 baht/lt respectively. It should be noted that at the char briquet's price between 0.75-1.75 baht/kg the IRR values would still be higher than the prevailing interest rate (17.5%) until the char briquet's price lower than 0.75 baht/kg. Thus, a pyrolysis conversion system would not be viable if the price of char briquets was lower than 0.75 baht/kg.

5.3 RESULTS FROM THE FIELD SURVEY

5.3.1 Energy Use in Surveyed Rice Mills

Table 5.14 shows a regional distribution of surveyed rice mills according to their energy use patterns. Of the total 158 rice mills surveyed, 116 mills (which accounted for 73.42%) used diesel engines, 18 mills (which accounted for 11.39%) used steam engines and 24 mills (or 15.19%) used electricity.

Of the 27 large-size rice mills selected for the survey, only 3 mills used diesel engines, 18 mills used rice husk and another 6 mills used electric motors, equivalent to 11.11%, 66.67% and 22.22%, respectively (see Table 5.15). For the 33 medium-sized rice mills, 26 mills used diesel engines and 7 mills used electric motors (equivalent to 78.79% and 21.21%,

Table 5.12 Determination of the Internal Rate of Return

Unit : baht

Year	Capital cost	Operating cost	Income	Net cash flow	PWF* 55%	Present worth	PWF* 60%	Present worth
0	-194,600		-194,600	-194,600	1.00	-194,600	1.00	-194,600
1		117,446	238,758	121,312	0.65	78,853	0.63	76,427
2		117,446	238,758	121,312	0.42	50,951	0.39	47,312
3		117,446	238,758	121,312	0.27	32,754	0.24	29,115
4		117,446	238,758	121,312	0.17	20,623	0.15	18,197
5	+41,513	117,446	280,271	162,825	0.11	17,911	0.10	16,283
						+6,492		-7,266

$$\text{IRR} = 55\% + (60 - 55)\left[\frac{6{,}492}{6{,}492 - (-7{,}266)}\right]$$

$$= 57.36\%$$

Payback period = 2.06 years at 17.5% interest rate

* Present worth factor

Table 5.13 Sensitivity of IRR Value vs. Char's Price

Char's price (baht/kg)	IRR value (%)	Payback period (yr)
0.50	5.86	-
0.75	19.75	4.75
1.00	32.98	3.47
1.25	45.69	2.59
1.50	57.36	2.06
1.75	68.78	1.72

Table 5.14 Regional Distribution of Surveyed Rice Mills According to Their Energy Use Patterns

Regions	Types of energy use		
	Diesel oil	Rice husk	Electricity
Northern	30	5	5
Northeastern	51	5	15
Central	16	7	2
Southern	19	1	2
Total	116 (73.42)	18 (11.39)	24 (15.19)

Figures in parenthesis are percent

Table 5.15 Energy Use Patterns of Surveyed Rice Mills

Sizes of rice mill	Types of energy use		
	Diesel oil	Rice husk	Electricity
Large	3 (11.11)	18 (66.67)	6 (22.22)
Medium	26 (76.79)	-	7 (21.21)
Small	87 (88.78)	-	11 (11.22)
Total	116	18	24

Figures in parenthesis are percent

respectively). Of the 98 small-sized rice mills, 87 mills (or 88.78%) used diesel engines and 11 mills (or 11.22%) used electric motors.

Based on the figures obtained from the survey, the number of rice mills using diesel engines was found to be 116 (or 73.42%). The diesel oil consumption per ton of paddy ranged from 7.82 to 10.79 litres. Using the average figure of 8.50 litres and assuming an efficiency of 25% for a diesel engine, the energy requirement was calculated at approximately 19,913 kcal/ton (calorific value of diesel oil is 9,371 kcal/lt).

5.3.2 Rice Husk Production in Surveyed Rice Mills

The survey of 158 sample rice mills revealed that the yield of rice husk ranged between 259.23 to 262.82 kg per ton of paddy. The yield of rice husk was found to be virtually independent of the milling capacity, with an overall average yield of 261.36 kg per ton of paddy (see Table 5.16). Considering the 17,368 million tons of rice output in the year 1980 and, using the average yield figure of rice husk of 261.36 kg per ton of paddy, then yearly rice husk production would be approximately 4.54 million tons.

Table 5.17 shows working months per year of the rice mills surveyed. The operational period of the rice mills varied from 4 to 8 months, depending on the supply of paddy and the amount of paddy stored for milling during the off-rice season. Large rice mills generally tended to operate longer than smaller rice mills. However, the reverse was found to be true in the Southern region.

It was determined that the daily working hour of the small mills depended on a number of requests for milling

Table 5.16 Production of One-Ton Rice Milling Rate in Surveyed Rice Mills

Sizes of rice mill	Products of one-ton paddy milling			
	Rice husk (kg)	Rice (kg)	Broken rice (kg)	Rice bran (kg)
Large	259.23	603.29	47.78	89.70
Medium	262.82	604.23	46.41	86.54
Small	262.04	605.48	43.73	88.75
Average	261.36 (26.14)	604.33 (60.43)	45.97 (4.60)	88.33 (8.83)

Figures in parenthesis are percent

Table 5.17 Working Months per Year of the Rice Mills Surveyed

Regions	Average working month		
	Large mill	Medium mill	Small mill
Northern	7.86	6.60	6.28
Northeastern	6.70	5.12	5.86
Central	8.10	4.30	5.60
Southern	4.00	6.33	7.47
Average	6.66	5.59	6.30

services, normally varying from 3-10 hr, while those of the medium and large mills (which regularly supplied themselve with their own paddy), varied from 10-24 hr (see Appendix 5). It should be noted that the operation for 24 hr/day was usually found only during the period between January and March, while the 10 hr/day operation was found in the remaining 5 months of the year.

5.4 SOCIAL EVALUATION

5.4.1 The Attitude of Rice Mill Owners toward Pyrolytic Gas

The gas produced by the pyrolysis system would be utilized in the rice mill to partially replace diesel oil for running the milling machine. In the event that the remaining gas could be utilized in drying paddy, the profit could be taken into account by doing an economic analysis including the oil replacement benefit and the income from selling char briquets and oil products.

In the preliminary study, owners of the sample rice mills were interviewed about their interest in the application of PT. PT was first explained in layman's terms. What could be expected from PT was also explained. The interview results show that the majority of rice mill owners using diesel engines expressed strong interest in PT (as high as 89.66% for the small mills and up to 100% for the medium and large mills), while owners of rice mills using electric motors and steam engines showed less interest (see Table 5.18).

In investigating the 27 sample rice mills for selection of demonstration sites, owners of the mills were interviewed about their interest in installation of demonstration units. Applications of PT, including profitability were explained. The

Table 5.18 Attitude of Rice Mill Owners towards Pyrolysis Technology

Unit : Percent

Sizes 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	-	-

interview results showed that of the 27 mills, 7 mills (or 25.9%) expressed strong interest and agreed to installation of demonstration units at their mills. Another 12 mills (or 44.4%) also expressed interest but with some uncertainty and another 8 mills (or 29.6%) had no comment (see Table 5.19). Of the 7 mills that agreed to installation, 2 were cooperatives and the other 5 were privately owned. It the uncertain group, 6 mills were cooperatives and the other 6 were privately owned. In this group, their uncertainties resulted from their lack of knowledge of PT. They wanted to consult with their relatives, corperations, board, or committee before allowing installation. However, it was anticipated that after PT was demonstrated at the selected rice mills, these owners would be approached again and would be favorably inclined to install PT at their mills.

After the plant demonstration was completed, the owners of mills from every part of the country showed much interest in the PT system. Many of them inquired by letters or came to TISTR to observe and to request more information.

The training and demonstration program in PT at TISTR revealed that approximately 200 rice mill owners from 40 provinces throughout the country attended to recieve training and observe the plant operation. Most of the participants expressed strong interest in PT and some of them requested information on installation and investment.

5.4.2 The Attitudes of Surrounding Communities Towards Rice Husk Char Briquet

The char briquet obtained from the rice husk pyrolysis system would have to compete with wooden charcoal. Since rice husk char briquet is slightly lower in heating value than wooden charcoal, it could only compete with wooden charcoal if its price were lower than that of wooden charcoal.

Table 5.19 Attitude of Rice Mill Owners towards Installation of Demonstration Units

Mill Sample No.	Administrative type		Interest & Agree	Interest with some Uncertainties	No Comment	No Interest
	Cooperatives	Private				
1		x	x			
2		x	x			
3	x			x		
4	x		x			
5	x				x	
6		x	x			
7	x			x		
8	x				x	
9	x				x	
10	x			x		
11	x				x	
12	x			x		
13	x			x		
14	x				x	
15	x		x			
16		x			x	
17		x			x	
18		x		x		
19		x	x			
20		x			x	
21	x			x		
22		x	x			
23		x		x		
24		x		x		
25		x		x		
26		x		x		
27		x		x		
Total	13 (48.15)	14 (51.85)	7 (25.93)	12 (44.44)	8 (29.63)	

In the preliminary study, 1541 randomly selected households in surrounding communities of the sample rice mills were surveyed to gain information on energy used for cooking and their interest in rice husk char briquet. It was found that wooden charcoal was the most commonly used for cooking fuel in all regions (70-87% of the households), followed by firewood (12-25%). Only a small percentage of the surveyed households used liquefied petroleum gas and electricity (see Table 5.20). On the average, each household used 51.6 kg of wooden charcoal and 90.9 kg of firewood per month at the average prices of 2.10 baht/kg and 1 baht/kg respectively (see Table 5.21).

Most of the people interviewed at first showed no interest in rice husk char briquet and expressed their disbelief in its applicability. However, after explaining that the fuel properties of rice husk char briquet were similar to wooden charcoal but cost less, most households were interested in rice husk char briquet.

Table 5.20 Types of Cooking Fuel Used in Surveyed Households

Unit : Percent of household

Regions	Types of Cooking fuel				
	Wooden charcoal	Firewood	Rice husk	L.P.G.	Electricity
Northern	71.20	24.69	0.41	2.47	1.23
Northeastern	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

Table 5.21 Average Energy Consumption per Household and Cost per Unit

Regions	Types of cooking fuel							
	Wooden 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
Northeastern	50.0	1.63	40.0	1.00	60.0	0.04	13.50	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	51.80	2.10	90.29	0.97	49.44	0.05	13.39	11.80

6

CONCLUSIONS

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CHAPTER 6

CONCLUSIONS

The following conclusions were drawn from the foregoing discussions;

The Preliminary Study

1. A systematic field survey of 158 sample rice mills throughout the country revealed that most of the rice mills were of small and medium sizes with daily milling capacities ranging between less than 5 tons/day to 20 tons/day of paddy. The daily and yearly operating time of the mills depended on the supply of paddy in each region, normally ranging between 3 to 24 hours and 160 to 240 days respectively, with the overall average of 12 hours and 200 days, respectively.

2. Study on the energy use patterns of the surveyed rice mills revealed that more than 73.4% of them used diesel engines while the remaining 11.4% and 15.2% used steam engines and electric motors respectively. The number of the diesel engined rice mills, over 92.8% were of small and medium sizes using engines with rating power of 30 hp or less.

3. It was also determined that the small and medium mills used diesel engines as high as 88.8% and 76.8% respectively, while the majority of large mills used steam engines, which accounted for 66.7%. Obviously, the oil consumption by rice milling industry was mostly shared by the small and medium mills.

4. The diesel oil consumption per ton of paddy for the milling processes was determined to range from 7.8 to 10.8

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litres. Using the average figure of 8.5 litres and assuming an efficiency of 25% for a diesel engine, the energy requirement was determined to be 19,913 kcal/ton.

5. Interviews of rice mill owners concerning their attitude towards PT revealed that most of the owners of the diesel engined rice mills showed very strong interest in PT while those of the steam and electric mills showed less interest.

6. Study on the marketability of char briquets revealed that more than 75% of the 1,541 surveyed households used wooden charcoal as their major cooking fuel with the average monthly consumption of 51.8 kg per household. This indicated a good market potential for the rice husk char briquets considering the forecasted trend in a shortage of wooden charcoal in the near future.

Technological Development

1. After modification in the pyrolysis system design and operating with the following field conditions--8 to 11% moisture content of the rice husk feed; varying the rate of input, 49.1-53.7 kg/hr; air-to-feed ratio, 0.68-0.73; and a char discharge rate of every 5 minutes for 2 seconds--the pilot plant was capable of converting one ton of rice husk per day into combustible char, gas and oil with the yields ranging between 35.5-39.8%, 41.8-50.9% and 13.5-18.4% of the feed respectively.

2. 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 the yields ranging between 43.7-47.0%, 40.0-45.6% and 3.7-6.7% of the feed respectively, and with a loss of approximately 11% in the process.

3. Due to the time constraint, there was still no available data from the demonstration plant operation at Pichit Province.

4. The energy input required for the demonstration plant operation, was determined 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 cents/kWh). The total energy output of the pyrolysis system was determined to be approximately 413 Mkcal/yr.

5. The gas produced 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 sustained maximum 35% of diesel oil reduction at the normal milling rate of 2 tons/hr.

6. The test on utilization of char briquets as a cooking fuel in comparison with wooden charcoal revealed that with the mass samples of one kg each, both had nearly the same temperature peaks and combustion periods ranging from 840-880°C and 1.5-2.0 hr respectively but the temperature of the char briquet samples decreased slightly faster than that of the wooden charcoal.

7. The test on utilization of tar oil as fuel of the open furnace revealed that the mixture of tar oil/furnace oil in the ratios of 20:80, 30:70 and 40:60 by volume could be easily combustible, except for the ratio of 50:50 by volume.

8. It was determined that the cost of the demonstration unit could be paid back within 2 years with a 61.8% annual internal rate of return, based on the following field conditions:

- Rice mill operating with diesel engine of 280 hp;
- Capacity : 40 tons/day;

- Working time : 10 hr/day and 300 day/yr;
- No. of workers : 2 persons;
- Capital cost of pyrolysis system : 194,600 baht;
- Working life of the system : 5 yr;
- Income : Char 124,020 baht/yr (1.50 baht/kg);
  Pyrolytic oil 11,280 baht/yr (2.00 baht/l.);
  Saving in oil 103,485 baht/yr (35% oil reduction).

9. After the plant demonstration and training program were completed, the rice mill owners from every part of the country showed much interest in the PT system. Many of them inquired by letter or came to TISTR to observe and to request more information.

The Promotion Plan

During the period of the promotion, NEA will play the role of administrative coordinator between the government agencies and private sectors concerned. NEA, in collaboration with TISTR, low-interest rate finance corporations, and regional rice-mill associations, will be an organizing committee for arranging seminars and workshops on PT. This will introduce the new technology to interested rice mills, as well as assess the potential demand for the applications, which will be very helpful in making financial arrangements for investment in PT.

For technical support, TISTR will be responsible for the transfer of the developed technology through equipment manufacturers by providing them with engineering designs and consultancy. Furthermore, TISTR will also provide engineering and cost data as well as arrange a training program in the operation and maintenance of the pyrolysis system to the rice mills where PT installation is requested.

7

RECOMMENDATION

CHAPTER 7

RECOMMENDATIONS

Since, at present, there are more than 40,000 rice mills operating throughout the country, and only two demonstration sites of rice husk pyrolysis, the current situation is inadequate to promote the technology; thus, the period for the demonstration should be extended until at least 3 demonstration units are installed in the Northeastern and the Southern regions of the country.

For the financial arrangement, NEA will approach low-interest rate financial sources proposing the investment project with the technical data back-up from TISTR. In case some rice mills could partly afford the investment themselves, NEA might subsidize them by providing the balance. The subsidy might be provided by requesting support from the government or international organization funds. By these means the investors would take part in the responsibility for the investment. In addition, tax incentives should be allowed to encourage more investment.

Since PT can process a wide variety of organic materials, it has an extensive application in other areas of energy sources, such as solid waste disposal, and the production of industrial feeds. Further investigation on other applications of pyrolytic products, i.e., char, gas and tar oil, is therefore strongly recommended.

In addition to its application among rice mills, PT might be also applicable in terms of process heat to other agro-industries, such as the coconut-milk production industry, and saw

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mills where the industrial wastes are adequate to be utilized as feeds for PT. In case the areas lack electric supply but considerable amount of wastes as feeds for PT are available, the application of PT for generating electricity should be further investigated, particularly the scale of economy.

Since the biomass gasification technology, at present, has been proved feasible only for using wooden charcoal as its feed, a costly process still, this processing cost could be reduced by the replacement of wooden charcoal with the rice husk char briquets produced from PT.

Eventually, the cost-reduction in the pyrolysis system operation should be further investigated, probably by using the energy recycling method.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Knight, J.A., (1979). "Progress in Biomass Conversion", Vol.1, edited by Kyosti, V, Sarkanen and David A. Tillman, Academic Press, Inc., New York.

2. Tatom, J.W. and others, (1977). "Pyrolytic Conversion of Agricultural and Industry Wastes to Alternate Energy Sources in Indonesia; A Feasiblity Study", a Report under AID/ASIA-C-1203 Project A-1914, Institute of Technology Bandung, Indonesia.

3. Tatom, J.W. and others, (1980). "Pyrolysis of Rice Husks in Indonesia", an Interim Report under USAID/GOI Project 497-0268, Institute of Technology Bandung, Indonesia.

4. Festin, T.F., (1981). "Pyrolysis of Wastes", a Report under BED/UNIDO Project, AW-016-78, College of Engineering, University of the Philippines, the Philippines.

5. CRUZ, I.E. and Tatom J.W., (1982). "Assessment to Energy Production from Biomass Waste Materials", Under UNIDO Project PHI/78/022/A/01/37, PNOC-Energy Research and Development Center, Quezon City, the Philippines.

6. Pitakarnnop, N. and others, (1979). "Industrial Solid Fuel from Lignite", Thailand Institute of Scientific and Technological Research, Research No. 19-12.

7. Anderson, L.L. and Tillman, D.A., (1977). "Fuels from Wastes", Academic Press, Inc., New York.

8. Agricultural Statistic Center, Ministry of Agriculture and Co-operatives, Thailand, (1974-1981). "Agricultural Statistics of Thailand" No. 108-110.

Previous Page Blank

9. Purakum, N. and others, (1976). "Report on the Study of Rice Milling Rates", National Statistical Office, Office of the Prime Minister, Thailand.

10. Thailand Institute of Scientific and Technological Research, Ministry of Science, Technology and Energy, Thailand. (1978). "Feasiblity Study on Production of Rice Husk Briquets", Research No. P 21-39, Energy Research Division.

11. National Energy Administration, Ministry of Science, Technology and Energy, Thailand, (1982). "Thailand Energy Situation", Energy Economics Section of the Regulatory Division.

APPENDICES

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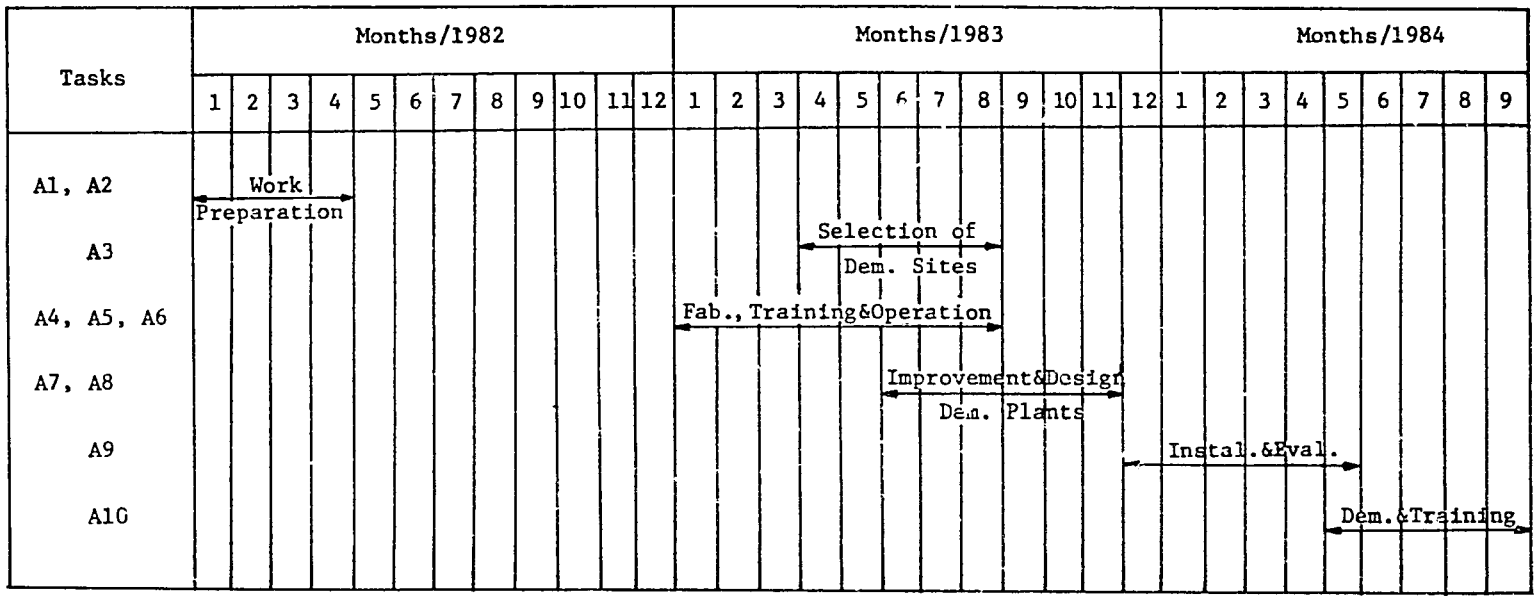
Appendix 1 Provincial Distribution of Number of Rice Mills in Each Region

Provinces	Number of rice mills						
	1974	1975	1976	1977	1978	1979	1980
Northern:							
Chiang Mai	636	691	723	752	760	785	808
Chiang Rai	665	886	1,201	1,364	1,524	1,673	1,698
Kamphaeng Phet	206	235	262	277	283	289	297
Lampang	404	477	515	529	656	794	1,116
Lamphun	100	100	101	101	120	132	156
Mae Hong Son	82	114	124	125	131	133	139
Nakhon Sawan	305	372	422	443	485	526	553
Nan	444	464	498	498	499	500	532
Payao	-	-	-	-	8	20	30
Phetchabun	243	258	278	289	300	328	420
Pichit	424	485	534	562	607	669	685
Phitsanulok	321	341	365	403	494	609	624
Phrae	492	502	521	533	549	552	564
Sukhothai	307	330	340	342	362	473	529
Tak	205	209	209	213	214	214	237
Uthai Thani	169	172	184	213	227	238	255
Uttaradit	625	670	711	725	744	762	777
Total	5,628	6,306	6,988	7,369	7,963	8,697	9,420
Northeasten:							
Buri Ram	1,172	1,279	1,378	1,455	1,582	1,755	1,709
Chaiyahpum	742	833	884	947	1,028	1,096	1,125
Kalasin	465	545	620	668	731	811	887
Khon Kean	631	738	886	968	1,073	1,164	1,996
Loei	338	361	396	420	454	482	525
Maha Sarakham	649	748	805	890	937	1,104	1,353
Nakhon Phanom	587	662	732	785	915	1,007	1,127
Nakhon Ratchasrima	1,179	1,328	1,480	1,626	1,732	1,831	1,966
Nong Khai	514	526	556	571	591	609	627
Roi Et	572	590	698	756	906	1,110	1,282
Sakon Nakhon	484	489	535	555	743	1,079	1,333
Si Sa Ket	730	817	896	1,110	1,379	1,563	1,581
Surin	724	793	842	911	1,012	1,264	1,412
Ubon Ratchathani	1,373	1,435	1,499	1,578	1,662	1,689	1,742
Udon Thani	569	682	816	961	1,092	1,201	1,317
Yasothon	237	272	340	369	388	427	462
Total	10,966	12,098	13,363	14,570	16,225	18,192	20,444

Appendix 1 (Continued)

Provinces	Number of rice mills						
	1974	1975	1976	1977	1978	1979	1980
Central:							
Ang Thong	50	72	83	87	99	104	109
Ayutthaya	94	135	153	209	227	240	257
Bangkok Metropolis	91	107	123	139	155	171	158
Chachoengsao	193	243	257	278	296	308	318
Chai Nat	205	235	278	309	321	326	334
Chanthaburi	128	135	162	173	224	232	236
Chon Buri	276	281	286	289	296	301	305
Kanchanaburi	127	145	160	172	177	190	201
Lop Buri	154	190	210	223	237	258	260
Nakhon Nayok	50	60	65	68	77	87	89
Nakhon Pathom	126	145	165	179	186	199	224
Nonthaburi	48	50	54	58	60	63	68
Pathum Thani	77	90	102	109	116	122	129
Phetchaburi	232	277	297	307	317	329	390
Prachin Buri	151	164	195	203	247	277	303
Prachuap Khiri Khan	34	45	51	54	55	57	57
Ratchaburi	166	191	223	252	262	275	284
Rayong	133	158	170	190	219	225	225
Samut Prakan	61	71	77	83	85	87	90
Samut Sakhon	34	39	42	43	45	45	47
Samut Songkhram	8	10	11	12	13	13	13
Sara Buri	138	156	173	185	198	201	208
Sing Buri	56	71	80	89	103	109	113
Supan Buri	201	233	261	290	315	333	347
Trat	127	164	182	194	205	210	210
Total	2,960	3,467	3,860	4,195	4,535	4,855	4,975
Southern:							
Chum Phon	98	105	112	113	132	144	152
Krabi	168	183	220	230	248	261	265
Nakhon Si Thammarat	1,128	1,170	1,210	1,219	1,283	1,340	1,363
Narathiwat	281	308	323	325	325	325	326
Pattani	234	243	243	247	247	247	248
Phangnga	95	114	132	140	145	148	155
Phatthalung	425	531	552	561	584	604	609
Phuket	9	12	12	14	14	14	14
Ranong	29	32	40	41	43	44	45
Satun	139	156	165	169	170	172	173
Songkhla	333	535	551	552	562	575	583
Surat Thani	410	410	421	424	427	429	432
Trang	103	109	122	124	125	125	125
Yala	77	89	110	117	138	140	141
Total	3,529	3,997	4,213	4,276	4,443	4,468	4,631

Appendix 2 Work Schedule



Fab. = Fabrication

Instal. = Installation

Dem. = Demonstration

Eval. = Evaluation

APPENDIX 3

SURVEY QUESTIONNAIRES

"Pyrolysis of Rice Husks" Component

Survey Areas

North	:	Phitsanulok, Pichit, Lampang, Chiangmai and Chiangrai
South	:	Nakhon Sri Thammarat, Songkhla, Phatthalung and Trang
Central	:	Ayutthaya, Ang Thong, Sing Buri, Sara Buri, Lop Buri, Supan Buri, Kanchanaburi, Chachoengsao and Prachin Buri
North-East	:	Chaiyaphum, Khon Kaan, Udon Thani, Si Sa Ket, Kalasin, Buri Ram, Loi Et and Ubon Ratchathani

Interviewer

Name .....

Date of interview .....

Comment

.....

.....

.....

GENERAL

1. Interviewed person

   Name ..... Age .....

2. Rice Mill

   Name .....
   Address .....
   Length of operation ..... year
   Capital cost ..... baht :
   Cost of engine ..... baht (Type :.....),
   Cost of milling machine ..... baht
   Monthly payment for ..... technicians; ..... baht/person
   and for ..... workers; ..... baht/person

RICE MILL'S OPERATION

3. Size of mill ..... Max. capacity ..... ton/day

4. Engine power ..... hp (Trade name .....)

5. Average daily rice milling ..... ton :

   Paddy supply from villager ..... %
   from buying ..... %
   and from others ..... %

6. Average daily milling capacity ..... ton
   (on a basis of 356 days a year)

7. Monthly interval for a large supply of paddy from ..... to .....
   approx. ..... ton per month and for a small supply from
   ..... to ..... approx. ..... ton per month.

8. Approx. rice milling rate per ton of paddy :

	rice	sticky rice
rice husk	..... kg	..... kg
bran	..... kg	..... kg
rice	..... kg	..... kg
broken rice	..... kg	..... kg
moisture content; of paddy	..... %	..... %
moisture content; of rice husk	..... %	..... %

ENERGY USE

9. Energy use for one-ton rice milling ..... lt of oil, valued at ..... baht

10. Recent type of fuel used .....
for present type, ...
Why change ?.....

VARIOUS EXPENDITURE OF RICE MILL

11. Milling cost :

Energy ..... baht/month
Wage ..... baht/month
Repair ..... baht/month
Maintenance ..... baht/month
Others ..... baht/month

12. Cost for repair and maintenance

Wage ..... baht/month
Cleaning ..... baht/month
Repair ..... baht/month
Others ..... baht/month

13. Do you expect to expand or improve yours mill ?
(Give some reasons).

.....
.....

14. If yes, what things do you expect to improve ?

.....
.....

RICE HUSK MANAGEMENT

15. How do you manage your rice husk product ?

☐ sold ☐ disposed by burning ☐ dumped nearby
☐ given free ☐ make other uses (specify) .....

16. If sold, to whom ? .....

where ? .....

at what price ? .....

17. If dumped, at what distance ? ..... km

In case of making contract, what the total cost per time ?
..... baht

In case of dumping by your own mill's worker, what the total cost per time ? ..... baht

18. If disposed by burning,

what the total cost per time ? ..... baht

19. If sold or given free, how the buyers or the free obtainer made use of it ? at what extent ? .....
.....
.....

ATTITUDE OF MILL'S OWNER

20. Have you expected to change your milling system to be operated by other types of energy ? Why ?

    ☐ Yes, ...

    ☐ No, ...

21. If other lower-cost energy is suggested, will you be interested in it ? Why ?

    ☐ Yes, ...

    ☐ No, ...

22. Explain what PT is in layman term and ask the mill's owners about their interest in PT application.

    ☐ Interest .....

    ☐ No interest .....

23. If your mill can be operated with electricity, will you still be interested in PT ?

    ☐ Yes, ...

    ☐ No, ...

24. If the goverment offers PT to replace your existing electric system used for the mill operation, will you be interested in it ? Why ?

    ☐ Interest .....

    ☐ No interest .....

QUESTIONNAIRES

FOR

RICE MILL OPERATING WITH DIESEL ENGINE

1. Capital ..... baht
   - diesel engine ..... baht
   - milling machine ..... baht
   - working area ..... baht

2. Max. capacity ..... ton/hr, or ..... ton/day
   - operating for ..... hr/day
   - normal capacity ..... ton/day
   - during investigation, ... ton/day
   - no. of working month in previous year..... month

3. Engine specification :
   - engine power ..... hp.
   - oil consumption ..... lt/hr, or ..... lt/ton of paddy
   - at the price ..... baht/lt
   - lubricating oil consumption ..... lt/ton
   - at the price ..... baht/lt
   - repair and maintenance cost ..... baht/yr

QUESTIONNAIRES

FOR

RICE MILL OPERATING WITH STEAM ENGINE

1. Have your mill been operated with steam engine since its inception ?

   ☐ Yes.
   ☐ No.

2. If yes, how long ? ..... year

   If no, it has been changed from operating with diesel engine since .....

3. Capital cost for steam mill ..... baht

   boiler ..... baht
   turbine ..... baht
   milling machine ..... baht
   working area ..... m^2

4. Max.capacity ..... ton/day (or ..... hr/day)

   Normal capacity ..... ton/day
   During investigation ..... ton/day
   Number of working months in previous year ..... months

5. Boiler specification :

   operating pressure ..... kg/cm^2
   water input ..... kg/hr (or ..... kg/day)
   supply of rice husk as fuel.. ton/hr (or ..... ton/day)
   capacity of boiler ..... ton
   perchased from .....

6. Repair and maintenance cost ..... baht/yr

7. Wage/Salary :

No. of administrative committee ..... persons,

each ..... baht/month

No. of technician ..... persons,

each ..... baht/month

No. of worker ..... persons,

each ..... baht/month

QUESTIONNAIRES

FOR

HOUSEHOLD SURVEY

1. House no. ..... Tumbon ..... Amphur .....

   Province ..... no. of residents ..... persons

   Occupation .....

2. Energy used for cooking

Type of Fuel	Monthly consumption	Sources	Price	Total baht/month	Remarks
Gas					
Fuel wood					
Rice husk					
LPG					
Others					

3. Would you like to change to other type of fuel ?

   ☐ No.

   ☐ Yes, What type ? .....

4. If any lower-cost fuels are proposed to sell, will you be interested in it ? Why ?

   ☐ Yes, ...

   ☐ No, ...

5. Energy used for lighting

- ☐ Electricity, monthly expense ..... baht
- ☐ Kerosene, monthly expense ..... baht
- ☐ Others (specify) ....., monthly expense .... baht

6. Have you ever used wood preservative materials ?

- ☐ No.
- ☐ Yes.

7. If yes, what kind of the materials ?

- ☐ Liquefied
- ☐ Powder

Appendix 4 Regional and Provincial Distribution of Surveyed Rice Mills and Surrounding Communities

Region	Province	Number of rice mills	Total	Percent	Number of households	Total	Percent
Northern	Pichit	5	40	25.32	64	379	24.60
	Phitsanulok	4			40		
	Chiang Rai	6			57		
	Chiang Mai	2			15		
	Lampang	9			82		
	Phetchabun	14			121		
Northeastern	Roi Et	1	71	44.94	9	716	46.46
	Nakhon Phanom	2			38		
	Si Sa Ket	2			36		
	Udon Thani	1			13		
	Ubon Ratchathani	5			64		
	Khon Kaen	8			78		
	Buri Ram	16			155		
	Kalasin	16			152		
	Chaiyaphum	20			171		
Central	Suphan Buri	7	25	15.82	61	233	15.12
	Kanchanaburi	1			8		
	Ang Thong	2			18		
	Sing Buri	5			43		
	Chachoengsao	5			40		
	Ayutthaya	–			23		
	Prachin Buri	2			19		
	Lop Buri	3			21		
Southern	Nakhon Sri Thammarat	6	22	13.92	51	213	13.82
	Trang	2			10		
	Phatthalung	6			75		
	Songkhla	8			77		

Appendix 5 Existing Conditions of Sample Rice Mills for Demonstration Site Selection

Rice mill sample No.	Power rating (hp)	Capacity		Actual operation		Oil consumption		Rice mill production (ton/day)
		(ton/day)	(ton/hr)	(hr/day)	(ton/day)	(lt/ton)	(lt/day)	
1	12	2.0	0.1	3.0	0.2	9.0	2.2	0.1
2	15	8.0	0.3	9.0	3.0	8.6	24.1	0.7
3	15	3.0	0.1	8.0	0.9	8.7	8.4	0.2
4	16	1.0	0.3	6.0	1.7	9.9	17.3	0.4
5	16	4.0	0.2	6.0	0.9	9.6	9.2	0.2
6	16	3.0	0.1	10.0	1.2	9.8	11.8	0.3
7	18	8.0	0.3	24.0	7.3	9.0	71.4	2.0
8	18	4.0	0.2	8.0	1.3	9.8	12.6	0.3
9*	20	5.0	0.2	12.0	2.4	-	-	0.6
10	20	4.0	0.2	6.0	0.9	8.5	8.2	0.2
11	22	4.0	0.2	4.0	0.6	9.1	5.8	0.2
12	24	-	-	-	-	-	-	-
13	30	20.0	0.8	10.0	8.3	8.5	70.5	2.1
14*	30	20.0	0.8	9.0	7.5	-	-	1.9
Average	12 - 30	7.1	0.3	8.8	2.8	9.1	22.0	0.7

Appendix 5 (continued)

Rice mill sample No.	Power rating (hp)	Capacity		Actual operation		Oil consumption		Rice mill production (ton/day)
		(ton/day)	(ton/hr)	(hr/day)	(ton/day)	(lt/ton)	(lt/day)	
15	56	24.0	1.0	24.0	24.0	10.7	256.1	6.0
16	60	36.0	1.5	6.0	9.0	10.2	91.4	2.2
17	60	20.0	0.8	9.0	5.0	9.6	48.0	1.2
18	65	36.0	1.5	6.0	9.0	7.3	66.1	2.2
19	65	24.0	1.0	9.0	9.0	8.6	77.0	2.2
20*	70	60.0	2.5	12.0	30.0	-	-	7.5
21*	75	20.0	0.8	8.0	7.5	-	-	1.9
22	75	17.0	0.7	6.0	4.2	7.7	32.2	1.0
23	75	16.0	0.7	12.0	7.9	7.7	60.7	2.0
Average	56 - 75	28.1	1.2	10.2	11.7	8.8	90.2	2.9
24	120	24.0	1.0	9.0	9.0	9.3	83.5	2.2
25	120	37.5	1.6	24.0	37.4	9.0	337.0	9.4
26	134	60.0	2.5	24.0	60.0	8.8	525.0	15.0
27	280	48.0	2.0	12.0	24.0	7.5	360.0	6.0
Average	120 - 280	42.4	1.8	17.2	32.6	8.6	410.5	8.1

* Operating with electric motor