THE USE OF SLUDGE FROM A MODIFIED STARCH FACTORY MIXED WITH CHARCOAL RESIDUE FOR BRIQUETTED FUEL

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Thesis

Entitled

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THE USE OF SLUDGE FROM A MODIFIED STARCH FACTORY MIXED WITH CHARCOAL RESIDUE FOR BRIQUETTED FUEL

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ABSTRACT

This study was the usage of sludge from a modified starch factory mixed with charcoal residue for briquetted fuel in 5 ratios (sludge : charcoal residue by volume) namely 5:5, 4:6, 3:7, 2:8 and 1:9 in order to find the appropriate ratios in the briquetted fuel production process. Then they were analyzed by physical properties, fuel properties to find the optimum ratio and brought such ratio to assess the possible production cost.

From the result of the experiment, it was found that the appropriate ratios of sludge from a modified starch factory mixed with charcoal residue would be 5:5, 4:6 and 3:7 that could be pressed in to briquettes due to the binding properties of sludge. Then these ratios were analyzed for physical properties (compressive strength in vertical line and horizontal line, shatter index) to present the ability of the briquetted fuel for its toleration in transportation; as well as fuel properties (moisture content, ash content, fixed carbon, volatile matter, total sulfur, heating value), to assess the quality of briquetted fuel product as well as to find the optimum ratio (by considering specifically the moisture content, ash content, heating value and total sulfur by comparing with other kinds of solid fuel and standard of community product). It was found that the moisture content was 8.62 %, 7.44 % and 7.13 % respectively. Having more value than the general firewood (4.30 %), general charcoal (4.65 %). As for the ratio of 5:5, having the moisture content beyond standard of community product (<8.0%); while the amount of ash content was 16.88 %, 13.57 % and 10.70 % respectively, having more value than general firewood (1.40 %) and general charcoal (10.20 %); the heating value was 5,006 cal/g, 5,482 cal/g and 5,885 cal/g respectively; having more value than general firewood (4,436 cal/g) but less than general charcoal (6,552 cal/g) and the total sulfur was 0.48 %, 0.41 % and 0.33 % respectively.

From this study, it was found that the optimum ratio was 3:7 (having the highest heating value and the least moisture content, ash content and total sulfur). From then these ratio were taken for economic analysis, and was found to be at the wholeprice of 0.50 baht/briquette; the amount of production (break even point) was at 1,811,414 briquettes/year, and the payback period was at 0.89 year.

KEY WORDS: BRIQUETTED FUEL/BINDER/CHARCOAL RESIDUE/
COMPRESSIBILITY/HEATING VALUE/MOISTURE CONTENT/
SHATTER INDEX

99 P.

การใช้ประโยชน์กากตะกอนจากโรงงานแป้งมันดัดแปรผสมกับเศษถ่านผลิตเป็นเชื้อเพลิงอัดแท่ง

(THE USE OF SLUDGE FROM A MODIFIED STARCH FACTORY MIXED WITH CHARCOAL RESIDUE FOR BRIQUETTED FUEL)

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บทคัดย่อ

การวิจัยนี้เป็นการใช้ประโยชน์กากตะกอนจากโรงงานแป้งมันดัดแปรผสมกับเศษถ่านผลิตเป็นเชื้อเพลิงอัดแท่งโดยศึกษา 5 อัตราส่วน (กากตะกอน : เศษถ่าน โดยปริมาตร) คือ 5:5, 4:6, 3:7, 2:8 และ 1:9 เพื่อหาอัตราส่วนที่เหมาะสมจากกระบวนการผลิตเชื้อเพลิงอัดแท่ง จากนั้นนำเชื้อเพลิงในอัตราส่วนที่เหมาะสมไปวิเคราะห์คุณสมบัติด้านกายภาพและ คุณสมบัติด้านเชื้อเพลิง เพื่อหาอัตราส่วนที่ดีที่สุดแล้วนำอัตราส่วนดังกล่าวไปประเมินความเป็นไปได้ของต้นทุนการผลิต

จากผลการทดลองพบว่าอัตราส่วนที่เหมาะสมของกากตะกอนจากโรงงานแป้งมันดัดแปรผสมกับเศษถ่าน คือ 5:5, 4:6 และ3:7 สามารถนำไปขึ้นรูปเป็นแท่งถ่านได้นั้นเนื่องจากกากตะกอนมีคุณสมบัติเป็นตัวประสาน จากนั้นนำอัตราส่วนนี้ไปวิเคราะห์คุณสมบัติด้านกายภาพ (ความทนทานต่อแรงอัดในแนวตั้งและแนวนอน ดัชนีการแตกร่วน) ซึ่งแสดงให้เห็นถึงความทนทานต่อการแตกหักในระหว่างการขนส่งของเชื้อเพลิงอัดแท่งที่ได้และคุณสมบัติด้านเชื้อเพลิง (ความชื้น ปริมาณเถ้า คาร์บอนคงตัว สารระเหย ค่ากำมะถันทั้งหมด และค่าความร้อน) เพื่อประเมินคุณภาพของถ่านอัดแท่งและหาอัตราส่วนที่ดีที่สุด(โดยพิจารณาเฉพาะคุณสมบัติความชื้น ปริมาณเถ้า ค่าความร้อนและปริมาณกำมะถันทั้งหมดโดยเทียบกับเชื้อเพลิงแข็งชนิดอื่นและมาตรฐานผลิตภัณฑ์ชุมชน)พบว่าค่าความชื้นเท่ากับ 8.62 %, 7.44 % และ 7.13 % ตามลำดับ มีค่ามากกว่าฟืนไม้ (4.30 %) ถ่านไม้ (4.65 %) สำหรับอัตราส่วน 5:5 มีค่าความชื้นเกินกว่ามาตรฐานผลิตภัณฑ์ชุมชน (< 8.0 %) ปริมาณเถ้าเท่ากับ 16.88 % ,13.57 % และ10.70 % ตามลำดับ มีค่ามากกว่าฟืนไม้(1.40 %) และ ถ่านไม้ (10.20 %) ค่าความร้อน เท่ากับ 5,006 cal/g 5,482 cal/g และ 5,885 cal/g ตามลำดับ และมีค่ามากกว่าฟืนไม้ (4,436 cal/g) แต่น้อยกว่าถ่านไม้ (6,552 cal/g) และค่ากำมะถันทั้งหมด เท่ากับ 0.48 % 0.41 % และ 0.33% ตามลำดับ

จากการศึกษานี้พบว่าอัตราส่วนที่ดีที่สุดคือ 3:7 (มีค่าความร้อนสูงที่สุดและมีค่าความชื้น ปริมาณเถ้า และค่ากำมะถันทั้งหมดต่ำที่สุด) จากนั้นนำอัตราส่วนดังกล่าวนี้มาวิเคราะห์ด้านเศรษฐศาสตร์พบว่าที่ราคาขายส่งแท่งละ 0.50 บาทต่อแท่ง ปริมาณการผลิตอยู่ที่ 1,811,414 แท่งต่อปี และระยะเวลาคืนทุนอยู่ที่ 0.89 ปี

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CHAPTER I
INTRODUCTION

1.1 Statement of the Problem

The consumption of energy in Thailand has been extremely increased. In 2004 the total energy demand of Thailand amounted to 61,262 kilo ton of oil equivalent, rising up 8.8 % from the previous year.[1] Therefore, energy conservation has been the policy of the country and renewable energy has been considered.[2] Fortunately, Thailand has the potential energy from biomass especially that from waste materials such as agro-residues, animal dung, solid waste and wastewater. The potential energy could be amounted to 650.11 penta joule equivalent to diesel oil 17,850 litre.[3] So there are many researches to bring this waste potential for renewable energy.

Sludge from wastewater treatment plant has been increased, and in the future the disposal of treatment plant sludge likely to become a major factor in waste management plan.[4] There are many methods to convert sludge into energetic resource. Briquetting has been an available technology for upgrading waste materials particularly in developing countries.[5] Research on utilizing waste materials as an energetic resource has been done. It was found that sludge from wastewater treatment plant mixed with agro-residues provides briquette fuel properties. Moreover sludge has a good binder characteristics.[6,7,8,9,10,11]

Since sludge from modified starch wastewater treatment plant has been generated in large amount causing significant impacts on the environment. The application of sludge from modified starch wastewater treatment plant as briquette fuel should be considered.[12] In addition charcoal residue from transfer and transport of charcoal are another form of fuel waste. Generation of charcoal residue as mentioned above may amount to about 10 % by weight in the most favourable case and 20 % or more in the worst one. The more charcoal is transferred and transported the more fine residues are produced. However, these fine residues remain energy potential. Charcoal residue can not be burned by usual simple charcoal burning methods; it is unsaleable. Hence, charcoal residue should be applied as briquette for a better resolution. [13]

Therefore, this research study aims to apply sludge from modified starch wastewater treatment plant mixed with charcoal residue to produce briquetted fuel. Furthermore, fuel properties and economic evaluation are also studied.

1.2 Objectives of Study

1.2.1 General Objective

To apply sludge from a modified starch factory mixed with charcoal residue to produce briquetted fuel.

1.2.2 Specific Objectives

1. To assess the physical and fuel properties of sludge from a modified starch factory.
2. To compare the physical properties of different mixing ratio of sludge and charcoal residue to produce briquetted fuel.
3. To compare the fuel properties of different mixing ratio of sludge from a modified starch factory and charcoal residue to produce briquette fuel.
4. To determine the optimum mixing ratio of sludge from a modified starch factory and charcoal residue to produce briquetted fuel.
5. To investigate the economic value of briquetted fuel from the optimal mixing ratio of sludge from a modified starch factory and charcoal residue.

1.3 Hypothesis of Study

1.3.1 The moisture of briquetted fuel will be decreased when mixing ratio of sludge decreases whereas charcoal residue increases.

1.3.2 The ash of briquetted fuel will be decreased when mixing ratio of sludge decreases whereas charcoal residue increases.

1.3.3 The heating value of briquetted fuel will be decreased when mixing ratio of sludge increases whereas charcoal residue decreases.

1.4 Variables of Study

1.4.1 Independent Variables :

Mixing ratio of sludge from a modified starch factory and charcoal residue.

1.4.2 Dependent Variables :

- Compressibility forming
- Physical properties: Density, Shatter Index, Compressive strength,
- Fuel properties: Heating value, Moisture, Volatile matter, Ash, Fixed Carbon and Total Sulfur
- Combustion: Period of Burning

1.5 Scope of study

1.5.1 This study used sludge from Activated Sludge System of Siam Modified Starch Factory, located at Ladlumkhaw District, Pathum Thani Province.

1.5.2 This experiment used fresh sludge from belt press machine.

1.5.3 This study used charcoal residue from mixed deciduous wood and crushed to become fine charcoal residue.

1.5.4 Compaction process used cold and low pressure densification method with conical has been used.

1.6 Definition of Keywords

Briquetted fuel: Densification of loose organic material, such as mixing between sludge from wastewater treatment plant of a modified starch factory with charcoal residue to improve fuel characteristics including handling and combustion properties.

Binder: Sludge from wastewater treatment plant used for binding charcoal particulate together.

Charcoal residue: Piece of charcoal from the black substance made by burning mixed deciduous wood slowly in an oven with little air, used as fuel.

Compressibility: Ability of densification to rod shape by screw press with diameter of 5 cm and length of 50 cm.

Heating Value: The energy released on combustion of sludge from a modified starch factory mixed with charcoal residue.

Shatter Index: Testing used to indicate the tolerance of briquette in transportation and storage.

Moisture Content: The quantity of water in the material, expressed as a percentage of the material's weight and the most critical factor governing the amount of useful heat from sludge from a modified starch factory mixed with charcoal residue combustion.

1.7 Conceptual Framework

1.7.1 Part 1: Study of Mixing Ratio

Characteristics of raw materials:
1. Physical properties
2. Fuel properties

↓

Ratio between sludge and charcoal residue by volume

↓

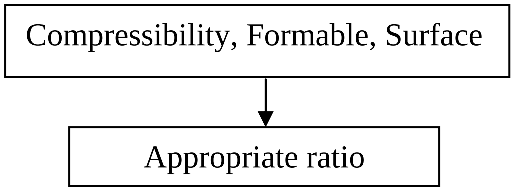


Figure 1.1 Conceptual framework part 1

1.7.2 Part 2: Study of Briquetted Fuel

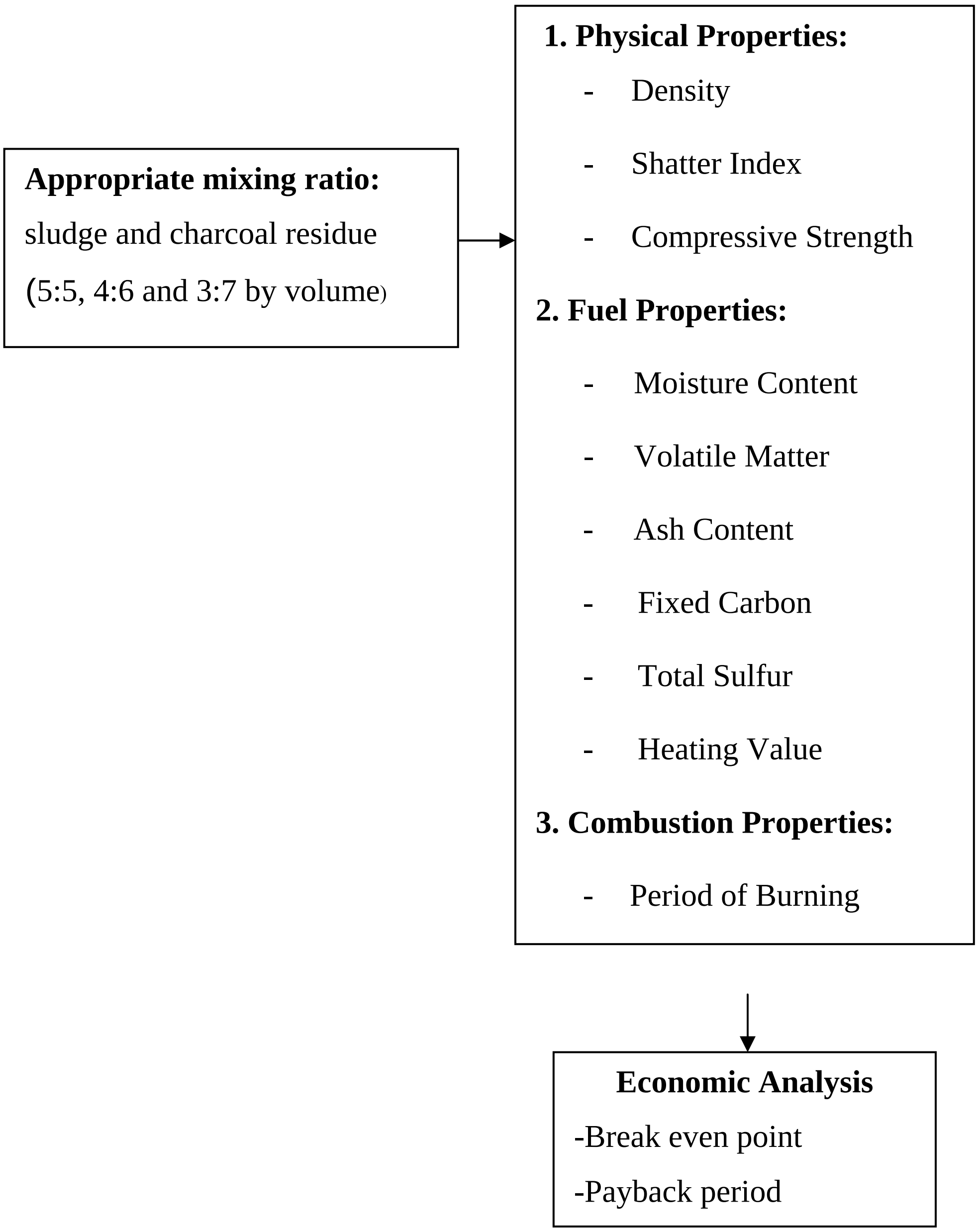


Figure 1.2 Conceptual framework parts 2

CHAPTER II
LITERATURE REVIEW

2.1 Introduction of Modified Starch

Cassava has many names across many continents. The English word is **cassava**, but in South American in the are around Brazil it is called **madioca**. In Africa where French is spoken it is called **manioc**. In Spanish-speaking countries it is called **yucca**. Here in Asia we call it **tapioca**. The origins of cassava are many, but the principle origin is in the hot areas of the American continents, especially in South America. Countries such as Guatemala, Mexico,Peru, and Honduras planted cassava for three to five thousand years before the plant was distributed across the Americas and elsewhere. In the 15^{th} century,slave traders and the Portuguese brought cassava to the African continent . [14]

At present, there are 78 tapioca starch factories in Thailand. 59 factories produce native tapioca starch, 7 factories modify tapioca starch and 12 factories produce derivatives like glucose, sorbitol and fructose. The factories may have significant impact on the environment, especially by the organically high loaded liquid effluent. Due to the great economical importance, to the subsequent impact on the environment and according to the present Thai law it had been concluded to implement special minimum environmental requirements for tapioca starch industry.

2.1.1 Modified Starch Standard Production Process, Sources of Wastes and Mass Balance

According to Thai Industrial Standard Institute, the meaning of modified tapioca starch for food industry is the converting native starch of tapioca converting could be chemically, and/or physically by heat and/ or by enzymes. Applications of these products are found i.e. in textile, paper industry. Modified starch is a white or light brow powder. In Thailand, most modified starch factories use chemical modification. Starch with specified characteristic requires a specified chemical reaction. The modified starch are ;

1. Thin boiling starch is the product from the reaction between starch and hydrochloric acid or diluted sulfuric acid.

2. Oxidized starch is the product from the reaction between starch and sodium hypochlorite.

3. Dextrin is the product from thermal application to starch.

4. Substituted starch is the product from adding substances to replace hydroxyl group in starch. The modified starch are;

5. Ether starch: is the product from etherification reaction between starch and ether group which are hydroxy - propyl starch, carboxytryl starch and cationic starch.

6. Starch ester: is product from the reaction between starch and any chemical with ester group

7. Distarch: is the product from the reaction between starch and substances which have more than one functional groups.

In principle, each modified starch processing is not much different. The normal steps of modified starch production are slurry make up, starch refining (modification), cleansing and washing, drying/cooling and packaging. Details of oxidized starch production process are the following steps.

2.1.1.1 Slurry Make Up

It has to be differentiated between two types of factories:

- Type 1: self supplying (with own root processing, leading to a larger amount of wastewater and residues)

- Type 2: native starch processing (using drying starch produced by other native starch factories) The type 2 factory has to reinsert the dry starch into water for further processing which happens in a mixed tank (40-50 m^3). The starch has to be diluted down to 17 % w/w which relates to a water demand of 5-6 m^3/ton input. For oxidized starch production, Slurry make up step consumes: fresh water around 5.0 m^3/ton tapioca starch Na_2CO_3 results to no solid and liquid wastes.

2.1.1.2 Starch Refining (Modification)

The modification of starch takes place in a batch reactor. The reaction conditions are monitored, and there are:

- concentration of modification agent
- Temperature, pH
- Reaction time

After reaction the modified starch slurry is in some cases neutralized and released to an intermediate tank for further treatment. For oxidized starch production, the solution is adjusted pH to 5 by adding hydrochloric acid (HCl) and react with sodium hypochlorite (NaOCl). Adjust pH to 3 by adding hydrochloric acid and add sodium hydrogen sulphite ($NaHSO_3$). The mixture is allowed for reaction to be the modified starch and store it in a storage tank. Though this process step results to no solid and liquid wastes.

2.1.1.3 Cleaning and Washing

The Slurry is cleaned in a separate mixed tank where fresh water (2-4 m^3/t input) is inserted. To separate the starch from the water a centrifugal separator is used. To increase the cleanness of the product further washing water is inserted here (2-4 m^3/t input). The heavy phase (starch slurry) is screened and released to the drying unit. Though this process step consumes: fresh water around 4 m^3/ton tapioca starch results to waste (process) water from centrifugal separator around 6.0 m^3/ton tapioca starch.

2.1.1.4 Dewatering and Drying

The starch slurry is inserted into a peeler centrifuge and dewatered. Finally it reaches the flash dryer/cooling. The drying step results to waste (process) water: around 2.85 m^3/ton of tapioca starch.

2.1.1.5 Summary of Mass Balance

Total time of the production is around 3 hours. Diagram showing production process and mass balance (only part which related to wastewater generation) is shown in Figure 2.1. Data of mass balance shows that wastewater is only generated from cleaning and washing step of 6 m^3/ton of tapioca starch and from dewatering step of 2.85 m^3/ton of tapioca starch. This step is also of lost starch of 50 kg/ton of tapioca starch.

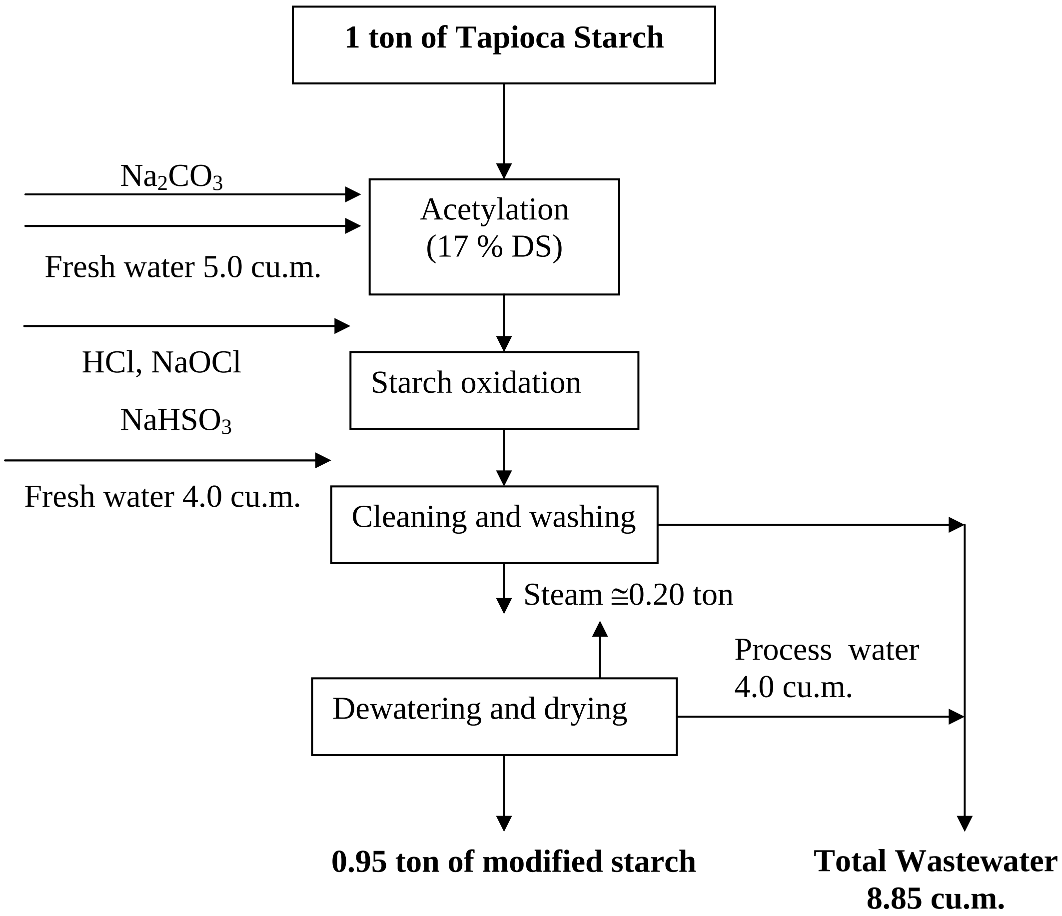


Figure 2.1 Modification of starch by acetylation and oxidation. [12]

2.1.2 Characteristics of the Residues from Modified Starch Production

An example of characteristic of liquid residues from cleaning/washing and dewatering/drying step of starch oxidation is the followings : Quantity 8.85 m^3/ton of starch, pH 4.76, COD 2.80 gm./L, BOD 1.35 gm./L SS 1.20 gm./L and Ratio of COD:BOD 2.07. Wastewater contains high organic matters which is easy to be degraded. High content of solids is because there are starches and products of chemical reaction of separated chemical in purification step. However it depends on house keeping and cleaning method of each factory. As the factory usually produce many types of modified starch, it is necessary to clean the reactor before the production process is changed. This amount of wastewater is low in volume but is heavily polluted in form of COD, BOD and SS. Characteristics of reactor wash water are: Quantity 5.0 m^3 per cleaning batch, pH 6.96, COD 32.80 gm/L, BOD 19.30 gm/L, SS 14.60 gm/L and Ratio of COD:BOD1.70. [12]

2.1.3 Siam Modified Starch Co., Ltd.

Siam Modified Starch Co., Ltd. is located at 38/6 Moo 11, Pathumthani-Ladlumkaew Rd, Ladlumkaew, Pathumthani, 170 workers and production rate 250 ton/day.Siam Modified Starch Co., Ltd. Creates international-modified tapioca (cassava) starch products utilizing indigenously produced agricultural raw materials which in Chemical Modification group one of Asia-Pacific’s major producers and exporters of tapioca starches derivatives, Siam Modified Starch also adds value to living standards of many Thai farmers and their families, whose lives are directly supported by the company’s activities. Produces modified tapioca starch for supply to customers in Thailand as well as for export to destinations including the USA, Asia, Europe, Australia and New Zealand. Currently the company exports the majority of its total output. A range of products produced by the modification of native tapioca starch-find a broad spectrum of applications in various industries. The company’s products sold under the “Siam Modified Starch” brand are used primarily in the foods, paper, textile, adhesive and special sectors such as surgical glove. [19]

Quantity of wastewater 800 m^3/day. Characteristic of the waste from modified starch production Quantity 8.85 m^3/ton COD 5,000 mg/L. This factory use Activated Sludge wastewater treatment plant and quantity of sludge 4 ton/day (%Moisture >50 %).In order to the sludge wastewater management use to be compost. To shown in Figure 2.2:

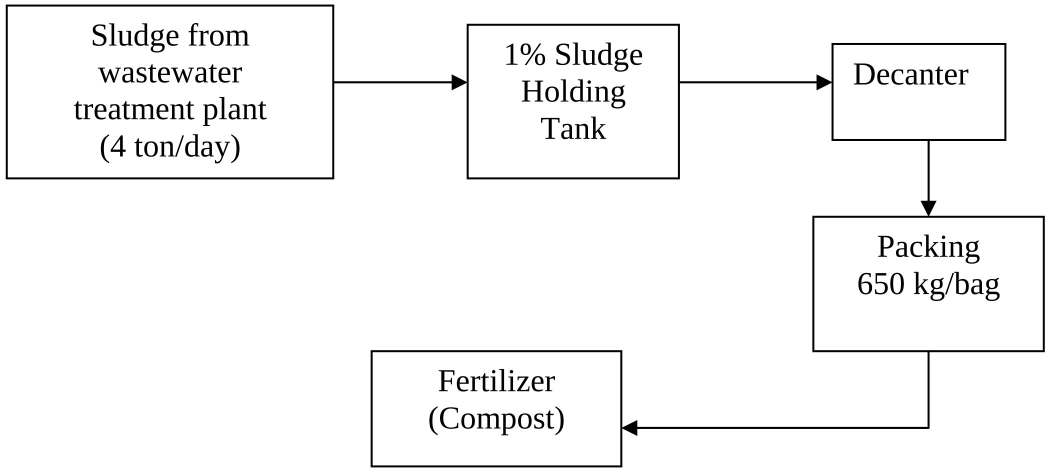


Figure 2.2 Sludge wastewater management of Siam Modified Starch Co., Ltd.

2.2 Energy from Sludge

Energy can be produced from the direct burning of sludge or from the combustion of sludge – derived fuels such as digester gas or pyrolysis gas [15] that in Figure 2.3 to shown processes release energy from sludge.

Lertskullbanlue A., [16] uses activated sludge as four samples are taken from wastewater treatment of textile plant, center plant, Huaykwang district and National of Petrochemical plant to study the pyrolysis kinetic of activated sludge is investigated with a thermogravimetric analyzer (TGA). They have volatile matter in the range of 31-60% and heating value in the range of 1600-5600 cal/g that can be converted to new source of energy.Consideration must be made when designing processes to recover energy from wastewater sludge.

In order to, both thermally dried and mechanically dewatered sewage sludge are burnt together with hard coal in a power plant. The officially approved amount of municipal sewage sludge amounts to ≤ 40,000 tons dry matters/year and a maximum mass flow of 4 % of the amount of coal. The dried sewage sludge is conveyed pneumatically. The mechanical dewatered sewage sludge is ground and dried together with the coal in the coal mills. The co-combustion of sewage sludge did not cause any substantial change of gaseous releases. The byproduct fly ash and gypsum are completely utilized. [17]

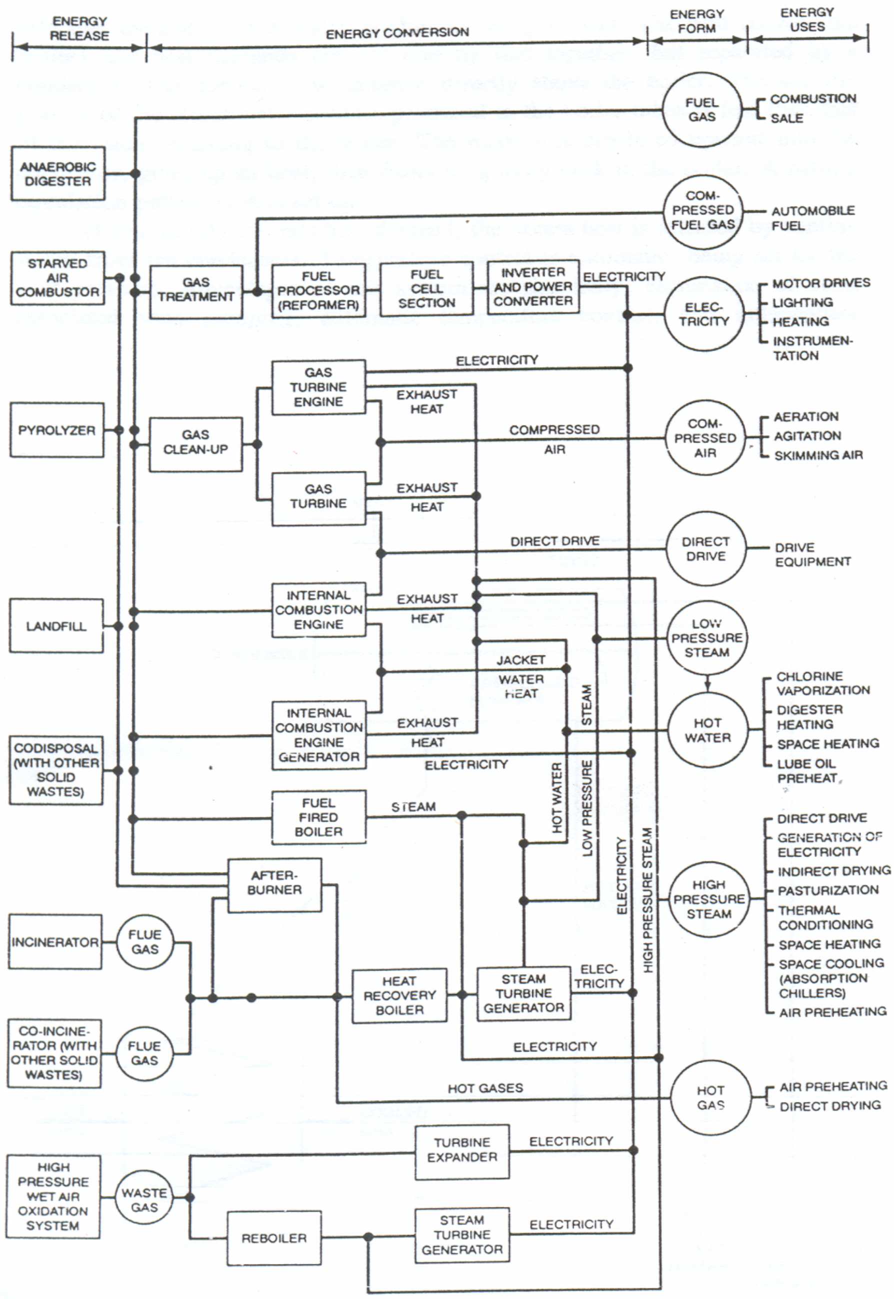


Figure 2.3 The convert energy methods of sludge

Jittoo P. *et al*, [18] studied about the performance of burning the sewage sludge in a fluidized bed incinerator. Two types of sewage sludge were selected :1.Untreated wet sewage sludge received from the community wastewater treatment system (Sipraya waste water treatment plant) and heating value was found to be 3,527 kJ/kg, 2. Pretreated sewage sludge in which its moisture content is reduced to 4% and palletized and heating value was found to be 11,352 kJ/kg.

2.3 Charcoal

Charcoal is the solid carbon residue of wood after other chemicals in the wood have been burned out or evaporated. The wood is heated slowly and evenly to about 100°C, where only the carbon remains, than it is cooled without air for later use as fuel. [20] Charcoal is used primarily as a fuel for outdoor cooking. In some instanes, its manufacture may be considered as a solid waste disposal technique. Many raw materials for charcoal manufacture are wastes, as noted. Charcoal manufacture is also used in forest management for disposal of refuse. [21]

2.3.1 Charcoal Production

As the wood is heated, the following processes take place: [20]

(a) From 60 °C - 170 °C	Water is evaporated;
(b) From 170°C - 270 °C	Most gases (CO_2 and CO some Alc. and tars are vaporised.
(c) From 270°C - 350°C	Most acetic acid, Methanol and tars are vaporised and burned;
(d) From 350 °C - 400°C	The wood is reduced to only carbon and a few tars; and
(c) Above 400 °C	all tar evaporate or burn.

During this process, the products are typically as follow;-

- Carcoal	36 %
- Water	24 %
- Wood Gas (CO, CO2, CH_4)	20 %
- Wood Spirit (CH_3COOH acid) CH_3OH and Acetone	2 %
- Wood Tar (Oils and Pitch)	12 %
	100 %

2.3.2 Uses of Charcoal [21]

2.3.2.1 For Domestic Purposes

In many countries it provides the necessary heat for proparation of meals as well as for hot water. In some countries, charcoal is used in stoves designed to provide also central heating. Charcoal is also a very popular fuel for grilling and barbecuing because it imparts a particularly nice flavour to the food.

2.3.2.2 For Industrial Heating Purposes

It replaces coke or fuel oil which in many countries is very expensive and has to be inported. Charcoal is used:

- For drying produce such as hops, tobacco and fish, in special kilns or burns;
- In stoves to heat water to be cieculated for the indirect drying of many different crops;
- As a fuel in the process of manufacturing lime and cement
- For the extraction of metals, particalarly iron,

2.3.2.3 Other Important Uses of Charcoal

- For foging, drawing purposes and sewage systems.
- In horiticulture, charcoal fines (small pieces and dust), are used in the vegetable garden, for increased yields in potting compounds where it “sweetens” the soil and as a top dressing around established plants such as roses and bougainvilles where it has been found that the colours are much improved.

A further important use of charcoal is in the control of pollution, but it is necessary to treat it with selected chemicals and steam when it is then known as activated charcoal.

Charcoal production in Thailand is spread all over the country. In every forested province or province adjacent to forests, there exists charcoal production, legal or illegal. The charcoal making has different purposes:

a) for private use
b) for comercial sale
c) partly for private use and partly for commercial sale

Wood for charcoal production have many species suitable as: Teng, Rung, Hieng, Pluang, Dang, Pakraw, Tabak, Kabark, Kabok, Kaw, Markha, Yang, Tiew, etc. They are sometimes called compositewood or deciduous wood. Deciduous forests are Mixed Deciduous forests and Dipterocarp deciduous (or Dry Dipterocarp) forests. Minor forest types such as Scrub forests, Beach forests and Swamp forests are found in some particular areas.

2.3.3 Mixed Deciduous Forest [23]

Forests of Thailand can be broadly classified into two main types, Evergreen and deciduous forests, based on dominant and subdominant species of the top canopy. Deciduous forest is divided into 3 sub-types;

2.3.3.1 Mixed deciduous forest is commonly found in the Northern, Central & Northeastern Thailand, but limited in Southern area. This forest includes medium size vegetations with bamboo. In the dry season, all vegetations will change the leaves & face forest fire. The important vegetations includes Peak, Afzelia xylocarpa Craib, Kylia kerii Craib & Hutch, Bambusa arundinacea Willd., etc.

2.3.3.2 Deciduous dipterocarp forest is commonly found in Northern, Central & Northeastern Thailand. About 70-80% of this forest is found in

Northeastern. The important vegetations are Phyllanthus emblica Linn., Sindora siamensis Teysm., etc.

2.3.3.3 Savanna forest is the post forest after its destroyed, degraded soil that the vegetations are not able to grown, savanna forest will be replaced. The important vegetations area a variety of grasses the lalang or cogon, genus Imperata that includes Careya arborea Roxb.Source: Apiset Pansuwan. Natural Resources Conservation & Environment. Lecture Doc.,Art Faculty, Silpakorn Univ., 1989.

In general, this type of forest is transparent consisted of media size trunks with bamboo. All vegetations will change leaves & easily get on fire in the dry season, but not severe damage. Important vegetations such as: Adina cordifolia Hook. f. Afzelia xylocarpa Craib. Alangium salvifolium Wang. Albizzia lebbek Benth. Albizzia lebbekoides Benth. Albizzia lucida Benth. Albizzia odoratissima Benth. Albizzia procera Benth.Albizzia chinensis Merr.Anogeissus acuminata Wall.Bauhinia racemosa Lamk.Bauhinia variegata Linn. Berria ammonilla Roxb. Bischofia javanica Blume. Cananga latifolia Finet & Gagnep. Careya arborea Roxb.Cedrela toona Roxb. Ex Rottle. Chukrasia velutina W. & A. For the bamboo in the Mixed Deciduous Forest, they are:Bambusa arundinacea Willd. Bambusa polymorpha Munro Bambusa tulda Roxb.Cephalostachyum pergracile Munro Dendrocalamus membranaceus Munro.

2.3.4 Charcoal Residue

Charcoal residue or charcoal fine have a much lower purity than lump charcoal. The fines contain, in addition to charcoal, fragments, mineral sand and clay picked up from the earth and the surface of the fuelwood and its bark. The fine powdered charcoal. Most of this undesired high ash material can be separated by screening the fines and rejecting undersize material passing, say, a 2 to 4 mm screen. This fine material may still contain more than 50 % charcoal depending on the level of contamination but, nevertheless, it is difficult to find uses for it. Material retained on the screen will be mostly fragments of good charcoal and, after hammer-milling is suitable for briquetting. Fines cannot be burned by the usual simple charcoal burning methods and hence are more or less unsaleable. But if fines could be fully used, overall charcoal production would rise by 10 to 20% .[13]

2.4 The Briquette Fuel

Biomass are agricultural waste, animal waste municipal solid wastes, urban wastewater etc as shown in the following Figure 2.4 can be converted into heat and power in combustion, gasification, and pyrolysis process or it can be used for production of synthetic fuels.[24]

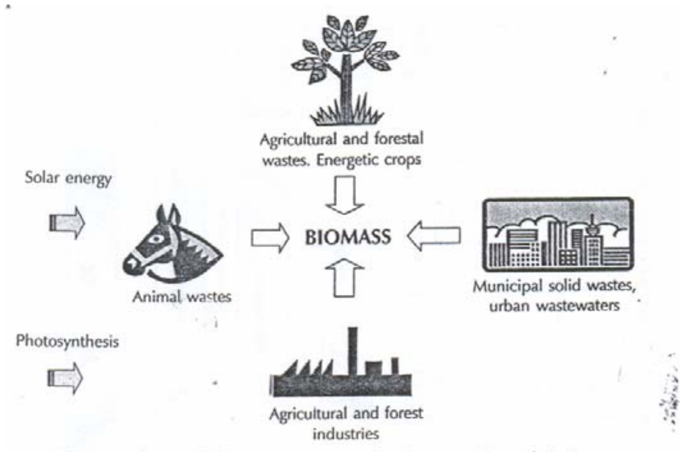


Figure 2.4 Scheme of the biomass sources for its energetic exploitation [24]

In addition, biomass compaction, which is also known as briquette fuel can have higher calorific value and strength. As the study of Reed and Bryant shows that the uncompressed agricultural material has the calorific value only 1/3 of charcoal by weight and 1/4 by volume, but the calorific value has become 2/3 of charcoal by weight and 3/4 by volume when it is compressed. [25]

2.4.1 Biomass Composition [26]

Biomass compositions are divided into 4 parts as shown in Figure 2.5:

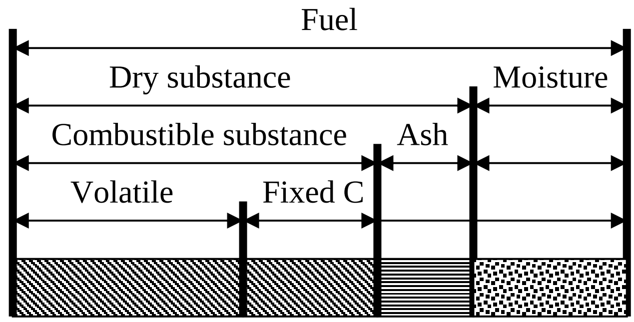


Figure 2.5 Show composition of biomass [26]

1) ***Moisture:*** most of the biomass contains considerably high moisture content because it comes from agricultural by-products. The biomass that is suitable for combustion should have less than 50 per cent of moisture.

2) ***Fixed Carbon:*** the part of biomass molecule structure has most carbon. If biomass has low percent of fixed carbon to shows as not good combustion.

3) ***Volatile Matter:*** The biomass that contains a great amount of volatile matter is highly combustible.

4) ***Ash:*** Most of biomass contains 1-3 per cent of ash except for rice husk that has around 10-20 per cent of ash, which causes problem in combustion and dumping.

Each biomass has a specific characteristic to show table which must to concern are following:

- Contribution of biomass
- Particle size
- Moisture
- Additive
- Quanlity of ash

Table 2.1 Typical characteristics of biomass fuels used at percent commercially for energy generating purposes [26]

Biomass type	Lower heating value on wet basis LHVw(kJ/kg)	Moisture content on wet basis MCw (%)	Ash content on dry basis Ac_d (%)
Bagasse	7,700 – 8,000	40-60	1.7-3.8
Cocoa husks	13,000-16,000	7-9	7-14
Coconut shells	18,000	8	4
Coffee husks	16,000	10	0.6
Cotton residues:			
Stalks	16,000	10-20	0.1
Gin trash	14,000	9	12
Maize:			
Cobs	13,000-15,000	10-20	2
Stalks			3-7
Palm oil residues:			
Fruit stems	5,000	63	5
Peat	9,000-15,000	13-15	1-20
Rice husks	14,000	9	19
Straw	12,000	10	4.4
Wood	**8,400-17,000**	**10-60**	**0.25 – 1.7**
Charcoal	**25,000-32,000**	**1-10**	**0.5-6**

2.4.2 Briquette Fuel Property

Generally, the study of briquette fuel property from the past of research shows that quality fuel is unnecssary to have as:

1. Density and strength: the high quality fuel should have high density in order to burn for a long time. Moreover, it should have high strength. After it has passed the Unconfined Compressive Strength Test.[28] This value is calculated from

the vibration in transportation that is 2 times over the vibration of normal transportation.

2. Sparking of fuel: the high quality fuel should not be sparked too much when it is burned.

3. Smoke: the high quality fuel should not give rise to the high smoke and violent odour when it is burned.

In order to, the high quality fuel should have the suitable moisture content is 6-12 per cent because the unsuitable moisture content causes decreasing of calorific value and easier to crack, low ash content, high fixed carbon that improves burning and the flammability quality, low volatile matter, high calorific value that depends on the carbon content, and low total sulfur. [6,7,8,9,10,11]

2.4.3 Making Briquettes [30]

The produce for mainly fuel densification:

- Material fines
- Binder : to stick the fines together
- Carrier : a liquid to distribute the binder
- Compaction device

The briquetting process can be divided into 4 stages:

2.4.3.1 Grinding: The charcoal that will use for the process of briquetting must be fine enough to form good briquette. The size of charcoal fines depends on the type of charcoal and the process of briquette. They have many methods for grinding such as using grinding/crusher machine.

2.4.3.2 Mixing: They are many recipes for making briquettes. Here are a couple of formulas for guidance: charcoal 100 kg mixing with starch 5-7 kg and water 30-35 kg or charcoal 100 kg mixing with tar 15-30 kg, Fuel oil 1 kg and water 30 kg. The exact mixture used will depend on how fine the charcoal is ground, the type and amount of binder used, and how much compaction can be applied. Small batches should be made until the briquettes are satisfactory. The most accessible place to mix is on hard packed earth, though this does cause a certain amount of contamination. Smaller batches can be done in drums, or you can use a concrete slab.

2.4.3.3 Compaction: In this stage to determine the shape and density of the briquette. Size and shape will depend on the end use and the desire of the consumer.

2.4.3.4 Drying: The simplest, cheapest method for drying is to just lay them out in the sun. A solar dryer can speed the process considerably. Waste heat from a retort can be harnessed for drying briquettes but internal dryer temperature must remain below briquette ignition temperature. Drying time will depend on the amount of moisture in the mix and the type of dryer used.

2.4.4 Advantages of the Briquette Fuel

Compaction does not increase calorific value per weight; it does increase value by volume as shown below: [30]

Table 2.2 Characteristics of densified wood [30]

Characteristics	Wood		Charcoal		Charcoal Briquettes	
	Medium Density Hard wood	High Density Hard wood	Medium Density Hard wood	High Density Hard wood	Medium Density Hard wood	High Density Hard wood
-Density of 1” pieces(g/cc)	0.61	1.00	0.325	0.475	0.6	0.9
-BTU per lb	7,700	8,000	12,800	13,500	12,800	13,500
-BTU per cu ft solid volume	300,000	500,000	256,000	405,000	473,00	756,000
-lbs required for $1x10^6$ BTU’s	130	125	79	74	79	74
-Solid Volume (cu ft) required for1 x 10^6 BTU’s	3.3	2.0	3.9	2.5	2.1	1.3

2.5 Binder

Briquette is one of several agglomeration techniques which are broadly characterized as compaction technologies. Agglomeration of residues is done with the purpose of making them more dense for their use in energy production. Raw materials for briquetting include waste from wood industries, loose biomass and other combustible waste products. On the basis of compaction, the briquetting technologies can be divided into: [31]

- Hot and high pressure compaction: This compaction is suitable for materials that contain lino- cellulose that will be melted down and becoming a binder when the materials recive more heat. [32]
- Medium pressure compaction with a heating device. [31]
- Cold and low-pressure compaction: They are two types that can be divided into cold and low-pressure compaction with binder and without binder. [32]

2.5.1 Classes of Binders [33]

Binders for coal briquetting are classified as organic, inorganic, and compound, with further subdivision as follows:

2.5.1.1 Organic Binders

These types have to be applied in a form sufficiently fluid to coat the particles and rely on their own cohesive properties to bind perticles.The binders as:

(a) Hydrophobic: Coal tar and pitch, Petroleum bitumen or asphalt, Wood tar, Synthetic and natural resins are applied in a molten state and strong bonding is obtained when the briquettes are cooled and the binder resolidified. On the one hand, have the advantage of being resistant to water and weather but producing smoke.

(b) Hydrophilic : Starch, Sulphite liquor, Sugars or molasses, Cellulose compounds, Vegetable pulps, Alginates, casein, Peat, lignite and wood are usually applied in the form of a paste, gel, dispersion, or solution in water, and to give

a strong bond they require drying – out after briquetting. The advantages of this are smokeless but produce briquettes, which weather poorly and disintegrate if wetted.

2.5.1.2 Inorganic Binders

These types require the addition of water and rely on chemical action to set; only relatively low briquetting pressure is necessary but the briquettes on leaving the mould must be handled carefully until they have set. These binders are relatively cheap, widely available, and smokeless. The disadvantage is that they contribute to the ash yield and can not resistant to weathering.

(a) Insoluble: Cement, Clay, Lime, Magnesia, Gypsum

(b) Water – soluble: Sodium or other, alkali silicates

2.5.1.3 Compound Binders

These type binders have been developed to overcome some of the disadvantages of cost and smokiness. There are divided as:

(a) Extended pitch- type: to improve the resistance to water and weathering of briquetters made from organic binders such as Pitch – emulsion of tar oil, sulphite liquor, and water, Pitch - emulsified, Pitch - anthracene oil or tar, and Pitch or asphalt – lime or cement or magnesia etc.

(b) Waterproofed : to be stronger and less smoky than when Inorganic binders alone is used such as Starch – pitch or bitumen or asphalt emulsion, Starch – phenol – fomaldehyde resin, Starch – coal or aluminium acetate or latex, and Starch – paraffin wax coating etc.

2.5.2 Binding Mechanisms of Densification [31,45]

The strength of such compacts is caused by van der Waals' forces, valence forces, or interlocking. In addition, particles in briquettes are boned to each other by a complex system of forces Natural components of the material may be activated by the prevailing high pressure forces to become binder. Some of the materials need binders even under high pressure conditions. Figure 2.6 shows some of the binding mechanisms.

These bonding forces are most effectually brought into play when conditions are such as to bring the surfaces of particles into intimate contact. These conditions are the use of high compression combined with shear forces on material of suitable size distribution. Briquetting process based on empirical relations between briquetting pressure and briquette density, briquette strength. The physical properties are most important in any description of the binding mechanisms of biomass densification. Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bounds in the contact area.

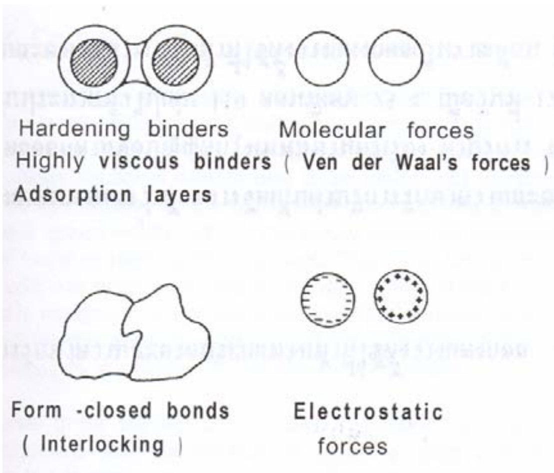


Figure 2.6 Binding mechanisms [31]

2.6 Briquette Technology [34]

2.6.1 Screw Presses

These machines operate by continuously forcing material into a die with a feeder screw. Pressure is built up along the screw rather than in a single zone as in the piston machines. Screw presses have three types as follows:

2.6.1.1 Conical Screw Presses

They manufacture one model with a claimed capacity of 600 to 1000 kg/in. It is reinforced with hard metal inlays to resist the very high wear experienced with this type of extrudes, especially when briquetting abrasive materials. The die is either a single hole matrix with a diameter of 95 mm or a multiple 28 mm matrix. The briquetting pressure is 60 to 100 MPa and the claimed density of the product is 1200 -1 400 kg/m³.The machine is equipped with a 74/100 kW 2-speed motor. Assuming a total of 100 kW for a production rate of 1000 kg/in one arrives at a specific energy consumption of 0.10 kW/kg/h. As shown in Figure 2.7.

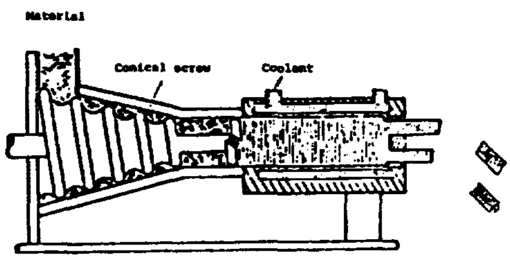


Figure 2.7 Conical Screw Press [34]

2.6.1.2 Screw Extruders without Die Heating

This machine is a low-pressure process and the manufacturer gives a lower limit of the moisture content at 30 %. The agricultural materialsis compressed to reduce its volume by half and the product is air dried after compression to be used as a boiler fuel.The capacity of the machine is 300 kg/in (wet basis). The rated power of the installed motor is 22/30 kW.

2.6.1.3 Screw Extruders with Heated Dies

The main features of this type of press is a screw which feeds the material from a feeding funnel. It has capacity of about 150 to 180 kg/hr. The briquettes have a characteristic hole through the centre from the central screw drive. The die is heated, most commonly by an electric resistance heater wired around the die. The central hole of the briquette will act as a chimney for the steam generated due to the high temperatures in the process. An exhaust is normally mounted above the exit hole from the mould where the briquettes are cut into suitable lengths. As shown in Figure 2.8 .

Source: *Bhattacharya et al, 1984*

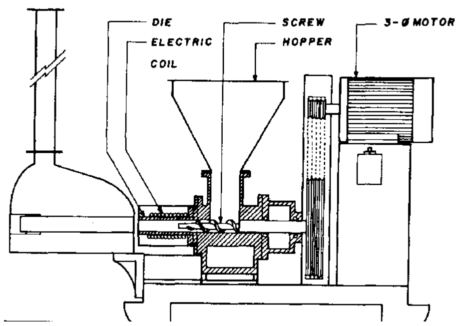


Figure 2.8 Screw extruders with heated dies [34]

2.5.2 Piston Presses

The piston press acts in a discontinuous fashion with material being fed into a cylinder which is then compressed by a piston into a slightly-tapering die. The compressed material is heated by frictional forces as it is pushed through the die. The lignins contained in all woody-cellulose materials begin to flow and act as a natural glue to bind the compressed material as shown in Figure 2.9 .Moreover, it can be driven either by mechanical means from a massive flywheel via a crankshaft or hydraulically. Mechanical presses generally produce hard and dense briquettes from most materials whilst hydraulic presses, which work at lower pressures, give briquettes which are less dense and are sometimes soft and friable.Piston presses are reliable, once they have been installed properly with dies shaped correctly for the raw materials used.

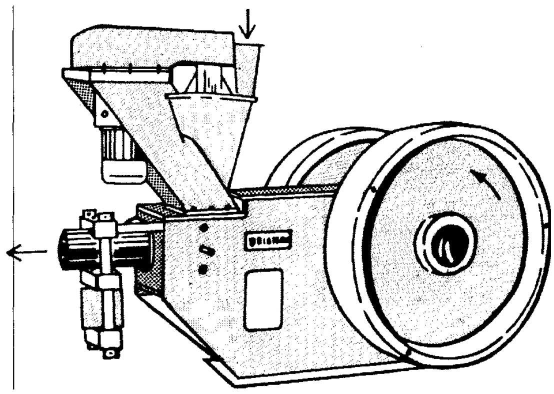


Figure 2.9 Typical Piston Briquetting Press [35]

2.5.3 Pellet presses

Pellets are the result of a process which is closely related to the briquetting processes described above. The main difference is that the dies have smaller diameters (usually up to approx. 30 mm) and each machine has a number of dies arranged as holes bored in a thick steel disk or ring. The material is forced into the dies by means of rollers (normally two or three) moving over the surface on which the raw material is distributed.The pellets will still be hot when leaving the dies, where they are cut to lengths normally about one or two times the diameter. Successful operation demands that a rather elaborate cooling system is arranged after the densification process.In addition to, it has a carpacity of about 200 to 8,000 kg/hr.

2.6 Related Research

Demirbas A. *et al*, [35] have demonstrated that waste paper and wheat straw or their mixtures can be compressed to a relative density greater than unity, and stabilized at that density without binder material. A reduction in the volume of the material also provides a technological benefit, so the material could be transported and stored more economically than is possible at present. The effects of the briquetting pressure on the density, moisture content and bending and compressive strengths of the briquettes were determined at six different pressures of 300, 400,500,600,700 and 800 MPa. The optimum moisture contents and compressive strengths were found to be respectively 18.0 % and 38.2 Mpa for waste paper, 22 0% and 22.4 MPa for wheat straw, and 18% and 32.0 MPa for a 20.0 % by weight of waste paper and straw mixture. The effect of the temperature and time on the briquette density of wheat straw was examined.

Yaman S. *et al.*, [36] studied olive refuse and paper mill waste to form fuel briquettes. For this purpose, the particle sizes of both biomass samples were decreased to-250 μm and then they were briquetted in a steel die under pressure between 150 and 250 MPa at ambient temperature. Effects of the moisture content of the biomass samples and briquetting pressure on the shatter index, compressive strength, and water resistance of the briquettes obtained were investigated. This study showed that the mechanical strength of the briquettes produced only from the olive refuse was not high enough. On the other hand, strong briquettes were produced using paper mill waste. When olive refuse was blended with fibrous paper mill waste, briquettes with sufficiently high mechanical strength could be produced. Burning profiles of the samples were derived applying derivative thermogravimetry technique under dynamic dry air atmosphere up to 1273 K with a heating rate of 40 $K \cdot min^{-1}$ and then combustion characteristics of the briquettes were compared.

Cobb J.T. *et al.*, [37] studied about co-processed fuel pellets from coal, biomass and waste. Numerous aggregates from waste coal fines, biomass, and other wastes, such as plastics, asphalt emulsion, and sewage sludge, are developed. E-Fuel was developed and commercialized as an economical method of producing fuel pellets from a paper-making waste sludge composed of wood fibres too short for use in paper manufacture, a waste plastic used to line food container cartons, and fine-sized coal. The addition of asphalt emulsion to fine coal is the GranuFlow Process technology, and results in an agglomerated product with improved dewatering characteristics and flowability properties. Conceptual flowsheets and preliminary capital and operating costs were developed for facilities to produce fuel pellets from three formulations. Premium fuel pellets from anthracite fines and waste plastic was developed for a premium fuel market, specifically the stoker and home-heating market. From coal fines and sewage sludge the medium cost/medium quality formulation was developed for a medium grade fuel market, specifically the electricity utility steam coal market. The low cost/low quality formulation was developed using coal fines, sawdust, and asphalt emulsion for a low grade fuel market, specifically the electrical utility steam coal market.

Pintuam P., [38] studied briquette fuel as from sawdust residues mushroom culture.This study showed that residual sawdust has potential and suitable to use as raw material for making the briquetted fuel that can be compensate the fuelwood 11//which was taken to be densified by the method of hot densification and cold densification which both with and without binder (The binder was fermented water hyacinth). The method hot densification and cold densification with binder were suitable. Besides, it found that the hot densification consumed more electrical power than the cold densification. These sawdust briquettes were taken to test the fuel characteristics and found that the heat value is nearly the same as the Eucalyptus wood though less than the Eucalyptus charcoal.

Nopporn S., [39] investigated the possibility of using ground coffee residue in making briquette fuel using a cold and low Pressure Densification Machine. Three types of binder, fermented water hyacinth, cassava residue and cassava glue were used. There were all 14 treatmented in this experiment; five of coffee residue with fermented water hyacinth at the ratios of 5:5 6:4 7:3 8:2 and 9:1, and five of coffee residue with cassava residue at the same ratio of using fermented water hyacinth, three of coffee residue with cassava glue at the ratios of 7:3 8:2 and 9:1 and one blank test of coffee residue alone for comparison. The physical and fuel properties of the briquettes were analysed, and their economic value was evaluated. In addition, the results were statistically analysed using Analysis of Variance and Duncan’s Multiple Range Tests.

From this report found that coffee residue had a calorific value of 6,038 Kcal/kg (25.28 MJ/kg), higher than firewood (4,436 Kcal/kg) but lower than charcoal (6,552 Kcal/kg). When mixed with fermented water hyacinth, cassava glue, and formed into a briquette, the calorific value was decreased to 4,700 – 5,700 kcal/kg depending on the type and amount of binder. Density of all briquettes was in the range of 0.5 – 0.9 g/cm^3 and decreased with the amount of binder. Measurements on the shatter index, which measures the briquettes tolerance to handling and transportation, were in the range of 0.82-0.99. Efficiency of heat utilization of the briquette was in the rage of 13.3 – 23.4 per cent, which is similar to the firewood.

Chaiyadejtayakul S., [6] studied the possibilities of utilizing the solid waste from production process of pulp and paper mills as briquetted fuel. Sludge cake from waste water tretment plant is proportionally mixed with fine wood-chip in 10 samples of 11 ratios each : 100:0 , 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90 and 0:100 by weight. After pressing the mixture into bars these are burned to obtain briquetted fuel .The briquetted fuel is analyzed to verify its heating value components as specified by ASTM. The feasibility study of production in comparison to the exising cost for solid waste management is also studued.

From this report found that mixtures of ratio from 100:0 to 40:60 could best result.However,as the ratio of wood chip increases, the chance of solid bars obtaining decreases and also the process is prolog and may result in incomplete mixture. When briquetted fuel was analyzed by ASTM, to found that mixing ratio 70:30 gave an optimum desired value and also heating value, compared to similar kinds of fuel such as paddy straw. As for production cost analysis,the above ratio resulted in a ratio of return of about 30.73 % of the price at 9 Bath/kg . This showed some adventage over burning fine wood chip as fuel.

Dechphon S., [7] studied about potential and efficiency of briquettes production by using sludge from sugar industry (filter cake) mixed with bagasse. The results show that three mixing ratio with highest bagasse content (6:4, 5:5 and 4:6 mixing ratio) were taken to analyze physical and chemical properties and found that the 4:6 mixing ratio showed the highest heating value when carbonization has been implimented to this mixing ratio that not suitable. For cost analysis of briquettes, the 4:6 mixing ratio was used to estimate and found that with the standard condition of the small and medium emterprizes, the volume of production was 347,700 briquettes/year and the cost of briquettes was 1.58 bath/briquettes.

Dumrongrojwattana N., [8] studied about fuel briquette from domestic wastewater sludge from Siphaya wastewater treatment plant mixed Acacia auriculiformis Cunn. To found that at the 1:1, 1:2 and 1:3 mixing ratio can pressed to be briquettes.The pressing time and electric energy for pressing are increase when the Acacia auriculiformis Cunn are increase that mean at the 1:3 mixing ratio, it spent the most pressing time and electric energy for pressing but it has the most thermal energy The cabonized briquettes have the higher thermal energy than the briquettes.The most thermal energy is from the carbonized briquettes from the mixer of sludge and Acacia auriculiformis Cunn at 1:3 mixing ratio so it is selected to analyze the economic feasibiliy. The analyze result at the production of 604,800 briquettes/year, price at 2.00 baht/briquettes and interest at 7 % gave the positive total net cash flow at 1,781,070 baht, positive net present value at 791,376 baht, benefit-cost ratio at 1.179, internal rate of return at 41.86% and payback period at 2 year and 3 months. So the production of cabonized briquettes from the mixer of domestic wastewater sludge and Acacia auriculiformis Cunn at 1:3 mixing ratio project is economic possible for investment.

Benjamatarakul A., [9] studied about utilized industrial wastewater sludge for producing briquettes.The sources of organic wastewater sludge were from seasoning powder and milk industries. The experiments started with improving the quality of sludge collected by anaerobic processes. Sludge without any pretreatment was used as a control . The paddy husk was used here to increase the heating value of sludge. The optimal mixing ratios between sludge and paddy husk was tested. Finally, the controlled sludge was improved its quality by burning into charcoals, as specified by ASTM . The cold compression type was used here for briquetting.

The result of sludge pre–treatment showed that the milk sludge was contained very high moisture content (90%) because it was not dewatered at the collection site . Regarding the seasoning powder sludge , it was easier to conduct pre –

treatment by anaerobic processes because it was dewatered at the site. The result gained of seasoning powder and milk sludge pre – treatment was that its heating value was decreased after pre – treatment processes .

The results obtained also indicated the optimal mixing ratios between seasoning powder sludge and paddy husk and mixing ratios between milk sludge and paddy husk were 1:1, 2:1 and 3:1 by volume which could easily be briquetted and was consumed lesser time for briquetting.

The briquetted fuel was tested for its physical and combustion properties. It was found that the solid fuel made from the mixing of seasoning powder sludge and paddy husk gave high combustion efficiency and good physical properties closed to lignite fuel with less amount of sulfer content. In case of burnt controlled sludge, it was found that its efficiency in term of energy released to boil water was increased. In addition, comparing between seasoning powder and milk sludge, the sludge obtained from a seasoning powder industry was much easier to handle than the one collected from a food industry.

Pakvilai N., [10] studied about the feasibility of organic industrial wastewater sludge from brewery and food being utilized for the production as briquette fuel. The results obtained also indicated that optimal mixing ratios between brewery sludge and eucalyptus leaves were 1:1, 1:2 and 1:3 by volume which could easily be briquetted and was consumed lesser time for briquetting. The optimal mixing ratios between food sludge and eucalyptus leaves were found at 1:2, 1:3 and 1:4 by volume.When there were tested physical and combustion properties that found the briquetted fuel gave high combustion efficiency and good physical properties close to charcoal wood fuel with less amount of sulfur content and efficiency in term of energy released to boil water was increased.

CHAPTER III
MATERIALS AND METHODS

3.1 Research Design

This study was designed as a laboratory experimental research. The experimental study was divided into 2 parts as follows;

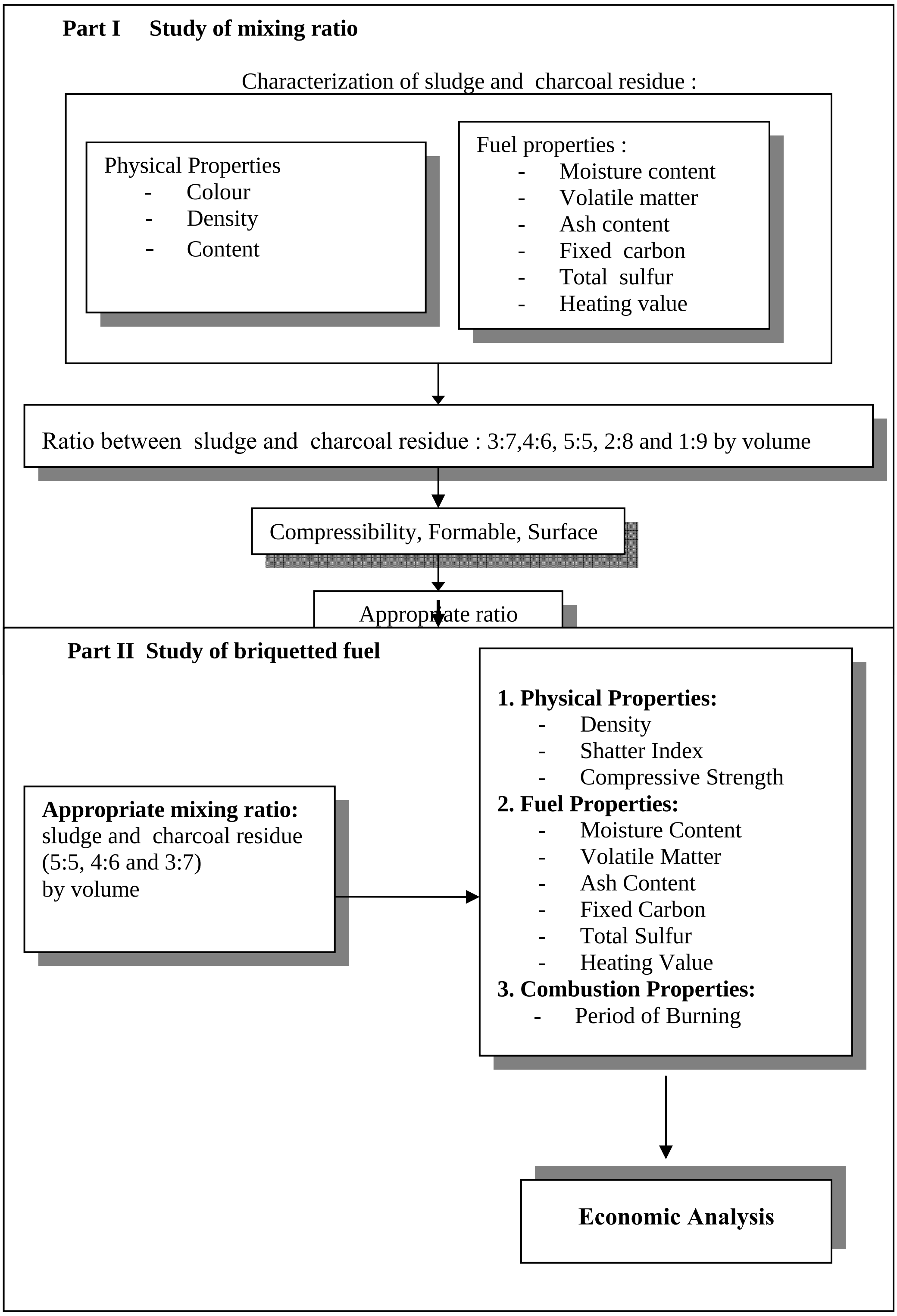
Part I Study of appropriate mixing ratio

This part, the physical properties and fuel properties of sludge from a modified starch factory and charcoal residue were tested. Different mixing ratios to produce briquetted fuel were studied. Then appropriate mixing ratios were determined from compressibility, formable and surface.

Part II Study of briquetted fuel properties

In this part, briquetted fuel derived from optimum mixing ratios of sludge from a modified starch factory and charcoal residue were studied for their physical properties and fuel properties.

3.2 Research Diagram



3.3 Materials, Equipment, and Chemicals

3.3.1 Materials

- Fresh sludge from belt press machine of activated sludge system, Siam Modified Starch Co.,Ltd. 38/6 Moo11, Pathumthani-Ladlumkaew Rd, Ladlumkaew, Pathumthani
- Charcoal residue from mixed deciduous forest wood and crushed to be fine charcoal

3.3.2 Equipment

3.3.2.1 Fuel Test Equipment

- Drying Oven
- Desiccator
- Crucible, as with as cover
- Muffle Furnace
- Hot plate
- Fitter Paper
- Isoperibol Bomb Calorimeter Model 126 + Parr Instrument

3.3.2.2 Briquette Equipment

- Crusher machine (Semeo brand, Motor 7.5 kW 10 horsepower speed 1,450 rpm 380/660 V)
- Basin for mixing
- Mixer
- Cup (500 ml)
- The cold and low-pressure densification and the conical screw press (Motor 1 phase 5 horsepower speed 1,470 rpm 220 V 50 Hz production rate 200 kg/hr the lenth of cylinder 27.05 cm. Inlet diameter 5.5 cm. Outlet diameter 5 cm.)
- Compressive strength taster

- Fine scale
- Coarse Scale
- Mask
- Shovel
- Gloves

3.3.3 Chemicals

- Distilled Water
- Barium, Chloride Solution (100 g/L)
- Eschka Mixture consist of Magnesium Oxide (MgO), Anhydrous sodium carbonate ($NaCO_3$) in ratio 2:1 by weight
- Hydrochloric Acid (conc.HCL : water,1:1)
- Hydrochloric Acid (conc.HCL: water1:9)
- Methyl Orange Indicator Solution (0.2 g/L)
- Sodium Carbonate, Saturated Solution
- Sodium Hydroxide Solution (100 g/L)

3.4 Research Methods

3.4.1 Preparation and Analyses of Raw Materials

3.4.1.1 *Randomization of sludge sample [4]*

1. Mixed all of sludge that will be used for the experiment homogeneously and then devide into four sections.

2. Take one section from (1) to mix homogeneously again and then devide into four section

3. Take one section from (2) to mixed into homogenously again and then devide it four section

4. Take one section from (3) to mixed into homogenously again and devide it four section. Take one section to analyze for the heating value and fuel properties by proximate analysis method.

3.4.1.2 Randomization of Charcoal fine sample

Charcoal fine for this experiment was taken from residues of charcoal from mixed deciduous wood. Charcoal residues are ground to have appropriate size (less then 3/8 ich) for briquette fuel making.

3.4.2 Briquetting

1. Mix charcoal fine with sludge to produce briquette fuel by volume in five ratios (sludge : charcoal residue) as 5:5,4:6, 3:7 ,2:8 and 1:9.
2. Press the mixture of charcoal fine and sludge with a screw press to obtain briquette fuel in cylinder shape. The briquette fuel has the diameter 5 cm. and length 50 cm Then, briquette fuel was cut into10 cm long.
3. Take the briquette to dry in the oven at 110° C temperatures for 2 days

3.4.3 Analysis of Briquette Fuel Properties

3.4.3.1 Physical Properties

A series of tests are performed to determine the Density, Compressive strength, and Shatter Index of the briquettes as shown in Appendix C.

Table 3.1 Physical Test Method

Parameters	Test method
1. Density	weight by volume
2.Compressive strength	by Universal Testing Machine
3. Shatter Index	Shatter testing

3.4.3.2 Fuel Properties

Analyses were done according to the American Society for Testing and Material Method (ASTM) (proximate analyses) as shown in Table 3.2 and Appendix C. Proximate analysis consist of moisture content, ash content, volatile mater, fixed carbon, total sulfur and heating value of briquetted fuel were tested.

Table 3.2 Method and standard to analyze sample

Parameters	Test method
1. Moisture Content	**ASTM D 3173** Standard Test Method for Moisture Content in the Analysis Sample of Coal and Coke
2. Volatile Matter	**ASTM D 3175** Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke
3. Ash Content	**ASTM D 3174** Standard Test Method for Ash Content in the Analysis Sample of Coal and Coke
4. Fixed Carbon	**ASTM D 3172** Practice for proximate of Coal and Coke
6. Total Sulfur	**ASTM D3177** Standard Test Method for Total Sulfur in the Analysis Sample of Coal and Coke : Eschka Method
5. Heating Value	**ASTM D 5865** Standard Test Method for Heating Value in the Analysis Sample of Coal and Coke

3.4.3.2 Combustion property

Timing by minutes for the period of burning is used for the combustion property analysis as follows:

1. 500 g of briquetted fuel for each ratio are tested with china bucket stove. As shown in Figure 3.1

2. Burn the briquetted fuel until the briquette blazing hot for 5 minutes. Then start to keep time and stop when the briquetted fuel out of light and until burns to become ash.

3. Test in the same way for each ratio.

Figure 3.1 Briquetted fuel burning

Table 3.3 Combustion Test Method

Parameters	Test method
Period of burning	Timing by minutes

3.4.4 Economic Analysis [40]

The assumptions in studying the capital value for the economic value analysis are as follows:

3.4.4.1. Factory Data

-There is a small industrial factory, located at Ayutthaya Province that consists of a cold and low-pressure densification, which is conical screw press type, crusher/a hammer mill chopper machine and mixing machine.

- This project is small scale industry and 5 years period.

- The operation system is operated 8 hours a day (300 day a year = 365 day/year-Sunday 52 day/year-holiday 13 day/year) and the productivity rate is 1,600 kg/day. The cold and low-pressure densification, which is conical screw press type, Crusher/a hammer mill chopper machine and mixing machine, are operated 8, 4 and 1.5 hr/day respectively.

- Use 4 -labor force and labor cost is 160 bath/person/day.
- There are apparatus and machine cost without building cost.
- The maintenance expense is 10 percent of machine purchase cost.
- There is no raw materials cost.
- Determined at wholesale price of briquette product was 0.50 baht/briquette (length 10 cm and diameter 5 cm).

3.4.4.2. Productivity Cost

1. Fixed cost
    - Building cost.
    - Machine cost
2. Variable cost
    - Electricity cost
    - Labor cost
    - Maintenance cost
    - Transportation and storage cost
    - Screw press cost

3.4.4.2. Methods for Determining Economic Value

In term of economic analysis, the determination of break even point and payback period are important for an analysis of economic value, the details of those factor are as follows:

1) Break even point

Break even point is used to determine the product quantity that is produced in order to make a total cost equals to revenue.Calculation is as follow:

equation:

$$N = \frac{F}{C-V}$$

Where: N = product quantity, briquette.

F = fixed cost, baht

C = product price, baht/ briquette

V = variable cost, baht/ briquette

2) Payback period

Payback period is used to determine the relative attractiveness of investment proposal. The essence of this technique is determination of the number of periods required to recover an initial invesment. Calculation is as follow:

$$\text{Payback period} = \frac{\text{investment cost}}{\text{Average net of return}}$$

Investment cost (baht) = Total cost (baht)

Average net of return (baht/year) = Profit (baht/briquette) x Productivity yield (briquette/year)

3.5 Study Facility

1. Technical Research of Fuel and Natural Energy Testing Center Department of Alternative Energy Development and Efficiency (DEDE), The Ministry of Energy

2. The Laboratory Section of Sanitary Engineering, Faculty of Public Health, Mahidol University

3. Department of Sciences Services, The Ministry of Science and Technology.

4. Office of Central Laboratory Service unit (OCLS). The Joint Graduate School of Energy and Environment (JGSEE); King Mongkut’s University of Technology Thonburi.

CHAPTER IV
RESULTS

This research used sludge from a modified starch factory mixed with charcoal residue in 5 ratios (5:5, 4:6, 3:7, 2:8 and 1:9 by volume). The appropriate mixing ratios for briquetted fuel production were determined. Analyses of physical properties, briquetted fuel properties and combustion property were done. Evaluation for production cost was performed.

4.1 Characterization of Raw Materials

Raw materials used were sludge which was waste from Siam modified starch factory Co; Ltd. It was used to be binder of charcoal residue. Both sludge and charcoal residue were analyzed for basic properties before subjecting to the briquette making process.

4.2.1 Physical Properties

The physical properties of sludge from a modified starch factory in term of density, color and texture are presented in Table 4.1.

Table 4.1 Sludge from a modified starch factory and charcoal residue properties.

Raw Materials	Physical properties		
	Density (g/cm^3)	**Color**	**Texture**
Sludge from a modified starch factory	1.00	Light Brown	Fine (like soil)
Charcoal residue*	0.20	Black	Coarse

Remark: ** Charcoal residue were ground to be charcoal fine*

The results in Table 4.1 show that physical properties of sludge from a modified starch factory had density 1.00 g/cm^3, light brown color and fine (like soil) texture and physical properties of charcoal residue had density 0.20 g/cm^3 black color and coarse texture.

4.2.2 Fuel Properties

Properties of sludge from a modified starch factory and charcoal residue were analyzed by proximate analysis method as the results shown in Table 4.2

Table 4.2 Sludge from a modified starch factory and charcoal residue fuel properties were analyzed by proximate analysis method.

Raw Materials	Fuel properties					
	Moisture Content (%)	**Ash Content (%)**	**Volatile Matter (%)**	**Fixed Carbon (%)**	**Total sulfur (%)**	**Heating value (cal/g)**
Sludge from a modified starch factory	41.20	15.20	34.60	9.00	0.58	2,087
Charcoal residue	5.40	8.90	17.10	68.60	0.24	3,889.63

The results (Table 4.2) show that fuel properties of sludge from a modified starch had moisture content 41.20 %, ash content 15.20 % volatile matter 34.60 %, fixed carbon 9 % and total sulfur 0.58 %, the fuel properties of charcoal residue had moisture content 5.40 %, ash content 8.90 % volatile matter 17.10 %, fixed carbon 68.60 % and total sulfur 0.24 %. The heating value of sludge from a modified starch factory was 2,087 cal/g whereas heating value of charcoal residue was 3,889.63 cal/g. The energy values from these samples were sufficient to produce briquetted fuel.

4.2 Production of Briquetted Fuel at Different Ratios

Characteristics of raw materials showed that charcoal residue had high heating value (3,889.63 cal/g) and sludge has a property like binder. [6,7,8,9,10,11]

Hence, charcoal residue should be the major raw material and sludge is a binder.[8] The ratio of sludge and charcoal residue by volume as 5:5, 4:6, 3:7, 2:8 and 1:9 to produce briquette by cold and low-pressure compaction were done. Production of the briquetted fuel at different ratios is shown in Table 4.3.

Table 4.3 Production of briquetted fuel at different ratios

Ratio (sludge: charcoal residue by volume)	**Compressibility**[1]	**Formable**[2]	**Surface**[3] **(Smoothness)**
5:5	✓	✓	✓
4:6	✓	✓	✓
3:7	✓	✓	✓
2:8	X	X	X
1:9	O	O	O

Remark: ***1. Compressibility****: ability of densification to rod shape by screw press with diameter of 5 cm and length of 50 cm.*

2. Formable*: ability of molding after densification to rod shape.*

3. Surface*: Appearance of briquetted fuel; determined by smoothness*

4. *✓ = Easy/good briquetting,* ***X*** *= Difficult/bad briquetting,* ***O*** *= Failed briquetting*

As shown in Table 4.3, the mixing ratios of 5:5, 4:6 and 3:7 by volume have good compressibility, formable and smooth surface. Therefore, there mixing ratios are determined to be appropriate ratios (see Figure 4.1)

5:5

4:6

3:7

Figure 4.1 Mixing ratio (sludge: charcoal residue) at 5:5, 4:6 and 3:7

On the other hand, the mixing ratio of 2:8 had poor compressibility, formable and rough surface with cracking, (As shown in Table 4.3 and Figure 4.2)

2:8

1:9

Figure 4.2 Mixing ratio (sludge: charcoal residue) at 2:8 and 1:9

Moreover, the mixing ratio of 1:9 had compressibility failure and unformable. It was clogged in the conical screw press as shown in Figure 4.2. Hence, the mixing ratios of 2:8 and 1:9 were unsuccessful briquetting.

4.3 Briquetted Fuel Properties

As shown in Table 4.3, the appropriate ratios for producing briquetted fuel were 5:5, 4:6 and 3:7. Briquette was then dried in an oven at 110° C temperatures for 2 days. After drying, they were subjected to be analyzed for physical properties, fuel properties and combustion property.

4.3.1 Physical Properties of the Briquetted Fuel

4.3.1.1 Density

The density of 3 different ratios of briquetted fuel (5:5, 4:6 and 3:7) ranged from 0.38 g/cm^3, 0.44 g/cm^3, 0.54 g/cm^3 respectively. Density of briquette was increased when the ratio of sludge decreased whereas that of charcoal residue increased as shown in Figure 4.3 and Appendix A.

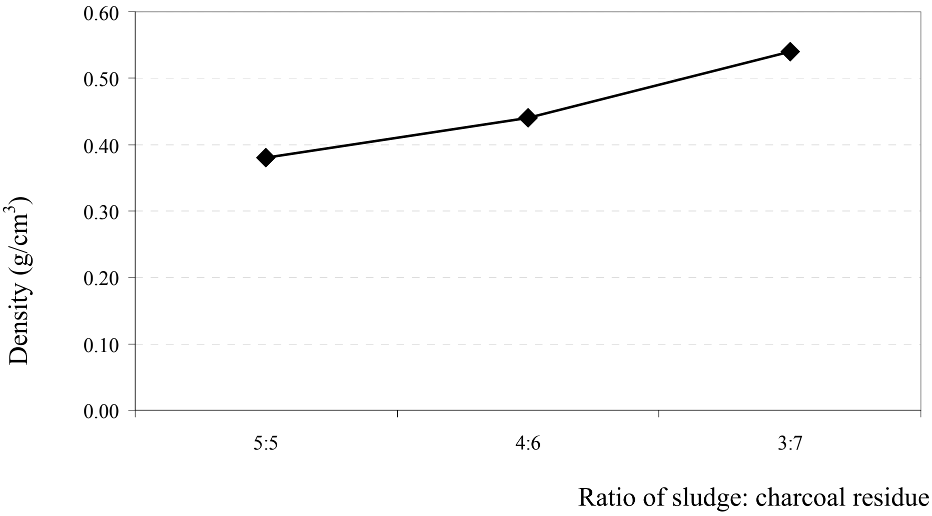


Figure 4.3 Density (g/cm^3) of briquetted fuel

4.3.1.2 Compressive Strength

According to experimental results as shown in Figure 4.4 and Appendix A, it is found that the briquettes had the vertical compressive strength: between 0.30 – 0.38 kg/cm^2. The vertical compressive strength was increased when the ratio of sludge decreased whereas that of charcoal residue increased. Moreover, the briquettes had the horizontal compressive strength between 0.11 – 0.22 kg/cm^2. The horizontal compressive strength was increased when the ratio of sludge increased whereas that of charcoal decreased.

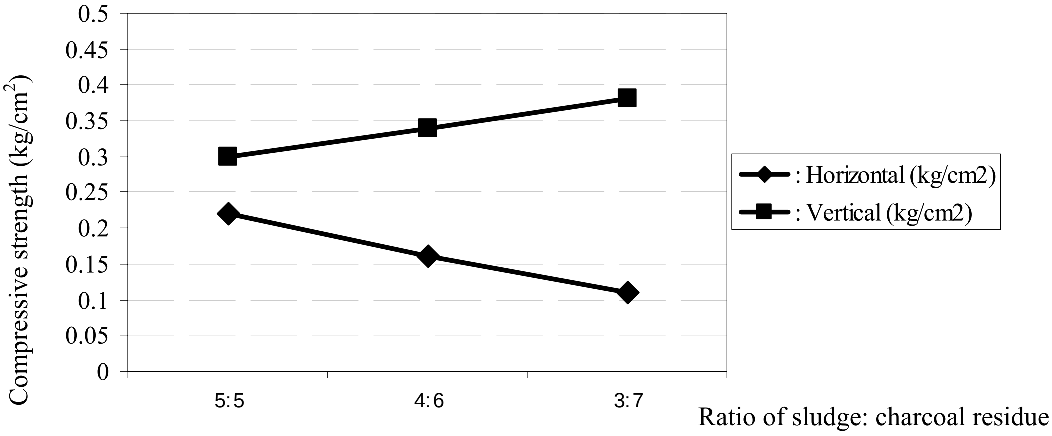


Figure 4.4 Vertical and horizontal compressive strength: (kg/cm^2) of briquetted fuel

4.3.1.3 Shatter Index

As results shown in the Figure 4.5 and Appendix A, The shatter index of the briquettes ranged 0.84 – 0.86. The briquette at the ratio 3:7 had the highest shatter index (0.86), while at the ratio 5:5 had lowest level of shatter index (0.84). The result showed that shatter index was increased when the ratio of sludge decreased whereas that of charcoal residue increased.

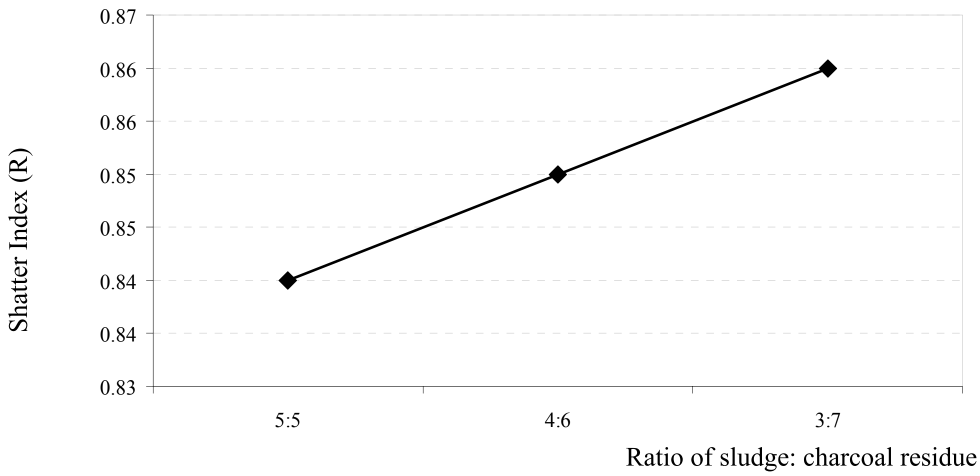


Figure 4.5 Shatter index of briquetted fuel

4.3.2 Fuel Properties of the Briquetted Fuel

As the results shown in Figure 4.6 and Appendix A, 3 different ratios of briquettes produced from sludge from a modified starch mixed with charcoal residue were analyzed.

4.3.2.1 Moisture Content:

The moisture content of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 8.62 %, 7.44 % and 7.13 % respectively. The moisture content was decreased when the ratio of sludge decreased whereas that of charcoal residues increased. As shown in Figure 4.6 and Appendix A**.**

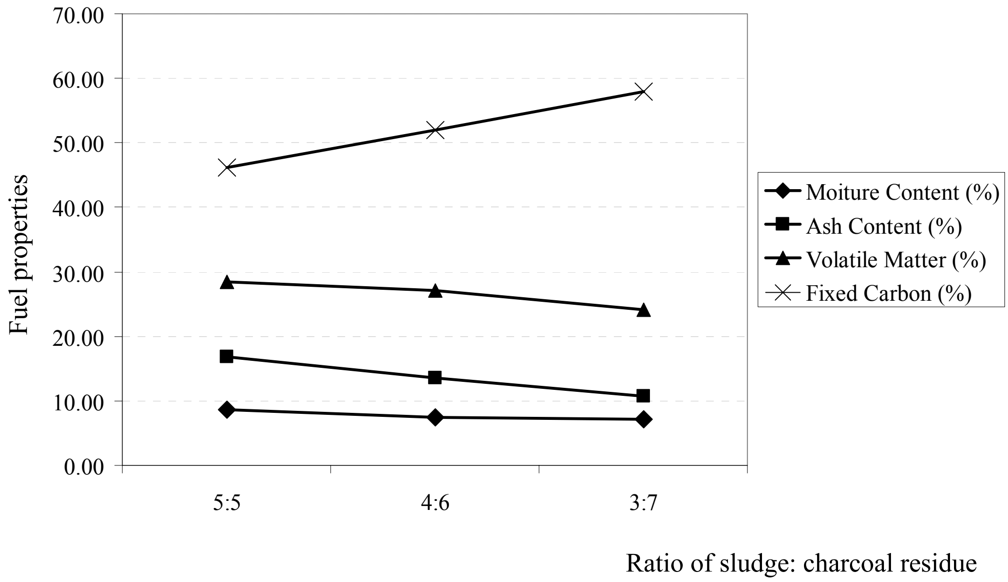


Figure 4.6 Fuel properties of briquetted fuel at different ratios

4.3.2.2 Ash Content:

The ash content of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 16.88 %, 13.57 % and 10.70 % respectively. The ash content was decreased when the ratio of sludge decreased whereas that of charcoal residue increased. As shown in Figure 4.6 and Appendix A**.**

4.3.2.3 Volatile Matter:

The volatile matter of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 28.39 % 27.08 % and 24.20 % respectively. The volatile matter was decreased when the ratio of sludge had decreased whereas that of charcoal residue increased. As shown in Figure 4.6 and Appendix A**.**

4.3.2.4 Fixed Carbon:

The Fixed Carbon of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 46.11 % 51.91 % and 57.97 % respectively. The fixed carbon was increased when the ratio of sludge decreased whereas that of charcoal residue increased. As shown in Figure 4.6 and Appendix A**.**

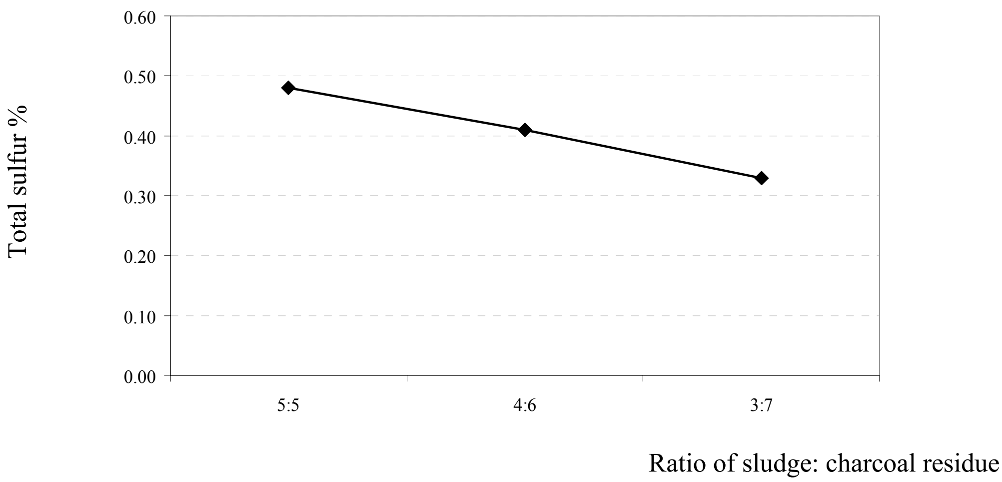


Figure 4.7 Total sulfur properties of briquetted fuel at different ratios

4.3.2.5 Total sulfur:

Total sulfur of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 0.48 % 0.41 % and 0.33 % respectively. The total sulfur was decreased when the ratio of sludge had decreased whereas that of charcoal residue had increased. As shown in Figure 4.7 and Appendix A.

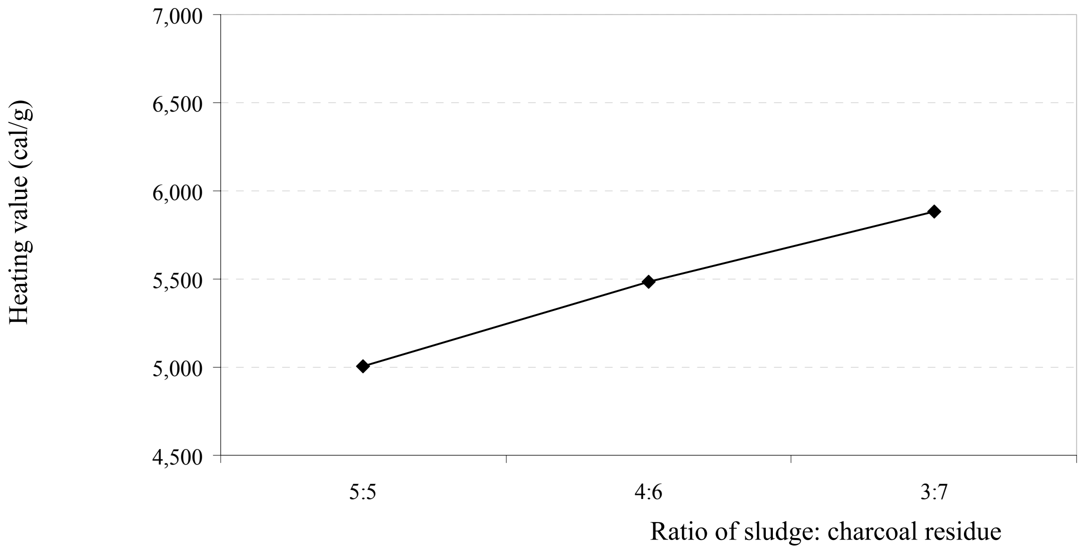


Figure 4.8 Heating value of briquetted fuel at different ratios

4.3.2.5 Heating Value

The heating value of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 5,006 cal/g, 5,482 cal/g and 5,885 cal/g respectively. The heating value was increased when the ratio of sludge decreased whereas that of charcoal residue increased. As shown in Figure 4.8 and Appendix A.

4.3.3 Combustion Property of the Briquetted Fuel

The period of burning by as for combustion property of the briquette produced from sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 148 min. 155.67 min. and 167.67 min. respectively. The period of burning was increased when the ratio of sludge decreased whereas that of and charcoal residue increased as shown in Figure 4.9 and Appendix A.

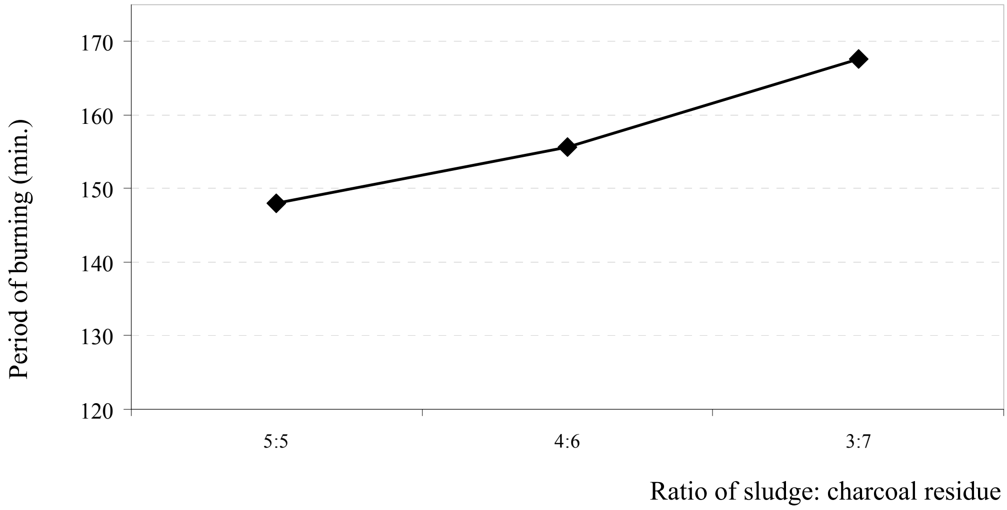


Figure 4.9 Period of burning of briquetted fuel

4.4 Economic Analysis

4.5.1 Weight and Length of Briquetted Fuel Product

The Weight of briquetted fuel product at the ratios of 5:5, 4:6 and 3:7 were 58.07 g 71.21 g and 90.44 g respectively. The length of briquetted fuel product at the ratios of 5:5, 4:6 and 3:7 were 9.57 cm. 10.07 cm. and 10.20 cm. The result showed that weight was increased when the mixing ratio of sludge decreased whereas that of charcoal residue increased.

4.5.2 Calculation

The economic analysis is calculated the capital cost as follows:

Capital cost [39]

There were 2 types of cost as follows: Fixed cost (Machine cost and Building cost) and Variable cost (Electricity cost, Maintenance cost, Screw press cost and Labor cost)

1. Machine cost and building cost

For briquette made from sludge from a modified starch factory mixed with charcoal residue, the machine costs are shown in Table 4.4

Table 4.4 Machine cost for producing briquetted fuel and building cost

Types of machinery	Cost (Baht)	Lifetime(year)	Depreciation cost
Machine cost			
1.Cold and low pressure densification, Conical screw press 5 Hz, Productivity 100 kg/hr [1]	170,000 (85,000 x 2)	10	17,000
2.Crusher/ hammer mill chopper 10 Hz productivity 1,250 kg/hr [2]	120,000	10	12,000
3. Mixer 5 Hz productivity 200 kg /hr [2]	90,000	10	9,000
Building cost[3]	350,000	20	17,500
Total	**730,000**		**55,500**

Source:From 1. *Utsaphattana Settakrit Co.Ltd,2007*

2. *THAI SUMI CO.,LTD ,2007 [41]*

3. *Assumed*

1.2 Electricity cost

The conical screw press, the hammer mill chopper and the mixing machine were operated 8 hr/day, 1.5 hr / day and 4 hr/day respectively. The electricity cost was calculated as shown:

Electricity (Unit) = Electricity power (kW) x Working hour (hr)

Calculation :

1) Conical – screw press 10 Hz (1 Hz = 0.746 kW)

Electricity per year = 7.46 kW x 8 hr/day x 300 day = 17,904 Unit

2) Crusher/ hammer mill chopper 10 Hz

Electricity per year = 7.46 kW x 1.5 hr/day x 300 day = 3,357 Unit

3) Mixing machine 5 Hz

Electricity per year = 3.73 kM x 4 hr/day x 300 day = 4,476 Unit

The electricity used : = 17,904 +3,357+4,476

= 25,737 unit/year.

The electricity cost = 2.978 baht /unit in 2006 [45]

or = 25,737 unit/year.X 2.978 baht /unit

= 76,645 baht/year.

Table 4.5 Fixed cost and Variable cost per unit of briquetted fuel made from mixing ratio of sludge from a modified starch factory and charcoal residue product.

Type	Cost (baht/yr.)	Remarks
Fixed cost		
1.Machine cost	380,000	- Productivity yield 480,000 kg/yr.
2.Buliding cost	350,000	
Total	730,000	
Variable cost		
1.Electricity cost	76,645	- 2.978 baht/unit
2.Maintenance cost	73,000	-The maintenance expense is 10 percent of machine purchase cost.
3. Screw press cost	168,000	- Change screw press every 100 hr [6]
4. Labor cost	192,000	- Salary 4,000 baht/person/month (calculate from labor cost is 160 baht /person/day, use 4-labor force) [Appendix F]
Total	509,645	
Total	**1,239,645**	

The cost of briquette product was calculated as follows;

Calculation :

Capital Cost/year = Fixed cost + Variable cost

= 730,000+509,645

= **1,239,645 baht**

Productivity yield = 480,000 kg/year

From this data, The capital cost were 1, 239,645 baht when productivity yield were 480,000 kg/year and determined at wholesale price of briquette product was 0.50 baht/briquette.

CHAPTER V
DISCUSSION

5.1 Characterization of Raw Materials

Raw materials (sludge from a modified starch factory and charcoal residue) were analyzed for their basic properties as follows:

Sludge from a modified starch factory: The physical characteristics of sludge from a modified starch factory were as follows: density 1.0 kg/L, light brown color, fine (like soil) texture. The fuel properties of sludge from modified starch were also analyzed using ASTM methods. The value of moisture content was 41.20 %, fixed carbon was 9 %, ash content was 15.20 %, volatile matter was 34.60 % and total sulfur was 0.58 %. Moreover, the heating value was 2,087 cal/g.

Charcoal residue: The physical characteristics of charcoal residue were as follows: density 0.20 kg/L, black color, coarse texture. Its fuel properties were also analyzed using ASTM methods. The value of moisture content was 5.40 %, ash content was 8.90 %, volatile matter was 17.10 %, fixed carbon was 68.60 %, total sulfur was 0.24 %, and heating value was 3,889.63 cal/g.

The characteristics of sludge from a modified starch factory and charcoal residue to produce briquetted fuel can be explained as follows:

1. Charcoal residue has more fix carbon than sludge from a modified starch factory. Therefore it has more heating value than sludge.
2. Charcoal residue has less quantity of sulfur than sludge from a modified starch factory. So it is appropriate to mix with sludge to increase heating value while generate less air pollution from sulfur dioxide than that of sludge.

3. Charcoal residue should be crushed to be charcoal fines [36] due to particle size and shape are of great importance for densification. It is generally agreed that material of 6-8 mm size with 10 – 20 % powdery component (< 4 mesh) gives the best results. [29] In addition, materials with characteristics like gum are suitable as binder. Sludge from sludge from a modified starch factory and charcoal residue has the similar characteristics as binder. [6, 7, 8, 9, 10, 11]

4. The heating value of charcoal residue (3,889.63 cal/g) is higher than sludge. Therefore, charcoal residue can be served as major raw material whereas sludge can be used as binder.

5.2 Production the Briquetted Fuel

5.2.1. The ratio of sludge and charcoal residue by volume of 1:9 cannot briquette in rod shape due to materials clogged in conical screw press. It might take place at the entrance of the dried resulting in jamming of the machine. [29] Apart from this, sludge with low moisture (< 20 %) does not have binder property. [8]

5.2.2 The ratio of sludge and charcoal residue by volume of 2:8 was difficult to briquetting because of its rough surface; It also had cracks on surface of the briquette after drying in the oven due to not enough binder.

5.2.3 The ratio of sludge and charcoal residue at 5:5, 4:6, 3:7 could produce briquette due to good binding. These mechanisms were occurred [29] with enough sludge quantity. Therefore the ratios of 5:5, 4:6, 3:7 were considered the appropriate ratios.

5.3 Briquetted Fuel Properties

5.3.1 Physical Properties of the Briquetted Fuel

5.3.1.1 Density

The briquetted fuel at the mixing ratios of 5:5, 4:6 and 3:7 had density of 0.38, 0.44 and 0.54 g/cm^3, respectively. The density was increased when the ratio of sludge decreased and charcoal residue increased. Therefore, when densification by cold and low pressure machine can be compress mixing ratio become thickness.

5.3.1.2 Compressive Strength

The briquetted fuel at the mixing ratios of 5:5, 4:6 and 3:7 had the vertical compressive strength: 0.30, 0.34, and 0.38 kg/cm^2, respectively. The vertical compressive strength was increased when the ratio of sludge decreased and charcoal residue increased. In contrast, the briquetted fuel had the horizontal compressive strength 0.22, 0.16, 0.11 kg/cm^2, respectively. The horizontal compressive strength was decreased when the ratio of sludge decreased and charcoal residue increased. The vertical compressive strength was greater than horizontal compressive strength in all samples. These findings suggest that, these briquettes should be put in vertical line to reduce bricking or damage from transportation. [6]

5.3.1.3 Shatter Index

The shatter index of the briquetted fuel at the mixing ratios of 5:5, 4:6 and 3:7 were 0.84, 0.85 and 0.86, respectively. The suitable fuel should have a shatter index between 0.5 – 1.0. [35] Therefore, the briquette made from charcoal residue mixed with sludge from a modified starch factory as binder is convenient to handle and transport. In addition, it was found that the shatter index dependable on the density and strength, meaning that there is a relationship among its physical properties. When the briquette has high density and strength, it usually has high shatter index. [8]

5.3.2 Fuel Properties of The Briquette Fuel

5.3.2.1. Moisture Content:

The moisture content of the briquette mixed with sludge from a modified starch factory and charcoal residue at the ratios of 5:5, 4:6 and 3:7 were 8.62 %, 7.44 % and 7.13 % respectively. This finding was in agreement with the hypothesis that moisture content of briquetted fuel will be decreased when mixing ratio of sludge decreases whereas charcoal residue increases. The moisture content can affect the fuel quality, therefore the moisture content of qualified fuel should be in the range of 4-8 %.[36] For this reason, all the briquettes that produced from sludge from a modified starch factory as binder should have a suitable moisture content. The moisture content standard by The Standard of community product, Thai industrial standard institute is < 8 % [41] as shown in Table 5.1. When compared with general firewood and general charcoal, the briquette made from sludge mixed with charcoal residue had more moisture content than the general firewood (4.30 %) and general charcoal (4.65 %)

5.3.2.2 Ash Content:

The ash content of the briquetted fuel at the mixing ratios of 5:5, 4:6 and 3:7 were 16.88 %, 13.57 % and 10.70 % respectively. This finding was in agreement with the hypothesis that the ash of briquette fuel will be decreased when mixing ratio of sludge decreases whereas charcoal residue increases. When ash content of 10.70 – 16.88 % of these ratios were compared with general firewood and general charcoal as shown in Table 5.1, the briquette made from sludge from a modified starch factory mixed with charcoal residue found to have more ash content than that of the general firewood (1.40 %) and general charcoal (10.20 %)

5.3.2.3 Volatile Matter:

The volatile matter of the briquetted fuel at the mixing ratios of 5:5, 4:6 and 3:7 were 28.39 % 27.08 % and 24.20 % respectively. All briquettes had volatile matter ranging from 24.20 – 28.39 %. Volatile matter was found less than the that of general firewood (73.32 %), but more than that of general charcoal (18.14 %) as shown in Table 5.1. It was found that general charcoal has less volatile matter than that of briquettes because in making charcoal, tar and gas were reduced from wood that passed carbonization process.

5.3.2.4. Fixed Carbon:

The fixed carbon in the briquettes at the mixing ratios of 5:5, 4:6 and 3:7 were 46.11 % 51.91 % and 57.97 % respectively. When compared with general firewood and general charcoal, the briquette made from sludge from a modified starch factory mixed with charcoal residue has more fixed carbon than that of the general firewood (25.27 %) but less than that of general charcoal (71.65 %) as shown in Table 5.1.

5.3.2.5. Total Sulfur:

The results of the experiment indicated that ash content of the briquette at the ratios of 5:5, 4:6 and 3:7 were 0.48 % 0.41 % and 0.33 % respectively. The quantity of total sulfur decreased when the mixing ratio of sludge had decreased and charcoal residue had increased.

5.3.2.6. Heating Value

The results of the experiment indicated that the heating value of the briquette at the ratios of 5:5, 4:6 and 3:7 were 5,006 cal/g 5,482 cal/g and 5,885cal/g respectively. This finding was in agreement with the hypothesis which states that the heating value of briquette fuel will be decreased when mixing ratio of sludge increases whereas charcoal residue decreases. Their heating values of 4,700-5,700 cal/g are higher than that of firewood (4,436 cal/g) but lower than charcoal (6,552 cal/g) as shown in Table 5.1.

Table 5.1: Proximate analysis values of briquetted fuel made from sludge from a modified starch factory mixed with agro-residue and other fuel

Type of briquette fuel	**Fuel properties**						
	Moisture Content (%)	**Ash Content (%)**	**Volatile Matter (%)**	**Fixed Carbon (%)**	**Total sulfur (%)**	**Heating value (cal/g)**	**Period of burning (min.)**
pulp and paper mills sludge cake : fine wood-chip [6]							
100:0	4.54	49.54	20.27	30.37	0.974	3,247	-
90:10	4.98	35.09	42.49	22.45	0.947	3,753	-
80:20	4.19	39.38	29.81	34.03	0.861	3,923	-
70:30	4.75	38.60	20.07	41.52	0.745	4,072	-
60:40	5.01	36.06	27.83	35.51	0.745	4,112	-
50:50	5.20	30.23	36.06	34.51	0.733	4,184	-
40:60	5.78	25.63	39.69	34.18	0.699	4,158	-
Sugar industrial sludge : Bagasse [7]							
6:4	2.10	77.10	20.40	2.50	-	1,230.00	-
5:5	5.00	63.40	28.90	7.70	-	1,540.00	-
4:6	3.30	69.15	24.60	9.76	-	1,958.00	-
General fire wood [37]	4.30	1.40	73.32	25.27	-	4,436.00	40
General charcoal [37]	4.65	10.20	18.14	71.65	-	6,552.10	82
Briquette as standard of community product[41]	< 8	-	-	-	-	>5,000	-

Type of briquette fuel	Fuel properties						
	Moisture Content (%)	**Ash Content (%)**	**Volatile Matter (%)**	**Fixed Carbon (%)**	**Total sulfur (%)**	**Heating value (cal/g)**	**Period of burning (min.)**
Modified starch factory sludge and charcoal residue (from this study)							
5:5	**8.62**	**16.88**	**28.39**	**46.11**	**0.48**	**5,006**	**148.00**
4:6	**7.44**	**13.57**	**27.08**	**51.91**	**0.41**	**5,482**	**155.67**
3:7	**7.13**	**10.70**	**24.20**	**57.97**	**0.33**	**5,885**	**167.67**

5.3.3 Combustion Properties

The results show that the combustion time covered the whole burning cycle of briquette at the ratio of 5:5 4:6 and 3:7 were 148, 155.67 and 167.67 minutes, respectively. The long period of combustion time cycle is caused by high density of fuel. [40]

5.4 Optimum Ratio

Among the, appropriate mixing ratio of 5:5, 4:6 and 3:7, their physical properties and fuel properties are compared with those of commercial briquette in market (The Standard of community product, Thai industrial standard institute from Table 5.1) to determine the optimum ratio as follows:

Moisture Content

The recommended moisture content by The Standard of community product, Thai industrial standard institute is < 8 %. [41] Moisture content of the mixing ratio at 3:7 (7.13 %) is found the best as compared to those of other two ratios (8.62 % for 5:5, 7.44 % for 4:6).

Ash Content

The mixing ratio of 5:5 has the most ash content (16.88 %), followed by the mixing ratio of 4:6 (13.57 %) and at the mixing ratio of 3:7 has the least ash content (10.70 %). Among the there ratios, the mixing ratio of 3:7 should be the best since good fuel should have low ash content.

Heating Value

The recommended heating value by The Standard of community product, Thai industrial standard institute is > 5,000 cal/g. [41] Heating value of the mixing ratio at 3:7 (5,885 cal/g) is found the best as compared to those of other two ratios (5,006 cal/g for 5:5, 5,482 cal/g for 4:6).

Total Sulfur

Sulfur content in fuel poses as significant effect to the environment, therefore, good fuel should contain low total sulfur. As the result to found that the mixing ratio at 3:7 % (0.33 %) is found the lowest as compared to those of other two ratios (0.48 % for 5:5, 0.41 % for 4:6).

Considering overall parameters as mentioned above the mixing ratio of 3:7 is determined the optimum ratio for this study.

5.5 Economic Analysis

The briquetted fuel product at the mixing ratio of 3:7 is determined as the optimum ratio. Thus, the project has sludge productivity of 4 ton/day and the weight of briquette fuel product at the ratios 3:7 is 90.44 g (90.44 x 10^{-3} kg).

Briquetted fuel productivity yield = 480,000 kg/year

5.5.1 Cost/briquette

Determined:

1. This project period is 5 year, the operation system is operated 8 hours a day (300 day a year = 365 day/year-Sunday 52 day/year-holiday 13 day/year) and the productivity rate is 1,600 kg/day. The cold and low-pressure densification, which is conical screw press type, Crusher/a hammer mill chopper machine and mixing machine, are operated 8, 4 and 1.5 hr/day respectively.
2. Use 4 -labor force and labor cost is 160 bath/person/day.
3. The maintenance expense is 10 percent of machine purchase cost.
4. There is no raw materials cost.
5. There is no materials residue cost.
6. Determined at wholesale price of briquette product was 0.50 baht/briquette.

Then: at the ratio 3:7 0.09044 kg = 1 briquette (length 10 cm and diameter 5 cm)

1 kg = 1 briquette / 0.09044 kg

= 11 briquette/kg

Table 5.2 Productivity yield at mixing ratio of 3:7

Productivity yield (kg/year)	Sludge (kg/year)	Charcoal residue(kg/year)	Briquette /kg	Briquette /day	Briquette /year
480,000	144,000	336,000	11	17,600	5,280,000

Total cost = Fixed cost + Variable cost

= 730,000 (baht) + 509,645 (baht)

= **1,239,645 (baht)**

From : Briquette/year = 5,280,000 (briquettes/year)

Total cost/ briquette = 1,239,645 (baht)/5,280,000 (briquettes/year)

= 0.2348 (baht/briquette)

Fixed cost/ briquette = 730,000 (baht)/5,280,000 (briquettes/year)

= 0.1383 (baht/briquette)

Variable cost/ briquette = 509,645 (baht)/5,280,000 (briquettes/year)

= 0.0970 (baht/briquette)

5.5.2 Break even point

From :

$$N = \frac{F}{C-V}$$

Where:

N = product quantity, kg. (Break even point)

F = fixed cost, baht

C = product price, baht/ briquette

V = variable cost, bath/ briquette

If the wholesale price of briquette product was = 0.50 baht/briquette

Break even point = 730,000 (baht) / 0.5 – 0.0970 (baht/briquette)

= 1,811,414 (briquettes)

5.5.3. Payback period

Total cost = 1,239,645 baht

Productivity yield = 5,280,000 briquettes/year

Total revenue/year = price x productivity yield

<u>If the wholesale price of briquette product was = 0.50 baht/briquette</u>

Total revenue /year	= 0.50 (baht) x 5,280,000 (briquettes/year)
	=2,640,000 (baht)
Profit/briquette	= sales price – total cost
	= 0.50 – 0.2348 (baht/briquette)
	= 0.2652 (baht/briquette)
Average net of return	= 0.2652 (baht/briquette) x 5,280,000 (briquettes/year)
	= 1,400,256 (baht/year)
Payback period/year	= investment cost / average net of return
	= 1,239,645 (baht)/1,400,256 (baht/year)
	= 0.89 year

At the price as 0.50 baht/briquette or 5.50 baht//kilogram have to product briquette fuel 1,811,414 briquettes and the payback period is 0.89 year. Hence, it is appropriate to wholesale at this price.

In charcoal market, the wholesale price is 4.25 baht/kilogram (April, 2007) and the retail sale price is 8.5 baht/kilogram (which show that the wholesale price of briquette fuel product is more than general charcoal market.)

CHAPTER VI
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 The briquetted fuel at the mixing ratio of 5:5, 4:6, 3:7 yielded vertical compressive strength of 0.30, 0.34, and 0.38 kg/cm^2 respectively but gave horizontal compressive strength of 0.22, 0.16, 0.11 kg/cm^2 respectively. Its vertical compressive strength was greater than the horizontal compressive strength for their briquetted fuel. These findings suggest that this briquette should be put in vertical line to reduce bricking or damage from transportation [6].

6.1.2 The moisture content of the briquetted fuel at the mixing ratio of 5:5, 4:6 and 3:7 were 8.62 %, 7.44 % and 7.13 % respectively.

6.1.3 The ash content of the briquetted fuel at the mixing ratio of 5:5, 4:6 and 3:7 were 16.88 %, 13.57 % and 10.70 % respectively.

6.1.4 The heating value the briquetted fuel at the mixing ratio of 5:5, 4:6 and 3:7 were 5,006 cal/g 5,482 cal/g and 5,885 cal/g respectively.

6.1.5 The mixing ratio of 3:7 yielded moisture content of 7.13 %, ash content of 10.70 % and heating value of 5,885 cal/g and total sulfur of 0.33 %. Moreover, its physical properties such as density was 0.54 g/cm^3; compressive strength: vertical line was 0.38 kg/cm^2 whereas horizontal line was 0.11 kg/cm^2; and Shatter Index was 0.86 (indicating high tolerance level). The physical and fuel properties of this mixing ratio met the standards recommended by The standard of community product, Thai industrial standard institute. [41] Therefore, the mixing ratio of 3:7 is determined the optimum ratio.

6.1.6 At the optimum mixing ratio (3:7), the yielded briquette was 90.44 g (90.44×10^{-3} kg) in weight or 11 briquettes/kg (length 10 cm and diameter 5 cm). From economic analysis, when the wholesale price of this briquette is 0.50

bath/briquette, break even point is 1,811,414 briquettes/year and payback period should be 0.89 year.

6.2 Recommendations

Recommendations for further study are as follows :

6.2.1 Comparison studies on commercial briquetted fuel, the use of different binder and other briquetting technology are suggested

6.2.2 Measurement of the emission for air pollution contaminants from briquetted fuel combustion should be performed.

6.2.3 Factors that involved in briquetting process such as time consumption electric power losing should be investigated.

6.2.4 Efficiency of fuel heat utilization such as ignition and smoke should be assessed.

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APPENDIX

Appendix A
Experimental Results

A-1 Physical properties of Briquetted fuel product

Table A-1 : Characteristics of the briquetted fuel density**.**

Ratio (sludge: charcoal residue)	Outer diameter (cm)	Inner diameter (cm)	Length (cm)	Weight (g)	Volume (cm^3)	Density (g/cm^3)
5:5	4.76	1.34	9.40	57.67	153.94	0.37
	4.64	1.42	9.80	59.34	150.12	0.40
	4.67	1.37	9.50	57.21	148.64	0.38
Mean	**4.69**	**1.38**	**9.57**	**58.07**	**150.90**	**0.38**
S.D.	**±0.06**	**±0.04**	**±0.21**	**±1.12**	**±2.73**	**±0.01**
4:6	4.85	1.58	9.90	71.52	163.40	0.44
	4.72	1.47	10.20	71.86	161.08	0.45
	4.78	1.51	10.10	70.24	163.08	0.43
Mean	**4.78**	**1.52**	**10.07**	**71.21**	**162.52**	**0.44**
S.D.	**±0.07**	**±0.06**	**±0.15**	**±0.85**	**±1.26**	**±0.01**
3:7	4.90	1.69	10.00	90.42	166.06	0.54
	4.81	1.57	10.40	91.13	168.76	0.54
	4.88	1.73	10.20	89.76	166.72	0.54
Mean	**4.86**	**1.66**	**10.20**	**90.44**	**167.18**	**0.54**
S.D.	**±0.05**	**±0.08**	**±0.2**	**±0.69**	**±1.41**	**±0.00**

Table A-2 Compressive strength of the briquetted fuel

Ratio (sludge: charcoal residue)	Compressive strength : Vertical (kg/cm^2)	Compressive strength : Horizontal (kg/cm^2)
5:5	0.28	0.21
	0.31	0.19
	0.31	0.25
Mean	**0.30**	**0.22**
S.D.	±**0.02**	±**0.03**
4:6	0.33	0.16
	0.36	0.18
	0.34	0.15
Mean	**0.34**	**0.16**
S.D.	±**0.02**	±**0.02**
3:7	0.36	0.12
	0.39	0.11
	0.38	0.10
Mean	**0.38**	**0.11**
S.D.	±**0.02**	±**0.01**

Table A-3 : Shatter Index of the briquetted fuel

Ratio (sludge: charcoal residue)	Weight (Before Test)	Weight (After Test)	Shatter Index (R)
5:5	5.00	4.19	0.84
	5.00	4.21	0.84
	5.00	4.21	0.84
Mean	**5.00**	**4.20**	**0.84**
S.D.	**±0.00**	**±0.01**	**±0.00**
4:6	5.00	4.24	0.85
	5.00	4.29	0.85
	5.00	4.26	0.85
Mean	**5.00**	**4.26**	**0.85**
S.D.	**±0.00**	**±0.03**	**±0.00**
3:7	5.00	4.33	0.87
	5.00	4.28	0.86
	5.00	4.31	0.86
Mean	**5.00**	**4.31**	**0.86**
S.D.	**±0.00**	**±0.025**	**±0.00**

A-2 Fuel properties of briquetted fuel product

TableA-4 Proximate analysis of the briquetted fuel made from sludge mixed with charcoal residue

Ratio (sludge:charcoal residue)	Moisture Content (wt.%)	Ash Content (wt.%)	Volatile Matter (wt.%)	Fixed Carbon (wt.%)	Total sulfur (wt.%)	Heating value (cal/g)
5:5	8.55	16.95	28.46	46.04	0.496	4996
	8.7	16.82	28.33	46.15	0.472	5,035
	8.62	16.86	28.37	46.15	0.483	4,987
Mean	**8.62**	**16.88**	**28.39**	**46.11**	**0.48**	**5,006**
S.D.	**±0.08**	**±0.07**	**±0.07**	**±0.06**	**±0.01**	**±26**
4:6	7.53	13.47	26.91	52.09	0.401	5,503
	7.4	13.61	27.22	51.77	0.424	5,447
	7.38	13.64	27.11	51.87	0.410	5,496
Mean	**7.44**	**13.57**	**27.08**	**51.91**	**0.41**	**5,482**
S.D.	**±0.08**	**±0.09**	**±0.16**	**±0.16**	**±0.01**	**±31**
3:7	6.96	10.65	24.14	58.25	0.308	5,867
	7.23	10.78	24.27	57.72	0.361	5,916
	7.2	10.67	24.18	57.95	0.310	5,872
Mean	**7.13**	**10.70**	**24.20**	**57.97**	**0.33**	**5,885**
S.D.	**±0.15**	**±0.07**	**±0.07**	**±0.27**	**±0.03**	**±35**

Table A-5 Combustion time of the 500 g briquetted fuel produce from sludge and charcoal residue

Ratio (sludge: charcoal residue)	**Period of burning (min.)**
5:5	145
	152
	147
Mean	**148**
S.D.	**±3.61**
4:6	157
	162
	148
Mean	**155.67**
S.D.	**±7.09**
3:7	171
	164
	168
Mean	**167.67**
S.D.	**±3.51**

Table A-6 Weight and length of the briquetted fuel made from sludge mixed with charcoal residue

Ratio (sludge: charcoal residue)	**Weight (g)**	**Length (cm)**
5:5	57.67	9.4
	59.34	9.8
	57.21	9.5
Mean	**58.07**	**9.57**
S.D.	**±1.12**	**±0.21**
4:6	71.52	9.9
	71.86	10.2
	70.24	10.1
Mean	**71.21**	**10.07**
S.D.	**±0.85**	**±0.15**
3:7	90.42	10
	91.13	10.4
	89.76	10.2
Mean	**90.44**	**10.20**
S.D.	**±0.69**	**±0.20**

Appendix B

Pictures of the Briquette Machine

Figure B-1 Crusher machine

Figure B-2 The cold and low-pressure densification and the conical screw press

Pictures of the experiment

Figure B-3 Raw material to make briquette fuel

Figure B-4 Mixing

Figure B-5 Raw materials ready for the briquette machine

Figure B-6 The briquette forming from briquette machine

Figure B-7 Briquetted fuel from briquette machine

Figure B-8 The Briquetted fuel was cut

Figure B-9 Briquetted fuel product

Pictures of the appropriate ratios

(Sludge : Charcoal residue by volume)

5:5

4:6

3:7

APPENDIX C

1.Physical Analysis

1.1) Density : Density can be calculated as follows :

$$\rho = M / V$$

where : ρ = density of the briquette fuel, g /cm^3

M = mass of the briquette fuel, g

V = volume of the briquette fuel, cm^3

1.2) Compressive strength : Using a band saw and suitable jigs to cut a briquette into a cube of length that is twice their diameter. Then, put it on the Universal Testing Machine (UTM) and test it. Operate the apparatus until the failure of briquette occurs, then record the maximum force that indicated at failure. Repeat the test on the same samples for 3 times. Then calculate the compressive strength as follows:

$$\delta_c = F/A$$

where : δ_c = compressive strength, kg/ cm^2

F = maximum force applied, kg

A = mean area of the face of the sample, cm^2

1.3) Shatter index: Shatter index test is used to indicate the tolerance of briquette in utilization, transportation and storage. In each experiment, 5 kg of the briquette in a plastic bag allowed to be fall freely from a height of 2 meters on to the cement floor 3 times that would show the tolerance. To determine the mass of contents of one container use a horizontal movement on the 20 mm test sieve . Each piece it the increment has been in direct contact with the sieve plate. Then turn each piece of the briquette retained on the sieve to determine whether it passes through the sieve. Before the next increment is sieved, remove determination of their mass. For each sample the shatter index can be calculated as follows:

R = M1/M2

Where R = shatter index.

M1 = mass of piece of briquette retained ,g

M2 = mass of the total contents of briquette before sieving, g

2)Proximate Analysis

The proximate analysis has been conducted by using the American Society for Testing and Material (ASTM).

2.1) Moisture content analysis: the moisture of briquettes were determined using ASTM D31773, the oven shall be constructed to have a uniform temperature between the limit of (104^{o}C to 110^{o}C . The apparatus use in this experiment are drying oven, desiccators and crucible with covers. And the procedure is shown as follows:

(1) Heat the empty crucibles under the conditions at which the sample is to be dried (104^{o}C for 1 hr),place the cover in the crucible cool over a desiccant for 15 to 30 minutes . Weigh one gram of sample or dip out with a spatula from the sample bottle approximately 1 g of sample put it into the crucible.

(2) after removing the covers, quickly place the crucibles in a preheated oven at 104 ^{o}C to 110^{o}C through which passes a current of dry air. Close the oven at once and heat for 1 hour,, open the oven, cover the crucibles quickly, cool in a desiccators and weigh as soon as the crucibles have reached room temperature or until a constant weigh, The, calculate the per cent of moisture in the sample as follows:

Moisture content,%=(A-B)/A x100

Where: A = sample used, g

B = sample after heating, g

2.2) Ash content analysis: this test method covers the determination of ASTM D3174 the apparatus were electric muffle furnace, desiccators and crucibles with covers. The procedure are shown as follows:

(1)Heat the empty crucibles under the conditions at which the sample is to be dried (450 to 500^{o}C for 30 minutes), place the cover in the crucible, cool over a desiccant for 1 hour.

(2)Transfer approximately 1 of the sample to a weighed crucible and cover quickly, then place the crucible containing the sample in a cold furnace and heat gradually at such a rate that the temperature reaches 450 to 500^{o}C in hour.

(3)Continue heating so that at the end of the second hour a temperature of 700 to 750^{o}C is reached. Continue heating the ash at 700 to 750^{o}C for two additional hours. After that, remove the crucible from the furnace, place the cover on it, then cool it under condition to minimize moisture pick up, and weigh. Calculate the ash percent in the sample as follows:

Ash content,% = (A-B)/C x100

Where: A = weght of crucible with cover and residue, g.

B = weight of empty crucible cover. g

C = weight of analysis sample used, g

2.3) Volatile matter analysis: This test method covers the determination of ASTM D3175. The apparatus are electric muffle furnace, desiccators and crucibles with covers. The procedure is shown as follows:

(1) Heat the empty crucibles under the conditions at which the sample is to be dried (450 to 500^{o}C for 30 minute), place the cover in the crucible, then cool over a desiccant for 1 hr

(2)Weight 1 g of the sample in a weighed crucible, close with a cover that fits closely enough so that the carbon deposit does not burn away from the underside. Then insert directly into the furnace chamber that shall be maintained at a temperature of 950 + 20^{o}C After heating for a total of exactly 7 minutes , remove the crucible from the furnace and without disturbing the cover, cool in a desiccators . Weight as Soon as cold. The percentage loss of weight minus the percentage moisture content equals the volatile matter. Calculate the weight loss percent and volatile matter as follows:

Weight loss. % = (A-B)/Ax100

Where: A = weight of sample used, g

B = weight of sample used after heating, g

Volatile matter,% = C-D

Where: C = weight loss,%

D = moisture content,%

2.4) Fixed carbon analysis: the fixed carbon that remains after the removal of the volatile matter content and the ash content (39). The fixed carbon content (FC), which is expressed as percentage (by mass is given by the equation:

FC = 100 – (A+V)

Where : A = ash content, %

V = volatile matter, %

2.5) Heating value analysis: this test method follows ASTM D2015. The apparatus and facilities are the procedure is shown as follows:

(1)Regulate the weight of the pellets of benzoic acid in each series to yiekd approximately the same temperature rise as that obtained with the coal tested in the same laboratory . the usual range of masses is 0.9 to 1.3 g.

(2)Rinse the bomb, invert to drain, and leave undried , add 1.0 ml of water to the bomb prior to assembly for a determination.

(3) connect a measured length of ignition wire to the ignition terminals, with enough slack to allow the ignition wire to maintain contact with the sample.

(4)Assemble the bomb and charge it with oxygen to a consistent pressure between 2 to 3 MPa. This pressure must remain the same for each calibration and each calorific;-value determination. Admit the oxygen slowly into the bomb so as not to blow powdered material from the sample holder

(5)Fill the calorimeter vessel (bucket) with the measured quantity of water adjusted from 1.0 to 2.0^{o}C below room temperature but not lower than 20^{o}C Use the same mass ff water in each test weighed to +05g . For 2000 ml, the proper quantity can be obtained by use of a volumetric flask calibrated to deliver 2000 ±0.5 ml. Place the calorimeter vessel in the jacket, connect the electrodes, and place the stirrers, thermometers and cover in position . the starting temperature should be within ± 0.5^{o}C

(6)Allow 5 min. for attainment of equilibrium. Adjust the jacket match the calorimeter temperature within 0.01^{o}C Take calorimeter temperature reading at one-minute intervals until the same temperature, within one-tenth of the smallest thermometer subdivision, is observed in three successive readings. Record this initial temperature t_1 and 20^{o}C Adjust the jacket temperature to match the calorimeter temperature during the period of rise. Take calorimeter temperature readings and record this as the final temperature

(7)Open the cover and remove the bomb . Release the pressure at a uniform rate. Open the bomb and examine the bomb interior. Discard the test if unburned sample or sooty deposits are found. Wash the interior of the bomb with distilled water containing the titration indicator and titrate the washings with standard sodium carbonate solution.

(8)Remove and measure, or weigh, the combined pieces of unburned ignition wire and subtract from the original length, or weigh to determine the wire consumed in firing. If the wire is weighed, remove the ball of oxidized metal from the end of each piece of wire before weighing. Calculate the gross calorific value as follows:

$$Q_v \text{ (gross)} = \frac{[(tE)-e_1-e_2-e_3)]}{g}$$

Where: Qv = gross calorific value, Btu/lb

T = corrected temperature rise (^{o}C)

E = energy equivalent, Btu/lb

e = Correction for the heat of formation of HNO_3, Btu

e = Correction for heat of combustion of ignition wire, Btu

e = Correction for difference between heat of formation of H_2SO_4 from the heat of formation of HNO_3, Btu

g = mass of sample

(1) Preparation of sample and mixture: thoroughly mix on glazed paper approximately 1 g of the sample, weighted to nearest . 0.1 mg and 3 g of Eschka mixture. The amount of sample to be taken will depend on the amount of BaC_{l2} required. Porcelain capsule or crucible and cover with 1 g of Eschka mixture.

(2) Ignition: Heat the crucibles over an alcohol, gasoline, gas flame or electrically heated muffle. The use of artificial gas for heating the sample and the Eschka mixture is permissible only when the crucibles are heated in muffle.

(3)Subsequent treatment: Remove the crucible and empty contents into a 200 ml beaker and digest with 100 ml of hot water for ½ to ¾ hr, while stirring occasionally. Place the wet filter containing the precipitate of barium sulfate. Place the wet filter containing the precipitate of barium sulfate ($BaSO_4$) in a weighted crucible, fold the paper loosely over the precipitate to allow a free access of air but prevent spattering. Smoke the paper off gradually in a muffle furnace and at on time allow to burn with flame. After the paper is practically consumed, raise the temperature to approximately 800 ± 50^{o}C and heat to constant weight. Weight the barium sulfate to the nearest 0.1 mg.

(4) Blanks and Corrections: the preferred method of correction is by the analysis of a weighed ratio of a standard sulfate using the prescribed reagents and operation in full compliance with the standard. Using the same amount of all reagents that were employed in the routine determination. If the standard sulfate analysis procedure is carried out once a week, or if anew supply of a reagent is used, for a series of solutions covering the approximate range of the weight of $BaSO_4$ determined for the sample, the deficiency or excess founded by the appropriate check determination. This is more accurate than the simple reagent blank If very high-purity reagents are used or extra precaution is exercised, there may be no sulfate apparent in the blank In other word , the solubility limit for $BaSO_4$ has not been reached, some sulfate in the sample can remain in solution or redissolve. Calculate the sulfur content as follows:

$$\text{Sulfur,\%} = \frac{(A-B) \times 13.738}{C}$$

Where: A = weight of $BaSO_4$ precipitated, g.

B = weight of $BaSO_4$ correction ,g

C = weight of sample, g

Appendix D

Heating Value of Some Thai wood Charcoal

No.	Wood species		Wood density air dry (g/cm^3)	Heat Value (cal/g)	
				Normal m.c.	Over dry
1	Acacia catechu	สีเสียดแก่น	.77	6,567	-
2	Adina cordfolia	กว้าว	.70	7,579	7,936
3	Albizzia odoratissima	คาง	.74	6,478	6,914
4	Anisoptera scaphula	ปีก	.64	6,923	7,295
5	Bambusa arundinacea	ไผ่ป่า	-	6,999	7,493
6	Bauhinia sp.	เสี้ยนต้น	-	7,025	7,333
7	Berrya mollis	เลียงมัน	.90	6,502	6,881
8	Bruguiera conjugata	ประสัก	-	6,749	7,137
9	Brugiera cylindrica	ถั่วขาว	.88	7,207	7,595
10	Bruguiera parviflora	ถั่วดำ	.98	7,211	7,598
11	Butea frondosa	ทองกวาว	.52	6,607	7,189
12	Carallia brachiata	กอแห้ง	.72	6,688	7,111
13	Cassia garrettiana	แสมสาร	.85	6,160	6,477
14	Cassia siamea	ขี้เหล็ก	.96	6,713	-
15	Ceriops roxburghiana	โปรง	.84	5,250	-
16	Chukrasia velutina	ยมหิน	.90	7,632	7,950
17	Combretum quadrangulare	สะแก	.68	7,030	7,363
18	Cotylebium lanceolatum	เคี่ยม	.91	7,088	7,808
19	Crateva roxburghii	กุ่มน้ำ	-	7,014	7,253
20	Cratoxylon pruniflorum	ติ้ว,ต้าว	.57	6,804	7,170
21	Cratoxylon spp.	แต้ว	.80	7,640	7,836
22	Crypteronia paniculata	เมี่ยงอาม	.62	6,934	7,300
23	Cuseatia sp.	ผ่าสาม	-	5,846	6,109
24	Dalbergia cochinchinensis	พยูง	1.08	6,929	7,385
25	Diospyros castunea	นางดำ	.99	6,220	6,506

No.	Wood species		Wood density air dry (g/cm^3)	Heat Value (cal/g)	
				Normal m.c.	Over dry
26	Diospyros ehretioides	ตับเต่าตุ้น	-	7,208	7,548
27	Diospyros lucida	กระดูกด่าง	-	7,074	7,547
28	Dipterocarpus alatus	ยางนา	.70	6,055	6,261
29	Dipterocarpus obtusifolius	เหียง	.75	7,203	7,503
30	Dipterocarpus	พลวง	.88	6,955	7,392
31	tuberculatus	แคฝอย	.55	6,782	7,208
32	Dolichandrone crispa	ซาก	1.06	7,613	-
33	Erythrophloeum	ซาก	1.12	7,059	7,808
34	succirubrum	เมา	.77	6,866	7,296
35	Erythrophloeum teysmanii	สะเม็ดชุม	-	7,096	7,461
36	Eugenia grandis	นวล	-	6,641	7,072
37	Eugenia grata	พวา	.83	7,257	7,623
38	Garcinia merguensis	พวา	.83	7,203	7,638
39	Garcinia speciosa	ไข่เน่าหิน	.82	6,692	7,370
40	Garcinia sp.	ไข่เน่า	-	7,429	7,771
41	Gardinia obtusfolia	ตะกร้อ	.94	6,488	7,052
42	Gardinia sp.	กะบก	.98	6,745	7,016
43	Garuga pinata	เลือดควาย	-	6,821	7,218
44	Irvingia malayana	ตะแบก	.93	7,426	7,524
45	Knema conferta	ใหญ่	.72	6,825	7,185
46	Lagerstroemia calyculata	เสลา	-	6,501	7,059
47	Lagerstroemia tomentasa	กะถินบ้าน	-	7,718	8,048
48	Leucaena glauca	ก่อใบใหญ่	.43	7,084	7,556
49	Lithocarpus sp.	ทัง	.74	6,610	7,018
50	Litsea grandis	ฝาด	.72	6,888	7,613
51	Lummitzera littorea	มะม่วงป่า	-	6,391	6,756
52	Mangifera calonenra	สาธร	-	6,584	6,938
53	Millettia kangensis	,กระเจาะ	-	7,506	7,834
54	Mitragyna sp.	กระทุ่มโคก	.56	7,311	7,647
55	Morinda Coreia	ยอป่า	.50	6,686	7,275
	Nauclea orientalis	ก้านเหลือง			
	Odina wodier				

No.	**Wood species**		Wood density air dry (g/cm^3)	Heat Value (cal/g)	
				Normal m.c.	Over dry
87	Vitex limonifolia	ตีนนก	.92	7,303	7,827
88	Vitex pubescens	นน	.85	7,091	7,525
89	Vitex sp.	สวองหิน	-	7,095	7,588
90	Xerospermum sp.	แลนบาน	-	7,031	7,362
91	Xylia kerrii	แดง	.90	7,035	7,384
92	Zollingeria dongnaiensis	ขี้หนอน	.81	6,570	6,989
93	-	เกาหลี	-	6,907	-

Source : *กลุ่มพลังงานจากไม้ ส่วนวิจัยและพัฒนาผลิตผลป่าไม้*

Appendix E
The Standard of community product

มผช.๒๓๘/๒๕๔๗

มาตรฐานผลิตภัณฑ์ชุมชน
ถ่านอัดแท่ง

๑. ขอบข่าย

๑.๑ มาตรฐานผลิตภัณฑ์ชุมชนนี้ครอบคลุมเฉพาะถ่านอัดแท่งที่ทำจากถ่านผงหรือถ่านเม็ดมาอัดเป็นแท่ง หรือทำจากวัสดุธรรมชาติมาอัดเป็นแท่งแล้วเผาจนเป็นถ่าน

๒. บทนิยาม

ความหมายของคำที่ใช้ในมาตรฐานผลิตภัณฑ์ชุมชนนี้ มีดังต่อไปนี้

๒.๑ ถ่านอัดแท่ง หมายถึง ผลิตภัณฑ์ที่ได้จากการนำวัตถุดิบธรรมชาติ เช่น กะลามะพร้าว กะลาปาล์ม ซังข้าวโพดมาเผาจนเป็นถ่าน อาจนำมาบดเป็นผงหรือเม็ดแล้วอัดเป็นแท่งตามรูปทรงที่ต้องการ หรือนำวัตถุ ดิบธรรมชาติ เช่น แกลบ ขี้เลื่อย มาอัดเป็นแท่งตามรูปทรงที่ต้องการแล้ว จึงนำมาเผา เป็นถ่าน

๒.๒ ค่าความร้อน หมายถึง พลังงานความร้อนที่ได้จากการเผาถ่านหนัก ๑ กรัม มีหน่วยเป็นแคลอรีต่อกรัม

๓. คุณลักษณะที่ต้องการ

๓.๑ ลักษณะทั่วไป

ในภาชนะบรรจุเดียวกันต้องมีรูปทรงเดียวกัน ขนาดใกล้เคียงกัน มีสีดำสม่ำเสมอ ไม่เปราะ อาจแตกหักได้บ้าง

๓.๒ การใช้งาน

เมื่อติดไฟต้องไม่มีสะเก็ดไฟกระเด็น ไม่มีควันและกลิ่น

๓.๓ ความชื้น

ต้องไม่เกินร้อยละ ๘ โดยน้ำหนัก

๓.๔ ค่าความร้อน

ต้องไม่น้อยกว่า ๕ ๐๐๐ แคลอรีต่อกรัม

๔. การบรรจุ

๔.๑ หากมีการบรรจุ ให้บรรจุถ่านอัดแท่งในภาชนะบรรจุที่สะอาด แห้ ง และสามารถป้องกันความเสียหายที่อาจเกิดขึ้นกับถ่านอัดแท่งได้

๔.๒ น้ำหนักสุทธิของถ่านอัดแท่งในแต่ละภาชนะบรรจุ ต้องไม่น้อยกว่าที่ระบุไว้ที่ฉลาก

๕. เครื่องหมายและฉลาก

๕.๑ ที่ฉลากหรือภาชนะบรรจุถ่านอัดแท่งทุกหน่วย อย่างน้อยต้องมีเลข อักษร หรือเครื่องหมายแจ้งรายละเอียดต่อไปนี้ให้เห็นได้ง่าย ชัดเจน

(๑) ชื่อผลิตภัณฑ์

(๒) ชนิดของวัสดุที่ใช้ทำ

(๓) น้ำหนักสุทธิ

(๔) เดือน ปีที่ทำ

(๕) ข้อแนะนำในการใช้

(๖) ชื่อผู้ทำ หรือสถานที่ทำ พร้อมสถานที่ตั้ง หรือเครื่องหมายการค้าที่จดทะเบียนในกรณีที่ใช้ภาษาต่างประเทศ ต้องมีความหมายตรงกับภาษาไทยที่กำหนดไว้ข้างต้น

๖. การชักตัวอย่างและเกณฑ์การตัดสิน

๖.๑ รุ่นในที่นี้ หมายถึง ถ่านอัดแท่งที่ทำโดยกรรมวิธีเดียวกัน ที่ทำหรือส่งมอบหรือซื้อขายในระยะเวลาเดียวกัน

๖.๒ การชักตัวอย่างและการยอมรับ ให้เป็นไปตามแผนการชักตัวอย่างที่กำหนดต่อไปนี้

๖.๒.๑ การชักตัวอย่างและการยอมรับ สำหรับการทดสอบลักษณะทั่วไป การบรรจุ และเครื่องหมายและฉลากให้ชักตัวอย่างโดยวิธีสุ่มจากรุ่นเดียวกัน จำนวนไม่น้อยกว่า ๓ กิโลกรัมเมื่อ

ตรวจสอบแล้วทุกตัวอย่างต้องเป็นไปตามข้อ ๓.๑ ข้อ ๔ และข้อ ๕ จึงจะถือว่าถ่านอัดแท่งรุ่นนั้นเป็นไปตามเกณฑ์ที่กำหนด

๖.๒.๒ การชักตัวอย่างและการยอมรับ สำหรับการทดสอบและการใช้งาน ความชื้น และค่าความร้อน ให้ใช้ตัวอย่างที่ผ่านการทดสอบตามข้อ ๖.๒.๑ แล้วจำนวนไม่น้อยกว่า ๓ กิโลกรัม เมื่อตรวจสอบแล้วตัวอย่างต้องเป็นไปตามข้อ ๓.๒ ถึงข้อ ๓.๔ จึงจะถือว่าถ่านอัดแท่งรุ่นนั้นเป็นไปตามเกณฑ์ที่กำหนด

๖.๓ เกณฑ์ตัดสิน

ตัวอย่างถ่านอัดแท่งต้องเป็นไปตามข้อ ๖.๒.๑ และข้อ ๖.๒.๒ ทุกข้อ จึงจะถือว่าถ่านอัดแท่งรุ่นนั้นเป็นไปตามมาตรฐานผลิตภัณฑ์ชุมชนนี้

๗. การทดสอบ

๗.๑ การทดสอบลักษณะทั่วไป ภาชนะบรรจุ และเครื่องหมายและฉลาก

ให้ตรวจพินิจ

๗.๒ การทดสอบการใช้งาน

ให้ทดสอบโดยการจุดตัวอย่างถ่านอัดแท่งแล้วตรวจพินิจ

๗.๓ การทดสอบความชื้น

ให้ใช้วิธีทดสอบตาม ASTM D 3173

๗.๔ การทดสอบค่สความร้อน

ให้ใช้วิธีทดสอบตาม ASTM D 5865

๗.๕ การทดสอบน้ำหนักสุทธิ

ให้ใช้เครื่องชั่งที่เหมาะสม

Appendix F

ตารางแสดงอัตราค่าจ้างขั้นต่ำใหม่ ซึ่งได้ประกาศให้มีผลใช้บังคับ ตั้งแต่วันที่ 1 มกราคม 2550

ค่าจ้างขั้นต่ำ	พื้นที่
191	กรุงเทพมหานคร นนทบุรี นครปฐม ปทุมธานี สมุทรปราการ และสมุทรสาคร
186	ภูเก็ต
172	ชลบุรี
168	สระบุรี
162	นครราชสีมา
161	ระยอง
160	ฉะเชิงเทรา พระนครศรีอยุธยา และ ระนอง
159	เชียงใหม่ และ พังงา
156	กระบี่ และ เพชรบุรี
155	กาญจนบุรี จันทบุรี และ ลพบุรี
154	ราชบุรี สมุทรสงคราม และ สระแก้ว
152	ตรัง ประจวบคีรีขันธ์ ปราจีนบุรี สงขลา สิงห์บุรี และ อ่างทอง
150	เลย และ อุดรธานี
149	ชุมพร ตราด ลำปาง ลำพูน สุโขทัย และ สุพรรณบุรี
148	กาฬสินธุ์ ขอนแก่น นครพนม นครศรีธรรมราช นราธิวาส บุรีรัมย์ ปัตตานี

ค่าจ้างขั้นต่ำ	พื้นที่
	ยะลา สตูล และ หนองคาย
147	กำแพงเพชร ตาก นครนายก นครสวรรค์ พัทลุง พิษณุโลก เพชรบูรณ์ สุราษฎร์ธานี และ อุตรดิตถ์
146	ชัยนาท ชัยภูมิ เชียงราย มหาสารคาม มุกดาหาร ยโสธร ร้อยเอ็ด ศรีสะเกษ สกลนคร หนองบัวลำภู และ อุทัยธานี
145	พิจิตร แม่ฮ่องสอน สุรินทร์ อุบลราชธานี และอำนาจเจริญ
144	พะเยา และแพร่
143	น่าน

หมายเหตุ: อัตราค่าจ้างขั้นต่ำพื้นฐานเป็นเงินวันละ 143 บาท

BIOGRAPHY

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