Feasibility Studies of Biomass Pellet from Sewage Sludge of Concentrated Latex Industry

Arif Billah

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Science in Sustainable Energy Management
Prince of Songkla University
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Author Mr. Arif Billah

Major Program Sustainable Energy Management

Major Advisor

....

(Asst. Prof. Dr. Wirach Taweepreda)

Co-advisor

....

(Asst. Prof. Dr. Kuaanan Techato)

Examining Committee:

....Chairperson
(Dr. Khamphe Phoungthong)

....Committee
(Asst. Prof. Dr. Wirach Taweepreda)

....Committee
(Asst. Prof. Dr. Kuaanan Techato)

....Committee
(Dr. Watsa Khongnakorn)

....Committee
(Dr. Thitipone Suwunwong)

The Graduate School, Prince of Songkla University, has approved this thesis as fulfillment of the requirements for the Master of Science Degree in Sustainable Energy Management.

....
(Prof. Dr. Damrongsak Faroongsarng)
Dean of Graduate School

This is to certify that the work here submitted is the result of the candidate's own investigations. Due acknowledgment has been made of any assistance received.

………………..……...……...............Signature

(Asst. Prof. Dr. Wirach Taweepreda)

Advisor

……. ………...……...……...............Signature

(Asst. Prof. Dr. Kua-anan Techato)

Co-advisor

…………...……………….........Signature

(Mr. Arif Billah)

Candidate

I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

………………………Signature

(Mr. Arif Billah)

Candidate

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Author Mr. Arif Billah

Major Program Sustainable Energy Management

Academic Year 2018

Abstract

The objective of this study is focused on the transformation of concentrated natural rubber latex Industry sewage sludge into useful energy by efficient and environment-friendly combustion processes. Sewage sludge is non-digested sludge which has been taken from the wastewater treatment. Biomass is one kind of valuable energy source to the world. Producing biomass from wastewater sewage sludge could be possible only after the treatment of wastewater. Normally, the moisture content in sewage sludge is 92%-99.5%, after dewatering through a decanter the moisture content comes 6.52 ± 0.11%.

Generally, the produced sewage sludge is disposed by spreading on land as fertilizer, landfill and combustion but they were banned due to environmental impact from sewage sludge. Presently, pellet fuel is becoming more interest, because of its demand and advantages. It is more effective and environmentally friendly than landfilling, agricultural uses of wastewater sewage sludge.

The sewage sludge characteristics were analyzed including the moisture contents, volatile matter, fixed carbon, hydrogen, carbon, the nitrogen of the sewage sludge, and heavy metals. The ash content and higher heating value of the biomass pellet fuel from concentrated natural rubber latex Industry sewage sludge was investigated. The heating value of biomass pellet fuel is higher than 3,620 ± 12 kcal/kg which is suitable for an alternative source of energy. Nowadays, many industries are using biomass for their boilers combustion. So, they possibly will use their own wastewater sewage sludge to produce the pellet fuel by way of energy and it would be economically beneficial as well.

Keywords: Fuel Pellet, Latex Industry Sewage Sludge Characteristics, Heavy Metals Content of Latex Industry Sewage Sludge, Ash Content of fuel pellet, Latex Industry Sewage Sludge pellet fuels heating value.

Acknowledgments

I would Principally like to thank **Assistant Professor Dr. Wirach Taweepreda**, as my advisor from the faculty of Polymer Science, Prince of Songkla University, for offering suggestions to improvement my work, proposal, research work until finished thesis. I would like to extend my thanks to **Assistant Professor Dr. Kua-anan Tachato**, as my co-advisor from the faculty of Environmental Management, Prince of Songkla University, for his tremendous guidance and support during the completion of this work. I would like to thank the Polymer Science Laboratory Service Center and Scientific Equipment Center Laboratory Service Center, Prince of Songkla University, my workplace for allowing me to join this master's degree program with kindly support. I would like to thank the Department of Sustainable Energy Management in Faculty of Environmental Management, Prince of Songkla University for supporting the facilities and everything. Finally, my thanks also send to my **Respected parents and my beloved family** members for all their love, encouragement and support me in my years of study and my entire life. In conclusion, I recognize that this research would not have been possible without financial assistance. For financial support, I would like to acknowledge the Faculty of Environmental Management, Prince of Songkla University.

The author alone assumes responsibility for discussion and conclusions of this thesis and any errors of it may contain.

Lastly, the most special thanks go to all readers.

Arif Billah

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List of Abbreviations and Symbols

- µm: Micrometer
- As: Arsenic
- C: Carbon
- Cd: Cadmium
- Cl: Chlorine
- Co: Cobalt
- Cr: Chromium
- Cu: Copper
- Fe: Iron
- H: Hydrogen
- Hg: Mercury
- HHV: Higher heating value
- Kcal/kg: Kilocalories per kg
- kg: Kilogram
- m3: Cubic meter
- MJ/ kg: Megajoules per kilogram
- N: Nitrogen
- Ni: Nickel
- O: Oxygen
- PAHs: Polycyclic Aromatic Hydrocarbons
- Pb: Lead
- PCBs: Polychlorinated Biphenyls
- PCDDs: Polychlorinated dibenzo-p-dioxins
- PCDFs: Dibenzofurans
- Ppm: Parts per million
- S: Sulfur
- Sn: Stannum
- Ti: Titanium
- US: United States
- Zn: Zinc

CHAPTER 1

Introduction

1.1. Background of Research

The energy demand is increasing nowadays in the entire world, reasons are the human population growth and there is global anxiety to fulfill the energy demand. Sustainable development has some significant challenges for the reason of highly increasing of population growth along with the urbanization rate. Thus, the technology demand for energy becoming more interests. Because of the population and urbanization increasing rate, the production of wastewater is increased. Presently, the necessity of energy is mostly provided by the source of energy which makes from pellet fuels. However, the anxiety of using biomass pellets are raising gradually, because of its availability in the future. Currently, the number of concentrated natural rubber latex Industry is high and producing a process of wastewater from concentrated natural rubber latex Industry is also high. So, to produce more energy it is necessary to recycle the "Concentrated natural rubber latex Industry sewage sludge" by converting it to an alternative source of energy.

In the sustainable development society growing production of municipal sewage sludge is a big challenge to manage it. Municipal European Union countries are predictable to produce about 8 million tons of municipal sludge each year. In 2010, the amount of stabilized municipal sewage sludge of Poland reached 613,000 million tons (dry matter), besides that the amount raises about 30,000 million tons per year (dry matter) on average (Stelte et al., 2011). Presently, the production of sewage sludge is not stopped, it's growing up continuously. Landfilling and incineration are the prime ways in the United State of America to handling sewage sludge (Gude, 2015). Lithuania produced 82,000 tons of sewage sludge per year and kept 60% to landfill, 26% for composted, 14% for agriculture (Praspaliauskas, Pedišius, & Reviews, 2017). Landfilling use as fertilizer, combustion these are the traditional treatments of sewage sludge. But the limitations of land create a big problem to practice landfilling treatment of sewage sludge (Folgueras, Alonso, & Díaz, 2013). The existence of organic contaminants and heavy metals, in sewage sludge, so the use as fertilizer is limited for this contains sewage sludge (Górka, Cimochowicz-Rybicka, & Kryłów, 2018).

Sludge has created through effluent or wastewater treatment and the wastewater is a combination of the water which arrived from residential, institutional, business and industrial institutions, in conjunction with water, storm-water and surface water (Gajalakshmi, Ramasamy, & Abbasi, 2002). Wastewater may contain bound undesirable elements, as well as organic, inorganic and cytotoxic substances, moreover as pathogenic, infective or disease-causing micro-organisms (McGhee & Steel, 1991). The core clusters of organic solids in wastewater are proteins, carbohydrates, fats, and oils. The protein contains concerning about 16% nitrogen, and in conjunction with urea are the key bases of nitrogen in wastewater (McGhee & Steel, 1991). For the form of crude type, the wastewater cannot be disposed of several motives. Firstly, biological decomposition of the organic materials in wastewater consumes oxygen and therefore, diminishes the amount of availability within received water for aquatic life, also the decomposition additionally produced a big quantity of malodorous gases. Secondly, several pathogenic or else disease-causing micro-organisms in unprocessed wastewater are a threat to human lives. Then thirdly, it's harmful compounds particularly substantial metals which would be dangerous to equally plants and animals, and lastly, the occurrence of phosphates and nitrogen possibility lead to uninhibited growth of aquatic plants (Gajalakshmi et al., 2002).

Wastewater is considered as a continuous process in the future. A large amount of sewage sludge is a big problem for our wastewater treatment plant in over the world. Because some traditional treatment of sewage sludge is not benefit-able to our environment like the landfill, agricultural uses of sewage sludge. So, discover some idea to produce energy from sewage sludge could be a part of filling up the energy demand. Energy conversion (biomass pellet fuel) from sewage sludge can produce energy. And, it could be a good and environmentally friendly treatment of sewage sludge. For wastewater sludge processing, dewatering of sewage sludge is a very significant stage. To reduce the cost of further sludge processing like thermal and transportation cost, dewatering curtails the mass and capacity of wastewater sewage sludge. Without dewatering of sewage sludge, it's not possible to produce biomass from the sludge. Because normally, the moisture content in sewage sludge is 92%-99.5% (Górka et al., 2018). Among the wastewater sources, the large part of wastewater comes from industry. So, every day a large amount of sewage sludge is generated from different industry. They must discharge that somewhere to reduce pollutions inside the industry. Industries need a lot of energy for every day's work. Nowadays, many industries are using biomass fuels for their boilers combustion. So, they could use their own wastewater sewage sludge for boilers combustion, by converting it to pellet fuel and it might be economical as well.

Thailand, Malaysia, and Indonesia produce about 70%-80% raw rubber and supply in South-East Asia (M. Mohammadi, H. C. Man, M. A. Hassan, & P. L. J. A. J. o. B.

Yee, 2010b; Xiaofei & Guohua, 2008). The natural rubber statistic (2008) says, the number of rubber factories in Thailand are 700, in Malaysia 357, the area under rubber plantation are 2 million hectares in Thailand, 1.3 million hectares in Malaysia, Natural rubber production in year 3.09 million tons in Thailand, 1.072 million tons in Malaysia, global supply of natural rubber 33.5% in Thailand and 10.7% in Malaysia (Chaiprapat, Sdoodee, & recycling, 2007; M. Mohammadi, H. C. Man, M. A. Hassan, & P. L. Yee, 2010a; Mohammadi et al., 2010b). Since the production of rubber products from natural rubber needs a large amount of water to operate, a large amount of wastewater generated by the effluent process (Babel & Rungruang, 2008; Leong, Muttamara, & Laortanakul, 2003). Industries must discharge their wastewater, nowadays they dewatered sludge and throughout to any empty land to landfill or use it as fertilizer in agricultural land. But, these practices are not good, because usually, sludge comprises heavy metals and toxic organic substances, pathogens, and nutrients such as nitrogen and phosphorus triggering eutrophication (Gil-Lalaguna, Sánchez, Murillo, Atienza-Martínez, & Gea, 2014; Jang, Cho, Park, Ha, & Park, 2014) which is harmful to the environment and soil too. Based on these backgrounds, this study is very essential for the latex industry sewage sludge management treatment and the environment pollutions as well.

1.2. Research Objectives

The main purpose of this study is to investigate the reliable treatment of the latex industry's sewage sludge, use it as a biomass resource to produce energy by making pellet fuel, and check the heating value and the percentage of the remaining ash content of the pellet fuels.

The specific objectives of this study are:

(1) To determine the technology of using sewage sludge as a biomass resource to produce energy.

(2) To determine the heating value and the remaining ash content of the biomass pellets from sewage sludge of concentrated latex industry.

1.3. Research Questions

(1) What is the benefit of the heating value of pellet fuel?

(2) What is the best solution to treat sewage sludge?

1.4. Research Significance

The importance of this research is the result of producing energy with lowing ash content less than 10% from concentrated natural rubber latex Industry sewage sludge mixed wood sawdust. The treatment of concentrated natural rubber latex Industry sewage sludge is friendly to our environment. Concentrated natural rubber latex Industry sewage sludge contains some heavy metals so it is not good to use as fertilizer or landfill due to the bad impact on the environment. Biomass pellet fuel is a reliable solution to the sludge. Fuel pellets have several applications starting from residential cookstove to large scale power plants. The standard pellets can be easily adopted in any biomass-based energy conversion devices, such as residential boilers, residential stoves, gasifiers, industrial boilers, etc. Pellets are easy to use and need less storage. It is also less dangerous to deliver than fossil fuels. And biomass pellet fuels are more advantageous because of the high energy content and weight. And it is more economical because we can get sludge free from industries, only the dewatering and transporting cost is a need, but it's not so high.

1.5. Research Scopes

This research has been done at Songkhla province in Thailand. There is much Concentrated Natural Rubber Latex Industry in this kingdom. The sewage sludge was obtained from "TAVORN RUBBER INDUSTRY" in Sadao. Mainly, the research was done by ten stages respectively.

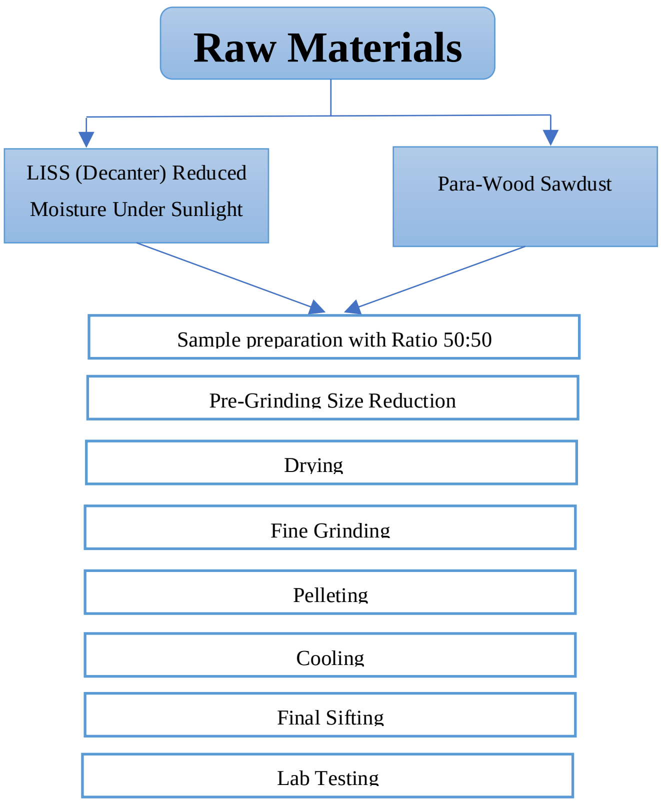

Figure 1. 1 Thesis Flowchart.

CHAPTER 2

Literature Reviews

2.1. Wastewater Treatment-Sewage Sludge Sources

Presently, the increasing production of sewage sludge in the world is a witness, and this is expected up to the next century that will be continued (Górka et al., 2018). Sewage sludge production depends on the percentage of household's wastewater which is allied to the vital treatment plants, and the progressive contraction of pollutions bounds on the effluent discharges, to achieve the higher efficiency of wastewater treatment and it is capable by the availability as well as, the increasing of environmental awareness also cannot be ignored (Sänger, Werther, & Ogada, 2001). On the other hand, for the difficulty of increasing transportation and disposal cost, every attempt should be made to reduce the amount of sludge removal by lowering the content of water from sludge (Krupp, Schubert, & Widmann, 2005). The limitations of the environmental, financial and technological issue which is given by a country or a city, that depends on the net quantity of sludge disposal availability (Kelessidis & Stasinakis, 2012).

The water which has been affected by human use is called wastewater. Wastewater comes from any sewer inflow like the commercial, domestic, industrial activities surface runoff (Tilley, Lüthi, Morel, Zurbrügg, & Schertenleib, 2008). So, wastewater is a byproduct of commercial, domestic, industrial activities. Figure 2.1 shows the hold or domestic wastewater and Figure 2.3 shows the industrial wastewater. Sewage sludge obtained after processing of wastewater from any wastewater treatment plant. Various sources of wastewater have different characteristics. Municipal wastewater comes from community activities, domestic wastewater comes from household activities, industrial wastewater comes from industrial activities.

Figure 2. 1 Domestic Wastewater.

Household or domestic activities wastewater sources are: (Almeida, Butler, & Friedler, 1999; Eriksson, Auffarth, Eilersen, Henze, & Ledin, 2003; Wilkie, Hatzimihalis, Koutoufides, Connor, & Technology, 1996).

(1) Flush toilets black water which contains human excreta and wipes.
(2) Floors, clothes, cars, dishes, etc. washing greywater comes from household activities.
(3) Cooking oil, lubricating oil, cleaning liquids, pesticides, drinks, etc. Surplus manufactured liquids are coming household or domestic activities.

Industrial activities wastewater sources are: (Fernández-Nava, Maranon, Soons, & Castrillón, 2008; Sedlak et al., 2005; Shen et al., 2012).

(1) Natural gas and oil produced water.
(2) Hydraulic fracturing used water.
(3) Acid and alkali manufacturing extreme pH wastewater.
(4) Natural rubber latex industry used water.
(5) Waters from industrial processing.
(6) Cyanide production, metal plating, pesticide manufacturing, etc. toxic wastewater.
(7) Pharmaceutical Manufacturing Organic or non-bio-degradable wastewater.

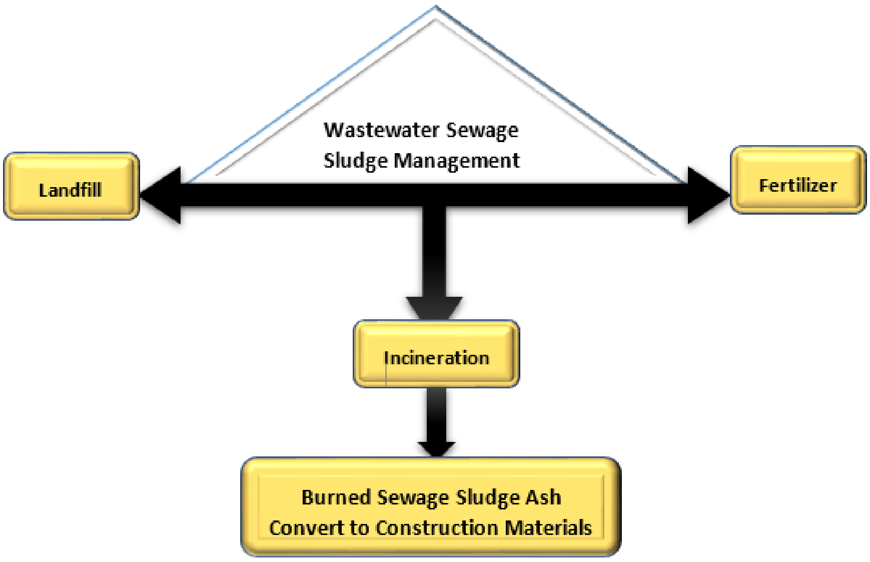

Figure 2. 2 Diagram of Wastewater Sewage Sludge Management.

2.2. **Wastewater Sewage Sludge and Remaining Ash Managements**

Wastewater sewage sludge disposal outlets are used as landfilling, fertilizer, incineration, and dumping in the sea (Lowe & Journal, 1993). Management of wastewater

Sewage sludge is a momentous challenge for all countries. The amount of sewage sludge generating is increasing continuously, so the handling process of wastewater sewage sludge becomes more ticklish. The definite concept of water protection will fail without any dependable disposal treatment of sewage sludge.

Figure 2. 3 Industrial Wastewater**.**

There are two main ways to managed sewage sludge: discharged to the land for landfilling and disposed to the agriculture land to use as fertilizer, that is subjected to composting and anaerobic digestion (Rizzardini & Goi, 2014). Incineration of sewage sludge is also a popular method for sewage sludge disposal and after burning of sewage sludge there are remain some ash and that ash could be used for preparing construction materials. Figure 2.2 shows the diagram of wastewater sewage sludge management.

2.2.1. **Landfill**

Disposal of wastewater sludge means sewage sludge disposed to any empty land, and it is a traditional process to manage the sewage sludge. This is a very common and easy way to dispose of sewage sludge. Sewage sludge comes from wastewater branches and then directly disposed to empty land for landfill without any treatment Figure 2.4 Landfill treatment of sewage sludge has started in some major cities in Europe, England, and the USA in the year 1875 (Stein, Boulding, Helmick, & Murphy, 1995). It was a forced choice for sewage sludge disposal. Without any treatment or receiving any watercourses, disposal of wastewater to the land can cause our environment became heavily polluted (Alnahhal & Spremberg, 2016).

Figure 2. 4 Landfilling by Sewage Sludge.

Raw sewage discharged directly into waterways were designed by many “sewage farms” as a preferred alternative way (Stein et al., 1995). But due to environmental pollution and the limitations of land, limited this practice. With the effective technological development of municipal sewage treatment, this procedure was progressively abandoned. So, the management of sewage sludge by landfilling was not the proper and environmentally friendly way. Presently, many kinds of research have done for the sewage sludge treatment which is much better than landfill.

2.2.2. **Fertilizer**

Composting and anaerobic digestion are the second way to dispose of sewage sludge in the agriculture land as fertilizer (Rizzardini & Goi, 2014). Directive 86/278/EEC has incited to used wastewater sewage sludge in the agriculture land as fertilizer for more than twenty years (Directive, 1986). After processing of sewage sludge and send it in cultivation land can improve the soil fertility in the long term (Jorge & Dinis, 2013). In Europe, many wastewater treatment plants recycle their sewage sludge on agricultural land (Smith & Sciences, 2009). Figure 2.5 shows fertilizer of wastewater sewage sludge. This plan is not accepted by all European countries, but it's supported by several scientific and restrictive authorities. There are many public debates about the uses of wastewater sewage sludge as a fertilizer in cultivation land, Netherlands and Flanders the Northern European counties stopped the practice of sewage sludge in their cultivated land. Sewage sludge has few hidden pollutants like heavy metals, pathogens, and many organic compounds, it is a proved question of the agronomical value of sewage sludge in agricultural land. Because this type of pollutants is not good for human, crops, animals, agricultural land as well as. In the wastewater heavy metals are existing due to the physical-chemical processes of wastewater (Hsiau & Lo, 1998).

Figure 2. 5 Fertilizer of Sewage Sludge.

Uses of wastewater sewage sludge in the cultivated land have limitations because of some major elements like copper, cadmium, zinc, lead, nickel, chromium, mercury this type of heavy metals (Hsiau & Lo, 1998). Table 1 shows some typical metals which are contained in sewage sludge.

Table 2. 1 Typical Metal Contains in Sewage Sludge are (Hsiau & Lo, 1998; Metcalf & Eddy, 1991).

Name of metal's	**Sewage sludge (Dry) mg/kg Range**	**Median**
Zinc	102-49,000	1700
Selenium	1.7-17.3	5
Molybdenum	0.2–214	4
Manganese	32–9871	260
Iron	1000–155,000	17,000
Cobalt	11.4–2490	30
Cadmium	1–3.420	10
Arsenic	1.2–230	10
Chromium	10.1–991,000	500
Copper	85–17,001	800
Lead	14–26,001	500
Mercury	0.7–56	6
Nickel	2–5400	80
Tin	2.7–329	14

Heavy metals are harmful to the soil for a long time. The soil might be lost its fertility for the contaminations of wastewater sewage sludge. More amount of chromium(Cr) in anaerobically digested sludge limited the use for agricultural purposes (Fytili, Zabaniotou, & reviews, 2008).

2.2.3. **Incineration**

In Europe, incineration is the most popular systems to dispose of wastewater sewage sludge. It is becoming more popular for legal limitations, and the harmful effects of other sewage sludge disposal system like agricultural use, sea disposal and landfilling. For this reason, (O. Malerius & J. J. C. E. J. Werther, 2003) thought the incineration will be the good treatment method in the long term for sewage sludge management. The method of incineration could be filled our energy demand with modern technology. Incineration can reduce a large amount of sludge approximately 10% after mechanical dewatering. By thermal processing, toxic organic compounds will flop from sewage sludge (Khiari, Marias, Zagrouba, & Vaxelaire, 2004). This technology can remove the odor from sewage sludge for our generations. Nevertheless, this is not a complete method of sewage sludge disposal, because approximately 30% of ash remain after incineration (O. Malerius & J. J. C. E. J. Werther, 2003). However, from the side of economic and environmental benefits by this treatment its better than other disposal methods. But should have the focus to find some advantageous treatment for sewage sludge ash management.

2.2.3.1. **Burned Sewage Sludge Ash Convert to The Construction Materials**

Presently, ash from burned sewage sludge is creating a big problem. Generally, the ash from burned sewage sludge disposed to the landfill. But for its metal content, it is considered highly toxic. As the development of our community, the demand for building materials is growing day by day. So, need to find some different sources for developing construction materials, and ash from wastewater sewage sludge could be an ideal source of that. The burning process of wastewater sewage sludge produced the ash, and it is one kind of waste, so ash must be disposed of somewhere. Some researcher is trying to find methods for producing building materials from sewage sludge ash like aggregates of concrete, as produce bricks, tiles, like an element of the synthesis of lightweight materials, like a raw material to cement production, subbases, embankments in road constructions, like alternative for cement or sand in cement stabilized bases (Smol, Kulczycka, Henclik, Gorazda, & Wzorek, 2015). Now it is an important challenge for waste management in the world to maintain the waste (Uyarra & Gee, 2013). Sustainable improvement in waste management is a significant target for the European Union (Ravindra, Kaur, & Mor, 2015). We can reduce our landfilling disposal cost of ash from burned sewage sludge, by producing building equipment (Donatello & Cheeseman, 2013). Some researcher found a few sources of waste that might be used for construction equipment's (Safiuddin, Jumaat, Salam, Islam, & Hashim, 2010). Here, in **Table 2.2** shows some possibility of producing construction materials and some sources of waste. Building materials from sewage sludge ash have some benefits like, can reduce the landfilling transportation cost, can get a new helpful source of building materials. During the burning process can destroy any pathogens from sewage sludge, and we can reduce our frost damage also.

Table 2. 2 Possibility to Use Burned Sewage Sludge Ash as Construction Materials and Some Sources (Safiuddin et al., 2010).

Name of Waste	Type of Waste	Materials can use for construction
Waste bricks, Tiles, concrete-rubble, etc. Construction and demolition debris.	Industrial	Concrete bricks block, coarse and fine aggregates, subcase pavement materials.
Waste steel slag rubber tire quarry dust, granulated blast-furnace slag, Phosphogypsum waste glass.	Industrial	Fine and coarse aggregates, tiles ceramic products, fine and coarse aggregates blended cement concrete bricks blocks.
Ash of palm oil fuel, Ash of rice husk, Organic fibers ash of palm oil fuel, Fly ash bottom ash.	Agricultural industry	Wall panels roof sheets reinforced polymer composites, aggregate concrete supplementary cementing materials, particle boards insulation boards cement boards, blended cement bricks tiles blocks.
	Mining/mineral	Tiles block surface finishing materials, Concrete bricks.

2.3. **Energy (biomass pellet fuel) Conversion of Wastewater Sewage Sludge**

Biomass fuel is one kind of valuable energy source to the entire world. Wastewater considered as a continuous process for our future. A large amount of Sewage sludge is a big problem for our wastewater treatment plant hole over the world. Because some traditional treatment of sewage sludge is not beneficial to our environment like the landfill, agricultural uses of sewage sludge. So, as the energy demand of community biomass pellet fuel from sewage sludge could be beneficial for us to reduce pollution and fill-up our energy demand. Because producing energy from wastewater sewage sludge having more interest (Rulkens, Bien, & Technology, 2004). The diagram of energy conversion from sewage sludge screening in Figure 2.6**.**

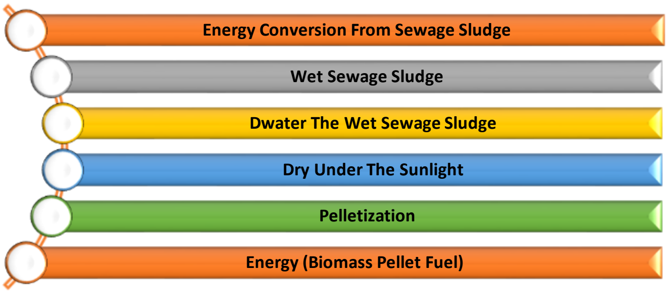

Figure 2. 6. Diagram of Energy Conversion of Sewage Sludge.

The energy efficiency of wastewater sewage sludge depends on the dewatering process of sewage sludge because after dewatering we can take the sludge for further energy processing. By producing energy from sewage sludge, it could be possible to reduce the amount of wastewater and our environment pollution as well as, because of contains heavy metals, toxic, pathogens of sewage sludge. Nowadays, fuel pellet from dry sewage sludge as energy is an environmentally and economical idea. It is a gracious solution for sewage sludge treatment and combustion also. Pellet fuel has some advantages like the handling process is not so critical it's simple, it can reduce the transportation cost of sewage sludge, it can give better storage abilities and energy as well as.

2.3.1. **Characteristics of Wastewater Sewage Sludge and Fuel (Energy) Components**

From the technical point of view, the municipal sewage sludges chemical and physical properties make the materials difficult to utilize. That matter is basically conditioned through the high-water contents in sewage sludge, for the green sludge it may exceed 99%, and by mechanical dewatering that can be reduced 80-65% (M. J. F. p. t. Wzorek, 2012). It is difficult to handle and transport the sewage sludge for the reason of high-water contents and the sludge is greasy. Moreover, there are some biologically operative substances remains in the sewage sludge, for this sake sewage sludge has the stinking odor and that is repulsive to the environment. Sewage sludge can be used as fuel for organic components fraction because organic components help to incineration. In the case of dry matter, sludge contains 3%-5% at the primary stage of sludge and have 55-70% organic substances (Werther, Ogada, & science, 1999). The content of organic substances reduced (dry matter) 40-55% after the fermentation process (Stasta, Boran, Bebar, Stehlik, & Oral, 2006). The Sewage sludge calorific value affected the possibility of that decline. The residue when methane series fermentation suggest the calorific value among 6.7–12.0 MJ/ kg (dry matter), that is below for the first sludge (dry matter 13.30– 17.51 MJ/kg) and for the excess activated sludge (15.00– 17.00 MJ/kg dry matter) (Houdková, Boráň, Ucekaj, Elsäßer, & Stehlík, 2008; Werle & Wilk, 2010; Werther et al., 1999). Some samples of sewage sludge properties are presented in Table 2.3 which is related to the energy.

Table 2. 3 Few samples, the formation of biologically stabilized sewage sludge *(M. J. F. p. t. Wzorek, 2012)*.

Parameters Proximate analysis	Unit	1 Sewage (Wzorek & Król, 2009)	2 Sewage (Marta Otero, Gómez, Garcia, & Morán, 2008)	3 Sewage (M Otero, Dıez, Calvo, Garcıa, & Morán, 2002)	4 Sewage (Groß, Eder, Grziwa, Horst, & Kimmerle, 2008)
HHV	MJ/kg	10.99–12.91	9.51	9.08	13.35
Ash*	%	35.51–40.28	53.80	36.62	43.30
Water	%	79.25–82.50	3.90*	76.20	8.50*
Volatilesa*	%	47.56–56.95	42.81	50.11	50.81
(Dry matter) Ultimate analysis wt.%					
Cl	%	0.86–0.18	-	0.058	-
N	%	3.98–4.37	3.10	3.94	3.79
H	%	3.37–3.72	3.30	3.66	4.12
C	%	23.75–27.24	22.70	21.81	30.10
O	%	26.57–27.90	15.50	18.07	17.84
S	%	1.11–1.18	1.60	1.10	0.85

HHV- high heating value.

* In the dry matter.

(PCBs, PCDFs, PAHs, and PCDDs) such as several organic micropollutants are contained in the municipal sewage sludge. However, By the heavy metals, the maximum significant and maximum numerous sets of micropollutants are formed. Through the process of wastewater treatment transfer the micropollutants and accumulate them in the materials of sewage sludge, and among a broad range, their contents in the sewage sludge may vary. Few samples of heavy metal contents in different type of sewage sludge are displayed in Table 2.4.

Table 2. 4 The contents samples of hint component in sewage sludge (M. J. F. p. t. Wzorek, 2012).

Heavy Metals ppm	**1(Sewage Sludge) (Wzorek & Król, 2009)**	**2(Sewage sludge) (Marta Otero et al., 2008)**	**3(Sewage sludge) (Shih, Chang, Lu, & Chiang, 2005)**	**4(Sewage sludge) (Fytili & Zabaniotou, 2008)**
Sn	0.06–1.13	23.1–27.1	-	1.7–17.2
Tl	0.15–0.64	-	-	2.6–329
As	2.77–6.72	6.2–15.3	-	1.1–230

Ni	1.96–33.39	16.0–50.0	37–179	23.2–36.5
Pb	36.34–64.89	20.0–49.5	26–465	13–223.0
Cr	28.0–53.56	106.0–380.0	66–2021	10–990,000
Fe	1236–57,994	23,586–26,000	-	1000–154,000
Zn	1931–3503	2432–6100	354–640	101–49,000
Co	2.88–9.30	10.9–40.0	-	11.3–2,490
Cu	104–193.5	80.0–800.0	80–2300	204–1337
Hg	0.91–2.57	1.99–2.50	-	0.6–56
Cd	1.03–3.09	-	2.3–10	1–3.410

It's possible to use the sewage sludge as fuel when it's moisture content is low, and possible to use with some other fuels or in a composition fuel product it may be the role as a component.

A high amount of organic carbon exists in wastewater sludge.(Griffith, Barnes, Raymond, & Technology, 2009) Griffith says, in a carbon isotope study and he recommended that the percentage of organic-carbons in the sludge of wastewater are 14%-25% of fossil-origin, and the percentage of plant-origin are 75%-86%. After the treatment of wastewater sewage sludge, the initial energy content is almost 60% (Shizas & Bagley, 2004). From various research, some data from pieces of literature which are based on coal, biomass, and the wastewater sewage sludge gross heating values are shown in Table 2.5. Compared to other low-rank fuels dried sewage sludge having an energy content and it's an enchanting source of biomass energy that is shown in the table.

Table 2. 5 Coal and Biomass of Wastewater Sewage Sludge Calorific Values are (Syed-Hassan et al., 2017).

Fuel	**HHV, dry basis (MJ/ kg)**
Sewage sludge	11.11 – 22.11 (16.06)
Leucaena leucopenia	12.77
Willow	21.21
Miscanthus	18.74
Sugarcane bagasse	17.06
Soybean stalk	17.51
Camphor	18.41
Hazelnut husk	17.15
Walnut shell	17.19
Olive stone	17.55
Lignite	11.81 – 21.91 (19.19)

Bituminous coal	25.41 – 33.16 (29.39)
Sub-bituminous coal	20.11– 29.00 (27.07)
Sawdust	18.14 – 21.40 (19.15)
Wood pellet	18.31 – 19.61 (19.08)
Hazelnut shell	18.41
Chinese fir	18.39
Switchgrass	19.61
Wheat straw	16.01
Cardoon	17.34
Paulownia	19.59
Poplar	19.38
Rice straw	14.96 – 15.87 (14.81)

2.4. **Wastewater Sewage Sludge Mechanical Dewatering Process Technology**

Wastewater sludge processing and dewatering of sewage sludge is a very much significant echelon. To reduce the cost of further sludge processing, like thermal and transportation cost dewatering can curtail the mass and capacity of wastewater sewage sludge. The high-water-content of sludge increases the sludge processing cost. Normally, the moisture content in sewage sludge is 92%-99.5% (Górka et al., 2018). Curtailing the moisture content of sewage sludge helps to reduce the sludge processing cost. It may help the following disposal of sewage sludge, to reduce the sludge volume by lessening the minimum amount of water content from sewage sludge (Christensen, Keiding, Nielsen, & Jørgensen, 2015). High organic compounds content of sewage sludge such as the gel may reduce the speed of the dewatering process, so the sewage sludge processing is problematic (Górka et al., 2018). By using the chemical and physical treatment of sewage sludge conditioning can be finished like, give high temperature, freezing the sludge, and for change the formation of sludge by adding some conditioners like (cement dust, coal dust, and ash) these are the physical treatment of sewage sludge conditioning. And adding some organic or inorganic compounds with sludge like (anionic or neutral polyelectrolytes, polymerized cationic) or (aluminum salts and iron) these are the chemical treatment of sewage sludge conditioning. Some researchers did some studies about water treatment sewage sludge utilization (Ahmad, Ahmad, & Alam, 2016). It is confirmed that aluminum precipitates can improve the dewaterability of sewage sludge by adding it with sludge (Górka et al., 2018). To improve dewatering put low pressure and low temperature to conditioning sewage sludge for wet oxidation method. By using this technique, the industrial wastewater sludge and municipal wastewater sludge is stabilized, because biological sludge can be smashed by giving high pressure and temperature. But after that dewatering is needed for remaining slurry, though in the sludge oxidation treatment, it can transfer the oxidizable constituents. However, now discuss three dewatering process: decanter centrifuges, rotary drum filters, and Belt presses and discuss the good and bad benefits of the dewatering process.

2.4.1. **Rotary Drum Filters**

In the year 1872, the rotary drum filter/vacuum dram filter was published as a wastewater sludge filter (K. S. Sutherland & Chase, 2011). It is one of the venerable filters to dewater the sludge from the liquid. It is used for washing and dewatering the wastewater sludge.

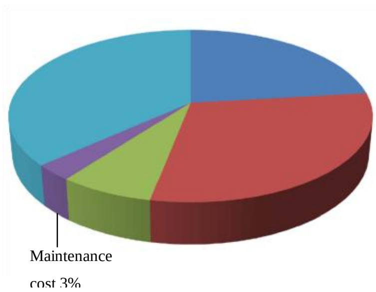

Figure 2. 7 Low Maintenance Cost Among Infrastructure, Capital, Labor, and Energy Cost (Shao et al., 2015).

It is made by a big rotating drum which is covered by a cloth. In the drum 50% - 80% space covered by cloth and under the cloth there is a water container to keep the water from sludge. The drum is rotating inside and that cloth which is covered in the drum sucked the slurry and throughout the water last, only the solid remains as a cake There is a dewatering zone Figure 2.8 inside the drum, so the drum is rotated out and then the cake is dewatered there. The continuous sucking by the cloth, the cake is become dewatered and throughout the water from it. At the final stage, drum discharge the cake as a solid product. String, belt, roll, pre-coat, scraper, these type of five discharge methods are used for rotary drum filers (Barnebl & Bliem, 1971; Haug & TECHNOLOGY, 1999).

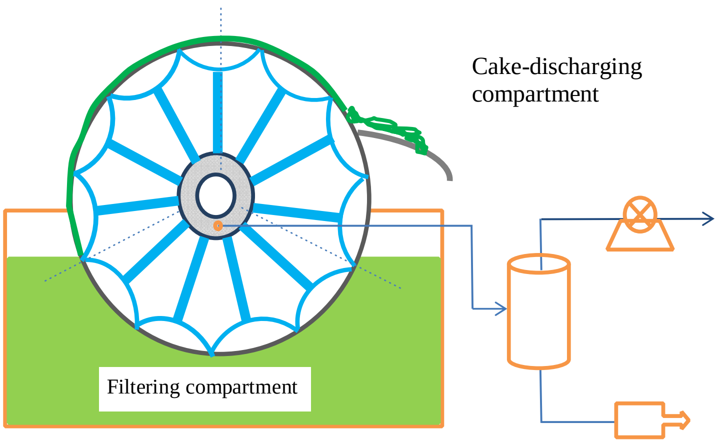

Figure 2. 8 Rotary Drum Filter Process (Shao et al., 2015).

Vacuum filter is not perfect for the large particle contains sludge, it is perfect for smaller particle less than 5 µm, because in a vacuum should not apply more than 0.25 bar (Wakeman, 2007). So, for the municipal sewage sludge, the vacuum filter is not suitable, but it is suitable for some industrial sewage sludge.

The advantages and disadvantages of rotary drum filter are*:* (Cripps, 1994; Milledge, Heaven, & Bio/Technology, 2013; Spellman, 2013; Wakeman, 2007).

Advantages

(1) The operating cost of the rotary drum is low Figure 2.7 because of its continuous and automatic operating system.
(2) It can control the cake thickness by its rotating speed variation.
(3) It has five discharge systems, so by changing its discharge system, we can modify very easily its process.

Disadvantage

(1) Up to 1 bar is the limitation of its pressure difference and structure as well.
(2) Other accessories are needed such as the vacuum pump, agitators beside the drum filter.
(3) The cake has remained moisture after discharge.
(4) Its energy consumption is high.
(5) It is not perfect for big particle sewage sludge.

2.4.2. **Belt Press Filter**

The belt filter or belt press filter is used for dewatering the liquid and separating water from the sludge, in the chemical industry or wastewater treatment plant. For apple juice, cider and winemaking production it used for these type of work (Citeau, Larue, & Vorobiev, 2011). The main applications of belt press filter are; dewatering of sewage sludge, pears apple and other fruits juice extraction, winemaking as well as, it is also used for industrial, urban and municipal wastewater treatment plant (Hwang, Min, & Science, 2003).

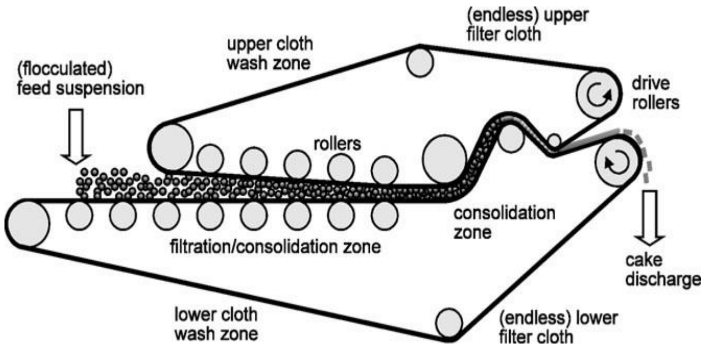

Figure 2. 9 Belt Press Filter Diagram (Wakeman, 2007).

By two nonstop filter cloths, the belt filter can be marked. Inside the belt filter, there are feed hopper, gravity zone, cloths, water drainage way, and pressure section for outside, there is a cake receiver Figure 2.9. Some passing pairs are there to rolling the clothes and belts through a system of rollers. Sludge comes from the feed hopper to the gravity zone, clothes are rolling there continuously, and water goes down to the drainage way and the sludge is become dewater as a cake. Finally, the cakes come out from the pressure section to the receiving container.

For ignoring the striking of belt filter, the feed must be flocculated and to be effectively finished the process of a belt filter, this is a key of a successful filtration and the gravity drainage has benefited when it is primarily fed to the belt. By polyelectrolytes process, the Conditioning of the sludge is continuing until come to the drainage zone. Few functional data of a belt press filter for municipal sewage sludge are specified in Table 2.6. It is suggested by Spinosa, that the concentration should be >3%–4% for a feed sludge (Spinosa, 1986).

Table 2. 6 Few Functional Sample Data For Municipal Sewage Sludge of a Belt Press Filter (Spinosa, 1986).

Type of Sludge	**Input percentages of solids concentration (%)**	**Cake percentages of solids concentration (%)**	**Polyelectrolyte dosage (kgte^{-1})**
Thermally conditioned	5.1–8	39–51	-

Aerobically digested	1–9	12–31	0.9–5.1
Raw activated	.6–4	12–33	1.1–6.1
Raw primary	3–11	26–45	0.7–4.6
Raw primary activated	3.1–7	21–35	0.7–5.1
Anaerobically digested	4–9	19–35	1.6–4.6

Advantages and limitations of belt press filter are*:* (Bahr, 1975; Hamilton et al., 2003; Hwang et al., 2003; Johnson, Buchanan, & Newkirk, 1992; Krishnamoorthy & Transfer, 2010; Pan, Huang, Cherng, Li, & Lin, 2003; Snyman, Forssman, Kafaar, Smollen, & Technology, 2000; Viessman, Hammer, Perez, & Chadik, 1998; Wakeman, 2007).

Advantages

(1) Belt press filter takes less time to dewatering sludge because its startup and shutdown time is quicker, and it has less noise for machine run.
(2) The availability of belt press filter is good and it’s easy to monitor from floor level, it has a long life to run and very easy to maintain so its cost for stuffing is low.
(3) Initial and running costs are low.

Limitations

(1) Need a big amount of water and time for frequently washing feeds.
(2) For a few feeds it is less operative without mixing from the digester, so need more operator and increase costs.
(3) For the high content of oil and grease feeds, the percentage of solid in the cake can be lesser to use the blinding process of belt press filter.

2.4.3. **Decanter Centrifuges**

Decanter centrifuges have a high rotational speed to disperse the elements from the various density. Most of the industrial works such in a single mixture which contains grease, solid and liquids together, decanter centrifuges are used to separate these types of different components. Centrifuges can continuously disperse the solid components from liquids in the slurry, for this reason, it is used mostly in wastewater treatment plant, oil, chemical, and food processing industries. For good drilling procedure of oil in the whole mud system, a centrifuge is the 5th purification machine. Horizontal orientation vertical orientation, and Conveyor/Scroll, these are the main types of the centrifuge. A vertical decanter centrifuge placed Figure 2.11 vertically and rotating assembly mounted vertically, at the bottom side is supported by a single bearing, from the drive head the bowl and the gearbox are suspended (Green, 2008). For high pressure and/or higher temperature operational works use vertical decanter centrifuge, because of its rotational and orientation seals provided at one end. Some functional data of a horizontal decanter centrifuge for the different type of municipal sewage sludge are specified in Table 2.7. However, open and non-pressurized horizontal decanter centrifuge is cheaper than the vertical decanter centrifuge (Records & Sutherland, 2001).

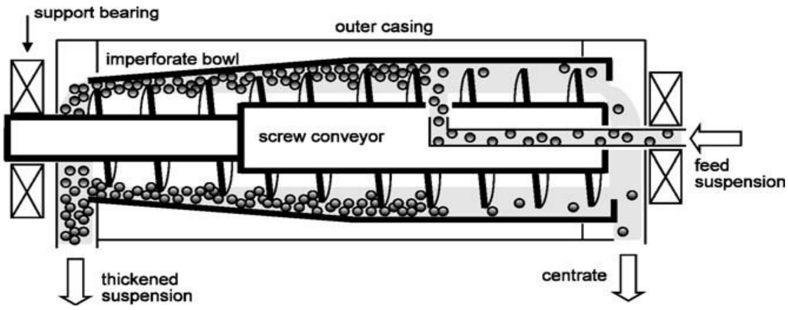

Figure 2. 10 Horizontal Decanter Centrifuges Schematic Diagram (Wakeman, 2007).

Horizontal decanter centrifuges placed horizontally, and rotating assembly is mounted horizontally, it is supported by two bearing both end sides which has a rigid frame Figure 2.10, for high-pressure applications, it’s sealing surface is very good (Altieri, Di Renzo, & Genovese, 2013). Feed entries from one side and solids clamped to the Conveyor/Scroll then the cakes come out from another side. It can produce 18,000 kg of solids per hour from up-to 300 US gallons (1.1 m^3) liquid feed per minute (Miers, Olson, & Gray, 1977).

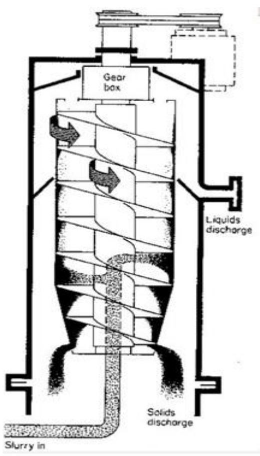

Figure 2.11 Vertical Decanter Centrifuges Schematic Diagram (K. Sutherland & Records, 2001).

By (centri-Dry) in a same machine thermal can drying and dewatering both, these are significant innovations of decanter centrifuges (Schilp, Leung, Hegarty, Ismar, & Kluge, 2000) the adjustable gate and compound beach of decanter centrifuges as well (Leung, 2001; Wallace, Shapiro, & separation, 1999).

Advantages and limitations of decanter centrifuges are*:* (Franzen, Alit, Michaud, Probstmeyer, & Tammone, 1994; Hensley & Hilpert, 2006; Hohne, Kontarinis, & Titel, 1981; Jackson, 1981; Records & Sutherland, 2001; Wakeman, 2007; Wells, 1993).

Advantages

(1) No odor problems and it has a clean look.

(2) Need a small area for installation, the device setup procedure is very easy, startup and shutdown processes are also fast.

(3) Decanter has various operating functions for dewatering.

(4) Though the machine is not so big, it has higher throughput (up to about 90 te h^{-1}) capacity.

(5) It has the capability to handle the higher solids content feeds.

(6) Compared to other processes it needs fewer labor costs.

(7) Compared to other machine-like belt press filter, it has high-level performance ability.

Limitations

(1) For high gravity force, it has high energy consumption.

(2) It can cause vibration and noise.

(3) It has high equipment capital costs.

Figure 2. 12 Decanter Centrifuge.

Table 2. 7 Horizontal decanter centrifuge for the different type of municipal sewage sludge functional data (Spinosa, 1986).

Type of Sludge	**Feed percentages of solids concentration (%)**	**Cake percentages of solids concentration (%)**	**Conditioner dosage (kg te–[1])**	**Solids recovered (%)**
Thermally conditioned primary + activated	9.2–14, 13.1–15	35.2–40, 29–35	0, 0.6–2.0	75–85, 90–95
Raw primary + activated	4–5.1	19–25	1.6–3.6	91–95
Raw primary	5–8.1	26–36, 28–36	0.6–2.6, 0	91–95, 70–90
Raw activated	0.6–3	4.2–12	5.1–7.5	86–90
Digested primary + activated	2.1–4, 4.1–7	15.1–18, 17–21	3.6–5.0, 2.0–4.0	90–95, 90–95

Chapter 3

Research Methodology

3.1. Methodology Overview

As a raw material the latex industry sewage sludge (LISS) was attained from "TAVORN RUBBER INDUSTRY" in Sadao, Songkhla province and another raw material para-wood sawdust was obtained from furniture industry in Songkhla province. Sewage sludge was dewatered by using decanter (Figure 3.1) for desirable parameter value and after that the dewatered sludge was exposed to the sunlight to reduce moisture.

After that in order to determine the remaining moisture content in sewage sludge and the characterization for conversion into biomass pellet fuel. The analyze done based on the American Standard Test Methods (ASTM D7582). The samples of dried sewage sludge were analyzed using ultimate analysis and proximate analysis and bomb calorimeter (Model: C5000) in order to find the heating values and chemical compositions of the sewage.

Thermogravimetric analysis (TGA) (Model: TGA 8000) method was used in proximate analysis in order to determine the Moisture Content (MC), Volatile Matter (VM), Fixed Carbon (FC) and Ash Content (AC) in weight percentage (wt %). The samples of dried sewage sludge (Decanter) and the biomass pellet fuel was heated 30^{o} C to 750^{o} C in the thermogravimetric analyzer sample weight approximately 11-15mg at a heating rate 10^{o}C/ min were analyzed in the TGA based on the American Standard Test Methods (ASTM EN 15104). The weight of the samples was recorded continuously as the temperature increased.

The samples were analyzed about 6 hours in order to make sure the process fully complete for determination of fixed carbon, volatile matter and ash content. In ultimate analysis, the CHN analyzer (Leco CHN- 630-100-500) was used to determine the Carbon (C), Hydrogen (H), Nitrogen (N) in the samples.

The total heavy metal determination is done by using atomic absorption spectrometer (AAS) method. The metals analyzed include: As, Cd, Cr6+, Cr3+, Cu, Pb, Zn, Hg. Samples digestion was carried out according, Acid digestion and hydride generation AAS method (Epa, 1992, 1996), Acid digestion and direct air acetylene flame method (EPA, 1996, 2007), Alkaline digestion and colourimetric method (Epa, 1992, 1996), Acid digestion, direct air acetylene flame, colourimetric (Epa, 1992, 1996, 2007) and calculation method, Acid digestion and direct air acetylene flame method (EPA, 1996, 2007), Acid digestion and direct air acetylene flame method (EPA, 1996, 2007), Acid digestion and direct air acetylene flame method (EPA, 1996, 2007), Acid digestion and cold vapor AAS method (EPA, 2007) respectively.

This experiment was carried out with the ratio of 50% latex industry sewage sludge (LISS) and 50% para-wood sawdust biomass pellet fuel. Which is shown in Figure 3.2. The sample is then directed towards the Andritz biomass pelleting factory for further processing.

Figure 3. 1 Sewage Sludge Drying Using Decanter and Sunlight.

Figure 3. 2 Fuel Pellet (50%sewage sludge + 50%wood sawdust).

Process flow for biomass pelleting of Andritz biomass pelleting factory are presenting below.

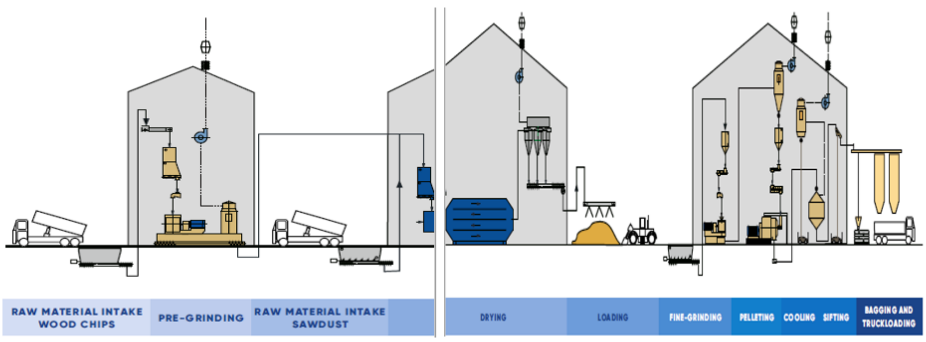

Figure 3. 3 Biomass Pelleting Process Flow

3.1.1. **Pre-Grinding Size Reduction**

Raw material intake: Dried sewage sludge size was reduced in a chipper and hammer mill before entering the drying process. Use of the 43“hammer mill in the pre-grinding stage boosts particle size distribution using an energy-efficient rotor and comes with replaceable wear liners for the grinding chamber.

3.1.2. **Drying**

Raw material intake: Sawdust and sewage sludge the drum drying system dehydrates raw materials before they enter into the fine-grinding process. To ensure the product is dried evenly, the raw materials are conveyed pneumatically through a stream of hot gases and dried in a convective process until it reaches a residual moisture content of approximately 10–12%.

3.1.3. **Fine-Grinding**

By finely grinding the raw materials in the 43“fine grinding hammer mill it is possible to achieve most homogeneous pelletizing raw material. Size lessening is important by way of it upsurges the total surface range, accordingly the quantity of contact points for interparticle tie prior to the palletization procedure (Mani, Tabil, Sokhansanj, & bioenergy, 2004). Noteworthy exertions are made to appraise the energy prerequisite throughout biomass size lessening. The milling appearance and energy prerequisite are sturdily reliant on the hammer mill screen size, and the finer grind entails high explicit energy. The large surface area and the open fibers of the ground product facilitate steam absorption in the cascade mixer. Any kind of binder was not used in this experiment. Binder should be used to make wood pellet or sewage sludge pellet, but for the co-pelletization no need to add binder. The accumulation of sewage sludge with wood sawdust might pointedly condense the dependence on the gravity to acquire pellets with solidity and high density (Jiang et al., 2014). Binder forms a matrix or bridge to make solid inter-particle bonding with biomass mechanisms (Pradhan, Arora, & Mahajani, 2018). Latex industry sewage sludge has rubber particles and it helps bonding for pelleting with Para-wood sawdust. Steam and high temperature soften the lignin in the para-wood sawdust and sludge, which allows pelleting to take place without the addition of binders. The 43“hammer mill variable hammer speed to optimize the grinding process by carrying the wood meal on to a cyclone or filter for separation.

3.1.4. **Pelleting**

Used flat die pellet mills, to ensure high output and effective control over pellet quality.

3.1.5. **Theoretical Aspects of Pelletization**

Pelletizer be made up of perforated solid steel die through combine of rollers. Through gyrating the rollers and die, the feedstock is forced through the perforations to form densified pellets (J. S. Tumuluru, Wright, Kenney, & Hess, 2010). Efforts have been made due to understand the rudimentary mechanism of the palletization process. Figure 3.4 shown a parallel illustration for a flat die pellet mill. As stated by (Holm, Henriksen, Hustad, Sørensen, & fuels, 2006), under stable state circumstances, the pelletizing pressure can statistically be stated as:

$$P_Y = \frac{P_{N_0}}{\nu_{RL}}\left(e^{4\mu\nu_{RL}c} - 1\right) \qquad (1)$$

whereas, PY indicates the pressure in longitudinal way, P_{N0} directs pre-stressing pressure, ν_{RL} is the Poisson's ratio, μ indicates the coefficient of friction, and c denotes the compression ratio.

$$\nu_{RL} = \frac{\text{longitudinal strain}}{\text{radial strain}} = \frac{dv}{dy}\bigg/\frac{\Delta r}{r} \qquad (2)$$

$$\mu = \frac{dF_\mu}{dF_N} \qquad (3)$$

$$c = \frac{y}{D} \qquad (4)$$

P_Y can be enhanced such that pellets making must be at a nominal energy input along with at an extreme pellet mill capacity whereas sustaining the pellet quality. Eq. (1) specifies that P_Y increases exponentially by the compression ratio (c), while possession the other parameters persistent. At what time pressure turn into too high, the pellet mill gets worked, as the rollers are not able to afford the required pressure to impulsion the material out. This results in gratuitously high energy approval of the pellet mill. Conversely, at what time the pressure is moreover low, pellets of average quality cannot be produced (Stelte et al., 2011).

However, the compression ratio (c) is a machine precise parameter which leftovers same for a given palletization unit throughout the operation. Assumed the values for ν and μ apparently differ with biomass natures, moisture gratified and temperature (Pradhan, Mahajani, & Arora, 2018). Conceivably, modification in any of those dispensation parameters will have an effect on PY, and by this means on overall process besides on pellet quality (Pradhan, Mahajani, et al., 2018). Descending friction upsurges when shredded biomass departs through the channel, the die temperature intensifications consistently. Once die influences a certain temperature and the friction declines to a confident level, the pellet can be strapped out; for the reason that at raised up temperatures flows to the surface and assists the binding procedure (Kaliyan, Morey, & bioenergy, 2009; Stelte et al., 2011; J. S. J. B. e. Tumuluru, 2014). Moisture content similarly controls the P_Y despite the fact of reducing the glass conversion temperature (J. S. J. B. e. Tumuluru, 2014). Moisture in biomass performances as a plasticizer which intensifications the smoothness of biomass constituent part, ensuing in lower friction inside the press frequency and accordingly reducing P_Y. Additionally, a diminution in biomass particle size rises friction because of upsurge in contact zone and thus consequences in a higher P_Y. Experimentations on palletization fundamentals are typically executed using single pellet press unit, expecting that the single pellet press (SPP) unit tolerate simulation of the palletization procedure of a marketable pellet mill (Pradhan, Mahajani, et al., 2018).

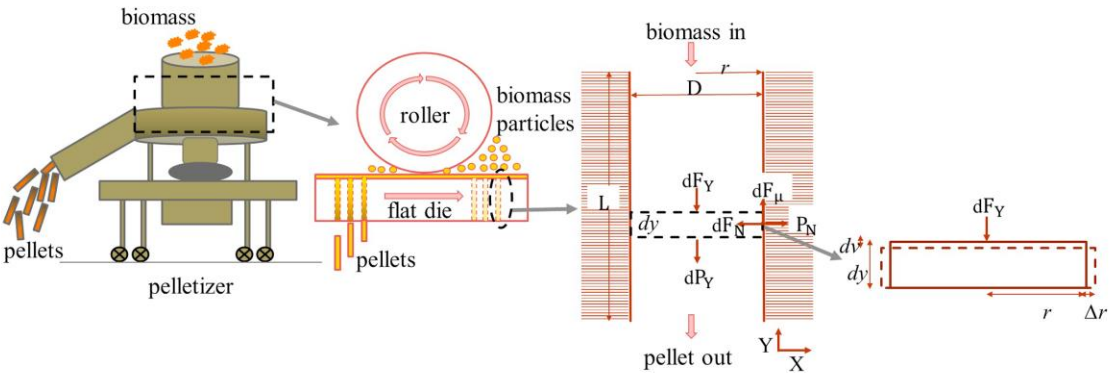

Figure 3. 4 Diagram of an Identical Specimen for a Flat Die Pellet Mill (Pradhan, Mahajani, et al., 2018).

3.1.6. **Cooling**

The intense friction applied in the die during the pelleting process causes additional heat to develop. Coolers are in place to reduce critical temperatures before sifting, packing and storing the pellets. The ANDRITZ counter-flow cooler solutions utilize the surrounding air to lower the temperature of the pellets, resulting in a pellet temperature 5 to 10 °C above room temperature.

3.1.7. **Final Sifting**

Finally, the pellets pass through a sifter to remove crumbs and dust which get recirculated back into the process.

After that the biomass pellet fuels are passed to the scientific equipment center for further analyzing.

3.1.8. **Process Control**

ANDRITZ modularly designed, computerized controls for individual key machines, complete processing channels, and complete plant controls.

3.1.9. **Environmental Aspects**

Every kind of waste is harmful to the environment after a certain time, reuse of waste is a smart and environmentally friendly idea. Nowadays, researcher's is looking to recycle the wastes to build a sustainable environment. Compared to other Asian countries Thailand has a big shear to export of natural rubber and latex products in entire Asia. Thailand, Malaysia, and Indonesia are produced about 70%-80% raw rubber and supply in south-east Asia (Mohammadi et al., 2010b; Xiaofei & Guohua, 2008). The natural rubber statistic (2008) says, the number of rubber factories in Thailand are 700, in Malaysia 357, the area under rubber plantation are 2 million hectares in Thailand, 1.3 million hectares in Malaysia, Natural rubber production in year 3.09 million tons in Thailand, 1.072 million tons in Malaysia, global supply of natural rubber 33.5% in Thailand and 10.7% in Malaysia (Chaiprapat et al., 2007; Mohammadi et al., 2010a; Mohammadi et al., 2010b). Since the production of rubber products from natural rubber needs a large amount of water to operate, a large amount of wastewater generated by the effluent process (Babel & Rungruang, 2008; Leong, Muttamara, Laortanakul, & Recycling, 2003).

TAVORN RUBBER Latex industry dispose their wastewater for land filling after dewatering the sludge through decanter. Nowadays, they disposed the sludge throughout to any empty land to landfill. But, these practices are not good, because of the land limitations and usually, sludge comprises heavy metals and toxic organic substances, pathogens, and nutrients such as nitrogen and phosphorus triggering eutrophication (Gil-Lalaguna et al., 2014; Jang et al., 2014) which is harmful to the environment and soil. Wastewater of latex rubber industries can consider as a continuous process. Therefore, without any doubt, recycle the wastewater sludge of latex rubber industries by making pellet fuel is an effective environmentally friendly method.

3.1.10. **Economic Aspects**

According to the TAVORN RUBBER Latex industry information, presently they disposed their sewage sludge to landfill and the cost of landfilling is 5000 THB per ton. Currently, they are not willing to use this treatment for their sewage sludge management because of cost, land limitations, environmental bad impacts. But, the industry owner is willing to give their sewage sludge if anyone want to take it free of cost. Every industry now used decanter to dewater their sewage sludge before disposing it, so no need dewatering cost to take the sludge from them.

On the other hand, utilizations of wood pellets are increasing nowadays. Utilizations of fuel pellets are discussed later. Industrial sector absorbs about 37% of world's total energy (Edelenbosch et al., 2017). In view of the constant growth of wood pellet market because of collective industrial and residential demand, the possibility of biomass pellets from latex industry sewage sludge and para-wood sawdust is projected to expand expressively. Thus, a preceding economic valuation of fuel pellet production from any feedstocks for energy exploitation is magisterial. The furniture industry marketing information of para-wood sawdust is 3 THB per kg. If convert it by dollar, then the cost for per ton is about 85 dollars.

Basic cost calculation of 50% sewage sludge and 50% para-wood sawdust pellets:

1 ton = 907.185 kg

1-ton wood pellet cost = 98 dollars (Ciolkosz et al., 2015).

If, the cost of para-wood sawdust is 3 THB per kg, then the cost of para-wood sawdust per ton in dollar is,

(907.185 x 3) = 2721.5 THB

= (2721.5 / 31.76)

= 85.69 dollars [1 dollar = ± 31.76 THB]

So, 50% sewage sludge and 50% para-wood sawdust pellets cost in dollar is,

(50% sewage sludge and 50% para-wood sawdust) = (Free + 42.845) [85.69 / 2 = 42.845]

= 42.845 ± dollar per ton.

Therefore, instead of 100% wood pellet, if we use 50% sewage sludge and 50% para-wood sawdust the cost of pellets around $42.845 per ton. Nowadays, the market of terrified biomass is in initial phase, still there is mechanical prospect on the use of terrified biomass in power generating businesses and other energy concentrated industries (Proskurina, Heinimö, Schipfer, & Vakkilainen, 2017).

Fuel pellets have several applications starting from residential cookstove to large scale power plants. The standard pellets can be easily adopted in any biomass-based energy conversion devices, such as residential boilers, residential stoves, gasifiers, industrial boilers etc. Presently, many industries are using biomass for boiling or other heating works. So, they could use sewage sludge and wood pellet for their work. Even, some industries can use their own sewage sludge to making pellet fuel and then can use it in their own industry grid boiler machine, as the processing of biomass pellet fuel as the process is not so difficult.

Chapter 4

Results and Discussion

4.1. Results and Discussion

In this study, the sewage sludge is characterized from two filters named sand filter and decanter. But for the experiment used sewage sludge from decanter because of the potential parameters value. Characterization of sewage sludge from the decanter and the sand filter are showed in Table 4.1 and Table 4.2 respectively. Table 4.3 shows the characterization of fuel pellet from sewage sludge mixed with wood saw dust at the ratio 50:50.

Table *4. 1* Characterization of sewage sludge from sand filter.

No.	Parameters	Unit	Results ± SD
1	Moisture	% wt	11.87 ± 0.22
2	Volatile matter	% wt	52.63 ± 1.41
3	Fixed carbon	% wt	9.33 ± 0.31
4	Ash	% wt	26.17 ± 1.92
5	Carbon (C)	% wt	27.18
6	Hydrogen (H)	% wt	5.32
7	Nitrogen (N)	% wt	6.61
8	Higher Heating Value	kcal/kg	2,789 ± 157

Table 4. 2 Characterization of sewage sludge from decanter.

No.	Parameters	Unit	Results ± SD
1	Moisture	% wt	6.52 ± 0.11
2	Volatile matter	% wt	62.94 ± 1.58
3	Fixed carbon	% wt	10.59 ± 0.27
4	Ash	% wt	19.96 ± 1.56
5	Carbon (C)	% wt	28.23
6	Hydrogen (H)	% wt	4.99
7	Nitrogen (N)	% wt	5.54
8	Higher Heating Value	kcal/kg	3,664 ± 168

4.1.1. Ultimate Analysis

The composition of C, H, N content for the sewage sludge samples are shown in Figure 4.1. The samples were found to contain mean percentage of 28.3% of Carbon, 4.991% Hydrogen, and 5.54% Nitrogen content. The composition of carbon obtained quite high compared to the previous study (Fairous, Rusnah, & Maryam, 2010; M. Wzorek, 2012). With high content of carbon, the sample of sewage has potential for converted into biomass pellet fuel. The heating value of sewage sludge will be low if ash content is high and carbon is low (Xiao et al., 2015). The high percentage of nitrogen content bound to organic matter in sewage sludge is a measure of the importance of sewage sludge for agricultural purposes (Mtshali, Tiruneh, & Fadiran, 2014). Latex industry sewage sludge is not potential to use as fertilizer due to the lower value of nitrogen.

Table 4. 3 Characterization of fuel pellet from sewage sludge mixed with wood saw dust at the ratio 50:50.

No.	Parameters	Unit	Results ± SD
1	Moisture	% wt	6.80 ± 0.13
2	Volatile matter	% wt	73.43 ± 1.25
3	Fixed carbon	% wt	14.84 ± 0.40
4	Ash	% wt	4.93 ± 0.98
5	Higher Heating Value	kcal/kg	3,620 ± 12

4.1.2. **Proximate Analysis**

Volatile matter and fixed carbon were found since all the combustible element was burned. The remaining mass after heating is ash. The high volatile matter content of sludge can dominate the burning process (Hein & Bemtgen, 1998). In this experiment volatile matter of latex industry sewage sludge (Decanter) and biomass pellet fuel from the sludge and para-wood sawdust is found effectively higher than some previous studies (Groß et al., 2008; M Otero et al., 2002; Marta Otero et al., 2008; Wzorek & Król, 2009). From the proximate result, the moisture, volatile matter, fixed carbon and ash content of sewage sludge (Decanter) was found 6.52 ± 0.11, 62.94 ± 1.58, 10.59 ± 0.27 and 19.96 ± 1.56 weight % respectively. From the proximate result, the moisture, volatile matter, fixed carbon and ash content of biomass pellet fuel was found 6.80 ± 0.13, 73.43 ± 1.25, 14.84 ± 0.40 and 4.93 ± 0.98 weight % respectively.

Moisture content influences net calorific value and combustion efficiency (Zamorano, Popov, Rodríguez, & García-Maraver, 2011). Moisture content of the raw materials has a significant role to produce biomass pellet fuel with effective moisture content. Pellets with high moisture result in dry matter loss during storage and transportation and also subject to early decomposition (Graham, Eastwick, Snape, & Quick, 2017; J. S. Tumuluru, Wright, Hess, & Kenney, 2011). Moisture content of pellets can be attributed to safe storage and efficient combustion (Bernhart & Fasina, 2009). A drop-in pellet density as the moisture content increases from 12 to 15% for various biomass samples (Mani, Tabil, & Sokhansanj, 2006). Although, 10–15% moisture content range sounds perfect for a typical biomass pelletization process (Kirsten, Lenz, Schröder, & Repke, 2016). In this study the latex industry sewage sludge (Decanter) sample moisture content is 6.52 ± 0.11 % which is effective as the perfect moisture content range (Kirsten et al., 2016). Therefore, the moisture content of biomass pellet fuel in this study is 6.80 ± 0.13 % which is in the perfect quality pellet fuel range (Kirsten et al., 2016). Amount of moisture in feedstock controls the pellet quality and overall process economics as well. Moisture content is one of the dominating factors affecting the pellet quality.

In the TGA curve of latex industry sewage sludge (Decanter) in Figure 4.3 shows that the sample weight decreased at the temperature 30o C to 750o C and the remaining ash is more than 20% which is quite higher and undesirable. On the other hand, in the TGA curve of biomass pellet fuel in Figure 4.4 shows the sample weight decreased at the temperature 30o C to 750o C and the remaining ash is less than 10% which is lower than other incineration method (O. Malerius & J. Werther, 2003). The perfect ash content of biomass pellet fuel is < 1% (typical) and < 5% (Barbanera et al., 2016; Pradhan, Arora, et al., 2018). Ash content of biomass pellet fuel in this study is 4.93 ± 0.98 %, and it's one of the significant benefits of this study. Higher ash content lowers the heating value and creates problems like clinker formation, sintering and dust emissions as well (Obernberger & Thek, 2004).

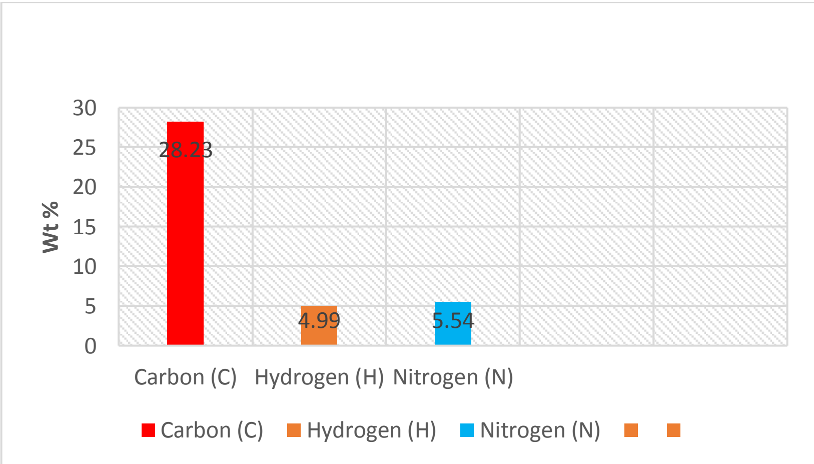

Figure 4. 1 Percentage of C, H, N in Latex Industry Sewage Sludge (Decanter).

The higher heating value of the biomass pellet fuel from latex industry sewage sludge (Decanter) and para-wood sawdust as the value obtained from proximate analysis (Table 4.3) is 3,620 ± 12 kcal/kg. In order to justify the result that obtained by the proximate analysis, the sample also being tested by using bomb calorimeter in order to get the calorific value by experimental analysis, this result is valid for producing a high heating value biomass pellet fuel from latex industry sewage and para-wood sawdust.

4.1.3. **Heavy Metal Contents**

By analyzing results of the total heavy metals content in latex industry sewage sludge (Decanter) samples presented in Table 4.4, the concentrations of As and Pb are the lowest compared with those of the other heavy metals.

Table 4. 4 Characterization the heavy metal content of latex industry sewage sludge (Decanter).

Metal	Unit	Result
As	mg/kg (wet weight)	1.25
Hg	mg/kg (wet weight)	None
Zn	mg/kg (wet weight)	2,562
Cd	mg/kg (wet weight)	None
Cu	mg/kg (wet weight)	29.9
Cr^{6+}	mg/kg (wet weight)	None
Pb	mg/kg (wet weight)	2.80
Cr^{3+}	mg/kg (wet weight)	None

The concentrations of heavy metals in the sewage sludge sample is in the followed order: As< Pb< Cu< Zn. The concentrations range of those metals is from 1.25 mg/kg (As) to 2,562 mg/kg (Zn). Heavy metal contents of latex industry sewage sludge (Decanter) shown in Figure 4.2. The higher concentrations of Zn in sewage sludge were found in this experiment compared to other heavy metals. Heavy metals are harmful to the soil for a long time, Soil might be lost its fertility for the contaminations of heavy metals in sewage sludge (Giller, Witter, & McGrath, 1999).

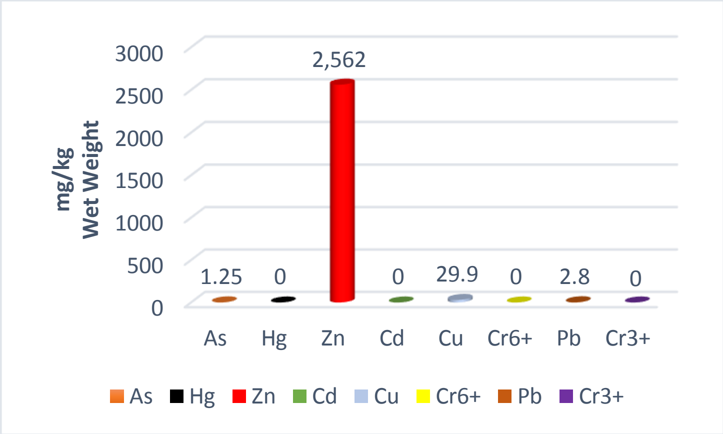

Figure 4. 2 Heavy metal contents of latex industry sewage sludge (Decanter).

Zinc is an essential trace element for humans, animals and plants, high concentrations of zinc are potentially toxic to plants, humans and animals (Merian, Anke, Ihnat, & Stoeppler, 2004). This experiment is reporting that the sewage sludge has no Hg, Cd, Cr3+, and Cr6+.

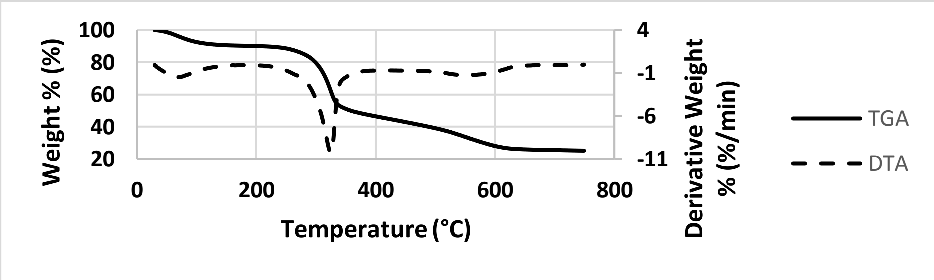

Figure 4. 3 TGA thermogram of Latex Industry Sewage Sludge (Decanter).

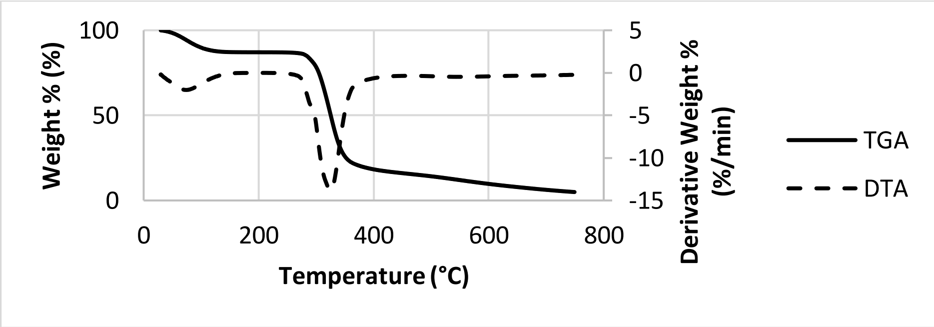

Figure 4. 4TGA Thermogram of Biomass Pellet Fuel from Sewage and Para-Wood Sawdust.

Generally, Cu were present in the highest concentrations, while the lowest values were obtained for Pb. According to the only available Croatian standard dealing with heavy metal concentration in latex industry sewage sludge (Decanter), in this study may not be used for agricultural purposes. Due to high concentrations of Zn and Cu (Netinger Grubeša & Barišić, 2016). Uses of wastewater sewage sludge in the cultivated land have limitations because of some major elements like copper, cadmium, zinc, lead, nickel, chromium, mercury this type of heavy metals (Hsiau & Lo, 1998).

Chapter 5

Conclusions and References

5.1. Conclusions

The project work was carried out to investigate the reliable treatment of the latex industry's sewage sludge, use it as a biomass resource to produce energy by making pellet fuel. Characteristic parameters such as ash content, moisture, volatile matter, fixed carbon, hydrogen, carbon, the nitrogen of the sewage sludge and the pellet fuels were also determined. The higher heating value of the sewage sludge (Decanter) was found 3,664 ± 168 kcal/kg and the remaining ash content was found 19.96 ± 1.56%. After pelleting, the higher heating value of the pellet fuels was found 3,620 ± 12 kcal/ kg, where the sewage sludge was mixed with wood sawdust. Only the sewage sludge remaining ash content was found at 19.96 ± 1.56%, but after pelleting, the sewage sludge where the sludge was mixed with wood sawdust and the ratio was 50:50. Then, the heating value was found almost analogous, but the remaining ash content was found 4.93 ± 0.98% which is quite lower than before pelleting.

The normal applies of wastewater sewage sludge disposal such as landfilling, fertilizer and dumping in the sea are no longer possible both environmentally and economically due to its bad impact on the environment. Globally the production of sewage sludge is mounting from commercial, domestic and industrial activities and it's considered as a continuous process. It is going to momentously difficult to handle and transport the sewage sludge for the reason of high-water contents and the sludge. So, the treatment could be a prevalent the process of sewage sludge handling soon.

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Appendices

Generation, Characterization and Management of concentrated latex Sewage Sludge

Arif Billah[1], Kuaanan Techato[1,3], Wirach Taweepreda[2,3]*, Minhaj Uddin Monir[4,5], Md. Ahosan Habib[1]

[1]Department of Sustainable Energy, Faculty of Environmental Management, Prince of Songkla University, Hat-Yai, Songkhla Thailand

[2]Department of Materials Science and Technology, Faculty of Science, Prince of Songkla University, Hat-Yai, Songkhla Thailand

[3]Environmental Assessment and Technology for Hazardous Waste Management Research Center, Prince of Songkla University, Hat-Yai, Songkhla Thailand

[4]Faculty of Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Malaysia

[5]Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh

*Corresponding author:

Abstract

Nowadays, latex industries in Southern Thailand are using generated sewage sludge for landfilling by following traditional practices, which is deleterious to the entire environment and has disposal management problem as well. The main focus of the present study was to identify a management technology of using sewage sludge generated by latex producing industries, as a source of production biomass for generating energy. This was done evaluating the heating value and the remaining ash content of biomass pellet fuel. The latex industry wastewater sewage sludge (LISS) and para-wood sawdust (PWS) were used as the raw materials then further sewage sludge dewatered through a decanter centrifuge and a flat die pellet mill was applied for co-pelletization. Thermogravimetric, ultimate, atomic absorption spectrometer, and a bomb Calorimeter were performed to determine the compositions, characteristics, mass concentration of trace metals, and its calorific value. In fine, the higher heating value of the biomass pellet fuel is 3,620 ± 12 kcal/kg, and 4.93 ± 0.98 % is the remaining ash content as well. Furthermore, the present research indicates that the method is environmentally and economically sound than the earlier management of LISS.

Keywords: LISS, LISS Characteristics, Co-palletization of LISS, Biomass Pellet Fuel.

VITAE

Name Mr. Arif Billah

Student ID 6010920033

Educational Attainment :

Degree	Name of Institution	Year of Graduation
Bachelor of Science in Civil Engineering (BSCE)	International University of Business Agriculture and Technology	2017

Scholarship Awards during Enrollment

1. The scholarship awards from thesis advisor project, Faculty of Polymer Science, funds for Master of science program from the graduate school, Prince of Songkla University, Hat Yai, Thailand.

Work – Position and Address

1. Trainee Engineer, Holy Homes Real Estate Ltd. January 2017 – April 2017.
2. Camping Supervisor, British American Tobacco Ltd. March 2015 – June 2015.