Sludge Calorific Value Mapping and Potential Energy Recovery for Malaysia

By

Kohila a/p Mariapan

(12617)

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Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(MR MOHD FAIZAIRI BIN MOHD NOR)

UNIVERSITI TEKNOLOGI PETRONAS
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SEPT 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken nor done unspecified sources or persons.

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KOHILA A/P MARIAPAN

ABSTRACT

Nowadays, the sewage sludge disposal is considered a serious issue in Malaysia for not only the largest contributor of waste material in Malaysia but also causes many environmental crises. Due to its abundance, sewage sludge is seen to have a potential to be a good resource of energy and thus reduce the environmental effect it has. In order to study the potential of energy recovery through sewage sludge, a detailed study on its characterization and calorific value of secondary sludge have been carried out. This paper discusses on the experimental work done on the sewage sludge sample to obtain Proximate Analysis, Ultimate Analysis and Higher Heating Value of the sludge samples. The sludge samples were dried in a heating oven to reduce the moisture content. These dried samples are then milled and sieved in order to obtain sample particle size of less than 250µm. A thermogravimetric analyser is used to study the characterization of sewage sludge and measuring the parameters in terms of weight percentage (wt%) such as the Moisture Content(MC), Volatile Matter(VM), Fixed Carbon (FC) and Ash Content (AC). Next the elemental composition is studied by running an Ultimate Analysis using the CHNS by distinguishing the weight percentage of Carbon, Nitrogen, Hydrogen and Sulphur. Lastly, the bomb Calorimeter was used to estimate the Higher Heating Value (HHV) of the samples. Once the characterization study has been done, Malaysian sewage sludge is compared to sewage sludge which has energy recovery potential or is already being used for energy recovery. Study reveals that sewage sludge in Malaysia has potential energy recovery since its characterization and heating value is in the range of with the reviewed sewage sludge. Lastly, based on the current Sludge Production Factor, energy generated through Malaysian Sewage sludge was estimated and yield a value of 7000 kWh/day.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Background of Study

Prior to independence, Malaysia had no proper sewage treatment system. At that point of time, conventional method such as pit and bucket latrines and direct discharge to the rivers and seas were practiced. In the 1960's, new towns were developed which increased the population density. There was a need for improvement in the sanitation sector. During that period, Individual Septic Tanks (IST) which used the sedimentation systems was introduced. As population grew, ISTs were being replaced by Communal Septic Tanks (CST). CSTs served the same purpose but served a larger population with its networks of pipes channelling to a centralized septic tank. Technology advancement in the next decade saw introduction towards aerated lagoons. These aerated lagoons served a larger population and enhanced capacity of oxidation ponds up to five times the original capacity. The need for improvement increased during the 1980's where secondary treatments via mechanised sewage treatment plants were introduced. Technology enhancement since then has allowed improvement in terms of sewage treatment method accommodating to population increase and etc [1].

The rapid increase in human population, along with fast moving industrialization and urbanization has resulted in a massive growth in the volume of wastewater produced around the globe. Wastewaters have to be treated accordingly at wastewater treatment plant which in turn produces solid waste products known as sewage sludge. Proper disposal of sewage sludge is a major concern due to the increasing amount of wastewater to be treated which in turn increase the generation of sewage sludge. Currently Malaysia is producing about 5 million cubic meters of sewage sludge per year. The amount has been predicted to escalate to 7 million cubic meters per year by 2020 [2].

Most common way of disposing sewage sludge from Sewage Treatment Plant in Malaysia is by landfill disposal. One of the landfill which is the focus study for Malaysia dispose area is Bukit Tagar Sanitary Landfill (BTSL) which is located

50km north of Kuala Lumpur and is accessible from the North-South Expressway through the purpose-built Bukit Tagar interchange. Situated in Ulu Selangor, the BTSL occupies a total land area of 1,700 acres, where is it developed in a 700-acre surrounding this landfill trajectory.

BTSL is vigilantly designed as a complete engineered Level IV landfill with High Density Polyethylene (HDPE) membrane liner, handling system leachate collection. BTSL is also engineered to lever municipal solid waste and other-toxic waste. With 120 million metric tonnes of free air space capacity, BTSL is expected to supply over 40 years solution to solid waste management in the Central region of Selangor and Kuala Lumpur, but with the hiking population in that area, prevention steps are to be taken.

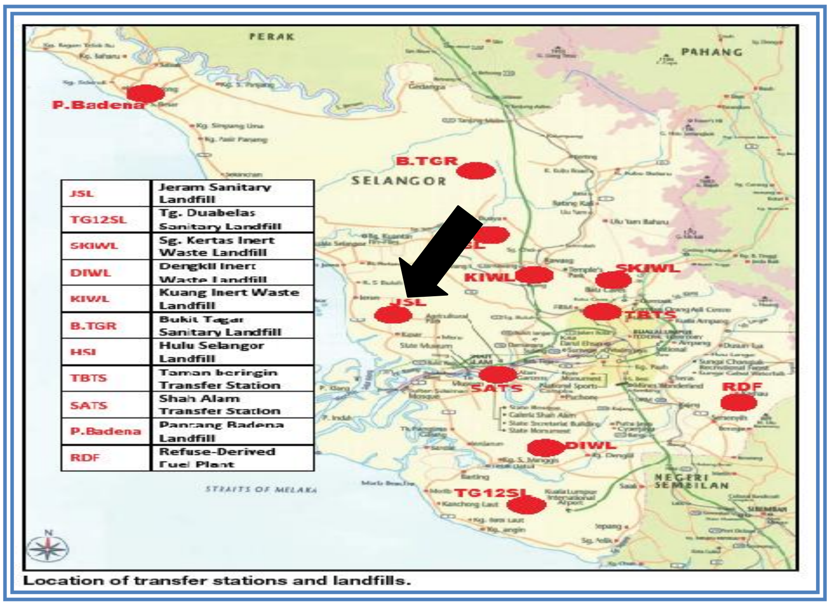

Figure 1 Location of Bukit Tagar and other Sanitary Disposal

Wastewater treatment is a complicated process which utilises mechanical, biological and chemical methods in various combinations [3]. The simplest way to summarize wastewater treatment can be seen as up to three level or stages of treatment: primary, secondary and tertiary. In primary treatment, screening and sedimentation is done to remove solid and organic matter. Higher content of organic is to be found from the effluent from the primary sewage treatment. In the secondary sewage treatment biological unit processes are used to remove biodegradable organic and suspended solid. Disinfection of sludge is also done in the secondary treatment.

In the tertiary treatment, nutrients, heavy metals and further removal of suspended solids and organic are removed. Effluent from this process is off high standard and suitable for reuse. Sewage Treatment Plants (STPs) in Malaysia do not implement the tertiary treatment as part of the treatment routine. [4].

Sewage sludge also known as biosolid, is the solid waste that is obtained after wastewater has been treated in a wastewater treatment facility. Sludge originating from the wastewater treatment operation is usually in a dilute suspension form which contains solid matter in the range of 0.25 wt% to 12 wt% of solid. Study on application of sludge, can be done by knowing the composition of the sewage sludge. This composition is characterised by six groups of components [5]: (i) nontoxic organic carbon compound (apprx. 60% on a dry basis), (ii) nitrogen (N) and phosphorus (P) containing components, (iii) toxic inorganic and organic pollutants, i.e., (a) heavy metals such as Zn, Pb, Cu, Cr, Ni, Cd, Hg and As (concentrations vary from more than 1000 ppm to less than 1ppm) and (b) polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dioxins, pesticides, linear-alkyl-sulfonates, nonyl-phenols, polybrominated fire retardants, etc., (iv) pathogens and other microbiological pollutants, (v) inorganic compound such as silicates, aluminates and calcium and magnesium containing compounds and (vi) water, varying from a few percentages to more than 95%. All these compounds exist in a mixture which is the major concern of sewage sludge. Organic carbon-, phosphorus-, and nitrogen-containing compounds can be considered as useful compounds. Sewage sludge maintenance involves renewal and useful reprocess of the valuable components. Sewage sludge is also maintained so that it impact on environment and human health kept under radar.

Due to its abundance of organic compound in the dried component, sewage sludge is seen as the next alternative for energy recovery [6]. In original sewage sludge the water content is very high (~ 95wt %) whereas, the concentrations of organic materials are relatively low which decreases the probable utilization of this waste [7], which reduces the efficiency of energy recovery. There are many alternatives for the recovery of energy from sewage sludge and it can be divided into nine options [5]: (i) anaerobic digestion of sewage sludge, (ii) production of bio fuels from sewage sludge, (iii) direct production of electricity from sewage sludge in microbial fuel cells, (iv) incineration of sewage sludge for energy recovery, (v) co-incineration of sewage sludge coal-fired power plants, (vi) gasification and pyrolysis of sewage sludge of sewage sludge, (vii) use of sludge energy and raw material for buildings, (viii) supercritical wet oxidation of sewage sludge and (ix) hydrothermal treatment of sewage sludge.

As for this research, incineration of sewage sludge for energy recovery purpose is given consideration. Incineration of sewage sludge is expected to fully oxidize the substance at high temperature. Incineration can be useful to by-products of mechanically dewatered sewage sludge or dried sewage sludge. The amount of energy that can be attained through incineration depends upon water content of the sludge and efficiency of incineration and dewatering processes the sludge had undergone such as mechanical dewatering and drying process. For this project, ultimate analysis was done to determine the carbon, hydrogen, nitrogen and sulphur content of the sewage sludge using CHNS equipment, proximity analysis where the changes occur in the sewage sludge in terms of (wt% moisture content, wt% volatile matter, wt% fixed carbon and wt% ash content) is studied using Thermogravimetric analysis and the High Heating Value is studied using a Bomb Calorimeter. The results obtained from these analysis and experiments will then be used to evaluate the potential energy recovery through Malaysian Sewage Sludge.

1.2 Problem Statement

Based on the perspective Sludge Production Factor (SPF), about 3.5 million m^3 per year of sewage sludge was produced by Malaysia's national sewage company, Indah Water Konsortium [8]. Sewage sludge was recognized as an **"upcoming waste problem"** which has to be solved. The condition concerning sewage sludge treatment and disposal depends on two different criteria, namely, the population of the particular area and the percentage connected to a waste water treatment plant. This means that the regional sewage production does not only depend on the population but also the number of waste water treatment [8]. Thus, **an increment in sewage sludge generation** has prompted the need to reuse the sewage sludge as an alternative for energy generation.

In line with this, the waste production is expected to be increasing at a staggering rate of 2% annually and landfills in Selangor are running scarce [9]. Over these years, many landfills have opted to close because the waste quantity generated yearly is much faster than the natural degradation process. In very close future, more active **landfills are expected to reach the authorized capacity**. Even though state authority accentuates on recycling programs alongside waste minimization plans, land filling is the primary of waste disposal [10]. Therefore, precaution steps should be taken to reduce the production of sewage sludge to avoid landfills from scarcity.

Besides that, another contributing factor is the **increase in disposal cost of sewage sludge**. It is estimated that the cost for transportation to and from Sewage treatment plants (STPs) and BTSL is around RM 80,000 to RM 120,000 per month. This is due to the heavy amount of the sewage sludge. The operational cost is estimated to reduce if the volume and the weight of sewage sludge exiting the sewage treatment plants are reduced.

1.3 Objective and Scope of Study

1. To study the characterization of secondary sewage sludge in Malaysia from Sewage Treatment Plant (STP) operated by Indah Water Konsortium (IWK)
2. Compare and evaluate different biosolid characteristics from different sources
3. Mapping generation of sewage sludge around Malaysia to be evaluated for power generation

2.0 LITERATURE REVIEW

2.1 Malaysian National Renewable Energy Policy & Action Plan

In the year 1980 The National Depletion Policy was introduced. The aim of this policy was to keep the exploitation of natural oil reserves under control. This was due to the rapid increase in the crude oil production. In addition to this, the Four Fuel Diversification Policy 1981 was planned to reduce dependency on oil as the main energy reserve.

These two policies had created path for the introduction of Renewable Energy (RE) in the Eighth Malaysia Plan 2001-2005(8^{th} MP). In the year 2000 the Fourth Fuel Policy was amended to develop the 8^{th} MP or the Fifth Fuel Policy, where Renewable Energy is recognized as the 5^{th} important fuel in the energy supply mix. To circumvent Malaysia from becoming net energy importer energy efficiency was encouraged in this 8^{th} Malaysia Plan [11]. During this period when the Fifth Fuel Policy was being implemented, renewable energy was expected to contribute to the country's national grid with a total generation mix of 5% of the total electricity demand by 2005 which at that time was about 500MW. In line with this the Small Renewable Energy Program (SREP) was launched in May 2001. This program was set up in the aim of; plants operating under this program will be eligible to sell up to a maximum of 10MW of electricity supply to the National Grid.

By the end of May 2003, a sum of 48 projects was permitted with a grid connected facility of 300 MW- Peninsular Malaysia and 50 MW – Sabah, to be connected to power utility grid. Of these, 28 projects were based on energy recovery from biomass, 16 mini-hydro and four landfill gas [14]. Fundamental to this is the proposed Renewable Energy Act [15]. Apart from the SREP projects, the energy generated off-grid was about 1065 GWh (1.3% of the total energy generated in 2003) derived from private palm oil millers and solar which was used for their own consumption. However, within the time of 8^{th} MP implementation only two (2) SREP projects were successfully installed which were:-

I. TSH Bio energy project in Tawau (10MW) – the first grid connected biomass power plant in Malaysia using the fuel mixture of empty fruit bunch (70%), fibre (20%) and dry shell (10%) from palm oil wastes

II. Jana Landfill in Puchong (2MW) – the first landfill gas power plant in Malaysia

The 9^{th} Malaysia Plan (2006-2010), reinforces the schemes for energy efficiency and renewable energy put forward in the 8^{th} MP that focused on better usage of energy reserves. The target of 5% of RE mix was revised to be 350MW in the 9^{th} MP. Out of the 350MW, 245MW was aimed to be achieved from biomass (193MW from palm oil wastes, 35MW from Municipal Solid Waste, 7MW from LFG, 10MW from rice husk) and the remaining 105MW was to be from mini hydro. Encouragement to reduce dependency on petroleum provides for more efforts to incorporate alternative fuels. This plan also discussed on the targeted power generation mix intended where half of the generation comes from natural gas, 26 % coal, 9% hydro, 8% oil, diesel 5%, biomass 1% as of 2010. With this development in process, the carbon concentration in the year 2020 is expected to be 40% lower than that of 2005. As of 2011 68.45 MW which is 20% from the 9^{th} MP target of renewable energy was connected to the utility grid.

A variety of tax exemptions were introduced for energy efficiency employed and renewable energy (RE) generators. In relation to this matter, Feed-in-Tariff is introduced for renewable energy generated. This means that, competent renewable energy installation can be set to a fixed to a first-rate price. Financial support for further research studies or development on renewable energy is allocated by the government.

2.2 Indah Water Konsortium Sdn Bhd (IWK)

Indah Water Konsortium Sdn Bhd (IWK) is a nationwide sewerage company which is owned entirely by the Government of Malaysia. Indah Water Konsortium Sdn Bhd provides sewerage services, operation and maintenance up to 5,567 public sewerage treatment plants and 14,190km network of sewerage pipelines. Indah Water Konsortium Sdn Bhd also provides services such as desludging and septage management for over 1 million individual septic tanks (ISTs). Indah Water Konsortium Sdn Bhd functions in most parts of Malaysia for operation and maintenance whilst providing technical proficiency to the under-developed area. The various types of treatment plants are shown in **Figure 2**:-

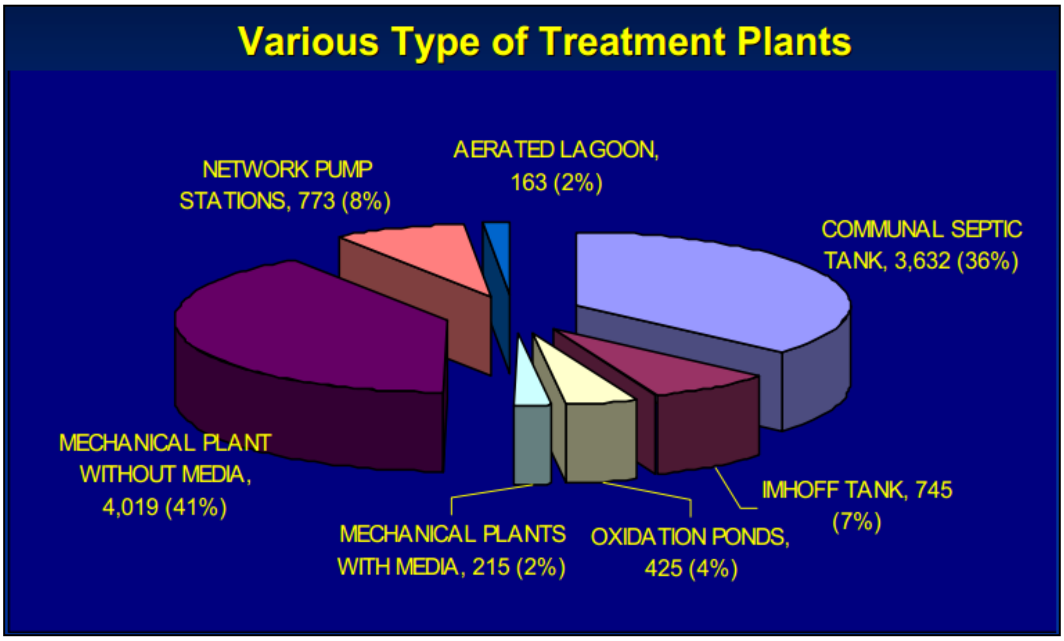

Figure 2 Various Type of Treatment Plants, adapted from [14]

There is approximately 1 million Individual Septic Tanks (ISTs) in Malaysia. The total connected population equivalent (PE) served by IWK is 18.9 million. The population equivalent catered by treatment plants is shown in **Figure 3**:-

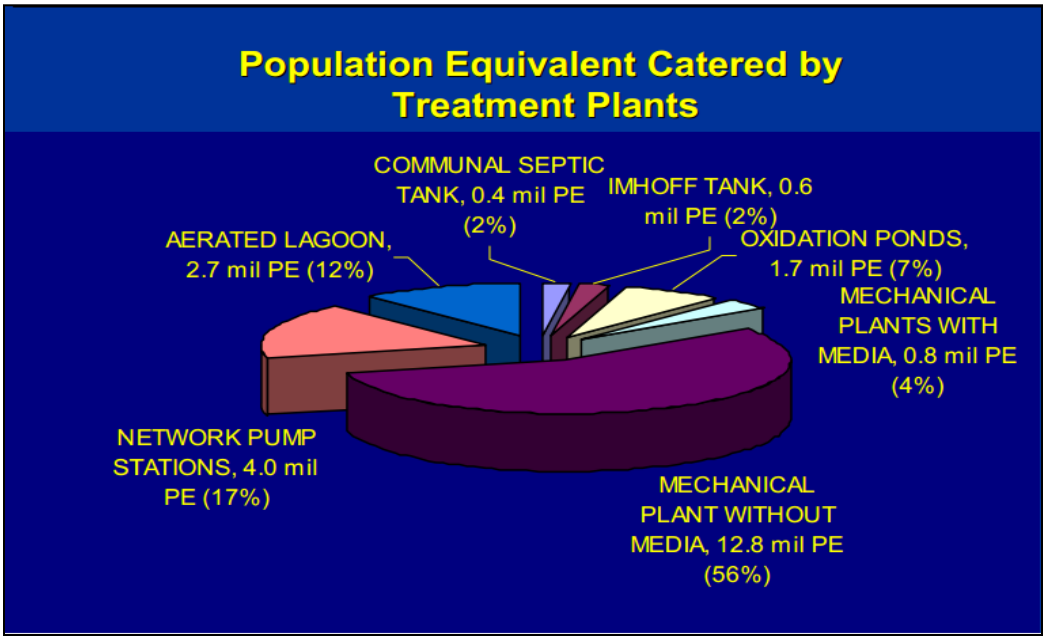

Figure 3 Population Equivalent Catered by Treatment Plants, adapted from [14]

For town area with high population where the receiving environment is not able to cope with the discharge, highly developed treatment system which produces high quality effluent is implemented. Whereas in order to serve small community, a less complicated system is installed.

Since the beginning of time, unit operations have been grouped together to provide various levels of treatment. Preliminary and Primary Treatment refers to physical unit operations and is the first stage of treatment applied to any stage. Secondary Treatment refers to biological and chemical unit processes, and lastly the Tertiary refers to combinations of all three. Preliminary sewage is basically installed to remove sewage constituents that may cause maintenance or operational problems [15]. **Table 1** below shows typical stages of sewage treatment. The primary sewage treatment is also mainly screening which focuses on sedimentation removal and suspended solids and organic matter. The effluent from primary treatment is to have high amounts of organic matter. Biodegradable organic and suspended solids are then removed in the secondary treatment phase. This is done using biological unit processes. Disinfection may be included in secondary sewage treatment. Nutrients, toxic substances including heavy metals and further removal of suspended solids and organic are done in the tertiary sewage treatment phase. The effluent from the tertiary phase is of high standard and suitable for reuse. There are no plans to build a tertiary treatment plant in Malaysia [4].

<table>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td rowspan="8">Sewage Inflow</td><td>Preliminary Treatment</td><td>Primary Treatment</td><td>Secondary Treatment</td><td>Tertiary Treatment</td><td rowspan="8">Effluent Discharge</td></tr>
<tr><td>Screening</td><td>Sedimentation</td><td>Activated Sludge</td><td>Filtration</td></tr>
<tr><td>Grit Removal</td><td rowspan="5">Floatation</td><td>Bio filtration</td><td>Disinfection</td></tr>
<tr><td>Grease Tank</td><td rowspan="4">Sedimentation</td><td rowspan="4">Tertiary Ponds</td></tr>
<tr><td>Pre-Aeration</td></tr>
<tr><td>Flow Measurement</td></tr>
<tr><td>Flow Balancing</td></tr>
<tr><td>Removal Of Rags, Rubbish, Grit, Oil, Grease</td><td>Removal Of Settleable And Floatable Materials</td><td>Biological Treatment To Remove Organic And Suspended Solids</td><td>Chemical Treatment To Remove Nutrients And Pathogens</td></tr>
</table>

Table 1Category of Sewage Sludge Treatment Processes [4]

2.3 Moisture distribution in Activated Sludge

The knowledge on distribution of water within an activated sludge should be vast in order understand the dewatering and drying methods needed to be used. J.Vaxelaire in his paper 'Moisture distribution in activated sludge: a review' discusses on classification of moisture distribution and measurement within activated sludge [16]. Water within sludge does not have similar properties due to presence of solids. During dewatering process, the proximity of water greatly affects the behaviour of water molecule. Usually, in these cases two types of water are considered. The first type is free water, where the elimination of this type of water during drying process is not affected by the solid matter in the sludge. Secondly, is the bound water, which the properties are modified in accordance to the presence of solid. Free water content is estimated by regarding to this difference in behaviour between free water and bound water. Since the bound water is the complement of the total water content, the remaining identification of water is the bound water. It is generally accepted that free water can eliminated by mechanical stress. Another definition used to distinguish free and bound water is that bound water remains unfrozen at temperature below freezing point of free water which is -20˚C.

Detailed classification of water rather than just two types can enable better understanding on water behaviour. In this case work done by Vesilind is taken as reference. According to Vesilind [16] [17], water is of four categories:

I. Free water: characteristic of water not dependant on the solid content of the material and is not affected by capillary force.
II. Interstitial water: water which is in the gap and interstitial spaces of material
III. Surface (or vicinal)water: water found on the surfaces of solid particles by adsorption and adhesion
IV. Bound (or hydration)

Based on previous studies, a clearer understanding on distribution of water within activated sludge is difficult to obtain. Therefore discussion was done on the most appropriate method to facilitate the use of data obtained.

First method discussed is the drying test. This technique is based on the drying curve which explains that the rate of evaporation of water depends on the type of bond between the water and the solid material. According to the drying literature [19], the drying curve depicts the evolution of the evaporation flux vs. the average moisture content. It basically has four different phases as seen in **Figure 4**:

I. Increasing temperature in a short period of time
II. Free water evaporation on the surface of material seen on a period of constant rate
III. The typical drying boundary progressing into the material can be seen in a falling rate period. Beneath this drying boundary there is free water migration. Above it only the bound water and the water vapour are removed. There will be an increase in the mass and heat transfer resistance as the drying boundary progresses into the material. This results in the decrease of the evaporation flux
IV. In the case of hygroscopic materials (activated sludge), a second falling rate period appears due to the very slow evaporation of more hardly bound water

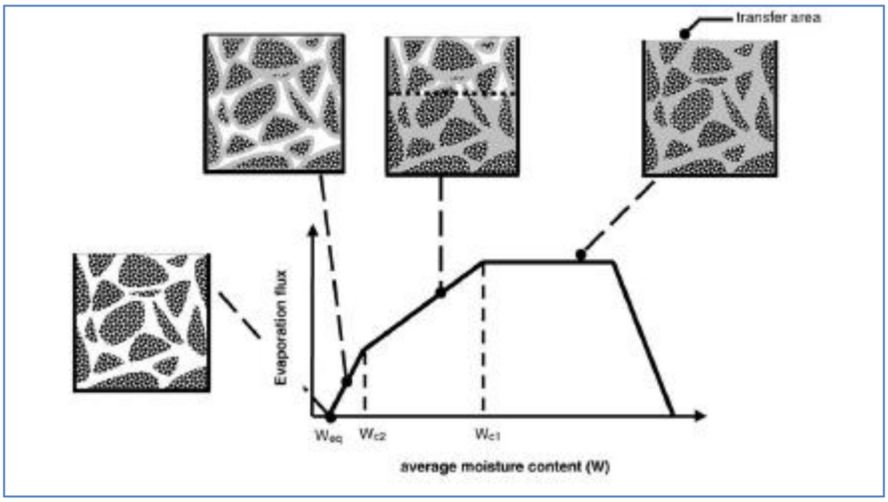

Figure 4 Classic drying curve [20]

The point of the drying curve falls in between the transition period of constant rate and the falling rate period. This portion is often used to estimate the amount of bound water [19]. This transition actually represents the shift from a period where the process of drying is controlled by external conditions to a period where the process is controlled by the transfer property of the sample. **It is necessary that both the sample mass and sample size during the tests are noted**.

The first test conducted was based on freezing properties which is the Dilatometric test. This method defines bound water as non – freezing at the same temperature as free water, which is typically at -20 ˚C. But the limitation to this test is that, the amount of unfrozen water in the sludge is said to be a combination of the effects of trapping of water in between the particles of the floc, the quantity of the ordered layers at the particles surface as well as the extent of intracellular ice formation. The same problem is seen with other methods which measure the amount of unfrozen water such as in differential thermal analysis and differential scanning calorimetry (DSC) tests.

If the bound water is assumed to not freeze at the given threshold temperature (-20˚C), the heat released by the sample during its measurement is directly proportional to the free water content of the sample. The bound water content can be determined by its difference to the total water content, which is measured by drying at 105˚C.

2.4 Sewage Sludge: Formation, Treatment and incineration [20]

Wastewater is basically wastes removed from residential, institutional, commercial and industrial institution. Sewage sludge is formed when wastewater undergoes treatment in its designated facility. Wastewater contains organic, inorganic, toxic substance as well as disease causing micro-organism and pathogens. Wastewater cannot be disposed in a raw form this due to biological decomposition of organic material in wastewater consumes a considerably high amount of oxygen which deprives aquatic animals from acquiring the available oxygen supply. Next, is because as mentioned it contains harmful pathogens which might affect human. Thirdly, the presence of phosphate and nitrogen might cause the aquatic plant to grow in an uncontrollable manner and also the heavy metal content of the sewage sludge is harmful to not only human but to animals and plant. Therefore, it is advised that all these content to be reduced before the sewage sludge is disposed.

Among all the by-products being processed, sewage sludge is records the highest volume of by-product being processes. Sewage sludge processing and disposal is one of the most complexes being face by personnel in wastewater sector. This is due to the harmful pathogens and micro-organism contained in the sludge. The main reason sludge processing is done before disposal is to reduce the quantity of the organic solid, eliminate harmful content and reduce smell. In order to achieve all these, sewage sludge is to undergo stabilization, conditioning and dewatering. Stabilization can be done using three different methods namely lime stabilization digestion and heat treatment.

Fluidised Bed Combustor (FBC) and Multiple-hearth furnace (MHF) have been regularly used as an energy recovery and waste managing method in highly populated metropolis like Japan, USA, Belgium, Denmark, France and Germany. During incineration, water contained in the sewage sludge is evaporated and organic matters are oxidized to form CO_2 and water. Ash from the process is land filled, which significantly reduces the waste volume required to dispose. However, incineration is associated to few problems such as:

I. incineration of sewage sludge include quality inconsistency
II. the need for sewage sludge handling systems
III. reduced boiler capacity because of the high moisture content

Dried, digested sewage sludge has an energy value similar to brown coal but the heat value in sewage sludge is much lower. Relationship between sewage sludge water content and heating value depicts a linear negative relationship. Dry matter content or lower heating value and composition of sewage sludge are the most important factors influencing energy recovery. An external energy supply is always used to dry and incinerate dewatered sewage sludge. In most cases sewage sludge incineration operations are net users of energy rather than sources of energy due to high water content in sewage sludge. Therefore incineration can be considered as a waste management rather than energy generation. Incineration also produces dangerous gaseous which requires different treatment system. Ash from this process should be given consideration for disposal but it may be used as a raw material for the construction industry.

Conventional incineration systems for sewage sludge management generally consume more energy than producing energy. Thus, they cannot be regarded as a beneficial use of sewage sludge management system. However, sewage sludge is likely to become a basis of renewable energy and produce ‘carbon credits’ under the increasingly popular low-carbon economy policy. As a result, mono incineration will remain as an accepted option for sewage sludge management

2.5 Fundamental Behaviours in Combustion of Raw Sewage Sludge

The author in this paper clearly discusses about the basic physical and chemical behaviour sewage sludge sample undergo during combustion. For comparison purpose, experiment was conducted with low-rank coal and softwood biomass and it was suggested that dried sludge contained more volatiles and ash. Furthermore, combustion of coal is wholly slow oxidation reaction of the residual char following rapid devolatilization, while combustion of dried sludge is dominated by the release of a relatively large quantity of volatiles. The main source of heat is provided by the combustion of volatile matter. Experiment was conducted using TG/DTA to distinguish the reaction steps of two sludge samples under a temperature program. The samples were conducted under similar temperature condition range of 25˚C - 800˚C at 10˚C/min under nitrogen and air atmosphere. TG and differential thermal (DTA) curve obtained from the experiments is shown below in **Figure 5** and **Figure 6**.

These curves which were obtained, also discusses on proximate analyses about the sludge sample. The reaction stages for sample A and B were very similar, indicating roughly water evaporation (~ 180˚C), volatile release (~350˚C) and the combustion temperature (~500˚C). This data also concludes that there is high water content and volatiles related to fixed carbon for raw sludge. The author the concludes the study by reiterating the stages of sludge combustion described as follows dehydration and devolatilization simultaneously takes place from the exterior surface to the interior, then steams are produces and volatiles flow out from the interior to the out surface.

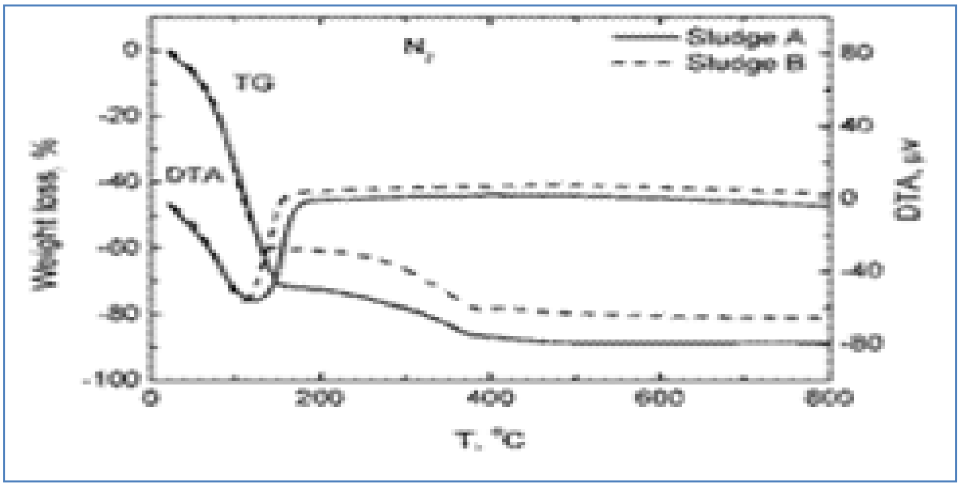

Figure 5 TG/DTA profiles for raw sewage sludge in. Conditions: mass 30 mg; heating rate 10 °C/min; gas flow 100 mL/min [22]

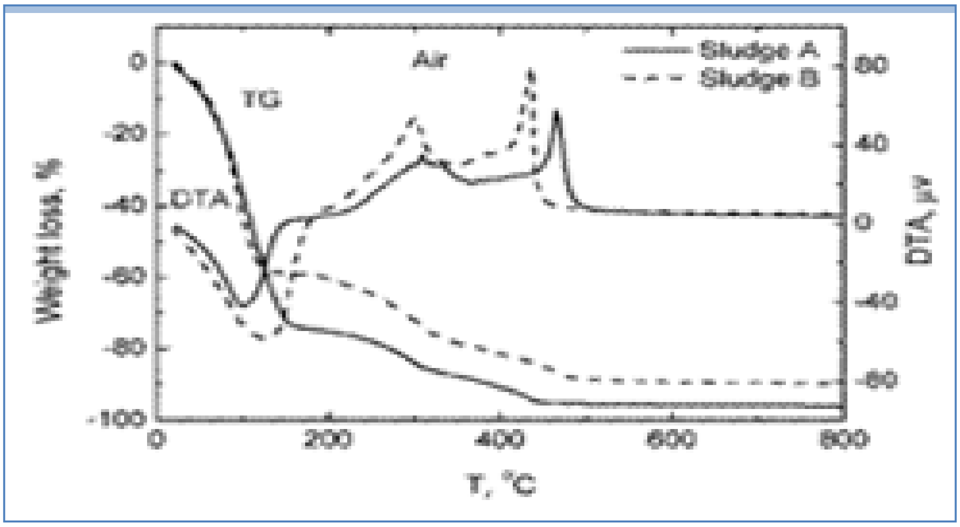

Figure 6 TG/DTA profiles for raw sewage sludge in air atmospheres. Conditions: mass 30 mg; heating rate 10 °C/min; gas flow 100 mL/min [22]

In this experiment, three combustion stages of raw sludge were identified by the temperature programmed TG/DTA technique. These stages were drying, volatile release/burning and char burning. **Figure 7** depicts the morphology of a combusting sludge pellet. There is a significant reduction in the size of the sludge pellet when the pellet is combusted at 900˚C. Molten droplets were observed to appear during that time. This provides observable evidence for volume reduction of sewage sludge, which proposes two stages for volume reduction. The first stage for pallet's reduction in size was due to moisture loss and volatiles whereas the second stage is due to ash melting and agglomeration [21].

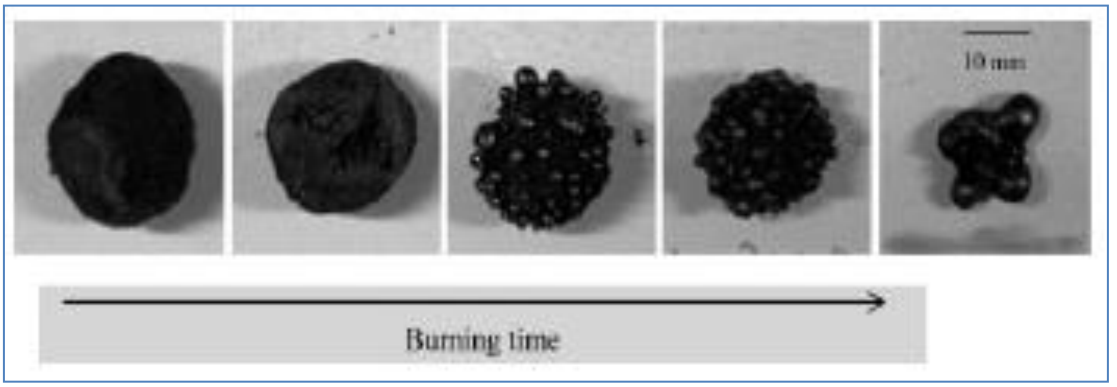

Figure 7 Morphology of a combusting sludge pellet [22]

Figure 8 shows the overall combustion process of raw sludge/ this process include six stages: dehydration, devolatilization/auto-gasification, volatiles combustion. Ash melting, and char combustion as well as ash agglomeration. **Table 2** also illustrates the chemical reactions occur in every stage.

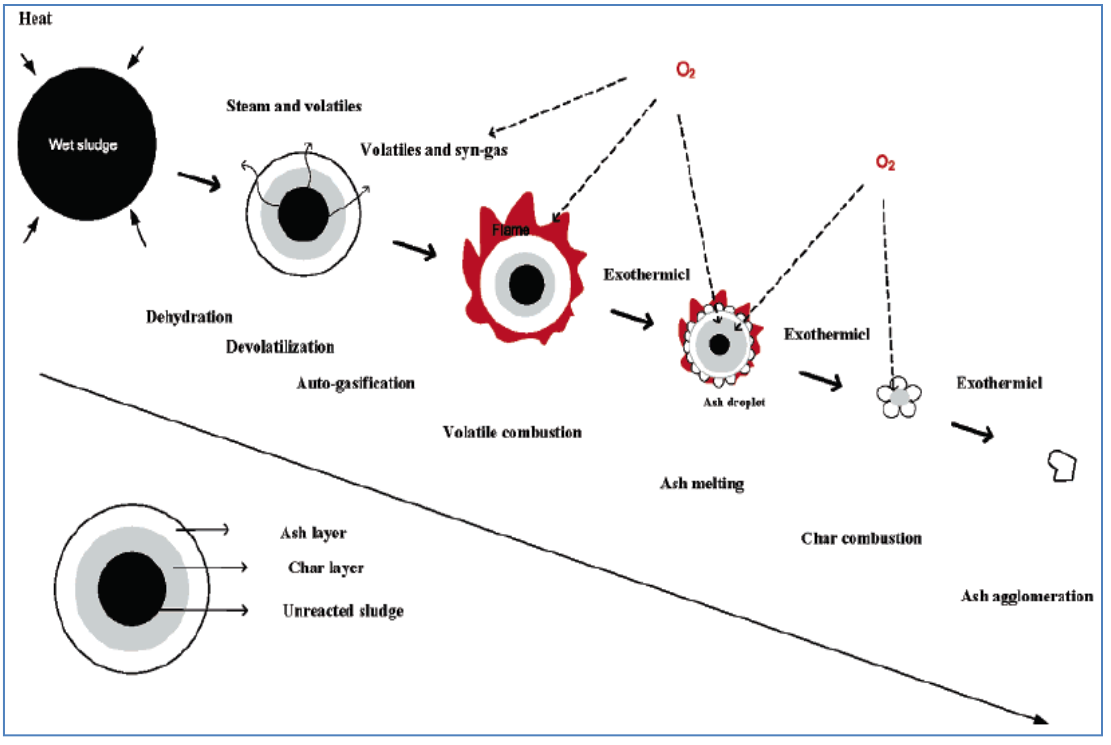

Figure 8 Overall combustion process of raw sludge [22]

Stage		Chemical Reaction
1	Dehydration reaction	H_2O (l) → H_2O (g)
2	Devolatilization reaction	CмHṇO → H_2, CO, CO_2, CмHṇ, Char,etc
3	Auto-gasification reaction	H_2O + Char → H_2 + CO
		H_2 + Char → CH_4
		CO_2 + Char → CO
4	Volatile combustion reaction	C_MH_N+ O_2 → CO_2 + H_2O
5	Char combustion reaction	Char + O_2 → CO_2

Table 2 Involved chemical reaction in raw sludge pellet combustion [22]

Dehydration (1) and devolatilization (2) processes include water evaporation, volatile formation, and their removal from the matrix. Due to burning of volatile matter on the surface, the pellet temperature will be higher in O_2 (combustion) condition compared to N_2 (pyrolysis). Due to this, the overall reaction of pyrolysis is relatively low compared to combustion. It is difficult to distinguish auto-gasification (reaction 3) between steam and char from devolatilization, because of the low yields of solid char and similar gaseous products for both effects. Auto-gasification should not be ignored in case of wet sample particularly large quantity of wet sample. An addition test was conducted to confirm this. The final solid products at 1300˚C were almost the same for combustion process and pyrolysis process. This is an indication that, moisture and volatiles released has the tendency to react with produced char N_2 atmosphere. The same condition was not found at 900˚C. Therefore, auto-gasification can happen for a large particle and at high temperature before O_2 diffuses to char layers under combustion circumstances.

The reaction which is taken to be the major reaction in sewage sludge combustion is the gas-phase combustion of volatiles (4). The formation flames depend on the concentration of oxygen supplied. The oxygen concentration affects formation of flames, so a brighter flame was observed during the combustion of sewage sludge pallet. A brighter flame was observed than that in the air atmosphere.

The heat which is rapidly released also aids in the development of ash droplets. According to the author, based on the experiments conducted, Char combustion (5) is the slowest response step for coal combustion but has no significance for sludge combustion due to smaller amounts of solid char residual after devolatilization. O_2 is prohibited from reaching the pellet during combustion because of the surface flux which contains water and volatiles. Gas-phase combustion is followed by char combustion and can recover the ash droplet agglomeration.

2.6 Effect of Proximity and Elemental Components on incineration of Sewage Sludge

2.6.1 Influence of Moisture Content

Sewage sludge is a multipart of inorganic and organic matter bound together by water. This water mentioned are composed of 70-75% of free water, 20-25% floc water and 1% each capillary and bound water [22]. Experiments done using the drying technique to test drying characteristics revealed drying of sewage sludge consist of two falling rate periods [23]. Based on the results obtained from these drying experiments, sludge moisture is distinguished as free moisture which is expected to be removed during first falling rate period, during the second falling rate of surface moisture is removed, and lastly bound water is not removable during the experiment [23]. Three important phenomena sewage sludge undergoes during drying are wet zone where the free water is easily distributed among the particles of sludge, then the sticky zone where the sludge is pasty and is unable to flow and finally the granular zone where the sludge is crumbly in nature and mixes freely. This understanding on sewage sludge is important due to the realization that technology developed to dry other matter might not be possible to dry sewage sludge.

However, during wet sewage sludge combustion, other factors related to high moisture contents are considered. Firstly, the **decrease in net energy released during sludge combustion, since energy is used for evaporation of the moisture in sludge**. If the net energy is not adequate, supplementary fuel must be supplied. Based on practical research, sludge used as an energy source incinerates autothermaly (which means without any auxiliary fuel)) once properly dewatered. Sludge cake with dry solids of 20 – 30 % can be incinerated only if auxiliary fuel is added but sludge cake with 50% of dry solids can be incinerated autothermaly [24]. Dewatering process can only achieve an end product with ~30% of dry solids. However, for a higher dry solid (eg 50% of DS needed for autothermic combustion) can be achieved by sludge drying. Therefore, sludge drying process is always crucial before any thermal process which sludge undergoes. Since the organic matter and mineral ballast vary upon sludges, the moisture value of, **%MC = 35%** is assumed as the **safe limiting value** for an **autothermic incineration process**.

In an experiment conducted by J.Wether, it was observed that, sewage sludge which is **fully dried and milled to a particle size less than 100-200μm**, the combustion efficiency was not substantially affected. There was a chance for 97-99% of combustion efficiency and CO emissions were considerably low [20].

2.6.2 Volatilization

Volatilization or pyrolysis is when carbonaceous substances decompose thermally with subsequent release of the volatiles. This process involves a series of complex chemical reaction which directs to the decomposition and breakage of the organic matter and the parting of different components into individual gases. Analysis done on composition of the gaseous product of pyrolysis (volatiles) have shown that generally H_2, CO, CO_2, and C_xH_y are the main components liberated during volatilization of sewage sludge. Combustion of volatile matter is regarded as a crucial step during combustion of sewage sludge. The total carbon content in sewage sludge is comprised of sum of carbonaceous volatile and fixed carbon. Sewage sludge has a considerably high amount of volatile matter. 80% of the sludge carbon released through the release of volatile matter.

2.6.3 Fixed Carbon

Succeeding the drying and volatilization process, the remaining sludge char will persist to react with oxygen until it burns out. Due to low fixed carbon in sewage sludge, the char burn out time is less than or comparable to the time span for the release and combustion of the volatiles. This is opposite when compared to coal. Coal has a relatively longer burn-out time of char compared to volatilization. Burning of carbon chars in sewage sludge will emit gaseous such as CO and CO_2 [20].

2.6.4 Ash Content

Ash content should be given very important consideration during incineration process. One of the reasons is that, high ash content can result in higher content of ash in the fuel gas. Depending on the ash content, furnace design and combustion process, ash can be removed from the bed of the furnace and carried away by the flue gas. For fluidized bed chamber (FBC) all of the ashes are carried away by the flue gas whereas for multiple hearths furnace and rotary about 10-20% of the ashes are flown away by the flue gas. Next, the ash disposal problem can be solved if there is low ash content post incineration process. Furthermore, in the experiment conducted by by J.Wether, it was observed that the **combustion efficiency decreased at a higher mass ratio of sludge due to increase ash production** [20]**.**

2.6.5 Nitrogen and Sulphur Element

Understanding the mechanism of NOx and N_2O formation through nitrogen element in the sewage sludge can be understood by reviewing the formation of NOx during coal combustion. NO and NO_2 formed during combustion sums up to NO_x . During the combustion process in the furnace, NO is the main compound with NO_2 being less than 5%. The formation of NOx through fuel nitrogen (N) is more multifarious. During coal devolatillization, some of the fuel nitrogen is released alongside with other volatiles whereas partly remains in the char. NOx is therefore formed in two different pathways as depicted. As for sewage sludge, the same trend is expected but with minor differences. This is due to the fact that sewage sludge has a high content of nitrogen, volatile matter, and ash but a low content of fixed carbon. Further, influencing factor is that sewage sludge has high content of moisture compared to coal but pre-dried sewage sludge has a lower content of nitrogen compared to mechanically dewatered sludge.

As for sulphur, emissions of SO_2, in a annihilated flame are correlated to the content of sulphur in sewage sludge. Studies show 90-100% of the fuel S is converted into SO_2 during combustion [20].

2.7 Characterization of Malaysian Domestic Sewage Sludge for Conversion into Fuels for energy Recovery Plants [25]

Due to increase in population in Malaysia especially in urban areas, Malaysia is experiencing a hike in treatment and disposal of domestic sewage sludge (DWS) and an increment financially in order to treat this sludge. According to the author the main challenges in processing DWS are managing the high moisture content and the unstable organic substance that decompose to create bad odours. Since it is weighed down with harmful pathogens that threaten human health, keen consideration should be given in handling this sludge. The author has also gave an overview in the global status regarding the various option of managing DWS which ranges from disposal into landfills to post processing techniques such as thermal treatment and direct usage as fertilizer. It was also mentioned that, Malaysia had very minimal exploration in the area of energy recovery options using the DWS. In order to estimate the suitability of DWS for energy recovery, its characterization for combustion property and chemical composition was studied. In usual cases, the measurable parameters referred are moisture content, heating value and the chemical properties obtained from proximity and ultimate analysis. Author also gave examples of similar studies done with DWS in other countries.

For this research study, the samples were collected from a mechanical waste water treatment plant in the city of Kuala Lumpur. The samples were dried at a temperature rating of 105˚C before running the test on bomb calorimeter for High Heating Value (HHV) and Thermogravimetric Analyzer for proximity analysis. An empirical formula deduced by [27] was used to predct the HHV for ash content less than 50% (db).

HHV = 255.75V + 283.88 – 2386.3 -- (1)

The variation between the experimental HHV and the theoretical HHV was calculated using the following equation:-

% Variation = 100 x (HHV predicted – HHV measured) / (HHV measured) ----- (2)

The mean heating value was found to be 15.7MJ/kg with a standard deviation of 0.17. The TGA results for the DWS indicate that the sample contains 12% of moisture content, 48.9 % of volatile matter, the amount of fixed carbon is to be 19% and the ash content resulted at 32%. Comparing to previous studies done on Malaysian DWS it is found that the carbon content and the ash content experimented in this research is relatively high low.

It was concluded in this study that the sample collected from Malaysia had similar characteristics to the data published on samples from other countries. In addition to that, since sample from Malaysia has a slightly higher fixed carbon content and lower ash and sulphur content, it has a huge potential of being used as fuel in energy recovery plants.

2.8 Determining Higher Heating Value using Proximate Analysis and Ultimate Analysis [26]

High Heating Value is usually determined by either experiments using bomb calorimeter or by modelling with its composition as the foundation. For this research studies, the author has modelled a correlation based on the proximate and ultimate analysis of sewage sludge from sewage treatment plant in Bangkok. Many models have been proposed for predicting the heating value of various materials with different compositions but as for sewage sludge heating value prediction, only few works has been done. The objective to be achieved through this study is to predict heating value based on sewage characteristics (proximate or ultimate analysis) for sewage sludge in Thailand. Physical or chemical compositions, proximate analysis, ultimate analysis are the three analyses usually used to predict heating values of3 models. The first two models are common when dealing with MSW and lignocelluloses materials or biomass while models for coal and liquid fuels is derived based on ultimate analysis. A total of 30 equations were developed consisting of variables and fixed constants. To select an appropriate form of heating value model equation, the error, simplicity, liability or even versatility were considered. For this research study, only models based on proximate and ultimate analysis were given consideration. The proposed equations were analysed with the objective to find the most appropriate form of equation for predicting heating value of sewage sludge.

Sample sewage sludge for this research study was collected in 20 different wastewater treatment plants around Bangkok. The collection was done in accordance to ASTM D346-90. Altogether there were 219 samples. These samples were then sun dried for 1-2 days prior to characterization. Proximate analysis was done based on ASTM D3172-89 to determine moisture content, volatile matter, fixed carbon and lastly ash content. Ultimate analysis was done with reference of ASTM D3176-89 for all samples and the weight percentage of carbon, hydrogen, nitrogen, sulphur and oxygen (by subtraction) elements were obtained. The heating values of samples used were obtained in accordance with ASTM D2015. Model patterns equated were fit with the experimental data by regression analysis. To select the most appropriate correlation, models with the highest coefficient of determination, R^2 was considered.

Error analysis was done to validate the selected models. For this the absolute and bias errors were considered. Both these quantities are defines as:-

$$\% \, absolute \, error = \left| \frac{(HHVc - HHV)}{HHV} \right| x \, 100\% \quad \text{---- (3)}$$

$$\% \, bias \, error = \left(\frac{HHV - HHV}{HHV} \right) x \, 100\% \quad \text{---------------- (4)}$$

Where, HHVc and HHV are heating values of each data point from calculation and experiment.

Compositions of sewage sludge are mainly volatile matter and ash content with the averages of 42.4% and 53.2% and can be as high as 60.2 and 80.3% respectively. On the other hand, fixed carbon comprises a total of 11.8%. In this research study, the heating value of sewage sample is as low as 4,000 kJ/kg to as high as almost 14, 000 kJ/kg.

Simple correlations between heating value and ultimate and proximate analyses were investigated using plots shown in **Figure 9** and **Figure 10**

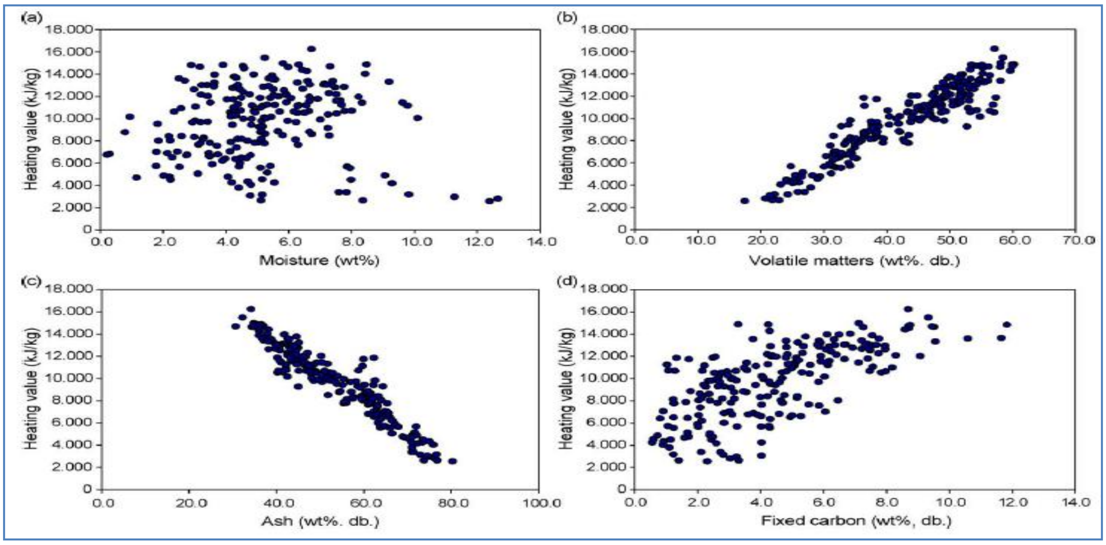

Figure 9 Correlation between heating value and proximate analysis [27]

Coefficient of determination should be reasonably high but at the same time the practical model should of a simple form. So, the simplicity of the model was also given consideration to avoid mathematical complication. The author then proposed two equations/models which are eq 1 which is based on proximate analysis and eq 2 which is based on ultimate analysis as shown below :-

HHV = 255.75V + 283.88F – 2386.38--- (5) based on proximate analysis

HHV = 430.2C – 186.7H – 127.4N + 178.6S + 184.2O – 2379.9----------- (6) based on ultimate analysis

After due consideration to the plots investigated, there are few **limitation** to the models suggested

I. the error occurs when models are applied to high ash content sludge thus having a low heating value
II. it is unlikely to deal with sewage sludge samples with low heating value as they are not attractive to underlines applications

Therefore the model suggested can be used for samples with ash **content less than 50%**. The selected models (eqs (5) and (6)) were then re-analysed with a range of data and were validated with absolute error of 5.9% and 6.4% [26].

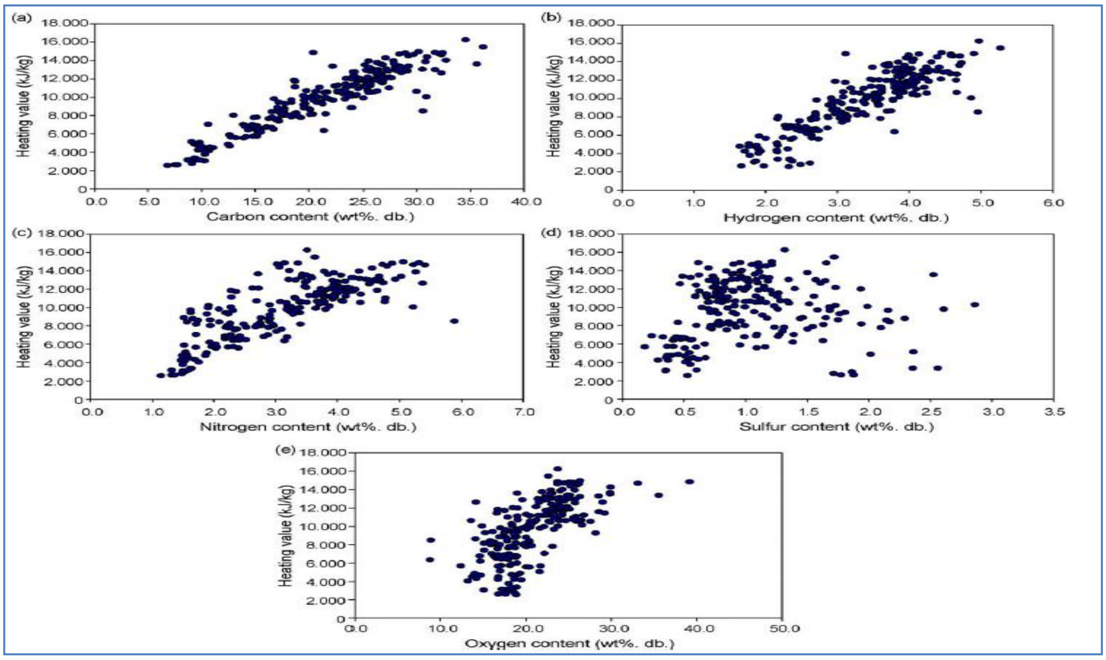

Figure 10 Correlation between heating value and ultimate analysis [27]

2.9 Biosolid characterization comparison

Landfill disposal of organic matters such as sewage sludge is banned in Sweden and many other Europe countries. This creates an urge for need of new alternative disposal method. Thermal process had been used in most Europe countries and certified its efficiency. The main purpose which is to reduce waste material is fulfilled as the toxic organics are eliminated and at the same time energy recovered. Currently, Sweden is moving from mono-combustion to co-combustion which is fairly preferred but also has risks. In his research, 'The fate of trace elements in fluidised bed combustion of sewage sludge and wood', Anna-Lena Elled had experimented on the energy recovery using municipal sewage sludge and wood pellet. The municipal sewage sludge was obtained from two wastewater treatment plant in Sweden. Ryaverket caters to 775,000 residents and is the second largest wastewater treatment plant in Sweden. Nolhagaverket caters to 42,000 residents of Alingsas. Ryaverket employs iron sulphate ($Fe_2(SO_4)_3$) for phosphorous removal and wastewater treatment in Nolhagaverket uses aluminium sulphate ($Al_2(SO_4)_3$) as precipitation agent.

The properties obtained from Ultimate and Proximate analysis of municipal sewage sludge from Ryaverket (MSSr), municipal sewage sludge from Nolhagaverket (MSSn) and homogenous wood pallet (WP) is shown below in **Table 3** and

Table 4

Element	C (%wt)	H (%wt)	N (%wt)	S (%wt)	O (%wt)
MSS Ryaverket	52.60	7.20	5.40	1.40	33.30
MSS Nolhalgaverket	50.20	7.30	5.00	1.20	36.20

Table 3 Ultimate Analysis for Municipal Sewage Sludge Ryaverket and Nolhagaverket and Wood Pallet

Component	Moisture Content (%wt)	Volatile Matter (%wt)	Fixed Carbon (%wt)	Ash (%wt)
MSS Ryaverket	8.00	48.00	12.00	32.00
MSS Nolhalgaverket	7.00	43.00	16.00	34.00

Table 4 Proximate Analysis for Municipal Sewage Sludge Ryaverket and Nolhagaverket and Wood Pallet

The higher heating values of these two (2) samples were also obtained and are tabulated in

Table 5 [27]

Sample	Higher Heating Value (HHV),kJ/kg
MSS Ryaverket	20,580.00
MSS Nolhalgaverket	19,500.00

Table 5 Higher Heating Value of Municipal Sewage Sludge Ryaverket and Nolhagaverket and Wood Pallet

In this research, M.Otero, author of ‘Co-combustion of different sewage sludge and coal: A non-isothermal thermogravimetric kinetic analysis’ has studied the combustion of 2 different sewage sludge samples from two different municipal wastewater treatment plants situated in León (Spain) were used in this work. In both the plants an aerobic suspended-growth water treatment is carried out. However, one of the sludge is from the urban wastewater treatment plant which is of a **very low industrialized** town (named SSL) and the other from the plant of a city with a **higher degree of industrialization** (named SSV). Both SSL and SSV went through a stabilization treatment by **anaerobic digestion, dehydration and thermal drying** in the wastewater treatment plant of origin. Samples of SSL and SSV were taken to the lab where they were analysed to determine the main properties that affect to thermal conversion by procedures described elsewhere [28]. Results from Ultimate and Proximate Analysis are tabulated in

Table 6 and

Table 7.

Component	Moisture Content (%wt)	Volatile Matter (%wt)	Fixed Carbon (%wt)	Ash (%wt)
SSL	4.30	58.00	38.2	31.2
SSV	3.90	42.80	22.7	53.8

Table 6 Proximate Analysis of Sewage Sludges and Coal from León (Spain)

Element	C (%wt)	H (%wt)	N (%wt)	S (%wt)	O (%wt)
SSL	38.2	4.3	4.5	0.9	20.9
SSV	22.7	3.3	3.1	1.6	15.5

Table 7 Ultimate Analysis of Sewage Sludges and Coal from León (Spain)

Higher heating value of Sewage Sludge from León, Spain is tabulated in

Table 8

Sample	Higher Heating Value (HHV),kJ/kg
SSL	17,606
SSV	9480

Table 8 Higher Heating Value of Sewage Sludge and Coal from Asturian, Spain

Study done on sewage sludge from Nigde, Turkey for suitability for gasification, an alternative of thermal utilization was studied [29]. It was concluded that sewage sludge can be gasified to produce low-quality combustible gas, and would be an acceptable alternative source to fossil fuels for the production of the clean energy. In order to evaluate the suitability of the sewage sludge, characterization tests were conducted

3.0 RESEARCH METHODOLOGY

3.1 Research Methodology

The method used to carry out this research is firstly by identifying the problem required to be solved and the objectives to be achieve. Hence, further research is done on this topic in terms of qualitative and quantitative. This is a crucial step before moving into the project deeper so a solid understanding will be obtained from various scholars and sources. The aim of this research study is to map the calorific value of sewage sludge from different sewage treatment plant around Malaysia. Therefore, a study on the characteristic and composition of sewage sludge has to be carried out. As for this matter, the Bomb Calorimeter, Thermogravimetric Analyser (TGA) AND CHNS were used.

Thermogravimetric Analysis is one of the instrumental methods used to analyse sewage sludge. For this research, thermogravimetry (TG) and differential thermal analysis (DTA) were carried out on the sample. Basically the TGA is used for proximate analysis where the moisture content, volatile matter, fixed carbon and the ash content of the sample sludge can be determined. Further analysis will be done on the changes and characteristic of sludge on the effect due combustion.

For this research, a standard fuse wire bomb calorimeter was used to measure Higher Heating Value (HHV) of the sewage samples. The Higher Heating Value can be defined as the number of heat units liberated by a unit mass of a sample when burned with oxygen in a confined are of constant volume [19]. The heat energy measured in the bomb calorimeter is expressed as kJ/kg.

Lastly, CHNS analysis was carried out on all samples. CHNS elemental analyser provides a mean for the rapid determination of carbon, hydrogen, nitrogen and sulphur contained on the samples.

3.2 Project Activity

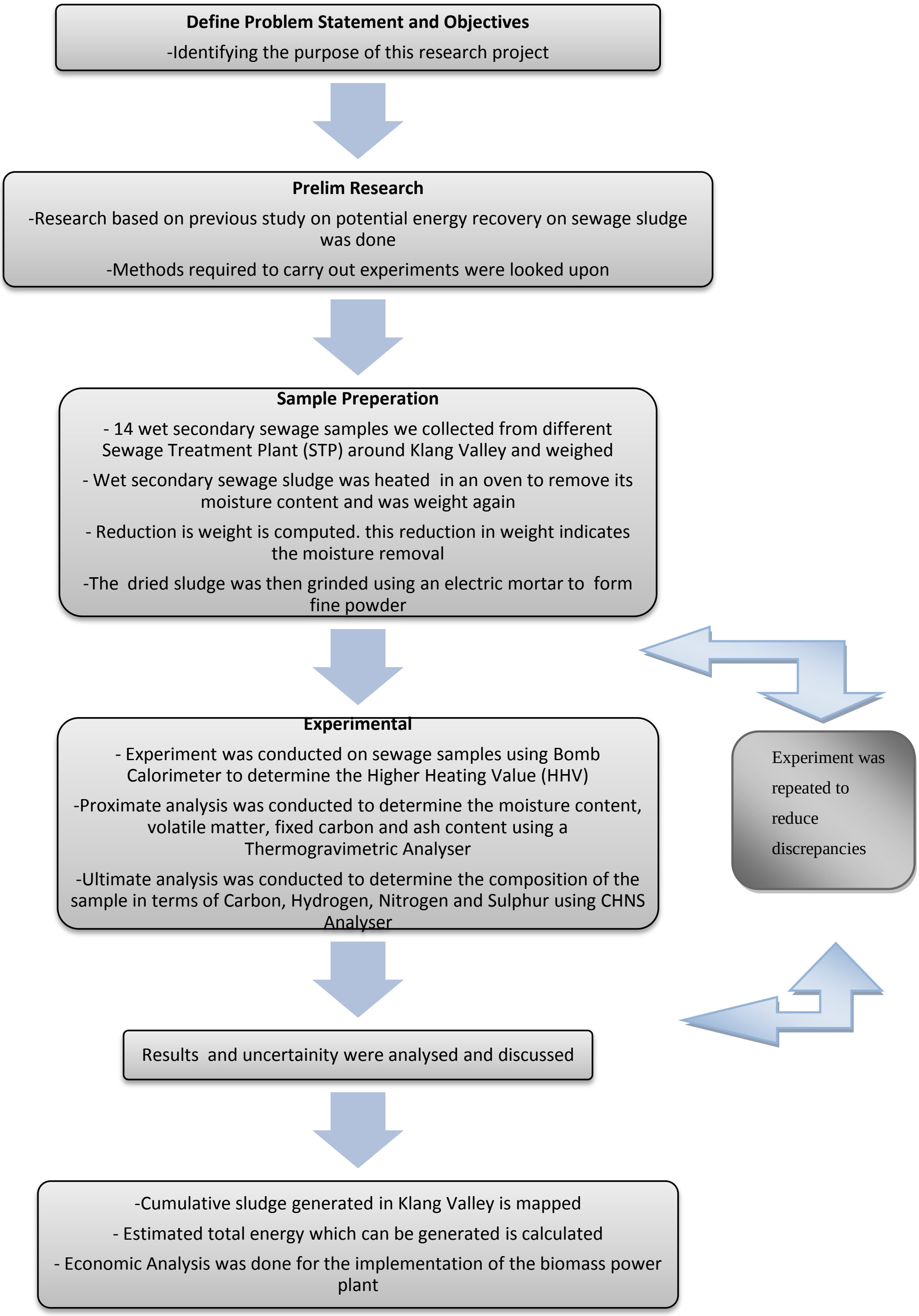

Figure 11 Project Activity

3.3 Experimentation

3.3.1 Sample Preparation (Collection, Moisture Removal, Grinding)

i) Sewage sludge consisting of samples from 14 different Sewage Treatment Plant around Malaysia was collected in sterilized plastic container. The initial weight of each samples were also recorded.

ii) Preparation of the sewage sludge samples we done in accordance to ASTM D346-90(1998)

iii) Before, the secondary sewage sludge samples could be tested; moisture from the samples should be removed.

Figure 12 Collected Raw Sewage Sludge

iv) Samples are transferred to a stainless steel plate to be heated. Once it has been transferred it’s placed in the heater and left to dry for 24 hours at 105˚C.

Figure 13 Sewage Sludge ready to be dried in the heating oven

v) Samples are collected from heating oven and the final weight of each samples were recorded again. The difference in weight indicates the moisture removed from the sample is computed.

Figure 14 Sewage Sludge after drying process

vi) Samples are then grinded on an electric mortar to form fine powder. This powder was then sieved with a sieving tool of 250μm of size.

vii) The sample particle which passed through this sieve was then collected and stored in new separate air tight containers to avoid contamination and to **avoid moisture**. The prepared samples were then used to run on the experiments.

3.3.2 Proximate Analysis using Thermogravimetric Analyser

Figure 15 Thermogravimetric Analyser

In this experiment, the parameters to be determined are Moisture Content (MC), Volatile Matter (VM), Fixed Carbon (FC) and Ash Content (AC) in weight percentage (*wt* %). This experiment was done by using Setaram Lab Sys evo TG/DTA/DSC 1600˚C. The detailed procedure can be obtained from APPENDIX 1-3. Samples with mass (10mg – 15mg) were analysed in the TGA in accordance to ASTM E1131-98. Inert gas (Argon gas) and pure Oxygen at the rate of 20 mL/min was flown at different times for this experiment. The standard condition set are shown on **Table 9**.

#	Type	Initial Temperature (˚C)	Final Temperature (˚C)	Temperature increment rate (K/min)	Gas
1	↗	20	30	20	Argon
2	→	30	30	0	Argon
3	↗	30	110	20	Argon
4	→	110	110	0	Argon
5	↗	110	600	20	Argon
6	→	600	600	0	Argon
7	→	600	600	0	Oxygen
8	↗	600	1500	20	Oxygen
9	→	1500	1500	0	Oxygen
10	↘	1500	20	20	Oxygen

Table 9 Standard Condition Used for Proximate Analysis in accordance to ASTM E1131-98

These standard conditions were decided upon based on the ASTM E1131-98 Standard Test Method for Compositional Analysis by Thermogravimetry. The results of experiment are obtained for interpretation once the experiment ends. **Figure 16** below shows typical graph obtained during experiment and the interpretation method.

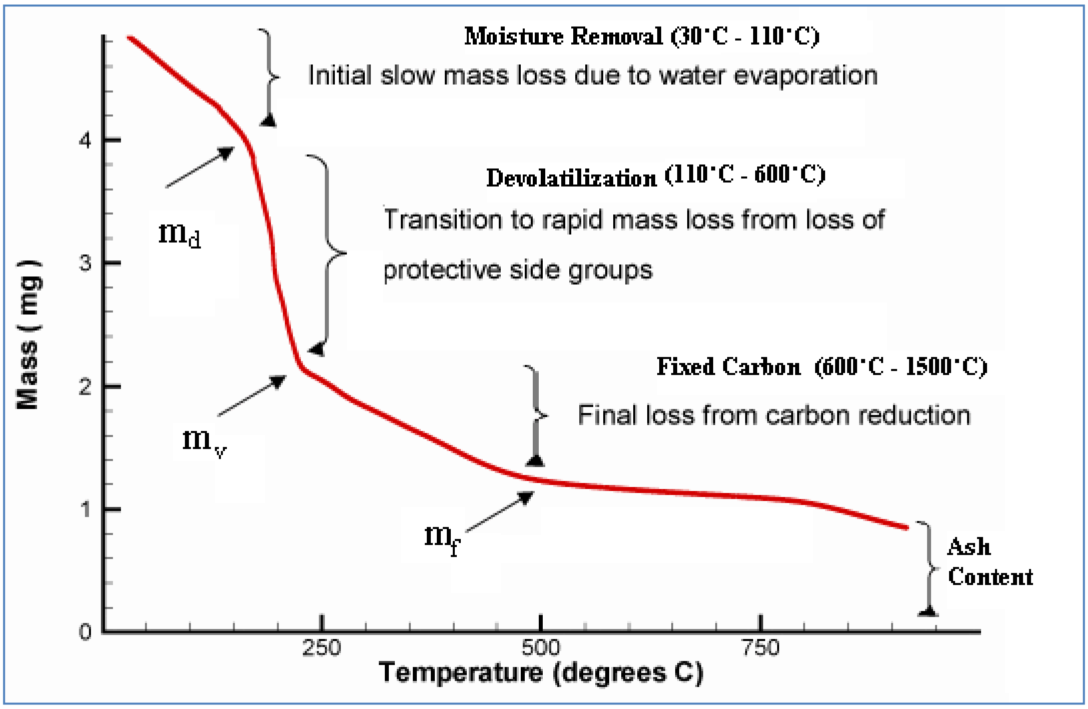

Figure 16 Example of Graph obtained in Proximate Analysis

Figure 16 depicts a graph of mass (mg) versus temperature (˚C) during incineration of sludge sample. The optimum temperature for moisture to be removed is expected to be between 30˚C-110˚C. Major mass loss is expected during devolatilization which is between 110˚C-600˚C and this leaves the char residue containing mainly fixed carbon that will be combusted from 600˚C-1500˚C. The rest of the residue is expected to be ash.

3.3.3 Ultimate Analysis using CHNS Analyser

Figure 17 CHNS Equipment

Ultimate Analysis is done to find the elemental composition of the sample in terms of Carbon(C), Hydrogen (H), Nitrogen (N), and Sulphur(S). This analysis was conducted using *CHNS analyzer (Leco CHNS-932, VTF-900).* Detailed Standard Operating Procedure (SOP) followed to conduct experiment is attached in APPENDIX1-4. The samples were prepared by wrapping samples of mass 1.5-2 mg each into a tiny aluminium case. A standard sample was prepared to find the variance between actual and theoretical value. Sulfamethazime was used as a standard sample for this experiment. **Table 10** shows the error difference calculation computed for CHNS equipment based on Sulfamethazime.

Sample	C (%)	H (%)	N (%)	S(%)
1.00	52.56	5.66	22.21	12.38
2.00	52.67	5.06	23.51	12.42
3.00	51.78	5.08	20.13	11.52
4.00	54.67	4.09	21.16	13.16
5.00	53.77	4.56	20.54	10.23
Average	53.09	4.89	21.51	11.94
Actual Value	51.70	5.07	20.13	11.52
Error difference (%)	$\left\lvert\frac{51.70-53.09}{51.70}\right\rvert x\ 100$ =4.25	$\left\lvert\frac{5.07-4.89}{5.07}\right\rvert x\ 100$ =6.86	$\left\lvert\frac{20.13-21.51}{20.13}\right\rvert x\ 100$ =3.53	$\left\lvert\frac{11.52-11.94}{11.52}\right\rvert x\ 100=$ 3.66

Table 10 Error Difference calculation for Standard Sample

The error difference is in the range of 2%-7%. Since the error differences are lower than 10%, it is still acceptable. Therefore the results generated from this equipment are reliable.

The results obtained from this experiment are used to calculate the theoretical value of Higher Heating Value for validity.

3.3.4 Obtaining High Heating Value using Fuse Wire Bomb Calorimeter

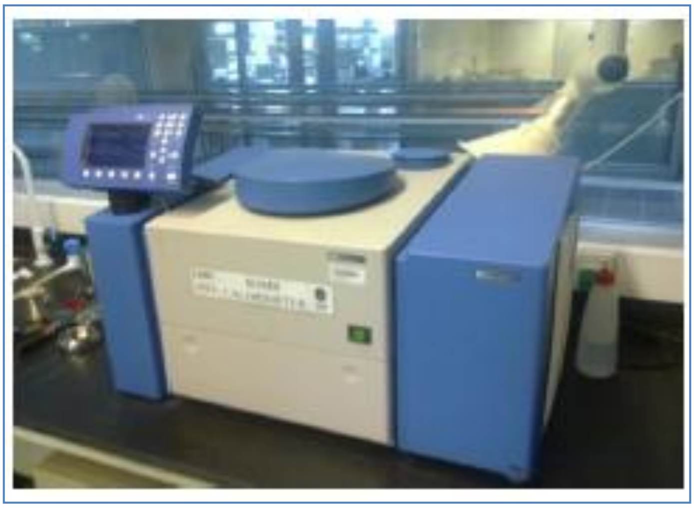

Figure 18 Bomb Calorimeter

The ASTM D2015 Standard Test Method for Gross Calorific Value of Coal and Coke by the Adiabatic Bomb Calorimeter procedure was used for determining heating value sample. The detailed procedure can be referred to in APPENDIX 1-5. Before measuring the heating value for secondary sewage sludge, a standard sample was used to determine the variance between actual results and theoretical results. In this case, benzoic acid was used.

Table 11 shows the computation of the error percentage. Therefore, the calibration error for the equipment is ±0.1 kJ/g

Sample	Heating Value for Standard Sample (Benzoic Acid) (kJ/g)	Measured Heating Value for Standard Sample (kJ/g)	Difference	Error percentage (%)
1	26.46	26.42	0.040	(0.04/26.46)x100=0.15
2	26.46	26.45	0.010	(0.01/26.46)x100=0.04
	Difference Average (kJ/g)		0.025	(0.025/26.46)x100 =0.10

Table 11 Error Difference of Bomb Calorimeter

4.0 RESULTS AND DISCUSSION

4.1 Initial Moisture Content

Figure 19 shows the initial and final state of sewage sample which had undergone drying process at 150˚C for 24 hours. **Figure 19 (a)** shows the initial condition of the sewage sludge sample. At this stage, samples were mostly contained lumpy flaky and colloidal solids dispersed in water [23]. **Figure 19 (b)** shows the sample after the drying process. It is observed that the sample was relatively hard compared to the initial state indicating of moisture removal from the sample prepared.

Figure 19 (a) and (b) Image of Secondary Sewage Sludge Sample before and after drying process

Mass of the collected samples was recorded **before and after** the drying process as well as at an interval of **4 hours**. **Table 12** shows the recorded initial and final mass and the percentage of moisture removed when the samples were heated for 24 hours at 105˚C.

Formula used to compute Initial Moisture Content (%) is as follows:-

$$Initial\ Moisture\ Content, \% = \frac{(Initial\ mass - Final\ mass)}{Initial\ mass}\ x\ 100\% \quad \text{-------------------------- (7)}$$

Sample No.	Venue	Initial Mass	Final Mass	Initial Moisture Content
		(mg)	(mg)	(%)
1	Bandar Seremban	19.2	16.1	16.15
2	Bandar Tun Razak	22.75	2.51	88.97
3	Batu Feringghi	17.93	2.42	86.5
4	Bayan Baru	34.74	5.28	84.8
5	Bunus	24.08	4.56	81.06
6	Gong Badak	22.73	5.14	77.39
7	Jelutong	27.86	4.26	84.71
8	KTU	17.25	5.13	70.26
9	Pantai Dalam	26.89	3.83	85.76
10	Seri Setia	17.34	4.28	75.32
11	Taman Dataran Segar	24.38	4.56	81.3
12	Taman Iping	11.07	6.72	39.3
13	Taman Semarak	25.23	4.06	83.91
14	Taman Tun Dato Ismail	28.43	3.97	86.04
Average				**74.39071**

Table 12 Initial Moisture Content (%) Table

Table 12 shows the initial moisture content of each as-received sewage sludge samples. The samples are assumed to be fully dried after a heating process of 24 hours at 105˚C. Therefore, the percentile difference between the initial and the final mass of the sample yields the initial moisture content. From this table, the initial moisture content of Malaysian domestic secondary sewage sludge ranges from

16.15% to 88.97 %. The average Initial Moisture Content of Malaysia secondary sewage sludge is computed to be 74.39%.

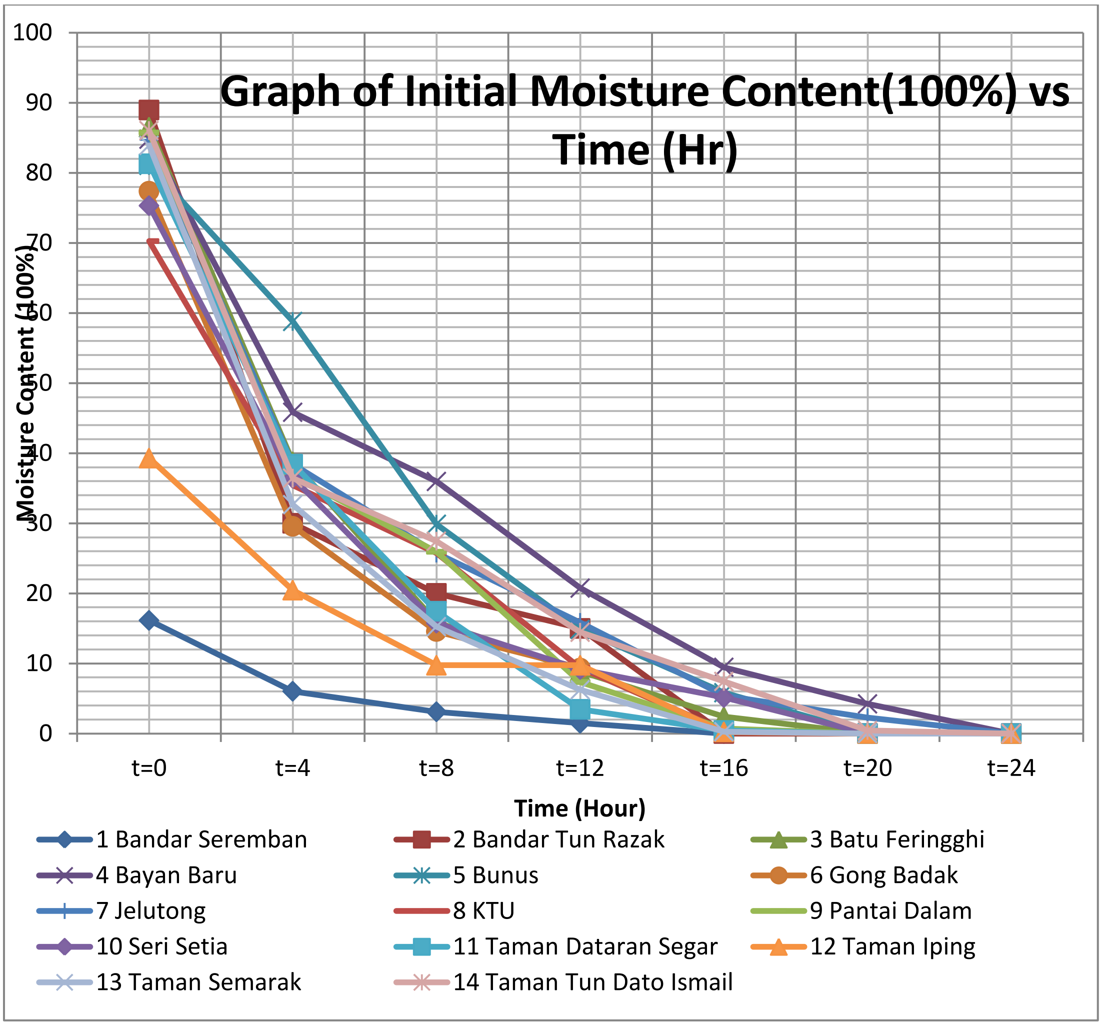

Figure 20 Graph of Initial Moisture Content

The drying trends of all the samples are shown in **Figure 20**. It is crucial to establish the moisture content trend for a better understanding on phenomena of moisture removal. As mentioned by J. Valexaire, water contained in sludge does not have similar properties such as vapour pressure, enthalpy, entropy, density and viscosity when compared to one another due to presence of solid [16]. **As mentioned in Section 2.6.3, the efficiency of combustion was increased by using well-dried and sieved (100-200µm)** [20]. This information aids engineers to design the drying equipment in an energy recovery plant.

4.2 Proximate Analysis

Proximate analysis is done to distinguish the Moisture Content (%MC), Volatile Matter (%VM), and Fixed Carbon (%FC) and Ash Content (%AC). For the proximate analysis conducted using the Thermogravimetry Analyzer (TGA), tests were conducted on 14 different samples and the values are as shown in **Figure 21, Figure 22, Figure 23** and **Figure 24**.

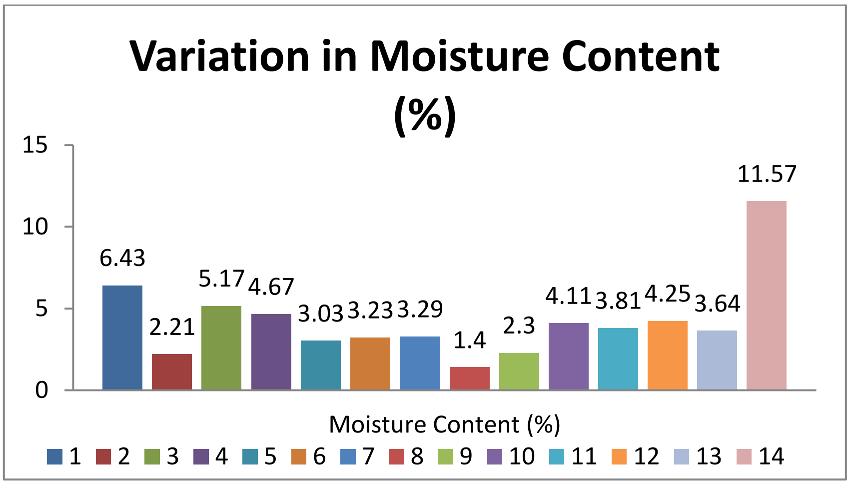

Figure 21 Variation in Moisture content (%)

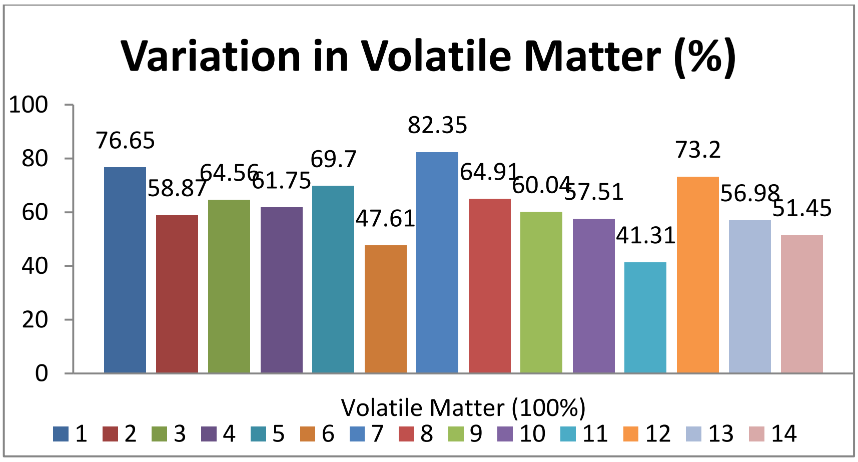

Figure 22 Variation in Volatile matter (%)

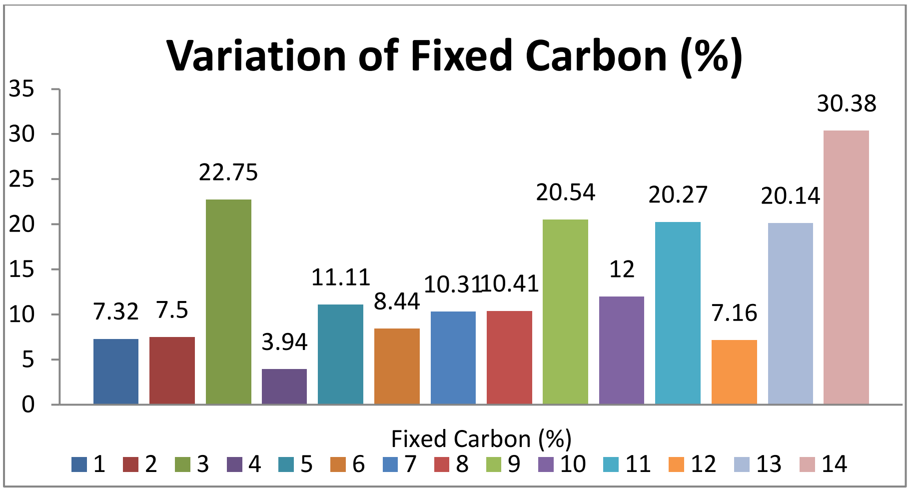

Figure 23 Variation of Fixed Carbon (%)

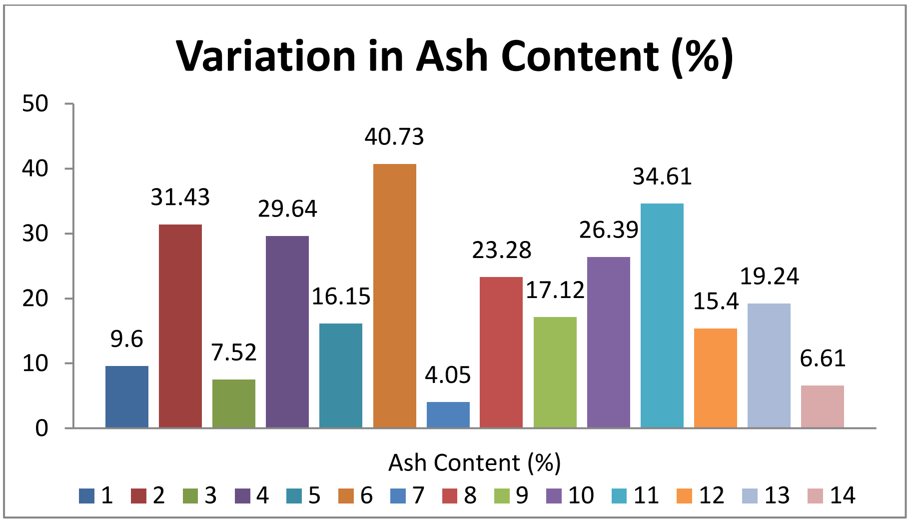

Figure 24 Variant in Ash Content (%)

The average value of all these data was obtained by taking the mean value of the samples is presented in a pie chart form in **Figure 25** for a better representation. This pie chart in **Figure 25** shows that in average, dried secondary sewage sludge generated in Sewage Treatment Plant (STP) around Malaysia contains 4 wt% of Moisture Content, 57 wt% of Volatile Matter, 13 wt% of Fixed Carbon and 26 wt% Ash Content.

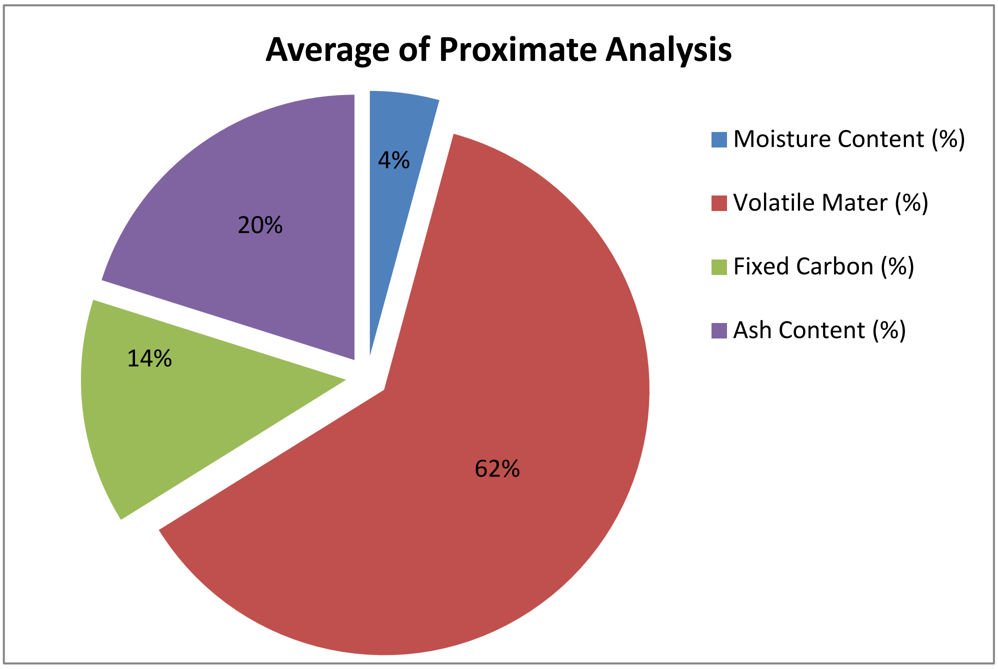

Figure 25 Pie Chart of Average of Proximate Analysis

According to the previous study done by Thipkhunthoda, it is mentioned that the compositions of sewage sludge are mainly volatile matter with the average of 42.4 wt% to 60.2 wt% [26]. The value of volatile matter contained in the present (62%) study is slightly higher than the range suggested by Thipkunthoda. The ash content in the present study accounts to 57% which is in the range with the ash content of Thipkunthoda's study which is 53.2 wt% to 80.3 wt%. Fixed carbon content which account at 13 wt% in the present study is relatively high compared to the previous studies which accounts at 11wt% [26].

Basically proximate analysis distinguishes two components of combustion which is the combustible and incombustible. Combustible components are component which ignites and burns and incombustible components on the other hand are component which does not ignite and burn. During a thermal utilization process, moisture content and ash content are known as the incombustible component. Combustible component are such as fixed carbon and volatile matter.

From Section 4.1, it was mentioned that the sewage sludge sample was dried fully but there are still traces and existence of moisture content when proximate analysis is done. As discussed in Section 2.3, water is mainly classified to 2 main types namely free water and bound water. Free water is not influenced by the solid content of the sewage sludge sample, which means that regardless of composition of the solid matter, when dewatered or dried, free water gets eliminated from the sludge. On the other hand, bound water is water bounded to the solid matter of the sludge and is part of the intercellular moisture of the sludge which is difficult to be eliminated even with drying process. In line with this reasoning, samples which were oven dried, fully dried due to free water elimination but bound water which is in the intercellular of the sludge exists and that is the moisture trace measured in proximity analysis.

Sewage sludge sample is expected to have low Moisture Content and Ash Content. Sewage sludge sample aimed for thermal utilization such as energy recovery is expected to have undergone dewatering and drying process. This is due to the fact that, high moisture content can reduce the overall efficiency its thermal utilization. This is mentioned in Section 2.6.1 of this report, where the energy supplied for incineration will be used to evaporate the moisture content. Once the moisture has been removed, then the volatilization process will take place.

Volatile mater is combustible compound of sewage sludge and is to be high to promote combustion. The significance of volatile matter to the combustion process is based on its content in the fuel concerned. As for coal volatilization is not always considered because combustion of coal is mainly due to fixed carbon and it is assumed that volatilization is simultaneous with combustion [20] but not the same case for sewage sludge as it is mainly composed of Volatile Matter. Combustion of volatile matter is thought to be a crucial step during sewage sludge combustion. Based on the experiments, it can be seen that sewage sludge has significantly high amount of volatile content, and according to J.Weather [20], 80% of total carbon content of sewage sludge is released with volatiles.

Fixed carbon combustion takes place after volatilization and it took the shortest time in this combustion process using sewage sludge. When compared to coal, coal has a longer char burning time compared to its volatilization process which is opposite of combustion of sewage sludge. This is because sewage sludge has low fixed carbon and the reason char burn-out time is less [24]. When a study was conducted on carbon load during combustion process in fluidized bed for sewage sludge and coals of different ranks, results show low carbon load in the bed during sewage sludge combustion due to its high percentage of volatile matter (~90%) and low fixed carbon content (~10%) . Dependence between the carbon loads found in the bed with the carbon content could be seen. Based on the finding on low carbon load value during sewage sludge combustion, sewage sludge appears to have similar characteristics with low ranking coal.

Sewage sludge ash content is also expected to be low as well. As mentioned in Section 2.6.1, depending on the furnace design, during combustion process in the furnace, the produced ash will be flown with the flue gas from the bed of the furnace. Combustion efficiency is also said to decrease at a larger mass ratio of sewage sludge due to production of ash [20].

In relation to this, sewage sample of current study has potential to be developed as fuel for energy recovery purpose due to its relatively high volatile matter and fixed carbon and low moisture content and ash content.

4.3 Ultimate Analysis of Secondary Sewage Sludge

Ultimate Analysis is done to distinguish elemental composition such as Carbon content (C wt %), Hydrogen Content (H wt%), Nitrogen Content (N wt%) and Sulphur Content (S wt%) of the sample in .The Oxygen content (O wt%) is computed by the formula below [27] :-

$$\text{Oxygen content (O\%)} = 100\% - [(\text{Cwt\%}) + (\text{Hwt\%}) + (\text{Nwt\%}) + (\text{Swt\%}) + \text{Ash Content (wt\%\%)}\ ]$$

Table 13 shows the elemental composition of the sewage sludge samples obtained in Sewage Treatment Plants (STPs) near Malaysia.

Sampe.	Venue	C (wt%)	H (wt%)	N (wt%)	S (wt%)	Ash Content (wt%)	O (wt%)
1	**Bandar Seremban**	34.35	4.47	5.37	1.21	9.60	45.01
2	**Bandar Tun Razak**	32.81	5.20	5.30	0.74	6.61	49.34
3	**Batu Feringghi**	33.23	1.79	2.91	0.29	31.43	30.35
4	**Bayan Baru**	31.85	3.64	5.53	0.93	7.52	50.53
5	**Bunus**	32.43	3.21	4.62	0.73	29.64	29.38
6	**Gong Badak**	30.91	3.89	3.52	0.78	16.15	44.75
7	**Jelutong**	30.00	3.26	4.23	0.96	40.73	20.83
8	**KTU**	34.45	2.19	4.67	0.94	4.05	53.70
9	**Pantai Dalam**	32.43	6.21	4.49	1.06	23.28	32.54
10	**Seri Setia**	30.52	3.29	4.73	0.81	17.12	43.52
11	**Taman Dataran Segar**	30.45	1.14	1.62	0.52	26.39	39.88
12	**Taman Iping**	30.07	4.10	4.94	0.72	15.40	44.78
13	**Taman Semarak**	35.98	1.43	1.64	0.32	34.61	26.02
14	**Taman Tun Dato Ismail**	34.07	4.98	5.44	0.62	19.24	35.64
Average		**32.40**	**3.49**	**4.21**	**0.76**	**20.13**	**39.02**

Table 13 Elemental composition of the sewage sludge samples

The averages of these values were taken to obtain an average value of the elemental composition which makes up sewage sludge samples. This graph also shows which elemental composition corresponding to the respective sample.

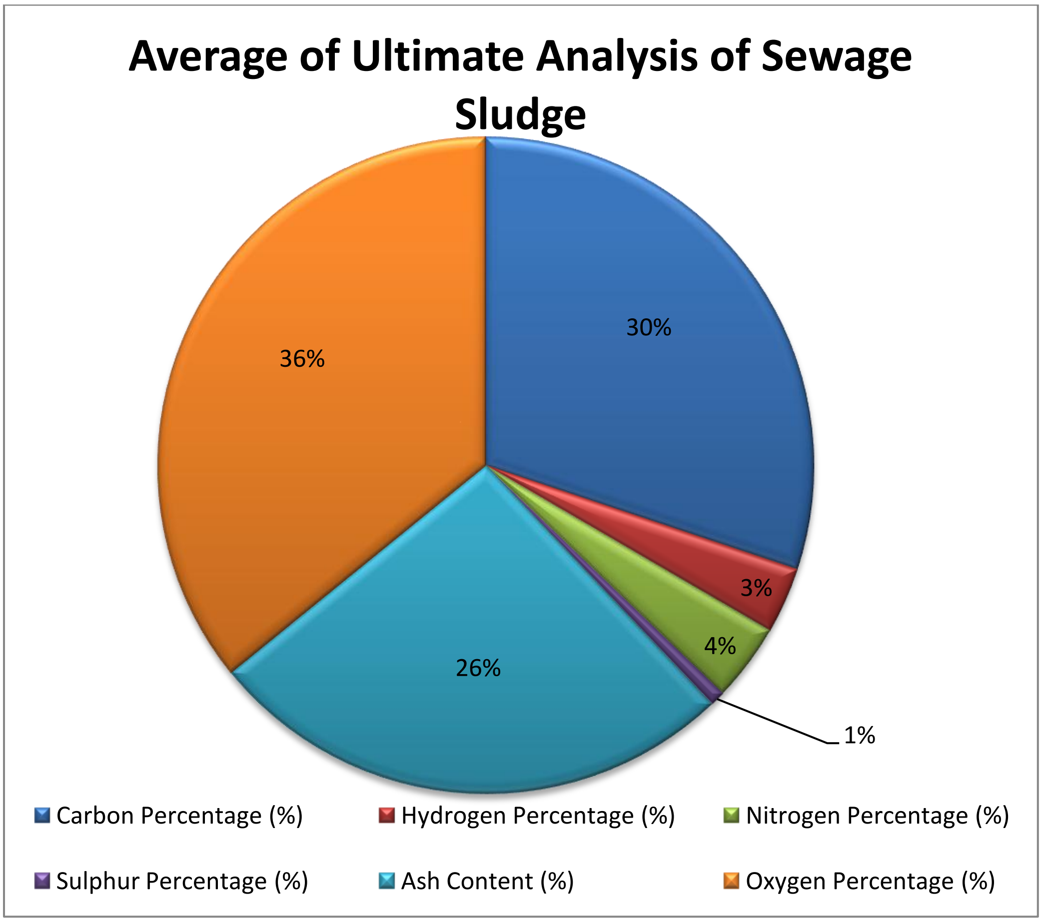

Figure 26 Pie Chart representation of average values of the elemental composition of sewage sludge sample

A pie chart was generated to represent the average values of the elemental composition of these sewage sludge samples in. Based on **Figure 26**, the samples were found to have an average of 30 wt% of Carbon, 3 wt% of Hydrogen, 4 wt% of Nitrogen, 1 wt% of Sulphur and 36 wt% of Oxygen.

In a previous study done by Thipkunthoda on Sewage Sludge from Thailand, the range obtained for Carbon content was 9- 31%. The value obtained in the current study which is 31% is in range with the previous study. Nitrogen content in obtained in the current study (1wt%) is in good agreement with the previously reported literature which was 1.5% to 4.3% and same goes to the sulphur content whether the value obtain in this study which is 1% is in range with the previous study which reported to have range from 0.4 wt% to 2 wt%. However, Hydrogen content reported in the current study which is 3% is slightly lower compared with the previous study by Thipkunthoda which stated to have hydrogen content of 4.2%-20% [26].

Carbon content tested for in ultimate analysis is the total carbon contained in the sewage sludge. As mentioned in Section 2.6.2, total carbon constitutes volatile matter and fixed carbon. Volatile matter which is the major part of the sewage sludge evaporates as gaseous components during volatilization whereas fixed carbon which constitute relatively less percentage of the sewage sludge consist of char which burns by reacting with oxygen. This char burning reaction which reacts to produce CO_2.

Nitrogen is responsible for the emission of gaseous such as NO_2 and NO which is collectively called NO_x. As mentioned in Section 2.6.5 of this report, this gaseous are produced in two different ways. One path is during volatilization, part of Nitrogen fuel volatilizes and partly remains within the char and combusts during combustion. The higher the Nitrogen content the higher the emission of this harmful gaseous. When compared to coal, sewage sludge has a higher emission of $NO_{x.}$

Sulphur fuel (S) contained in the sewage sludge emits $SO_{2.}$ Around 90-100% of the fuel contained in the sewage sludge is converted to this harmful gaseous, $SO_{2.}$ Referring to the obtained data in current studies, the Sulphur content of sewage sludge is considerably low compared to that of coal. Therefore, emission of SO_2 is low in sewage sludge combustion.

When the previous work and the present work are compared, this ultimate result is acceptable since the values are in the range of the proposed value. Some discrepancies such as for Hydrogen can be seen due to the equipment. This is inevitable because it is due to calibration/instrumentation error as calculated earlier in Section 3.3.3. As for the emission of harmful gases, future studies can be conducted on ways to reduce these emissions.

4.4 Experiment on Higher Heating Value (HHV) of Sewage Sludge Sample

Higher heating value of the sewage sludge samples were measured using a Adiabatic Bomb Calorimeter. The unit used to distinguish this parameter is in terms of kJ/kg.

Table 14 shows the gross Higher Heating Value of sewage sludge samples. Gross Heating Value of Malaysian Sewage sludge obtained through experimentation is **17,429.71 kJ/kg**.

Higher heating value was also predicted using correlations Eqs (5) as suggested by Thipkhunoda in the study 'Predicting Heating Value using Proximate and Ultimate Analysis for Sewage Sludge in Thailand' [26]. The predicted value of Malaysian Secondary Sewage Sludge using value of Proximate Analysis values were **17,354.46 kJ/kg.**

This prediction was found to be within an error difference of 0.43% as computed below when compared to the experimental value. The small difference between the two values suggests the appropriate use of the HHV equation to compute higher heating value of Malaysian Sewage Sludge.

Sample No.	Venue	High Heating Value (Experimental) (kJ/kg)	High Heating Value / Proximate Analysis (Theoretical) (kJ/kg)	Error Differences_exp_Prox (wt%)
1	Bandar Seremban	19,310.00	19,301.34	0.04
2	Bandar Tun Razak	18,567.00	19,402.46	4.31
3	Batu Feringghi	14,567.00	14,804.55	1.60
4	Bayan Baru	20,945.00	20,589.16	1.73
5	Bunus	14,635.00	14,531.72	0.71
6	Gong Badak	18,459.00	18,600.32	0.76
7	Jelutong	13,582.00	12,190.37	11.42
8	KTU	20,392.00	21,606.89	5.62
9	Pantai Dalam	19,567.00	17,176.08	13.92
10	Seri Setia	17,834.00	18,806.23	5.17
11	Taman Dataran Segar	16,547.00	15,732.71	5.18
12	Taman Iping	18,063.00	18,372.45	1.68
13	Taman Semarak	12,569.00	13,937.70	9.82
14	Taman Tun Dato Ismail	18,979.00	17,910.39	5.97
Average		**17,429.71**	**17,354.46**	**0.43**

Table 14 Higher Heating Value based on Experimental and Proximate Analysis

Figure 27 shows a graph which has a better representation of **Table 14**. The difference is computed using the formula given:-

$$\boxed{\begin{aligned}&\%\, Difference\\ &= \left|\frac{(HHVt - HHVe)}{HHVt}\right| x\ 100\%\end{aligned}} \quad \text{---} \ (8)$$

$$\%\, Difference = \left|\frac{(\mathbf{17,354.46 - 17,429.71})}{\mathbf{17,354.46}}\right| x\ 100\%$$

= <u>**0.43%**</u>

In the study done on 'Characterization of Malaysian Domestic Sewage Sludge for conversion into fuels for energy recovery plants', the author obtained a mean value of 15,700 kJ/kg for the experimented sewage sludge and 15,600 kJ/kg for predicted heating value of the past study. Comparing the current study done the predicted Heating Value is higher compared to the experimented and the predicted heating value of the past study [25].

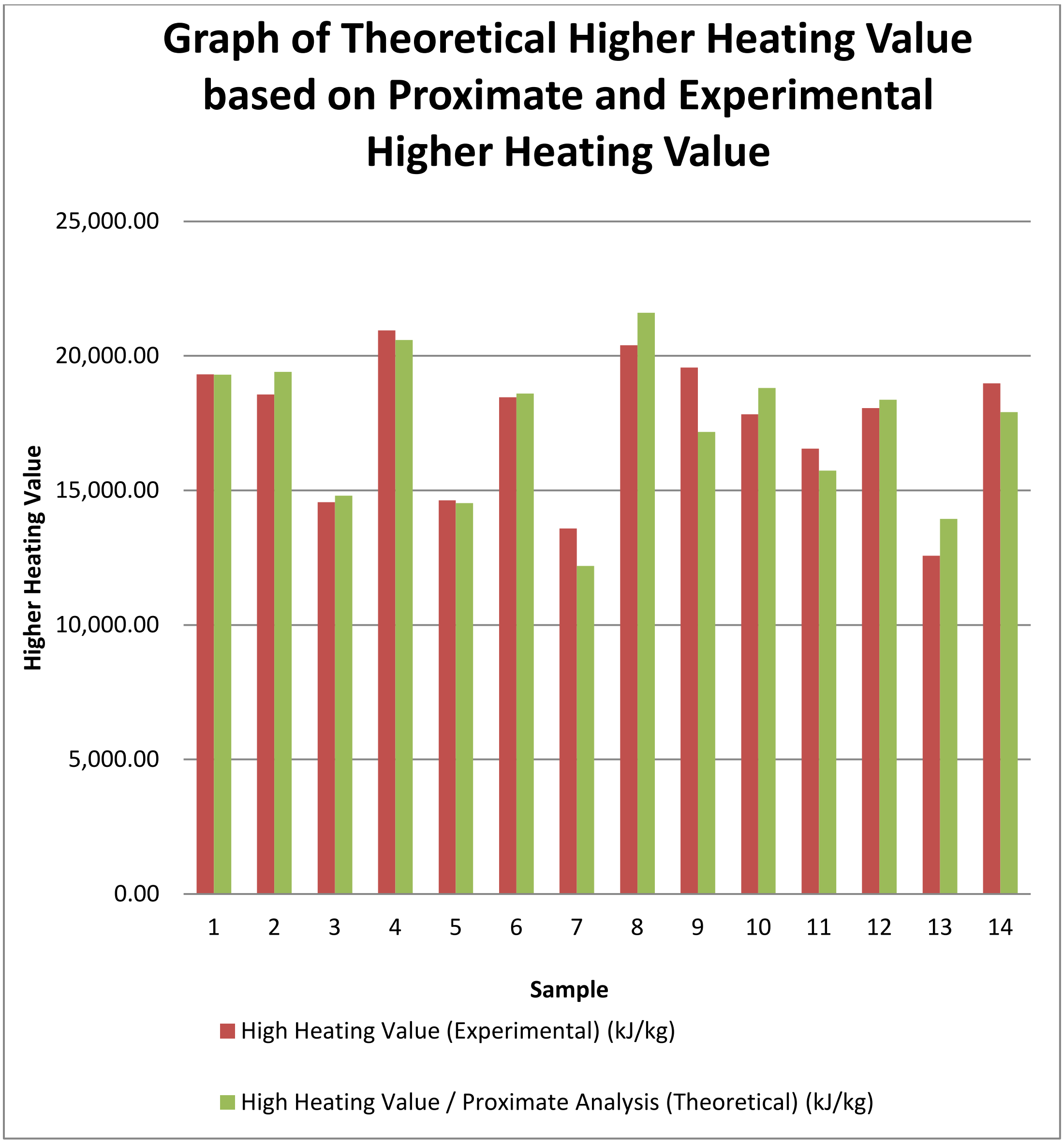

Figure 27 Graph of Higher Heating Value based on Experimental and Proximate Analysis

4.4 Comparison

For the current study, few samples of Malaysian secondary sewage sludge had been tested for characterization. These samples underwent ultimate analysis, proximate analysis and had been tested for its higher heating value. To evaluate these secondary sewage sludge samples' potential for energy recovery, samples are compared with different types of sludge. This evaluation also enable for preliminary feasibility study on potential for energy recovery of the sewage sludge of the current study. The comparison samples were reviewed from various research papers which were discussed in Section 2.7 of this report.

Figure 28 and **Figure 29** below depicts the comparison discussed in Section 2.7 graphically with the aid of the table of origin of the sample with the description of each samples given in **Table 15**.

#	Venue	Description
1	Malaysian Sewage Sludge	- Secondary Sewage Sludge from 14 different Sewage Treatment Plant
2	MSS Ryaverket,Sweden	- employs iron sulfate ($Fe_2(SO_4)_3$) for phosphorous removal
3	MSS Nolhalgaverket,Sweden	- uses aluminum sulfate ($Al_2(SO_4)_3$) as precipitation agent
4	SSL León,Spain	- went through a stabilization treatment by anaerobic digestion, dehydration and thermal drying - sludge is from the urban wastewater treatment plant which is of a very low industrialized town
5	SSV León,Spain	- went through a stabilization treatment by anaerobic digestion, dehydration and thermal drying - from the plant of a city with a higher degree of industrialization
6	Nigde, Turkey	- Description unavailable

Table 15 Graph Legend including Description of Samples

4.4.1 Ultimate Analysis

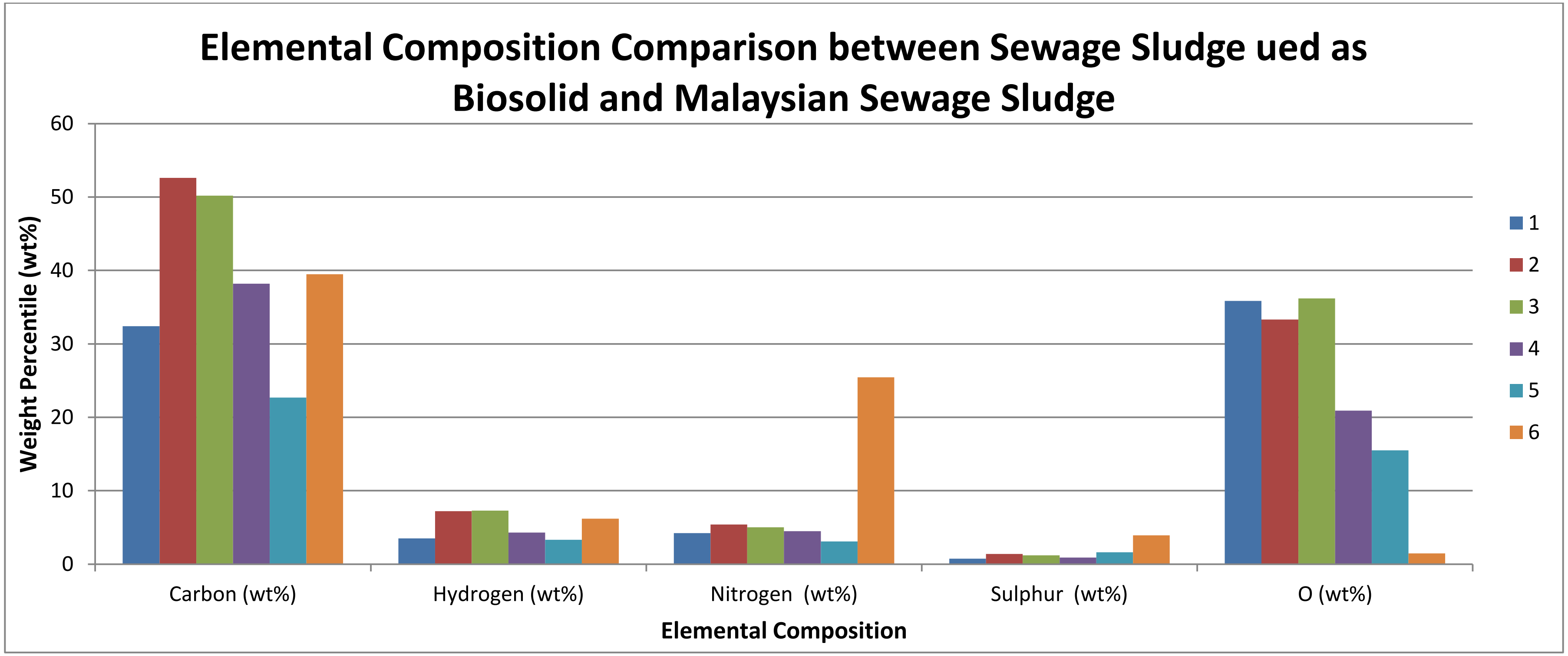

Figure 28 Elemental Composition comparison between Sewage sludge used as biosolid and Malaysian Sewage Sludge

The bar chart in **Figure 28** represents a comparison between the elemental composition between sewage sludge as biosolid and Malaysian sewage sludge. For the carbon composition, it can be observed that the MSS Nolhalgaverket, Sweden records the highest amount of carbon composition which is 50.2 wt%. On the other hand, SSV León,Spain observed the lowest composition of carbon. Malaysian Sewage sludge records a relatively low amount of carbon content compared to the sludges reported in this review which is about 13%. As for hydrogen, both samples from Ryaverket, Sweden and Nolhalgaverket, Sweden have the highest composition. Malaysia has the fourth highest hydrogen content compared to all these samples recorded. Based on the nitrogen composition Malaysian sewage sludge and Nigde, Turkey had a huge marginal difference in composition compared to other venues. Nitrogen content of other samples recorded were relatively similar to the results obtain with Malaysian Sewage Sludge. Sulphur composition was low for all venues. However, Nigde, Turkey recorded the highest composition for sulphur content whereas Malaysia has the lowest recorded sulphur content. The composition of oxygen was rather high for all venues except Nigde, Turkey. In this case, MSS Nolhalgaverket, Sweden and Malaysian Sewage Sludge have the highest oxygen composition compared to other venues.

A slightly higher carbon and hydrogen content in Malaysian Sewage sludge can result in a vivid stand for Malaysian Sewage sludge to be opted for energy recovery option. However, it should be taken into consideration that nitrogen and sulphur content should be low as Malaysian Sewage sludge shows the expected characteristics. The inference behind this is that nitrogen produces nitrogen oxide NO and nitrogen dioxide NO_2 which are cumulatively known as NO_x Sulfur Dioxide, SO_2 which are considered harmful gases and should be taken severe consideration if these emission is expected. Both these products are harmful and thus should be maintained at a minimal content or should be lowered through treatment. The carbon content should be increased in order to fulfil the benchmark set by other sewage sludge used as biosolid and this can be done by further study on effect of treatment of sewage sludge content. Based on the characteristics obtained through ultimate analysis, it shows that Malaysian sewage sludge has potential to settle as an energy recovery option.

4.4.2 Proximate Analysis

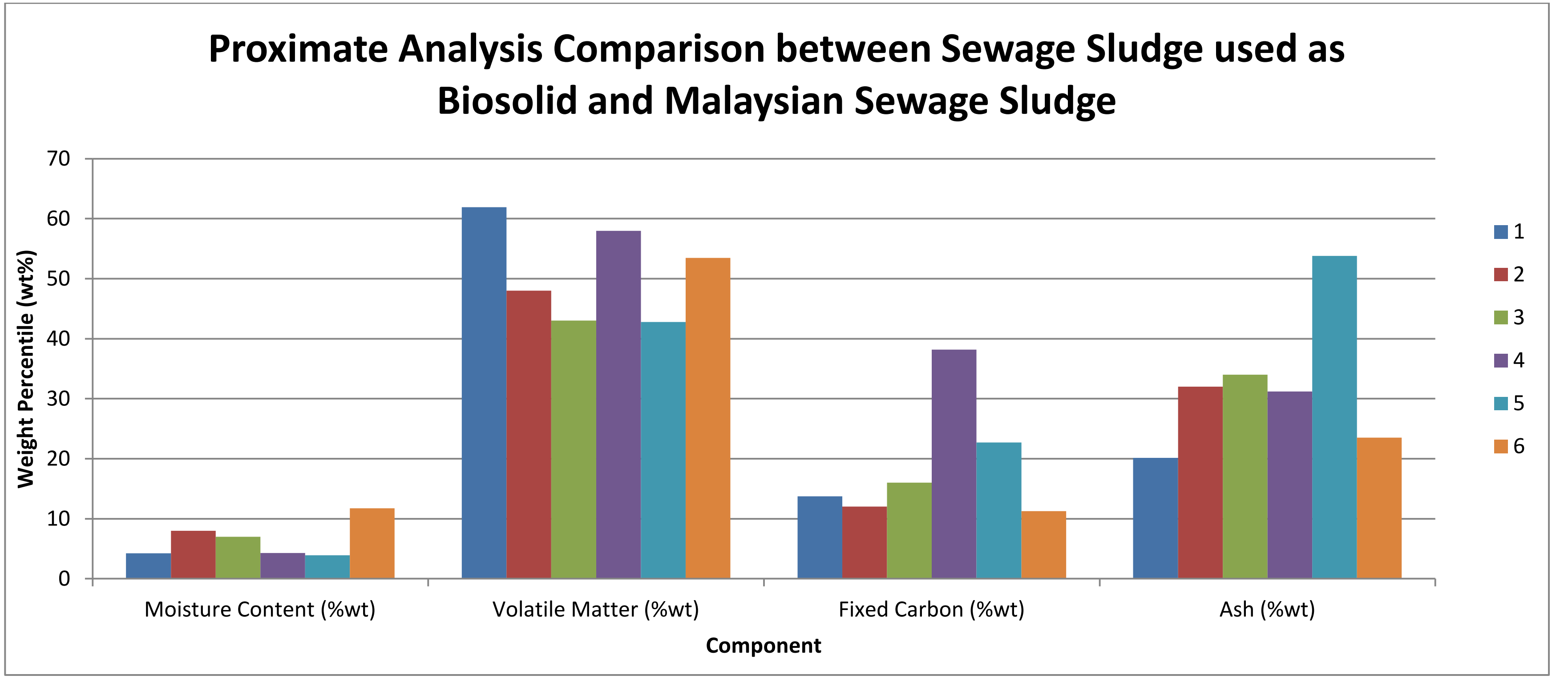

Figure 29 Proximate Analysis comparison between Sewage sludge used as biosolid and Malaysian Sewage Sludge

The comparison using proximate analysis to compare between five selected components in sewage sludge for different region including Malaysia was successfully evaluated. Firstly; the moisture contents at Nigde, Turkey was analysed to be the highest in moisture composition with a percentage weight of 11% followed by 8% from MSS Ryaverket,Sweden. Likewise Malaysia and SSL León,Spain records about 4.3% to 4% respectively. In addition to the analysis, SSV León, Spain gives the lowest moisture contents with a percentage weight of 3.9%. As a result Malaysia stand-out as one of the best possible means for energy recovering using the sewage sludge components since moisture contents is low whereby leading to less cost effectiveness in the overall process.

The tropical weather in Malaysia as an added advantage causing reduction in the moisture contents ensuring very rapid evaporations for volatile matters. However, among all the six selected Europeans and Asia countries, Malaysia shows the highest percentage weight worth 62% of volatile matter content followed by sample from León, Spain with percentage weight of 58%. Nigde, Turkey and MSS Ryaverket,Sweden at the other hand; records 54% to 48% respectively. Further analysis shows that, MSS Nolhalgaverket, Sweden and SSV León, Spain produces equal amount of volatile matter at a percentage weigh of 45%.

The process of eliminating the moisture contents and volatile matters led to another component also known as fixed carbon, it is important to know that fixed carbon is not the actual carbon but an estimated amount of carbon present after the removal of moisture and volatile contents. Therefore using proximate analysis to determined fixed carbon components shows that SSL León, Spain recorded the highest percentage weight of 38%, SSV León, Spain generated 22% while the rest part of the countries such as (Malaysian), (MSS Ryaverket, Sweden) and (MSS Nolhalgaverket, Sweden) recorded percentage weight ranging from 13% to 15%. Likewise Nigde, Turkey was analyzed to be 11% as the lowest fixed carbon contents compares to other countries.

Lastly; the by-products after combustion of coal or the residue left over resulting from the incinerating powdered coal in energy recovery also refers to Ash components. Proximate analysis was used to figure out these Ashes components from the selected countries. Record shows that SSV León, Spain constitutes about 44.5% as the highest ash component while Malaysia indicated lowest ash components of 20%. Similarly, Nigde, Turkey recorded second lowest value of 24%. Nevertheless; (MSS Ryaverket, Sweden), (MSS Nolhalgaverket, Sweden) and SSL (León, Spain) shows a slight percentage weight variation of 32%, 34.8% and 31% respectively.

4.5 Estimation of Energy Generation

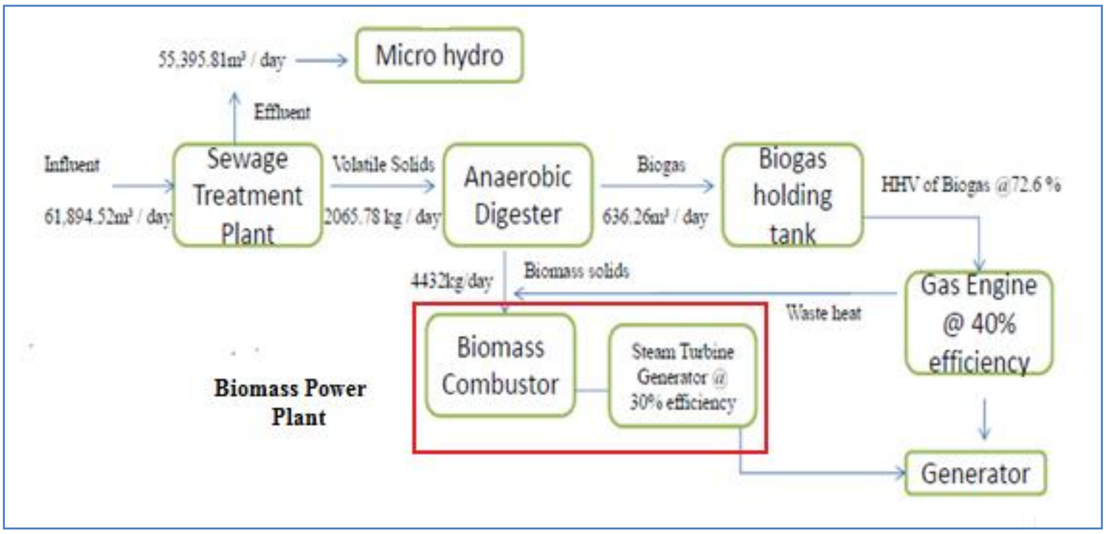

Figure 30 Energy Production from STP (Malaysian Plant) [30]

Since characterization study on Malaysian Sewage Sludge has proved that Malaysian Sewage Sludge has potential energy recovery, estimation of energy generation has to be calculated. The basic function of biomass power plant is to convert energy from biomass to electricity as seen in **Figure 30**. In Malaysia, influent of average 61,895 m^3/day [30] is channelled to Sewage Treatment Plants. The effluent consisting of mainly water is to be directed micro hydro generation whereas the balance volatiles solid is channelled to the anaerobic digester where it is digested and the result is approximately 4438kg of biomass solids/day.

Therefore the first thing to figure out the energy content of the biomass which in this case, the energy content or the Higher Heating Value (HHV) of Malaysian Sewage Sludge is 17,429kJ/kg.

In a biomass power plant the energy conversion takes place in two stages. First energy conversion takes place in the boiler which regards to the combustion process and the second energy conversion is during the steam cycle. As for the boiler and combustion efficiency, the efficiency is taken to be 88% on a High Heating Value (HHV) basis that is the normal range for a properly optimized power plant. As for the steam cycle efficiency, Modern Rankine which is mostly adopted in biomass power plants has efficiencies that differ from 32% to 42%. This efficiency depends purely on the steam constraints. Higher steam pressure and temperatures in the range of 600°C and 230 bars have efficiencies around 42 %. As for this case, a steam efficiency of 37% is assumed. Therefore the overall efficiency is (88% x 37%) 32.56%.

Heat rate (kJ/ kWh) is the heat input necessary to produce one unit of electricity (1kWh) is calculated. 1kW is equivalent to 1kJ/s or 3600kJ/Hr. If the energy conversion computed earlier was 100%, then in order to produce 1kWh of energy a total 3600kJ of energy would be needed. But in this case the overall efficiency is 32.56%. Therefore, the Heat Rate is (3600kJ/kWh / 32.56%) 11,056kJ/kWh.

Since Malaysian Sewage Sludge has a Higher Heating Value (HHV) of 17,429kJ/kg, in order to produce 1unit of electricity (1kWh), (11,056kJ/kWh / 17,429kJ/kg) 0.634 kg of dried sewage sludge is required. With the solid production of 4438kg/day, electricity generation though sewage sludge would be (4438kg/day / 0.634 kg/kWh) **7000 kWh/day**.

5.0 CONCLUSION

Basic characterization of sewage sludge was carried out to evaluate its potential source of energy. 14 Sewage sludge samples were collected from Sewage Treatment Plants (STPs) around Klang Valley. The sewage sludge which was dried at 105˚C for 24 hours before being experimented was measured to have an initial moisture content of 74.39%. These dried samples were then milled and sieved to obtain a sample particle size of lesser than 250µm. Ultimate analysis conducted proved that, Malaysian Sewage sludge had an acceptable value of elemental composition where there is an average 30 wt% of Carbon, 3wt % of Hydrogen, 4 wt% of Nitrogen and 1 wt% of Sulfur and 36 wt% of Oxygen. As for Proximate analysis which was conducted to study the characteristics of sewage sludge during combustion, shows that Malaysian sewage sludge has an average of 4 wt% of Moisture Content (MC), 62 wt% of Volatile Matter (VM) 14 wt% of Fixed Carbon (FC) and lastly 20 wt% of Ash Content (AC). Average higher Heating Value obtained for all 14 samples tested with a Bomb Calorimeter yielded 17, 429.71kJ/kg. Higher Heating Value was predicted to be 17, 354.46 kJ/kg by using a correlation developed by Thipkunthoda from Thailand using sewage sludge from various parts in Thailand. The correlation is valid to be used in Malaysia as it had an error percentage of 0.43% when compared to the experimental value obtained.

The characteristic study and results done on Malaysian Sewage sludge was then compared to characteristics of sewage sludge from 5 different venues which have the potential for energy recovery. The collected data is found to have similar data as the data collected in other parts of the world. However, with a slightly higher fixed carbon and lower ash content in this waste material, it has a vivid potential of being used as fuel in an energy recovery plant.

Once Malaysian sewage sludge was settled for energy recovery option, results obtained in the current study and information obtained from other literatures were used to estimate the power generation if energy recovery option is considered using Malaysia sewage sludge .The estimation done on the power generation based on the current Sludge Production Factor yielded a satisfactory value which **7000 kWh/day**. Objectives have been fully achieved.

As for future works related to this research, further studies on the effect of combustion related sewage sludge such as gas emission could be studied further. Ash handling method, environmental effect of ash disposal and ways to curb it could also be made as an aim to achieve.

REFERENCE

[1] D. A. M. B. I. W. K. S. B. Ir.Haniffa Hamid, "Sewage Treatment Trends in Malaysia," *THE INGENIUER,* no. Series 3, pp. 46-53.

[2] Consumers’ Association of Penang, "MALAYSIA COUNTRY REPORT," Taipei, Taiwan, 2001.

[3] S. L. W. R. K. M. Rhyner C.R, "Waste management and resources recovery," 1995.

[4] Indah Water Konsortium, "Sewarage Treatment Method," 2013. [Online]. Available: http://www.iwk.com.my/v/knowledge-arena/sewage-treatment-methods.

[5] W. Rulkens, "Sewage sludge as a biomass resource for the production of energy: Overview ans assesment of the various options," *Energy & Fuels,* vol. 22, pp. 9-15, 2008.

[6] J. L. Y. Z. F. W. L. H. W. Rong Han, "Dewatering and granulation of sewage sludge by biophysical drying and thermo-degradation performance of prepared sludge particle dring succedent fast pryolysis," *ELSEVIER,* 13 december 2011.

[7] A. C. J. F. R. Fullana, "Formation and Destruction of Chlorinated Pollutants during sewage sludge incineration," *Environ.Sci.Technol,* p. 38, 2004.

[8] S. Zaini Ujang, "Waste Water Sludge Global Overview (2nd Edition)," *WATER 21 MARKET BRIEFING SERIES,* pp. 74-75, 2011.

[9] G. P. Ling, *Space Running Out for Dumpsites,* Selangor, 2012.

[10] M. B. R. M. A. Mohd Idrus Hj Mohd Masirin, "An Overview of Landfill Management and Technology :A Malaysia Case Study at Ampar Tenang," *PSIS ENVIRO,* pp. 157-158, 2008.

[11] T. S. J. Pat Bodger, "National Energy Policies and the Electricity Sector in Malaysia," 2009.

[12] SUSTAINABLE ENERGY DEVELOPMENT AUTHORITY MALAYSIA, "Renewable Energy Status in Malaysia," 4th December 2012.

[13] Prime Minister's Department, "Tenth Malaysia Plan (2011-2015)," The Economic Planning Unit, Putrajaya, 2010.

[14] I. A. K. M. Din, "“Towards Sustainable Sewerage Development - Sharing Malaysia’s Experiences For Replication”," ^th Ministerial Conference on Environment and Development in Asia and The Pacific (MCED-6), Kazakhstan, 20120.

[15] IWK, "Sewage Treatment Systems," 2013. [Online].

[16] P. J. Valexaire, “Moisture Distribution in activated sludge : a review,” *water research,* 2004.

[17] V. P. Smith JK, “Dilatometric measurement of boundwater in wastewater sludge,” *water res,* 1995.

[18] Koey RB, “Introduction to indistrial drying operations,” *Pergamon Press.*

[19] R. J. K. WR, “Use dilatometric and drying techniques for assesing sludge dewatering charecteristic,” *Water Environ Res,* 1992.

[20] T. O. J.Weather, "Sewage Sludge Combustion," *Pergamon,* p. 57.

[21] Y. N. M. M. H. M. T. S. a. C. K. Hong Chui, "Fundamental Behaviour in Combustion of Raw Sewage Sludge," pp. 77-80, 2005.

[22] M. TJ, Water supply and Sewerage, New York, 1991.

[23] L. P, "Development in the thermal drying of sewage sludge," 1995.

[24] O. J. Grabowski Z, 1998.

[25] A. I. M. N. M. A. A.H Abbas, "Characterization of Malaysian Domestic Sewage Sludge for Conversion into Fuels for Energy Recovery Plants," in *National Postgraduate Conference (NPC)*, Kuala Lumpur, 2011.

[26] V. M. P. P. R. e. a. Puchong Thipkhunthod, "Predicting the heating value of sewage sludge in Thailand from proximate and iultimate analysis".

[27] L.-E. A. L. B.-Å. A. Anna-Lena Elled, "The fate of trace elements in fluidised bed combustion of sewage sludge and wood," *Fuel*, vol. 86, no. 5-6, p. 843–852, March–April 2007.

[28] L. C. M. G. A. G. A. M. M. Oteroa, "Co-combustion of different sewage sludge and coal: A non-isothermal thermogravimetric kinetic analysis," *Bioresource Technology,* vol. 99, no. 14, p. 6311–6319, September 2008.

[29] A. M. R. H. Murat Dogru, "Gasification of sewage sludge using a throated downdraft gasifier and uncertainty analysis," *Fuel Processing Technology,* vol. 75, no. 1, p. 55–82, 18 January 2002.

[30] I. K. P. P. Prof. Ir Dr Abd Halim bin Shamsuddin, "Harnessing Renewable Energy from Biosolid and Bioeffluent from Sewarage Treatment Plant".

APPENDICES

APPENDIX 1-1

Gantt Chart

Final Year Project I

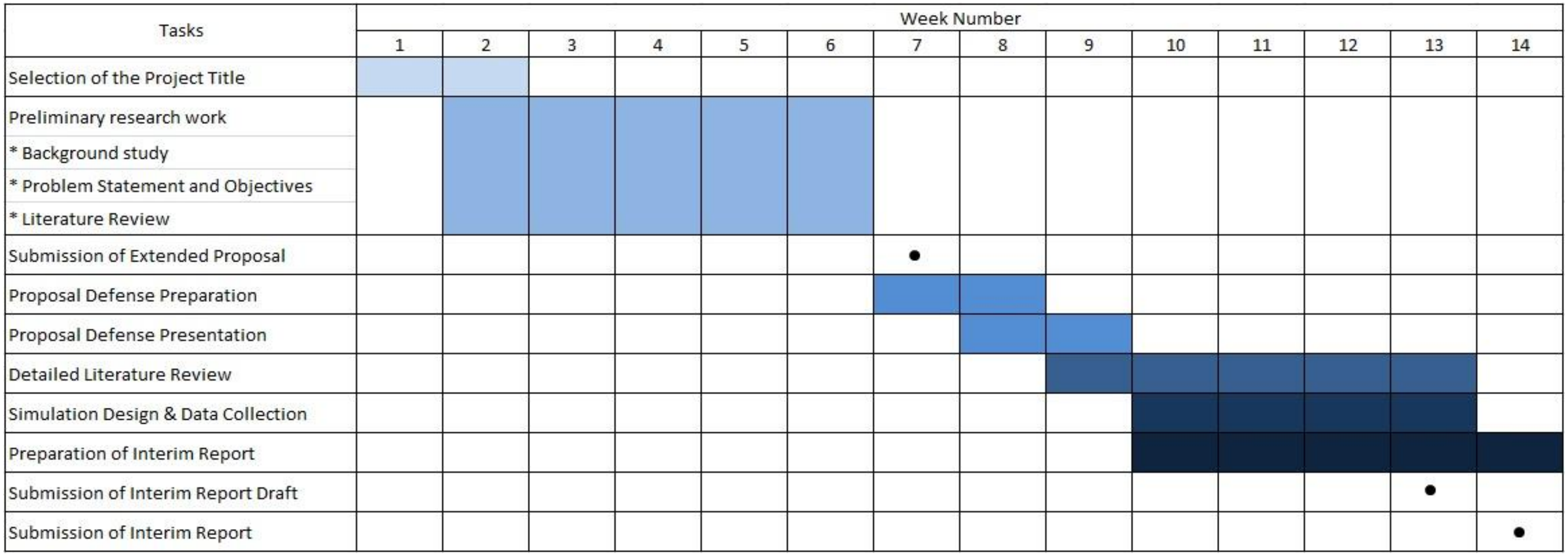

Figure 31 Gantt Chart (FYP I)

APPENDIX 1-2

Final Year Project II

Tasks	Week Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continues	■	■	■	■	■	■	■								
Submission of Progress Report							●								
Project Work Continues								■	■	■	■	■			
Pre-SEDEX										●					
Submission of Draft Report											●				
Submission of Dissertation (soft bound)												●			
Submission of Technical Paper												●			
Oral Presentation													●		
Submission of Project Dissertation (Hard Bound)															●

Figure 32 Gantt Chart (FYP II)

APPENDIX 1-3

Standard Operation Procedure (SOP) of a Thermogravimetry Analyzer (TGA)

Apparatus Preparation

i. Powering on the Labsys Evo (green LED should be switched on)
ii. Powering on the Uni Chiller, the temperature should be noted to be T = 25˚C
iii. The Gas supply which is the Air-Ar supply should be noted to be P = 1.5 bar
iv. Computer turned on and the 'Data Acquisition' programme is initiated

'Run a Tare'

i. The furnace is raised by actuating the switch on the sides of the apparatus simultaneously
ii. The balance is locked by turning the wheel knob clockwise
iii. The rod and gas sweeping tool are installed
iv. The reference crucible along with the empty sample crucibles are placed on the sensor
v. On the 'Data Acquisition' programme, click 'Run a Tare' and wait until the Tared TG value becomes "0"
vi. Next the sample crucible is removed from the furnace and is filled with the sample about one third of the crucible
vii. The sample crucible is then placed in the sensor again, making sure that the reference crucible is at the rear and the sample crucible is at the front
viii. The balance is released by turning the wheel knob anti-clockwise
ix. The furnace is then lowered

Running the programme

i. The Data Acquisisiton programme is resumed
ii. Apparatus connection are checked (the gas and chillers connection)
iii. The experiment properties are entered
- Name of experiment
- Sample mass
- Crucible type (Al_2O_3 µl)

iv. The procedure properties are then checked

- End mode (STOP)
- Temperature
- Carrier Gas
- TG range
- Safety Temperature

v. The zone properties are now entered

- The experimental conditions are entered
- The corresponding valves are checked
- It should be ensured that the TG tare is ticked for the first line to indicate that the tare has been run

vi. “Start Experiment “ button is clicked to start the experiment

APPENDIX 1-4

Standard Operation Procedure (SOP) of a CHNS

PREPARATION

1. Sample is measured to weigh apprx 1.5mg
2. Sample is then placed in an aluminium case and is folded multiple times to form a flat sheet.

START-UP

1. Make sure all pressure gas is set at 40 psi and is OPEN
2. Power is turned on by turning up the switch
3. Set to operator unit
4. Turn to standby mode and wait until T,C purge complete
5. Analyzer mode is turned on until wait till it system indicated to have reached 1000˚C
6. All temperature value is checked by pressing ambient monitor in diagnosis folder
7. Leakages of gas is checked by clicking on leakage icon
8. Sample of BLANK 5 time and STANDARD 5 time is prepared

SHUT DOWN

1. Standby mode is set
2. Made sure the oxi.fur standby mode is 650˚C
3. All gas are switched off
4. OFF mode is turned and power is switched OFF

APPENDIX 1-5

Standard Operation Procedure (SOP) of a Bomb Calorimeter

1. Oxygen gas regulator is turned on
2. Refrigerator and Bomb Calormeter is switched on and wait for 20 minutes until the system stabilizes
3. Measured sample (~1g) is placed on crucible with a cotton thread secured with a loop tied on the middle of the ignition wire and placed into the decomposition vessel
4. Description of the sample entered onto the Description Interface on the equipment
5. The decomposition vessel is then suspended into the filling head of the measurement cell cover
6. The equipment is the activated by pressing the START button. The measurement cell cover will then close and the vessel will be supplied with oxygen. The vessel is then filled with water. Once the system starts the experiment, a graph of the reaction over time is displayed on the interface display
7. When the experiment is completed, the decomposition vessel is removed and cleaned as a preparation step for the following experiment.
8. Steps 3 to Steps 7 are repeated for the succeeding samples
9. Bomb Calorimeter, Refrigirator Bath and Resgulator Oxygen is turned then off