LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
FACULTY OF TECHNOLOGY
BIOENERGY TECHNOLOGY

MASTER'S THESIS

INTEGRATION OF THE FOOD WASTE DISPOSER UNIT TO THE EXISTING SEWAGE SYSTEM

Examiners: Professor, Dr.Sc. (Tech.) Mika Horttanainen
Dr.Sc. (Tech.) Mika Luoranen

Lappeenranta

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ABSTRACT

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Among the numerous approaches to food waste treatment, the food waste disposers method (FWDs), as a newcomer, has become slowly accepted by the general public owing to the worries about its impact on the existing sewage system. This paper aims to justify the role of FWDs in the process of urbanization in order to better prepare a city to take good care of the construction of its infrastructure and the solid waste treatment.

Both the literatures and the case study help to confirm that FWDs has no negative effects on the wastewater treatment plant and it is also environmental friendly by reducing the greenhouse gas emissions. In the case study, the Lappeenranta waste water treatment plant has been selected in order to figure out the possible changes to a WWTP following the integration of FWDs: the observation shows only minor changes take place in a WWTP, in case of 25% application, like BOD up 7%, TSS up 6% and wastewater flowrate up 6%, an additional sludge production of 200 tons per year and the extra yield of methane up to 10000m^3 per year; however, when the utilization rate of FWD is over 75%, BOD, TSS, and wastewater flowrate will experience more significant changes, thus exerting much pressure on the existing WWTP. FWDs can only be used in residential areas or cities equipped with consummate drainage network within the service sphere of WWTP, therefore, the relevant authority or government department should regulate the installation frequency of FWDs, while promoting the accessory application of FWDs. In the meanwhile, WWTP should improve their treatment process in order to expand their capacity for sludge treatment so as to stay in line with the future development of urban waste management.

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NOMENCLATURE

Abbreviations

AD	Anaerobic Digestion
BOD	Biochemical Oxygen Demand
BNR	Biological Nutrients Removal process
COD	Chemical Oxygen Demand
C-N	Pre-Denitrification process
FOG	Fat, Oil and Greases
FWD	Food Waste Disposer
FW	Food Waste
GHG	Green House Gas
GFW	Ground Food Waste
GWP	Global Warming Potential
MLSS	Mixed Liquor Suspended Solids
MSW	Municipal Solid Waste
PE	Population Equivalent
rbBOD	Readily Biodegradable Chemical Oxygen Demand
rbCOD	Readily Chemical Oxygen Demand
TH	Thermal Hydrolysis
TSS	Total Suspended Solids
VFA	Volatile Fatty Acid
VSS	Volatile Suspended Solid
WWTP	Wastewater Treatment Plant

Symbols

CO_2	Carbon Dioxide
CH_4	Methane
N_2O	Nitrogen Dioxide
P	Phosphorus
N	Nitrogen
TN	Total Nitrogen
AC	Alternating Current
DC	Direct Current
TS	Total Solids

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1. INTRODUCTION

1.1 Background

After the second industrial revolution, each country has started to benefit from the rapid development of their industry and economy. With the development of modern technology, the quality of human life is also improving, however, little attention has been directed to the environmental concerns, especially the solid waste treatment.

Poor management of municipal solid waste would restrict urban development. At present, landfill is the main method for MSW treatment, as prior to landfill, the refuse sorting plays a key role in pretreatment. The MSW falls into four categories: recyclable waste, bio-waste, hazardous waste and others. After sorting, the amount of landfill waste would decrease by more than 50%, and the hazardous waste will be disposed of separately. With the fast pace of urbanization and population growth, the landfill capacity very soon approaches its upper limit, hardly satisfying the needs of daily solid waste treatment. Besides, there are two critical challenges in terms of landfill: treatment of the leachate which might pollute the groundwater, as secondary pollution; waste sorting poses huge workload.

For better management and treatment of municipal waste, the food waste disposers (FWDs) were developed as a pretreatment unit in bio-waste treatment. The old model of FWDs was invented in 1927 in USA. It is usually electrically-powered, and installed under a kitchen sink between the sink's drain and the trap which shreds food waste into pieces small enough (generally less than 2 mm) to pass through plumbing. FWDs are widely used in North American households, but far less commonly used elsewhere. In nations with ready access to water and an industrial base, these devices are generally permitted. In Sweden, some municipalities encourage the installation of disposers so as to increase the production of biogas and reduce the amount of waste going to landfill. [1]

1.2 Objectives

The future trend of waste treatment is to recover energy from solid waste. The bio-waste may produce organic fertilizer by means of biotechnology; it can also be used for biogas generation with anaerobic technology. Therefore, the purpose of this thesis is to study the effect of FWDs on the existing sewage plant after the inhabitants start to use FWDs.

One of the most important aims of this work is to study what changes will take place in sludge treatment plants when FWDs are put in use. And also the estimation of the biogas to be produced from ground waste sludge. Specifically the following considerations will be covered:

- The effect on wastewater treatment plant, if FWDs installed.
- The amount of sludge change as a result of the FWDs utilization.
- Estimation of the biogas yield when ground food waste mixes with wastewater
- Discussions on integration of FWDs into the current sewage system.

1.3 Thesis Structure

The thesis consists of seven chapters dealing with the main theory about the effect on existing sewage system when FWDs are used. The focus is particularly placed on the changes in the sludge treatment plant. After the first introductory chapter, Chapter 2 depicts the food waste disposal approaches, with regard to the global warming; Chapter 3 describes the structure of the Food Waste Disposal, the principles of the process, advantages and impacts. When the food waste was ground by FWDs, the ground waste will transfer to Wastewater Treatment Plant (WWTP), the effect of the ground waste on existing sewage system is introduced in Chapter 4. Attention is also given to disposal method in the existing sewage system. Chapter 4 focuses on the effect of ground waste on WWTP. The case studies and experimental results are summarized in Chapter 5, it aims to study the changes in WWTP of Lappeenranta, and the amount of sludge and biogas produced. Chapter 6 draws the conclusion.

2. FOOD WASTE

2.1 The Properties of Food Waste

2.1.1 Physical Properties of Food Waste

Important physical characteristics of food waste include specific weight, moisture content, particle size and size distribution, field capacity, and compacted waste porosity. The discussion is limited to an analysis of residential, and some commercial food waste.

Table 1. Typical specific weight and moisture content data for residential and commercial food wastes [2]

Food Waste		Specific weight, kg/m^3		Moisture Content % by weight	
		Range	Typical	Range	Typical
Residential	Food Waste (mixed)	130 ~ 480	290	50 ~ 80	70
Commercial	Food Waste (wet)	500 ~ 950	540	50 ~ 80	70

2.1.2 Chemical Properties of Food Waste

Information on the chemical composition of the components that constitute food waste is important in evaluating alternative processing and recovery options. For example, the feasibility of combustion depends on the chemical composition of the waste.

Table 2. Typical proximate analysis an energy data for food wastes found in residential, commercial and industrial [2]

Type of Food waste	Proximate analysis % by weight				Energy content, Btu/lb		
	Moisture	Volatile matter	Fixed Carbon	Non-Combustible	As Collected	Dry	Dry ash-free
Fats	2.0	95.3	2.5	0.2	16135	16466	16836
Food Waste (mixed)	70.0	21.4	3.6	5.0	1797	5983	7180
Fruit wastes	78.7	16.6	4.0	0.7	1707	8013	8285
Meat waste	38.8	56.4	1.8	3.1	7623	12455	13120

Table 3. Typical data on the ultimate analysis of the combustible food wastes found in residential, commercial and industrial [2]

Type of Food waste	Percent by Weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food Waste (mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit wastes	48.5	6.2	39.5	1.4	0.2	4.2
Meat waste	59.6	9.4	24.7	1.2	0.2	4.9

2.2 Food Waste & Global Warming

The amount of food waste accounts for about 20% of municipal waste. It biodegrades easily and contains over 70% moisture, during its storage, it tends to precipitate, leach and give off bad smell to attract vermin. When mixed with other dry wastes, the food waste will likely get stuck to and contaminate them, thus compromising the mechanical sorting and separating of dry recyclables. The food waste not only reduces the calorific value and energy recovery in the course of incineration, but also increases the volume of emissions due to its high moisture content. [3]

Fats, oils and greases (FOG) are called "brown grease" normally. FOG is generated when people prepare and cook foods, and the industries generating FOG are meat processors, restaurants, food preparation businesses, cafeterias in schools and residential homeowners. Whenever food is cooked with oil there will be a need to get rid of the cooking oils and greases [4]. FOG can be converted into fuel diesel or biogas with such high energy yields that it turns out to be the best sources both financially and in terms of Global Warming Potential (GWP). (Figure 1, cubic meter of Biogas produced per cubic meter of residual)

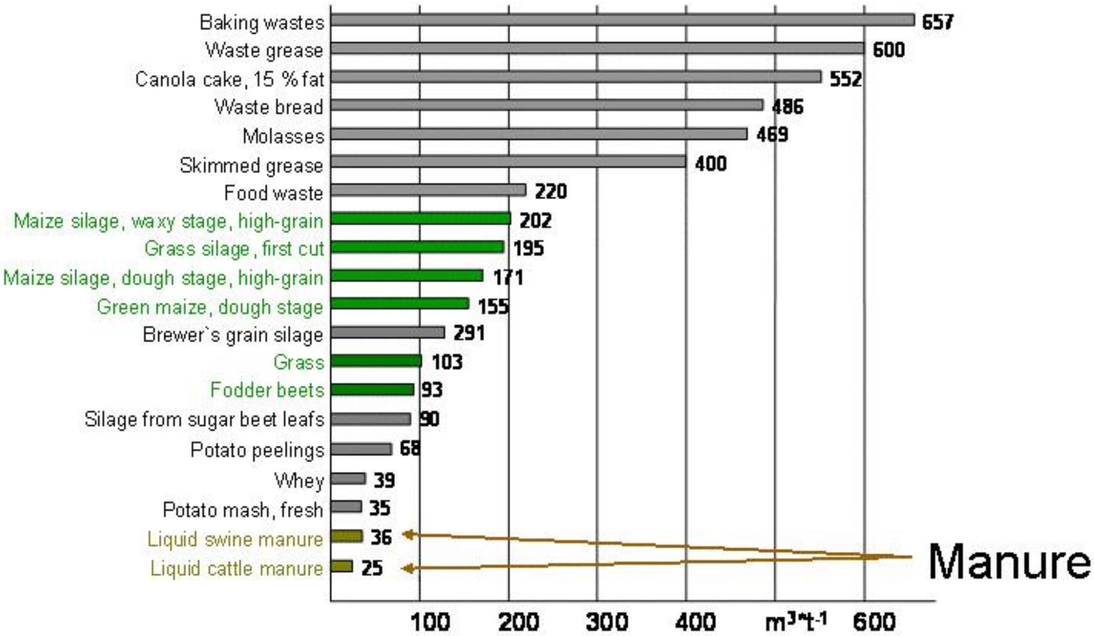

Figure 1. Potential Biogas Yield [5]

GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale, which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by convention equal to 1). A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted, otherwise the value will be meaningless. Carbon Dioxide has a GWP of exactly 1 (since it is the baseline unit to which all other greenhouse gases are compared, Table 4. [6]

Table 4. GWP values and lifetime [7]

GWP values and lifetime [2007 IPCC]	Lifetime (years)	GWP Time Horizon		
		20 years	100 years	500 years
Methane	12	72	25	7.6
Nitrous Oxide	114	289	298	153
HFC-23 (Hydrofluorocarbon)	270	12000	14800	12200
HFC-134a (Hydrofluorocarbon)	14	3830	1430	435
Sulfur Hexafluoride	3200	16300	22800	32600

The direct CO_2 evolution from treating food waste is of no consequence to GWP because it is short-cycle CO_2, i.e. it was atmospheric CO_2 in the recent past, before it was fixed by plants, and therefore returning it as CO_2 as a result of treating Food

Waste has no effect. However, escape of CH_4 from whatever source does have GWP because it has been transformed from the CO_2 that was fixed by plants, into CH_4, which was not a constituent of the original atmosphere. CO_2 from fossil fuels contributes to GWP because the carbon has not been in the atmosphere for millions of years. [3]

2.3 The State Of The Art in Food Waste Management

2.3.1 Home composting

Home composting could be a good method, however, only a small proportion of households are willing or able to practice it and the variability of performance of the practice means that estimating GWP is probably meaningless. The composting transforms the biodegradable carbon to short-cycle CO_2 easily, but some CH_4 is also produced. CH_4 could be oxidized at the surface of the compost bin.

Good composting (aerobic) requires an adequate ratio of carbon to nitrogen in the feed material, and open structure to allow the passage of air and adequate moisture to maintain the biomass. Most households in urban areas do not have either the facilities or inclination to practice home composting.

The efficiency of aerating home composting systems is different from site to site. Undoubtedly, some home composting will emit CH_4 and N_2O, because of oxygen deficient. The compost worms are emitting N_2O frequently, which are abundant in the later stages of home composting.

2.3.2 Centralized Composting

Separate curbside collection of Food Waste has a larger GWP than mixed waste collection because of longer collection rounds or lower payloads and the imperative of more frequent collection to avoid odor nuisance. Smith et al. estimated that allowing for the decay of compost added to soil over 100 years (the conventional time scale for GWP calculation) the use of compost on land would sequester the equivalent of 22 kg short-cycle CO_2/t FW treated by composting. [8]

Curbside collection of garden waste with Food Waste has been shown in many municipalities in many countries to increase the total mass of waste collected because of its disincentive to home composting. Compost can be manufactured into competitive growing media [9] but it is never going to earn a lot of money because of the cost of blending, bagging, distribution, marketing etc..

Table 5. GWP components of curbside collecting source-segregated Food Waste, treating by composting [3]

Components	**GWP kg CO_2e/t Food Waste**
Separate curbside collection and conveyance	+24
In-vessel composting incl. electricity	+18
Carbon-sequestration in soil	-22
Fertilizer offset	-36
Delivery from composting site to land application	+2
GWP for separate collection and centralized composting	**-14**

2.3.3 Landfill Disposal

Modern efficient landfills capture a lot of the landfill gas which is 50-65% CH4 and use it as renewable fuel. The CO_2 from burning this CH_4 is short-cycle. However, there is some leakage from the capped area and from the working area of the landfill before it is capped and managed for landfill gas capture.

The GWP of curbside collection of Food Waste as part of mixed waste can be assumed to be less for landfill than for separate collection for composting or Anaerobic Digestion (AD). The following discussion applies to a modern landfill site that has been constructed and managed to best practice standards with efficient landfill gas collection and use of that landfill gas for electricity generation. When biodegradable waste is placed in a landfill, the first stage of degradation is aerobic; this releases short-cycle CO_2, which has no GWP.

When the available oxygen has been used, degradation becomes anaerobic; initially the pH decreases because of volatile fatty acid (VFA) production, this mobilizes metals. Later, methanogenic bacteria develop and convert the VFAs to landfill gas; metals are re-precipitated as the pH increases.

Even the best techniques of landfill construction and landfill gas pumping result in some landfill gas leakage, and since this is 50-65% CH_4 by volume, the GWP is very significant. On the positive side, landfills sequester significant amounts of carbon. The components of GWP from land-filling biodegradable waste are shown in Table 6.

Table 6. GWP components of curbside collecting FW as part of mixed waste, treating by landfill [3]

Component	GWP kg CO_2e/t Food Waste
Mixed waste collection and conveyance	+14
Electricity generation form landfill gas	-32
Methane from leaking landfill gas	+1114
Short-cycle carbon sequestrations	-272
Fuel use within the landfilling operations	+8
GWP for the landfilling	**+832**

2.3.4 Incineration

Incineration is attractive to householders and industry because of its practicability. It is not subject to the problems of physical contaminants (plastics, glass, metals, rags, etc.) that are significant for the other routes.

The cost of operating waste incinerators and their emission controls is expensive; water vapor from FW adds to the volume of emission. The value of electricity and heat from burning wet waste (sewage sludge) is relatively trivial. Smith et al. found incineration was one of the more expensive options for whole MSW [8]; the putrefied fraction has the lowest net calorific value of any of the combustible fractions confirming that offset income from energy generation would be negligible. In contrast, dry MSW, without Food Waste, has a very useful energy yield.

Table 7. GWP components of curbside collecting FW as part of mixed waste, treating by landfill [3]

Component	**GWP kg CO_2e/t FW**
Delivery of ash to landfill	+1
Mixed waste collection and conveyance	+14
Incineration incl. emission clean-up, offset by energy use	-2
GWP for the incineration	**+13**

2.3.5 Centralized Anaerobic Digestion

Although the composting could convert biodegradable carbon to CO_2 (using energy), the anaerobic digestion converts it to biogas, which contains about 65% CH_4 and 34% CO_2 with traces of other gases. The CH_4 is contained and can be used as renewable energy, i.e. it has a negative GWP contribution because of offsetting fossil fuel.

With the cooperation of wastewater disposal, it would be possible to "turbo-charge" the AD infrastructure that already exists at the larger wastewater treatment plant (WWTP), which would obviate many of the planning issues of developing a treatment site.

The yield of biogas depends on the material (Figure 1). Thermal hydrolysis (TH) pressure-cooks the feed at 160 °C for 30 minutes, which increases the digestibility of the organic matter, sterilizes the feed and reduces its viscosity to such an extent that the solids loading can be trebled and the digesters continue to be fully mixed.

Table 8. GWP for curbside collected Food Waste, treating by AD [3]

Components	GWP kg CO_2e/t FW	
	70□ + AD	**TH + AD**
Separate curbside collection and conveyance	+24	+24
Treatment (incl. electricity generated)	-132	-183
Delivery from AD site to land application	+4	+2
Carbon-sequestration in soil	-22	-22
Fertilizer offset	-36	-36
GWP for Centralized Anaerobic Digestion	**-162**	**-215**

2.3.6 Food Waste Disposers

FWD could separate FW at source without the hygiene issues, odor and inconvenience of storing it on site pending curbside collection. Although the FWDs are uncommon in some countries, and the sewerage experts regard it as controversial usually, but FWDs have been shown repeatedly to have no adverse effect on water resources, sewerage or wastewater treatment and that, FWDs provide a good solution for those unwilling or unable to home-compost. [3]

The output of FWDs is very biodegradable and carried very easily at the designed self-cleansing velocity of sewers. The ground waste would be converted to sewage sludge after transference to WWTP, and all of the sewage sludge is treated by anaerobic digestion, either at the WWTP where it arises or at sludge treatment centers to which it is transported from smaller WWTP for digestion. The biogas is used as renewable energy and the bio-solids are dewatered and applied to farmland as nutrient-rich soil improver thus completing nutrient cycles and conserving organic matter.

Table 9. GWP components of FW separated at source by FWD and treated by AD [3]

Components	**GWP kg CO_2e/t FW**
Fertilizer offset	-36
Carbon-sequestration in soil	-22
Delivery from WWTP to land application	+3
Treatment including electricity generated offset	-150
Conveyance (electricity use…)	+6
GWP for FWDs + sludge treatment by AD	**-199**

2.4 Benefit to Climate Change

With population growth and climate change posing more pressure ahead, it is more and more compelling to regard FW and other organic residuals as potential resources for recovering energy and bio-fertilizer, which can complete nutrient cycles and conserve the soil organic matter.

As people of different lifestyle may show variable interests for the food waste management, there is no single best method for food waste treatment. However, the anaerobic digestion and FWDs delivering to WWTP where sludge is digested have nearly equivalent GWP and better than such alternatives as landfill, incineration and centralized composting. AD is also more conservative on nitrogen fertilizer content in the residuals. Physicochemical stripping of N and P from digested dewatering liquors appears to have considerable cost benefits compared with biological treatments that aim to waste the soluble N and (re)capture the P into the bio-solids. [3]

3. FOOD WASTE DISPOSER UNIT

3.1 Introduction

The food waste, which accounts for 10% ~ 20% of domestic waste, is a problematic component of municipal solid waste, creating problems related to public health, sanitation and environment at phases from internal storage to the truck-based collection. When being burned in waste-to-energy facilities, the high moisture content of food waste makes the generation process rather difficult; in case of landfills (a method now abolished in the EU), the food waste decomposes and generates methane gas, which is a highly potent GHG, 25 times stronger than carbon dioxide on a 100 year GWP (Global Warming Potential) horizon. [1]

The food waste disposer (FWD) is installed under sink in the kitchen; it could grind the food waste into small particles (2mm-4mm) easily which are then rinsed into sewer by water. Thus, the proper use of such disposer is to effectively treat food waste as liquid (averaging 70% moisture), and utilize existing infrastructure (underground sewers and wastewater treatment plants) for its management. Modern wastewater plants are effective at processing organic solids into fertilizer products (known as bio-solids) with advanced facilities also capturing methane for energy production. [1]

Figure 2. Food Waste Disposers (FWDs) [10]

3.2 Device Structure

Figure 2 shows the inner structure of FWDs device: a model of FWDs from ISE (In-Sink-Erator) production. The main parts of the device are: Quiet Collar, Anti-Vibration Mount, Multi-Layer Soundlimiter, GrindShear Ring, Undercutter Disk and Jam-Sensor.

Figure 3. Inner FWDs [10]

3.2.1 Magnetic Cover Start Activation

Magnetic Cover Start Activation offers an extra margin of assurance by running only when the cover is on.

Figure 4. Magnetic Cover Start Activation [10]

Control disposer is turned on using the cover. Four magnets have been set in the FWDs, two on the cover and two on the disposer switch. When the cover is put in position and turned on, the magnetizing will then switch on the power.

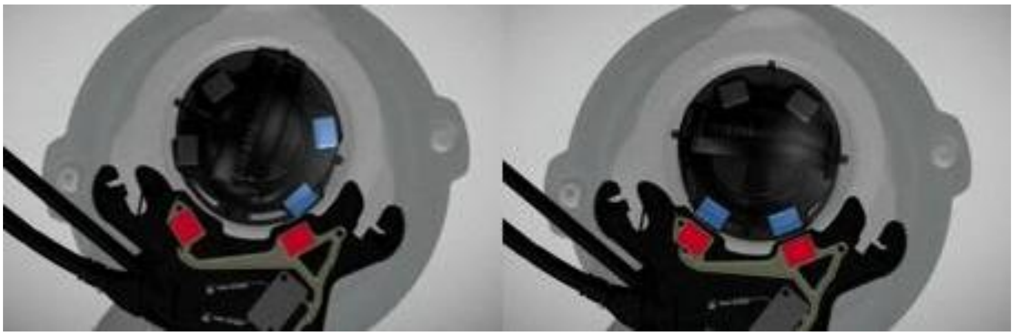

Figure 5. The switch of Disposer [10]

The cover has double sides, another could be used in plug of the sink.

Figure 6.The another function of the Cover [10]

3.2.2 Quiet Collar^{TM} Sink Baffle

The baffle's design causes running water to pool in the sink's opening. The resulted "water dam" acts as a cap on the disposer and reduces the noise from the sink's opening.

Figure 7. Quiet Collar [10]

Figure 8 shows the water dam. It is made of rubber, like a cap of disposer it protects the finger when putting food waste in to disposer.

Figure 8. Water Dam [10]

3.2.3 Anti-Vibration Mount^{TM}

One noise insulation layer has been added between grinding chamber and mouth of disposer.

Figure 9. The position of the Anti-Vibration Mount in disposer [10]

The Anti-Vibration Mount insulates the disposer in a cushion of rubber, which reduces the transfer of noise and vibration from the disposer to the sink.

Figure 10. Anti-Vibration Mount reduces noise [10]

3.2.4 Multi-Layer Sound Limiter^{TM} Insulation

The multiple layers of open and closed cell material both muffle and trap noise emitted by the disposer.

Figure 11. Multi-Layer Sound Limiter [10]

The sound seal plus^{TM} covers the outside of grinding chamber, thus reducing the sound transmission effectively.

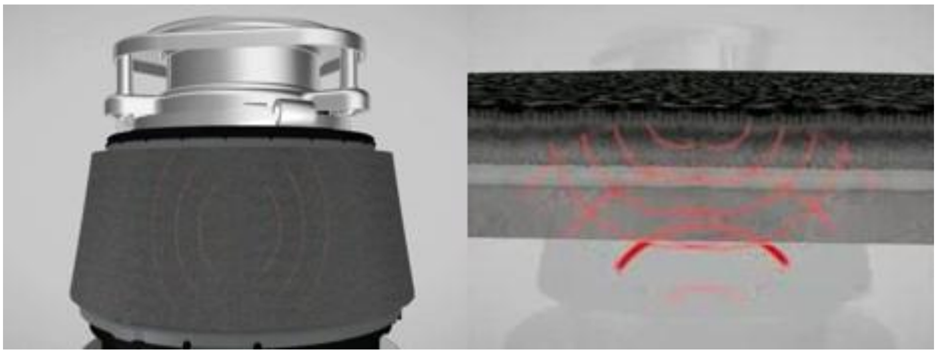

Figure 12. Sound Seal Plus^{TM} [10]

3.2.5 GrindShearRing^{TM}

The GrindShear Ring is one part of grinding chamber. The ring includes two functions to dispose food waste, grinding and shearing. The GrindShear Ring is an ideal solution to process the stringy foods like cornhusks and celery

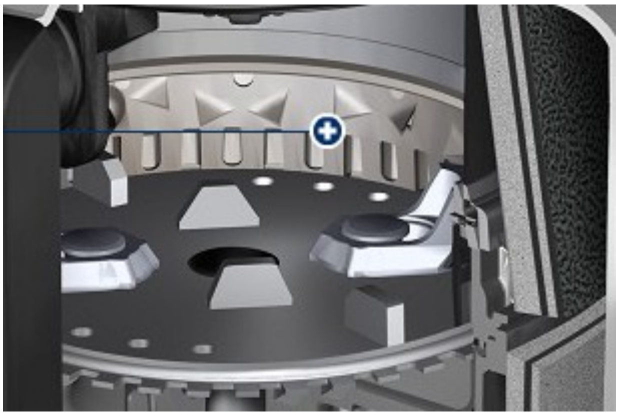

Figure 13.GrindShear Ring [10]

As the food waste enters into the grinding chamber, the grinding plate and two lugs start to rotate with high speed and then the food waste will be ground into small particles along the surface of the ring, this is the first stage of food waste grinding.

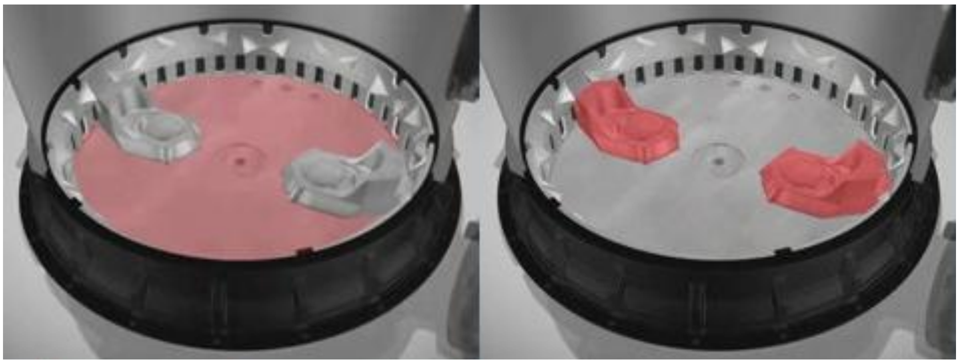

Figure 14. Grinding plate and lugs [10]

After the first phase of grinding, the leftover particles are forced through a series of 40 pass-through windows and sheared into even finer waste. It is called the second grinding stage. (Figure 15)

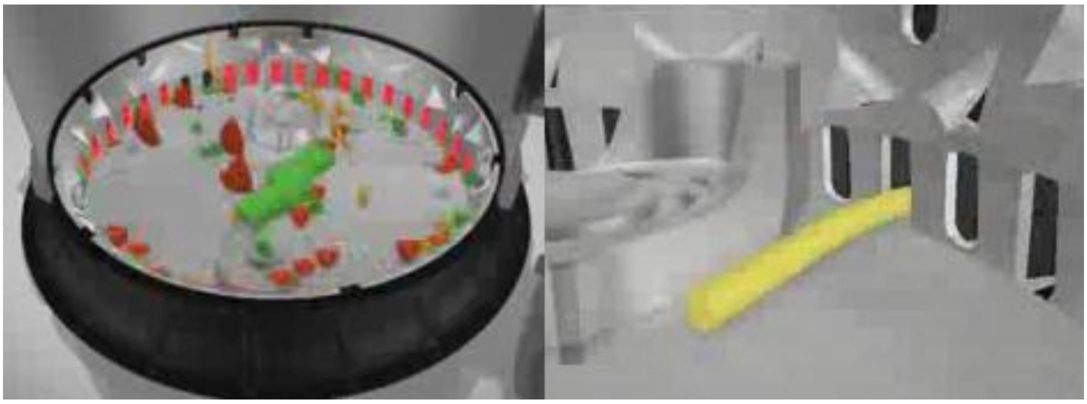

Figure 15. Series of 40 windows [10]

3.2.6 Tri-Action Lug System

The Tri-Action Lug System performs three important functions. As previously shown, the swivel lugs work with the GrindShear Ring to perform the first and second stages of grinding. The Tri-Action Lug system also includes fixed lugs design to grind particles finer than swivel lugs alone.

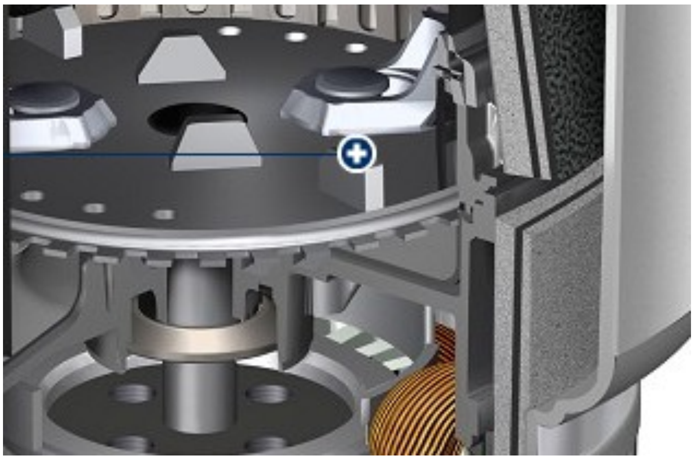

Figure 16. Tri-Action Lug System [10]

Lastly the system's lug configuration propels water throughout the grinding chamber, enabling to rinse it clean after each use.

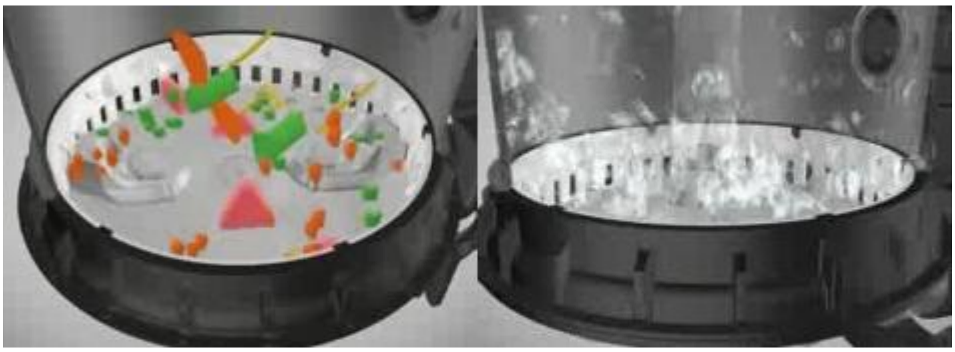

Figure 17. The functions of Tri-Action Lug (Red triangle is lugs) [10]

3.2.7 Undercutter Disk

Located along the leading edge of the shredder plate, the undercutter mechanism performs the third stage of grinding. It cuts particles one more time after they have passed through the GrindShear ring to help eliminate clogs.

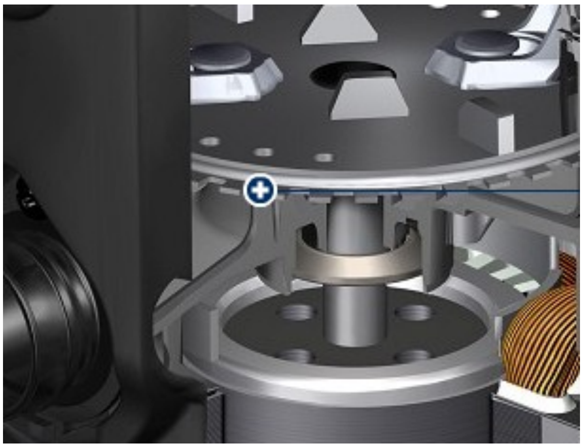

Figure 18.Undercutter Disk [10]

As the food particle passes through the GrindShear, the undercutter disk cuts them one more time, and this is the third stage of grinding.

Figure 19.Undercutter disk cuts particles one more time [10]

3.2.8 Jam-Sensor Circuit

The heart of disposer is called Jam-Sensor Circuit. It supports strong movement to grind and shear the food waste. It also produces a powerful hammering effect that breaks through the toughest jams.

Figure 20. Jam-Sensor Circuit [10]

When sensing a jam imminent, it automatically engages to increase the rotational torque of motor up to 500% while simultaneously pulsing at a rate of 60 times per second.

Figure 21.increase the rotational torque of motor up to 500% [10]

3.2.9 Bio-Charge Injection Technology

This is a special model in FWDs, one bio-charge has been added to the disposer. The principle of the technology is to utilize a natural microorganism to help break down the food waste.

Figure 22. Bio-Charge Injection [10]

When switching on the disposer, the bio-charge fluid is automatically injected into the grinding chamber. Each dose amounts to 300 million microorganisms. The microorganism not only accelerates the breakdown of food waste and also helps breakdown other waste like toilet paper. It gives off a citrus aroma to help control odors from the sink and drainage. There's also a surfactant to help break down soap and grease film that accumulates in drainpipes

Figure 23. Bio-Charge automatically injected to grinding chamber [10]

3.3 Operation Principle

The core component of FWDs is its grinding chamber, which is made of stainless steel. The grinding chamber sets a cutter disk with two or four lugs, but without any sharp edges, very safe, durable and maintenance-free. Though cutter disk rotating at high speed is driven by AC motor or DC motor to crush the food waste into small particles by centrifugal forces, the grinding chamber has a filtering effect, which block the food solid particles automatically. The cutter disk's full load speed in working status is 2400~5500 rev/min that is driven by DC motor and about 1450~1750 rev/min by AC motor. The particle of ground waste is less than 4 mm in diameter, can be easily rinsed by water but won't plug the drainage and sewers. Therefore, it is installed under kitchen sink generally; the FWDs are cylindrical in shape, 300~400mm high and 130~200mm in diameter, around 4 kg in weight. It could be hidden inside a cupboard and connected to the drainage. [11]

The operation of FWDs method follows: turn on the tap and then feed the food waste or leftover into the FWDs through the opening, break big bones, if any, into small pieces before feeding. Secondly close the opening and turn on the switch, keep the water flowing into the device during working time, turn off the tap and switch in 25~35 seconds, the food waste will have been crushed into particles and rinsed away by water. The working time of device depends on the amount of food waste, the maximum working time does not exceed one minute while the monthly electricity consumption is 1kW/h. [11]

3.4 Environmental Impact and Disadvantage

After FWDs utilization, the users will change the habit of garbage treatment, and avoid air pollution indoors and improve the sanitation. For urban sector, FWDs could cut down the MSW transport indirectly and reduce secondary pollution to city due to the waste transportation. Besides, it helps to extend the life time of land-filling place, and increase the energy efficiency in incineration plant; it can also ease up the polluting impact on the dry waste which could then be recycled. FWDs can be an accessory facility for waste separation. [11, 12]

However, it may be difficult for existing old wastewater plants to handle the extra load of FWDs. The load of organic carbon that reaches the wastewater plant increases, which in turn increases the consumption of oxygen. If the wastewater treatment is well controlled, the organic carbon in the food may help to keep the bacterial decomposition running. Carbon may be deficient in that process, if no wastewater treatment is performed properly, the extra load of pollutants will be detrimental to the environment and chemicals in the waste become more problematic. [12, 13]

4. THE EFFECT OF GROUND FOOD WASTE ON SEWAGE SYSTEM

4.1 Existing Sewage System Overview

Sanitary sewers carry both domestic and industrial wastewater to the raw wastewater pumping station at the treatment plant. The wastewater flows by gravity rather than pressurized pipe flow in the sanitary sewer pipes. Conventional wastewater treatment may involve three main stages, including primary, secondary and tertiary treatment.

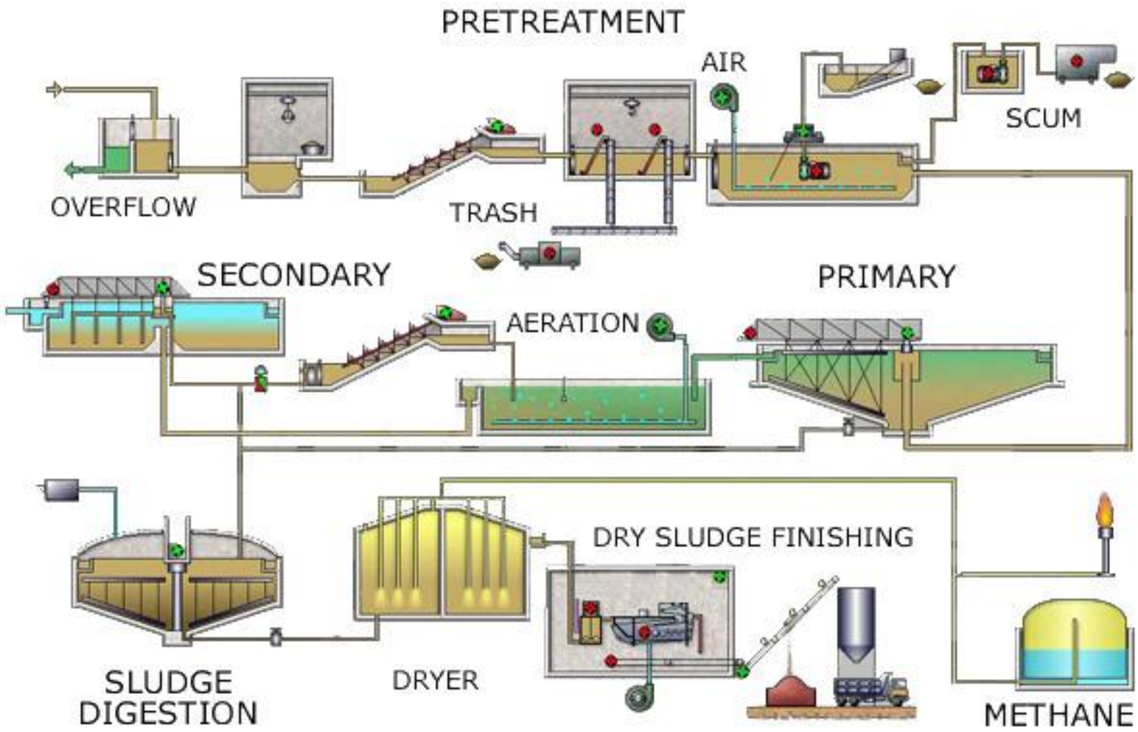

Figure 24. Process Flow Diagram for a typical large-scale wastewater treatment plant [14]

Preliminary Treatment: Bar Screens could remove wastewater constituents, such as sticks that may cause maintenance or operational problems. There is the bar screen located inside the Raw Wastewater Pump Building. The trash is collected and properly disposed of. The screened wastewater is pumped to the Primary Settling Basins.

Primary Treatment: There are two Primary Settling Basins allowing smaller particles to settle from wastewater by gravity, and suspended solid and organic substances are removed by chemical additives or filtration. A surface skimmer collects scum or grease floating on top of the basins. Scrapers collect the solid matter that remains (called "primary sludge"). A typical sedimentation basin may remove from 60% to 65% of suspended solids and from 30% to 35% of BOD from the sewage. This primary wastewater flows out to the next stage of treatment. [15]

Secondary Treatment: The process is designed to substantially degrade the biological content of the wastewater. The aerobic biological processes have been used for the settled sewage liquor treatment in majority WWTP. The Aeration Basin supplies large amount of air to mix the primary wastewater, and help bacteria and protozoa to consume biodegradable soluble organic contaminants (e.g. organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into floc. Adequate oxygen is supplied to support the biological process at a very active level.

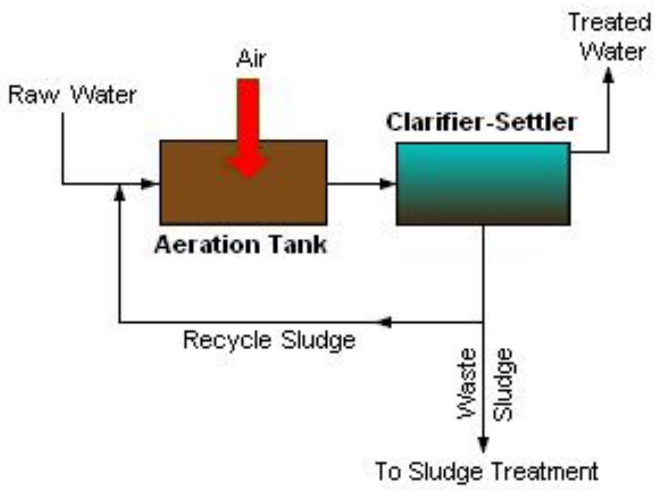

Figure 25. Schematic diagram of an activated sludge process [16]

In the settling basin a filter removes a small percentage of the suspended organic matter, while the majority of the organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. With this aerobic oxidation and nitrification, the organic solids are converted into coagulated suspended mass, which is heavier and bulkier that can settle to the bottom of basins by gravity. 90~95% of this organic solids, called "activated sludge," is returned to the aeration basins to help maintain the needed amount of microorganisms. The remaining 5~10% is pumped to the anaerobic digester. The effluent of the filter is therefore, passed through a sedimentation basin, and called secondary clarifier or secondary settling basin or humus basin. [15]

Tertiary Treatment: The final treatment stage, which is also called "effluent polishing", is aimed to raise the effluent quality before being discharged to natural bodies of water (ground, river, lake, sea, etc.).

4.2 Impact of Ground Food Waste on Sewage System

As Paolo Battistoni reported, there will be no significant solids sedimentation to occur if materials like pieces of bones, shells and so on are not introduced into the FWDs. [17] In this experiment, Paolo Battistoni selected 35 families (content 95 persons) and also industrial FWDs (content 60 persons). Therefore the FWD utilization rate factor was about 60% of the inhabitants in this small town. The local WWTP was designed with treatment capacity of 250 population equivalent (PE) and maximum flow rate of 6.87 m^3/h. As for tap water consumption overloads due to the FWDs utilization, the literature data reported a daily consumption increase of 1~4.5dm^3 per person; therefore, the range of incoming flow rate fell between 48 ~ 52m^3 per day. Compared with the typical daily influent and the flow rate peaks, no significant changes took place after FWDs were put into operation, as Figure 26 show. [17]

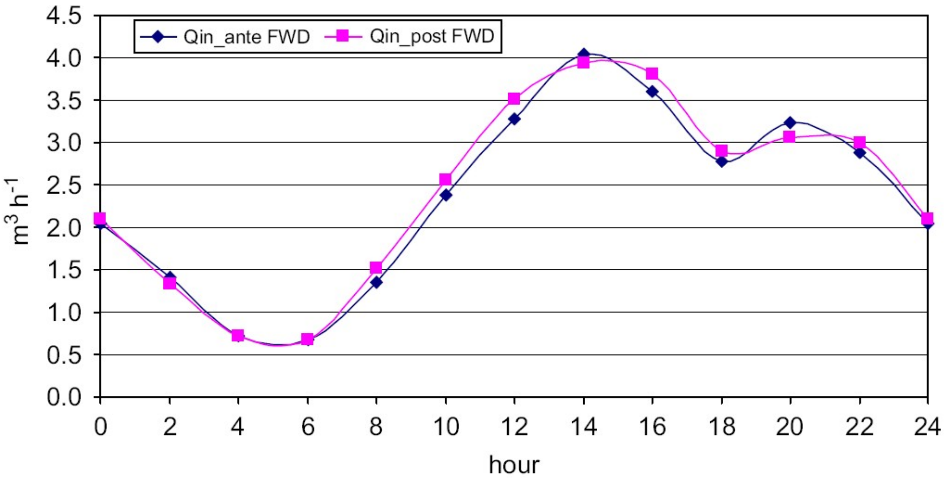

Figure 26. Typical daily fluctuations of influent to the WWTP, before and after the FWDs installations [17]

According to Paolo Battistoni experimental result the influent COD (chemical oxygen demand), TSS (total suspended solid), N and P during the experiment were quite variable after FWDs were installed, involving maximum proportional increase of TSS 30%, COD 44% and TN 19%. Concerning the COD and its biodegradability, the ratio of COD/TN, rbCOD/COD and COD/TSS were 9.9 to 12, 0.2 to 0.24 and 1.4 to 2.6, respectively (Figure.27, 28, 29, 30). This change of inflow characteristics involved a good enhancement of the nitrates biological de-nitrification (+27%). [17]

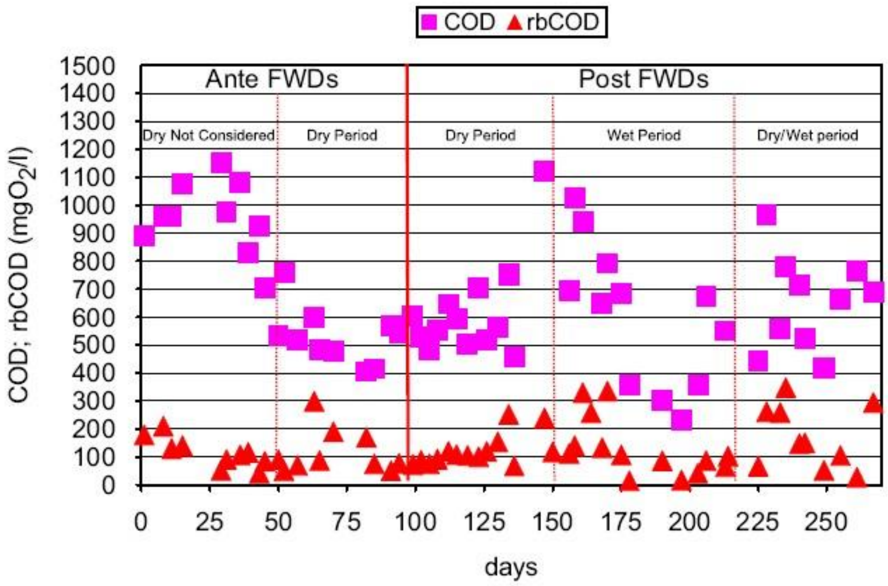

Figure 27. Change on COD [17]

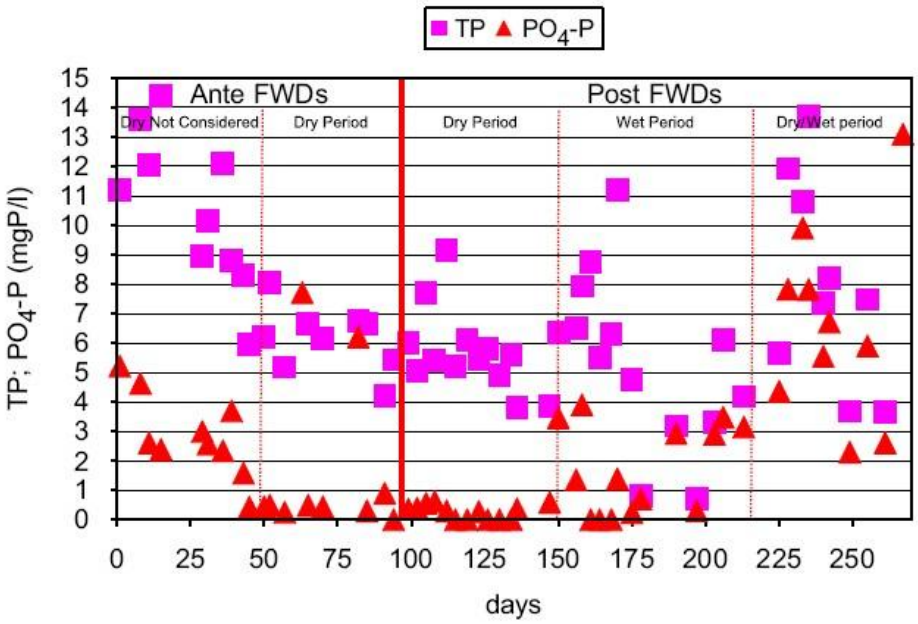

Figure 28. Change on Phosphorus [17]

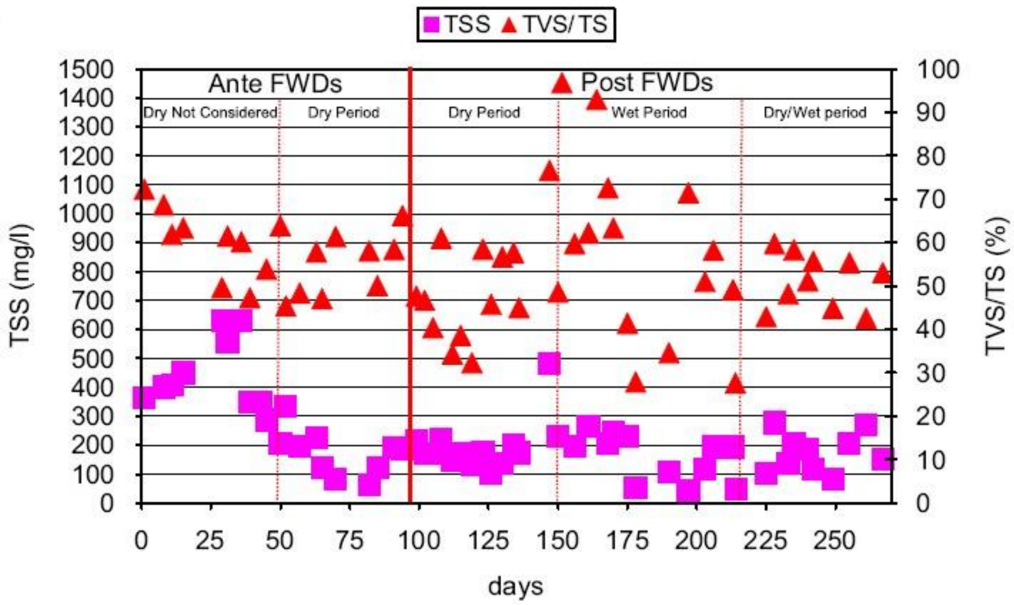

Figure 29. Change on Suspended Solids [17]

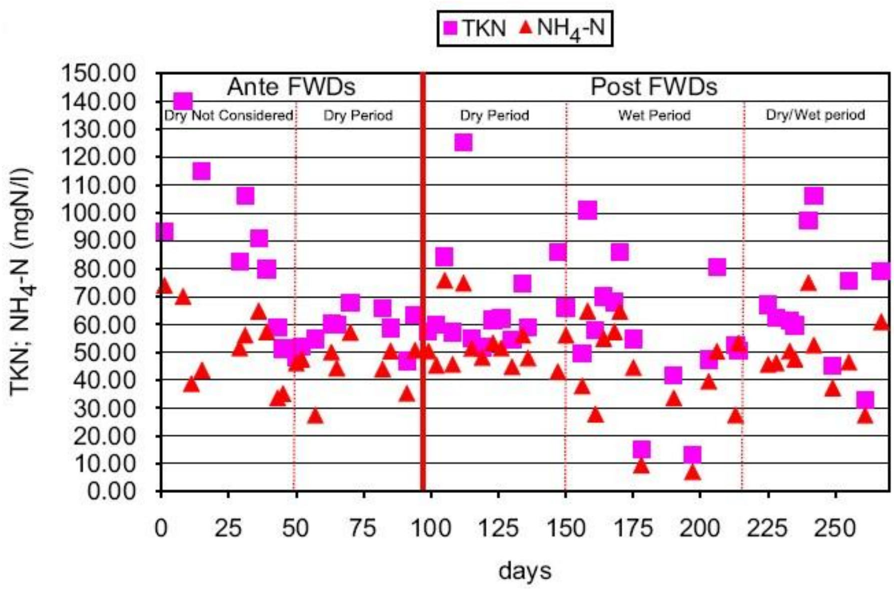

Figure 30. Change on Nitrogen [17]

4.3 Effect on Sludge

Sewage sludge is produced as a by-product of the sewage treatment process. Sewage could exploit the benefits deriving from the use of biogas for the production of energy through the anaerobic digestion process. The typical activated sludge process for carbon and ammonia oxidation was not considered as it is well known that the main consequences of organic wastes disposal in sewers for that kind of process are the increases in oxygen consumption and sludge production [18, 19]. As Galil N et al. [19] research, the total penetration market factor of operating FWDs was about 60% of the resident population in a given area, driving the specific sludge production increase from 20 to 37 g/PF·d (dry solids) for the activated sludge process, if the primary settling was present, the production amount could increase from 50 to 80g/PE·d. And the additional energy potential increase by 54% ~ 73% was detected, due to anaerobic digestion application. [19]

Bolzonella et al. have done an experiment, which is simulation of ground food waste mixed with real wastewater in order to evaluate the effects of the pollutant load increases on the performance of wastewater treatment process. The two different types of wastewater treatment processes were considered in this experiment: the typical Pre-Denitrification process (C-N) and the Biological Nutrients Removal process (BNR). The detailed results are summarized in Table 10. [18]

Table 10. The results of experiment in sludge treatment [18]

		C-N removal Process		BNR Process	
		Wastewater	Wastewater + GFW	Wastewater	Wastewater + GFW
Without primary settler	MLSS [kg/m^3]	5	7.7	5.4	8
	Oxygen Consumption [kg/h]	340	566	360	587
	Waste Sludge [kgTS/d]	1867	4035	1360	5670
	Biogas [m^3/d]	1470	2460	1070	3455
With primary settler	MLSS [kg/m^3]	3.2	4	3.75	4.2
	Oxygen Consumption [kg/h]	280	316	284	325
	Waste Sludge [kgTS/d]	4530	7185	4318	8032
	Biogas [m^3/d]	3320	4470	3153	4990

According to the result of this experiment, the waste sludge production was nearly doubled (from 4530 kgTS/d to 7185 kgTS/d) in the C-N removal process with primary settler, and also the production of biogas increased by 30% (from 3320 m^3/d to 4470 m^3/d). Otherwise, the values of the process without primary settler are significantly lower.

The role of the ground food waste contribution to sludge production was more significant in the BNR process. The activated sludge concentration was increased from 5.4 kg/m^3 to 8 kg/m^3 and the oxygen consumption was also increased from 360 kg/h to 587 kg/h, due to the ground food waste in the wastewater. Therefore, the production of waste sludge increased to 5670 kgTS/d from 1360 kgTS/d, and the biogas produced almost tripled. When the primary settler was not present in the BRN process, the production of waste sludge increased from 4318 kg/TS to 8032 kg/TS, and the production of biogas also increased from 3153 m^3/d to 4990 m^3/d.

5. ESTIMATION OF SLUDGE PRODUCTION AFTER FWDs OPERATION IN LAPPEENRANTA

5.1 Background

5.1.1 Lappeenranta City Overview

Lappeenranta (Latitude: 61.03E, Longitude: 28.11E) is a city and municipality that resides on the shore of the lake Saimaa in South-Eastern Finland. It belongs to the region of South Karelia with approximately 72,000 inhabitants (31 March 2010). The average altitude is 106 meters. [20]

Figure 31. Location of Lappeenranta City [20]

5.1.2 The Wastewater Treatment Plant in Lappeenranta

The WWTP in Lappeenranta is called Toikansuo, which was built in 1975 and expanded in 1978-1982. The capacity of the plant was designed to service 100000 inhabitants with the flow rate being 30000 m^3/d and the wastewater cleaning up to 17000m^3/d on average (approximately 6 million m^3/a). [21] The original design data of Toikansuo WWTP are:

Q_{mit} = 30000 m^3/day

BOD_7 = 13500 kg / day

Phosphorus = 450 kg / day

The WWTP process includes mechanical pre-treatment, chemical treatment and biological treatment. Figure 32 shows the flow chart of Toikansuo WWTP. [22]

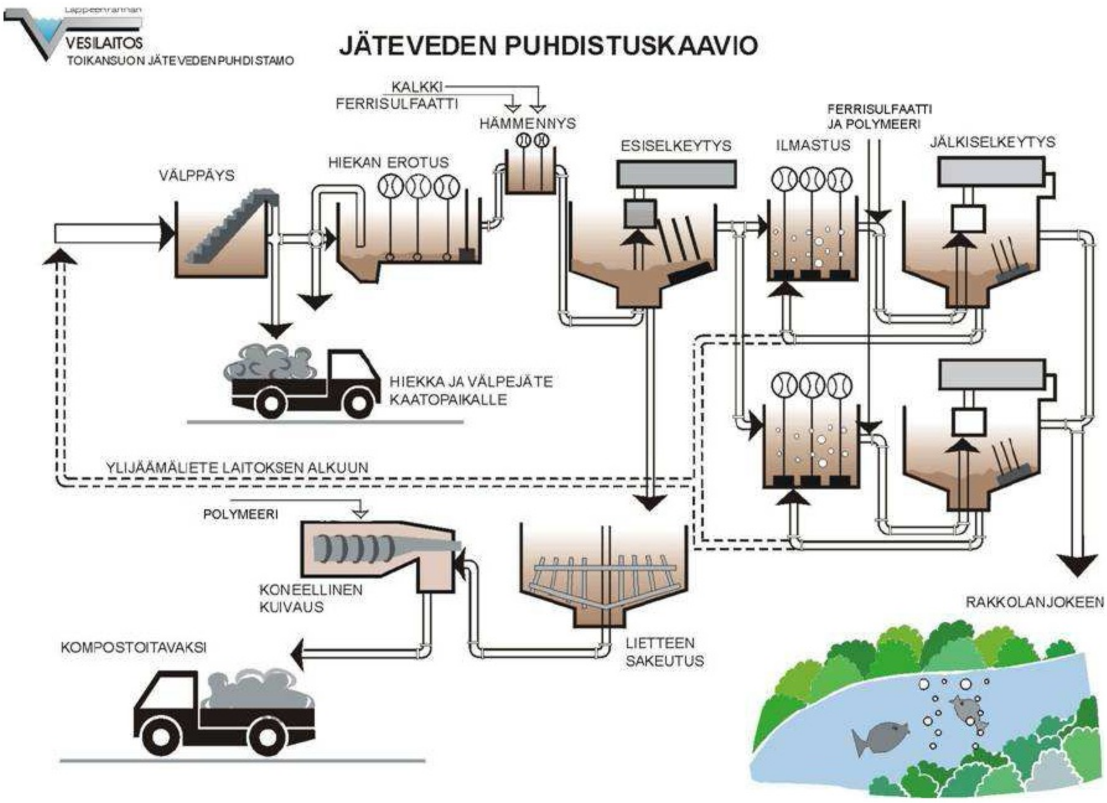

Figure 32 Flow Chart of WWTP in Lappeenranta [22]

Primary treatment is screening, its aim being to remove the coarse solids from the water (including the fibrous impurities and sand). Chemical treatments of wastewater serve to remove primarily the phosphorus. Ferric sulfate solution coagulants are used and fed into the process before preliminary sedimentation. Next stage is the final sedimentation. Thickening of sludge process will collect the sludge, which is from preliminary sedimentation and final sedimentation. After that the sludge will be fed into sludge dewatering centrifuge with the dried sludge gathered onto pallets and transported to the composting Vapo Oy. [22]

5.1.3 Wastewater Data of Lappeenranta

The Data of wastewater characteristics of Lappeenranta are shown in Table 11.

Table 11. Data of wastewater of Lappeenranta [21, 23]

	Influent (kg/d)	Effluent (kg/d)	Removal efficiency (%)
BOD_7	4304	96	97.8
P	198	6.7	96.6
TS	6358	167	97,4
COD_{Cr}	10703	757	92,9
N	897	301	66,4

5.2 Estimation Method

5.2.1 Estimation Method of Sludge and Gas Production before FWDs installed

In this case study that there is no anaerobic digestion of sludge in WWTP of Lappeenranta nowadays. The calculations are estimated gas production potentials.

Primary Setting:

The percentage of TSSc removed is 97% [24], thus, the TSSm removed could be calculated by 97% of TSSm. The TSSm to secondary is TSSm minus TSSm removed.

Where : TSSc = Total suspended solids expressed as concentration

TSSm = Total suspended solids expressed as a mass

Determining the volatile fraction of primary sludge:

Volatile fraction of TSSc in influent is 97%(Table 11 shown). The Volatile suspended solid in influent prior to grit removal is 97% times TSSm. Assumed volatile fraction of incoming TSSc discharged to the secondary process is 85% [26]. Thus, VSSm in secondary influent would be calculated with:

85% times TSSm to secondary

VSSm in primary sludge could be calculated in:

(VSSm in influent prior to grit removal) – (VSSm in secondary influent)

where: VSSm = Volatile suspended solid expressed as a mass

The percentage of volatile fraction in primary sludge is:

[(VSSm in primary sludge) / (TSSm removed)] 100%

Secondary process

Estimating the mass of volatile solids produced in the activated-sludge process that must be wasted.

$P_{x,VSS} = Y_{obs} \times (S_0 - S)$ Eq. 1

Where: $P_{x,VSS}$= Net waste activated sludge produced each day

Y_{obs} = Observed yield = 0.3125 [24]

S_0= Influent substrate concentration = 250 g/m^3 (15000 kg/d)

S can be calculated with $Q_{mit} \times [65\% \times TSSc \times 1.42 - BODc \times 0.68]$

S = Effluent substrate concentration

BODc = Biochemical oxygen demand expressed as concentration

Q_{mit} = Wastewater flowrate

"Fraction of the biological solids that are biodegradable is 65%. The value of BODc can be obtained by multiplying the value of UBOD by a factor of 0.68 [24]"

Estimating the TSSm that must be wasted assuming the volatile fraction represents 0.80 of the total solids

$TSSm = P_{x,VSS} / 0.80$

Estimating the waste quantities discharged to the thickener

TSSm = TSSm wasted – effluent TSSm

Flotation Thickeners

Assumed solid recovery: 90%

The TSSm to the digester can determine:

90% × (the waste quantities discharged to the thickener)

Sludge Digestion

Determining the total solids fed to the digester and the corresponding flowrate:

TSSm = Solids from primary settling + The TSSm to the digester

Determining the VSSm fed to the digester:

(Percentage of volatile fraction in primary sludge × Solids from primary settling) + (0.80 × The TSSm to the digester)

Determining the mass quantities of sludge after digestion:

Assuming that the total mass of fixed solids does not change during digestion and that 50% of the volatile solids are destroyed [24].

Fixed Solids = TSSm fed to digester – VSSm fed to digester

TSSm in digester sludge = Fixed Solids + 50% × VSSm fed to digester

Determining the volume of methane after digestion:

Methane yield = 0.128 m^3/kg of VSS destroyed [25]

Methane yield = 0.128 m^3/kg × 50% ×VSSm fed to digester

The calculation details are presented in appendix I.

5.2.2 Estimation Method of BOD, TSS and Flowrate after FWDs installed

After FWDs installed the BOD, TSS and Wastewater flow will be changed, the amount of change in these items would depend on FWD utilization rate. In this case study，the FWD utilization rate has been assigned as 25%, 50% and 75% respectively in order to estimate the changes in production of sludge and methane.

- Food Waste Ground:

  $Y_{\text{Food waste ground}} = Y_{\text{Food}} \times g \times m$

Where:			
	Y_{Food}	Food waste generated per year	[t/a]
	g	Estimated food ground 75%	
	m	% Utilization rate of FWDs (25%, 50% or 75%)	

- Amount of water needed to grind food waste:

  $W_{\text{Food waste ground}} = w \times Y_{\text{Food waste ground}}$

  Where: w — Amount of water needed to grind 1 kg of food waste

- Volume of food waste ground expected to be disposed down the drainage:

  $V_{\text{Food waste ground}} = (Y_{\text{Food waste ground}} \times MC) + W_{\text{Food waste ground}}$

Where: MC Moisture Content

- Percentage of Increase in wastewater flow:

  $I_{WW} = (V_{Food\ waste\ ground} \div V_{WW}) \times 100\%$

  Where: V_{WW} Wastewater flowrate

  I_{ww} Percentage of wastewater increase

- New Wastewater Flow rate

  $V_{NewWW} = V_{WW} + (I_{WW} \times V_{WW})$

- Volume of Food waste ground:

  $V_{Food} = Y_{Food\ waste\ ground} / \rho$

  Where: ρ Density of Food Waste

- New BOD loading after installation FWDs

  $$\text{New BOD} = \frac{(X_{BODWW} \times V_{WW}) + (X_{BODFood} \times V_{Food})}{V_{WW} + V_{Food}}$$

  Where: X_{BODWW} BOD loading of the current wastewater sewage

  $X_{BODFood}$ Average BOD of food waste

- New TSS loading after installation FWDs

  $$\text{New TSS} = \frac{(X_{SSWW} \times V_{WW}) + (X_{SSFood} \times V_{Food})}{V_{WW} + V_{Food}}$$

  Where: X_{SSWW} TSS loading of the current wastewater sewage

  X_{SSFood} Average TSS of food waste

The calculation details are presented in appendix II. And the calculation method of sludge and methane production is the same as the last section and the results will be presented in the next section.

5.3 Results Presentation

Table 12 has shown the results of estimation calculation in the case study.

Table 12. Results of Estimation Presentation

	No FWDs	FWDs Utilization rate		
		25%	50%	75%
BOD influent [kg/d]	4304	4600	5000	5300
TSS effluent [kg/d]	6358	6800	7200	7500
Wastewater Flow [m^3/d]	30000	32000	34000	35000
TS [t/a]	2000	2200	2300	2400
Methane [m^3/a]	140000	150000	160000	170000
BOD effluent [kg/d]	96	100	110	120
TSS effluent [kg/d]	167	176	190	200

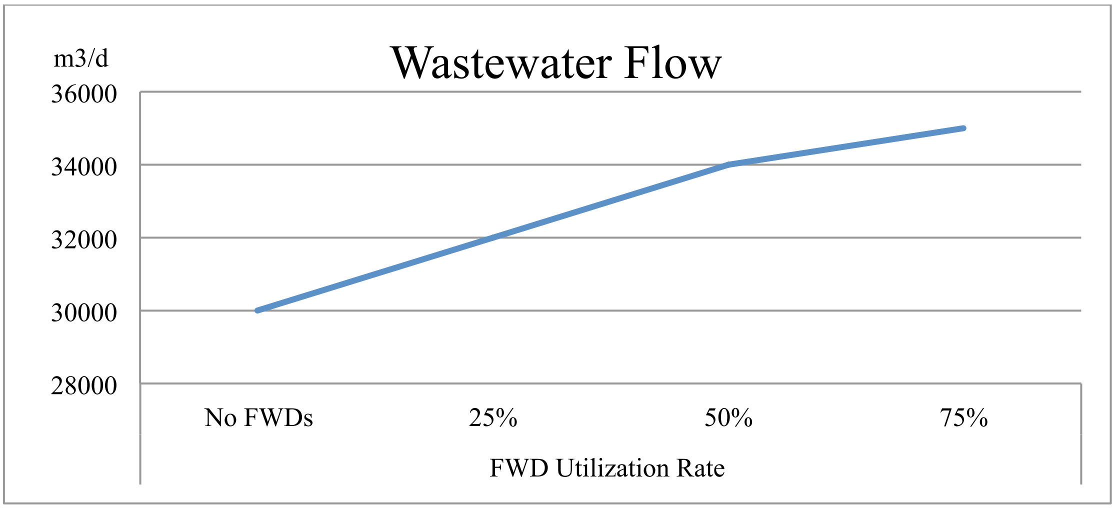

Figure 33. Change on wastewater flowrate after integration of FWDs

As Figure 33 shows, there is no significant change on wastewater flowrate after integration of FWDs; only 6% increase of wastewater flowrate, when FWDs utilization rate is 25%; about 18% increase of flowrate, if the FWDs market share reaches 75%.

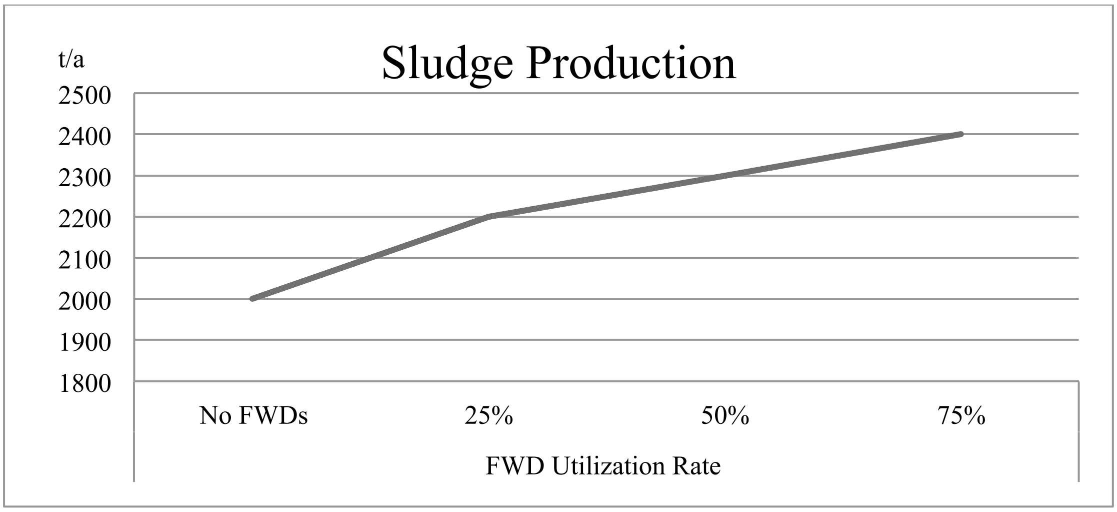

Figure 34. Change on Sludge Production after integration of FWDs

It could contribute to an excess of 200 tons sludge per year, if the FWD utilization rate is 25%. (Shown in Figure 34.)

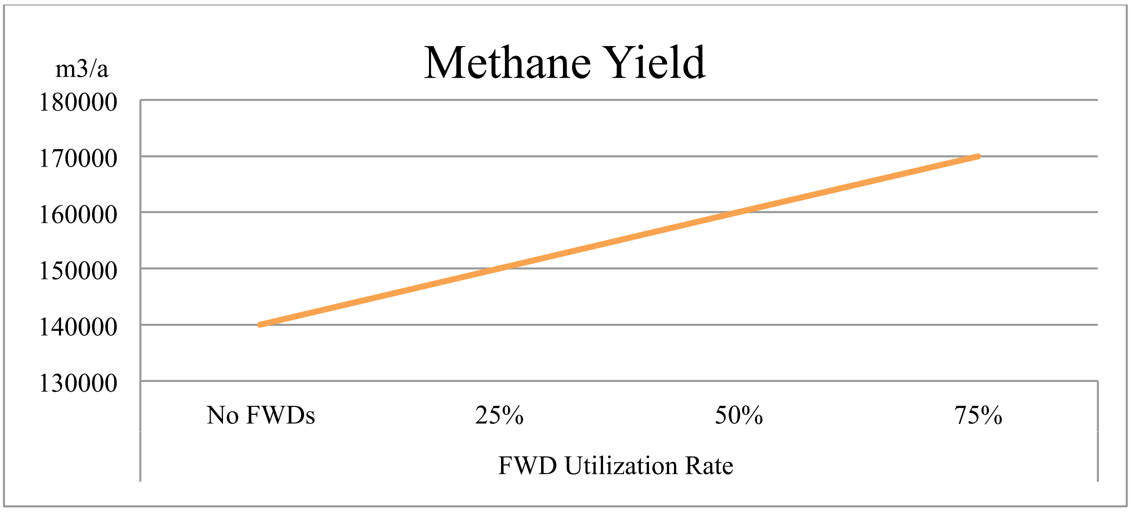

Figure 35. Change on Methane Yield after integration of FWDs

There is no AD process on WWTP of Lappeenranta, thus the volume of methane yield is estimated to increase by 10000 m^3 per year with the FWDs installed. (Figure 35 and Table 12)

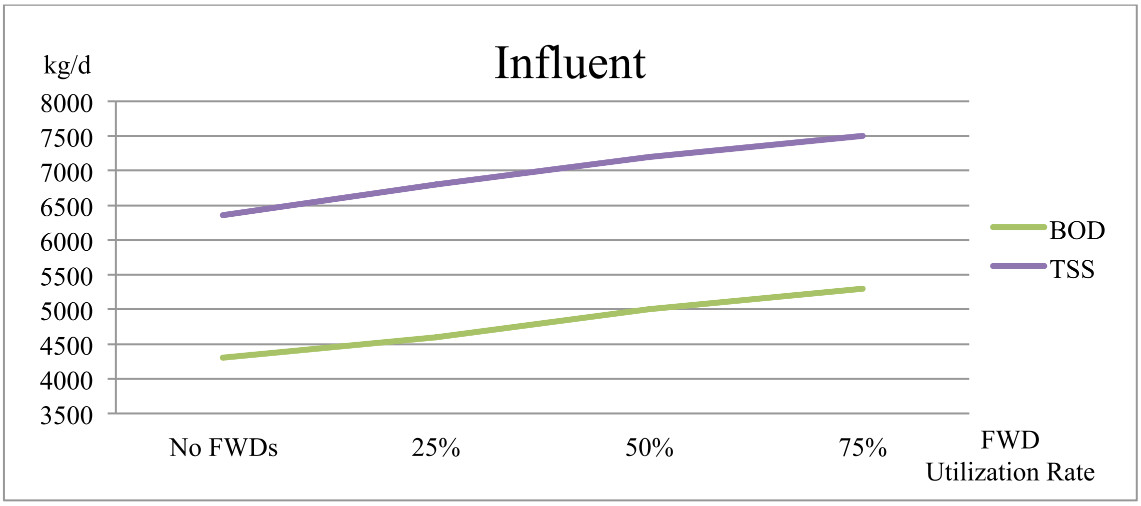

Figure 36. Change on influent characteristics

The BOD and TSS loading of the wastewater are not changed significantly, it has proved again that there won't be any specific influence on WWTP when FWDs installed.

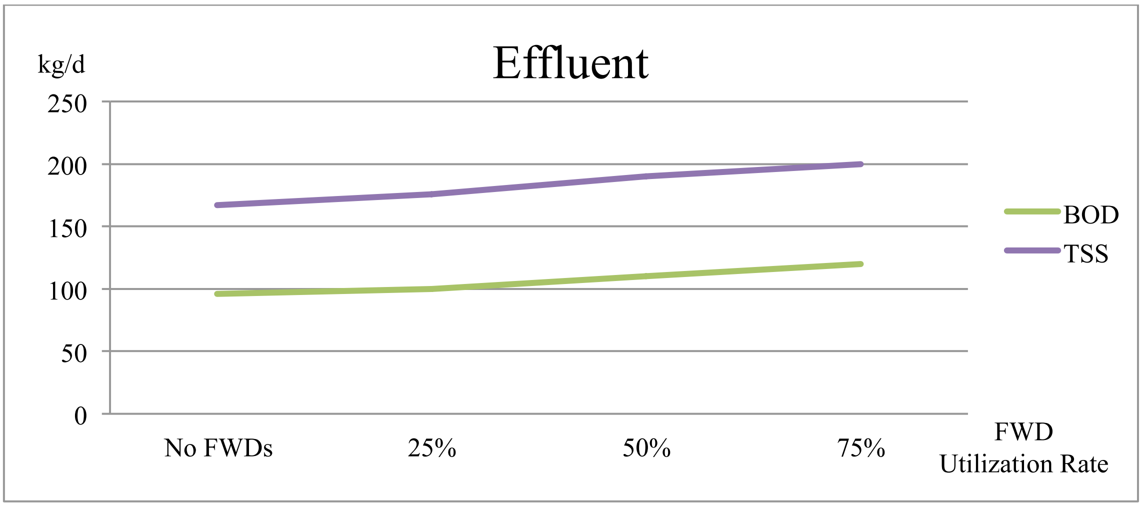

Figure 37. Change on effluent characteristics

The same situation as influent, there is almost no changed on BOD and TSS loading of the effluent water, if compare with before FWD installed.

5.4 Discussion

This case study aimed to estimate the effects of installed FWDs on WWTP of Lappeenranta, on the basis of the assumed respective FWDs utilization rate as 25%, 50% and 75%, so as to calculate the sludge production, methane yield and TSS/BOD loading in wastewater (see Table 12).

In general, the FWDs exert no significant effect on WWTP of Lappeenranta. When FWDs utilization rate is 25%, the sludge production was nearly increases10% from 2000 to 2200t/a and the same applies to the methane yield from 140000 to 150000 m^3/a. However, as the utilization rate of FWDs reaches 75%, the values of Water flowrate (18% increase), TSS (19% increase) and BOD (23% increase) are considerably enhanced; it thus puts some pressure on the existing WWTP, but then the methane yield (20% increase) and sludge production (20% increase) are also remarkably on the increase per year.

6. CONCLUSION

As a new disposal method of domestic bio-waste (food waste), the FWDs can change the current way of MSW management; it can significantly mitigate the secondary pollution of city environment owing to the transportation of MSW, meanwhile, the lifetime of urban landfill plant can also be extended. As to the domestic sanitation, the FWDs can remarkably improve the kitchen hygiene, minimize the breeding of insects and prevent the spreading of germs, and positive changes will take place in terms of how to handle the domestic waste. In spite of the numerous benefits of FWDs, the application has not become very popular yet simply because of the people's worry about the impact of ground food waste on wastewater treatment plant.

In fact, as shown in many literature publications and experiment reports reviewed (Paolo B. 2006, Bolzonella D. 2003, Galil N and Yaacov L. 2001, Natasha M. 2003, etc.); FWDs have no negative effects on wastewater treatment plant. The estimation calculation in the case study has also proved this. Due to the centrifugal force produced when the device is operating, it can increase water pressure and flow rate, so the ground food waste will not block the sewage pipe of building and urban drainage network. Of course, when a large number of FWDs are installed and put into use, the consistency of sludge will be increased by small amount in urban drainage network, and then the silt clean-up will be on the increase. However, it will not affect the normal operation of drainage system and wastewater plant; on the contrary, as the ground food waste enters into the wastewater treatment plant, it will provide additional amounts of rbCOD to enhance the biological removal of nutrients [18], it is beneficial to biological processes (e.g. BRN process) in the wastewater treatment plant. Anaerobic Digestion process is one of the most important parts in WWTP; the estimation of case study indicates that after FWDs installation, the amount of activated sludge will increase about 10% ~ 30%, resulting in the volume of methane yield increase by 10000m^3 per year.

Biogas as a clean energy is used widely in the world and the transformation of waste into energy is an important manifestation of sustainable development. The most important environmental concern in the 21st century is global warming. The assorted disposal approach of food waste would make the difference in GHG contribution; the FWDs can provide raw materials (ground food waste) for biogas yield on WWTP, thus, reducing the GHG emission caused by landfill indirectly. The food waste treatment by FWDs, which serves as the pre-sorting process of domestic waste, will decrease the moisture contents of domestic waste and drastically improve the efficiency of the incineration plant. Moreover, as the remaining wastes are mostly inorganic waste, they will not be contaminated by wet-waste (food waste), so the recycling process will be facilitated.

The FWDs only can be used in residential area or cities equipped with consummate drainage network within the service sphere of WWTP; otherwise, if the ground food waste is discharged into body of water directly, it will lead to more pollution of waters. Although the FWDs is friendly to WWTP, and will not put huge pressure on the existing drainage network and WWTP, even if the numbers of FWDs users increase suddenly. However, the relevant authority or government department should control the installation frequency of FWDs while promoting the accessory application of FWDs. In the meanwhile, the WWTP should improve their treatment process (e.g. using BNR process, extended the aeration time) in order expand their capacity for sludge treatment so as to stay in line with the future development of urban waste management. [26] Natasha Marashlian and Mutasem El-Fadel have proposed the action plan for integration of FWDs within an urban area (See Appendix. III).

The FWDs application would make an effective integration of solid waste disposal with wastewater treatment and achieve the win-win target by leaving bio-waste to WWTP (Figure 38). It can help to increase the biogas yield in WWTP, and mitigate the pressure on MSW management as well. More importantly, in this way the GHG emission reduction and generation of clean energy will be beneficial to prevent global warming and protect the environment.

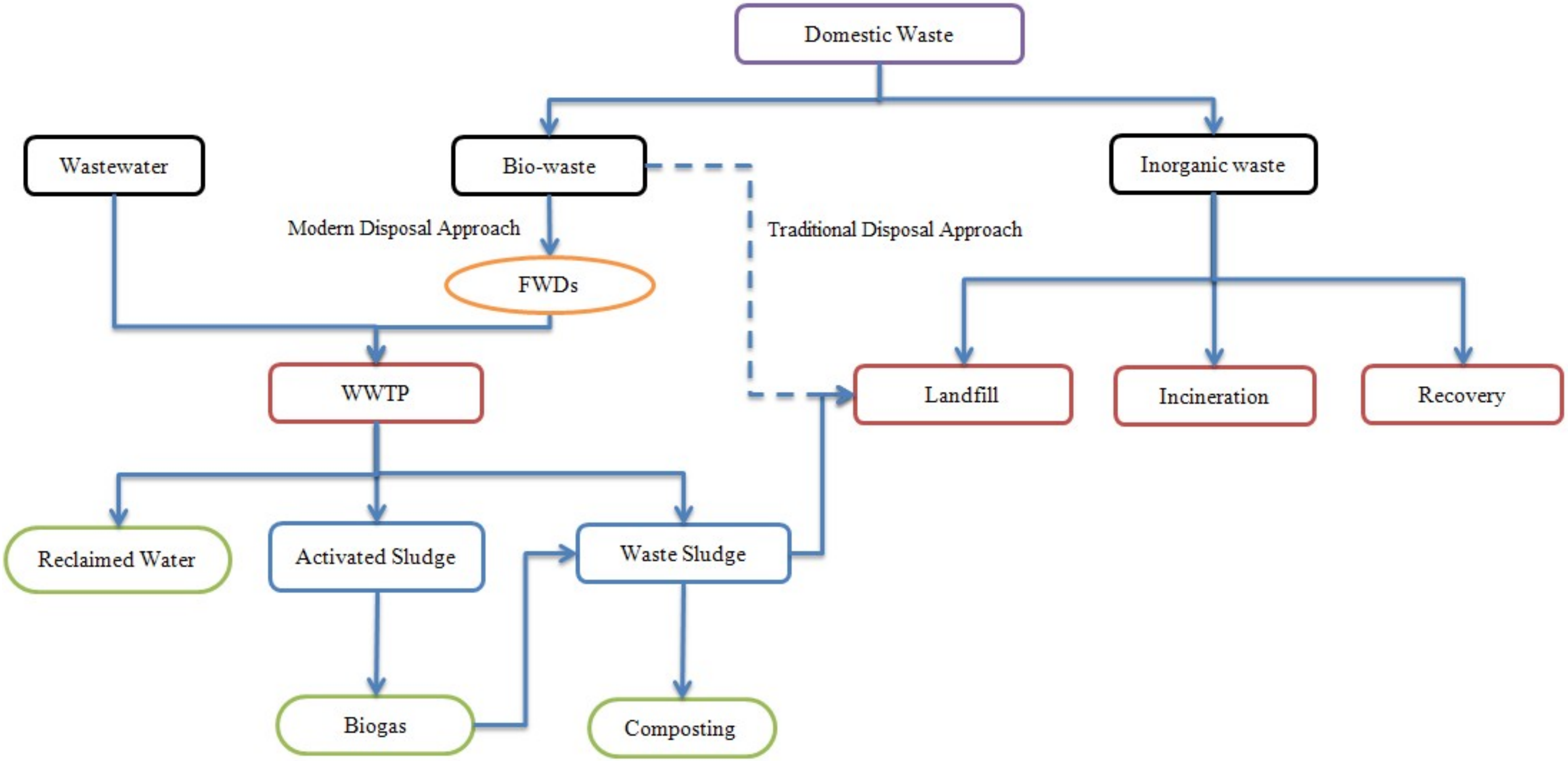

Figure 38. Flow Chart of Integration of FWDs to Sewage System

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Appendix I: Estimation of sludge and Gas Production before FWDs installed

As the table 11 shown, the TSSm is 6358 kg/d, TSSc removed is 97%

Primary Setting:

TSSm removed = 97% × (6358 kg/d) = 6167.26 kg/d

TSSm to secondary = (6358- 6167.26) kg/d = 190.74 kg/d

Determine the volatile fraction of primary sludge:

Volatile fraction of TSSc in influent = 67% [26]⇒

Volatile suspended solids (VSSm) in influent prior to grit removal =

67% × 6358 kg/d = 4259.86 kg/d

Volatile fraction of incoming TSSc discharged to the secondary process = 85%

⇒ VSSm in secondary influent =

85% × 190.74 kg/d = 162.13 kg/d

VSSm in primary sludge = (4259.86 – 162.13) kg/d = 4097.73 kg/d

Volatile fraction in primary sludge= [(4097.73) / (6167.26)] × 100%= 66%

Secondary Process:

Y_{obs} = 0.3125 [26], TSSm in effluent is 167 kg/d (Table 11)

UBOD of biodegradable effluent TSSc is 65% × TSSc × 1.42 = 152.58 kg/d

BODc of effluent suspended solids = BODc × 0.68 = 103.57 kg/d

S = 152.58 - 103.57 = 48.82 kg/d

S_0 is 250 g/m^3 (7500 kg/d)

$P_{x,VSS} = Y_{obs} \times (S_0 - S) = 0.3125 \times (7500 - 48.82) = 2328.49$ kg/d

Estimate the TSSm that must be wasted assuming the volatile fraction represents 0.80 of the total solids ⇒

TSSm = (2328.49 kg/d) / 0.80 = 2910.61 kg/d

Estimate the waste quantities discharged to the thickener

TSSm = 2910.61 kg/d – 167 kg/d = 2475.31 kg/d

Flotation thickeners

Assumed solids recovery 90%

Determine the TSSm to the digester:

TSSm = 90% ×2475.31 kg/d = 2470.78 kg/d

Sludge Digestion

The total solids fed to the digester and the corresponding flowrate:

TSSm = Solids from primary settling + Waste solids from thickener ⇒

TSSm = (6167.26 + 2470.78) kg/d = 8638.04 kg/d

Determine the VSSm fed to the digester

VSSm = (66% ×6167.26 kg/d) + (0.80 × 2470.78 kg/d) = 6074.35 kg/d

Assume that the total mass of fixed solids does not change during digestion and that 50% of the volatile solids are destroyed.

Fixed Solids = TSSm – VSSm = (8638.04 – 6074.35) kg/d = 2563.68 kg/d

TSS in digested Sludge:

2563.68 kg/d + 50% × 6074.35 kg/d ≈ **5600 kg/d** ≈ **2000 t/a**

Methane yield:

Methane yield = 0.128 m^3/kg of VSS destroyed [25]

Methane yield:

0.128 m^3/kg × 50% × 6074.35 kg/d ≈ **388.76 m^3/d≈ 140000 m^3/a**

Appendix II: Estimation of BOD, TSS and Flowrate after FWDs installed

Assumption of parameters:

Food waste Moisture Content (MC):	75%
Water needed to grind waste (w):	0.0117 m^3/kg [26]
Food Ground (g):	75%
Utilization rate of FWDs (m):	25% or 50% or 75%
Density of Food Waste (ρ):	290 kg/m^3 [2]
BOD of Food waste ($X_{BODFood}$):	7042000 mg/m^3 [26]
TSS of Food waste (X_{SSFood}):	1537000 mg/m^3 [26]

Actual parameters:

Food Waste generated (Y_{Food}):	4633t/a = 12.69 t/d [23]
Population:	72000
Wastewater flow (V_{WW}):	30000 m^3/d
BOD (X_{BODWW})	4304 kg/d (143466.67 mg/m^3)
TSS (X_{SSWW})	6358 kg/d (211933.33 mg/m^3)

- Food Waste Ground:

$Y_{Food\ waste\ ground} = Y_{Food} \times g \times m$ = 12.69 t\d × 75% × 25% × 1000 kg/t = 2379.9 kg/d

- Amount of water needed to grind food waste:

$W_{Food\ waste\ ground} = w \times Y_{Food\ waste\ ground}$ = 0.0117 m^3/kg ×2379.9 kg/d = 27.85 m^3/d

- Volume of food waste ground expected to be disposed down the drainage:

$V_{Food\ waste\ ground} = (Y_{Food\ waste\ ground} \times MC) + W_{Food\ waste\ ground}$ = (2379.9 kg/d × 75%) + 27.85 m^3/d = 1812.82 m^3/d

- Percentage of Increase in wastewater flow:

$I_{WW} = (V_{Food\ waste\ ground} \div V_{WW}) \times 100\%$ = (1812.82 m^3/d ÷ 30000 m^3/d) ×100% = 6%

- New Wastewater Flow rate

= $V_{WW} + (I_{WW} \times V_{WW})$ = 30000 m^3/d+ (6% ×30000 m^3/d) ≈**31812.81 m^3/d**

- Volume of Food waste ground:

$V_{Food} = Y_{Food\ waste\ ground}/\rho$ = 2379.9 kg/d ÷ 290 m^3/kg = 8.21 m^3/d

- New BOD =

$$\frac{(X_{BODWW} \times V_{WW}) + (X_{BODFood} \times V_{Food})}{V_{WW} + V_{Food}}$$

$$= \frac{\left(143466.67\ ^{mg}/_{m^3} \times 30000\ ^{m^3}/_{d}\right) + \left(7042000\ ^{mg}/_{m^3} \times 8.21\ ^{m^3}/_{d}\right)}{30000\ ^{m^3}/_{d} + 8.21\ ^{m^3}/_{d}}$$

$$= 145353\ ^{mg}/_{m^3} = 0.145\ ^{kg}/_{m^3}$$

New BODm in influent: New BOD × New Wastewater flow rate

=0.145 kg/m^3 × 31812.81 m^3/d ≈ **4624 kg/d**

- New TSS =

$$\frac{(X_{SSWW} \times V_{WW}) + (X_{SSFood} \times V_{Food})}{V_{WW} + V_{Food}}$$

$$= \frac{\left(211933.33\ ^{mg}/_{m^3} \times 30000\ ^{m^3}/_{d}\right) + \left(1537000\ ^{mg}/_{m^3} \times 8.21\ ^{m^3}/_{d}\right)}{30000\ ^{m^3}/_{d} + 8.21\ ^{m^3}/_{d}}$$

$$= 212296\ ^{mg}/_{m^3} = 0.212\ ^{kg}/_{m^3}$$

New TSSm in influent: New TSS × New Wastewater flow rate

=0.212 kg/m^3 ×31812.81 m^3/d ≈ **6754 kg/d**

Appendix III： Action Plan for Integr ation of FWDs within an Urban Area