Waste-to-Energy Development Using Organic Waste Recycling System (OWRS): A Study Case of *Giwangan* Market

Syamsul Ma'arif*‡, Wira Widyawidura**, M. Noviansyah Aridito**, Heni Dwi Kurniasari**, M. Kismurtono***

*Department of Mechanical Engineering, Universitas Proklamasi 45, Yogyakarta, Indonesia
**Department of Environmental Engineering, Universitas Proklamasi 45, Yogyakarta, Indonesia
***Research Unit for Natural Product Technology, Indonesian Institute of Sciences (LIPI), Indonesia
(arief.syams@up45.ac.id, wirawidura@up45.ac.id, noviansyaharidito@up45.ac.id, henienvir17@gmail.com, m_kismurtono@yahoo.co.id)

‡ Corresponding Author; Syamsul Ma'arif,

Tel: +62 815 4869 5337, Fax: +62 274 486008, arief.syams@up45.ac.id

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Abstract- Food wastes were the major problem in the traditional market since there were inadequate organic waste processing facilities provided. Most of all these wastes end into the landfill, and the wastes have high energy recovery potential to be generated with a scientific treatment. This research proposes the waste-to-energy implementation planning for energy harvesting from the organic waste generation of the Giwangan traditional market, Yogyakarta Province, Indonesia by using organic waste recycling system (OWRS) as a pretreatment technology. The proposed recycling system consists of two major processes such as dewatering process and pyrolysis process. The dewatering process aims to decrease the water content and remind solids, where the pyrolysis process aims to convert solids into charcoals. The product of dry organic material from the OWRS system becomes the input for gasification to produce synthetic gas as fuel on the internal combustion engine. Pretreatment process by using OWRS system can increase the calorific value of food waste by 5,815.33 kcal/kg, and it can remove the water content of fruit waste and vegetable waste up to 99.25% and 99.06% respectively. The liquid product from OWRS system generates the C/N ratio with value 4.06. The implementation of OWRS system which produces the updraft for gasifier process can generate the energy by 5.14 kW and achieves the efficiency by 11% of electrical power from the total organic waste generated by Giwangan traditional market.
Keywords- Dewatering, Gasification, Pyrolysis, Traditional Market, Waste-to-energy.

1. Introduction

The use of biomass for energy production has been increasing lately according to energy demand [1]. As the largest tropical archipelago nation in the world, Indonesia has abundant biomass resources to be used as a source of energy. Indonesia's bioenergy resource potential reaches 32,000 MW, but in fact, only 1740.4 MW of installed capacity or the utilization is only 5.4% of the total potential of electrical power based bioenergy resources [2]. Since the enactment of the regulation on the National Energy Planning (Presidential Regulation of the Republic of Indonesia No. 22 of 2017) where the regional government is required to compile a regional energy planning, the Yogyakarta Provincial Government seeks to increase the regional energy mix in the renewable energy sector, especially biomass. One of the strategies for the utilization of national energy sources by the Regional Governments of Yogyakarta Province includes utilization of biomass waste for electricity generation, one of which can be obtained from municipal solid waste (MSW) derived from traditional market waste.

The Giwangan market is the largest traditional market in Yogyakarta Province, located in Giwangan village, Subdistrict of Umbulharjo, Yogyakarta, Indonesia which is dominated by foods and vegetables. Most of the traditional markets are lack of infrastructures to handle the organic wastes and bring the stigma of the dirty environment [3]–[5]. When the organic wastes produced by 800 stalls of the market are accumulated and mismanaged, air pollution from produced gas will be a severe problem. Instead, the organic wastes are valuable materials which can be converted into thermal or electric energy with specific treatments. Currently, there are two areas in the Giwangan market which are used as garbage collectors, east and west area. The eastern area is intended to collect non-organic wastes, while the western area is aimed at collecting organic wastes. Most of the wastes are then transported to the central landfill every day. Only 10% of the total organic wastes collected at the western area is processed into compost and liquid fertilizer at the small facility known as an integrated waste treatment plant (IWTP) which belongs to the Giwangan market.

Since the Giwangan market produces much biomass from organic solid waste, the waste-to-energy conversion can be done in the thermochemical and biochemical process [6]–[11]. Biomass combustion process is the conversion of biomass into thermal energy [12]. Thermochemical-based energy conversion requires fuel with high temperature and low water content, while biochemical-based energy conversion uses biomass with high water content since microorganisms which involved in the decomposing process need wet conditions [13], [14]. The thermochemical process uses an incineration technology which relies on the heat from the combustion process. The combustion process converts water from liquid into steam to drive the steam turbine generator to produce electricity [15].

The gasification output is obtained through partial combustion of biomass in a slight oxygen environment to produces synthetic gas that contain mainly combustible gases (CO, H_2, and CH_4) and non cmbustible gases (CO_2 and N_2) [16],[17]. The combustion temperature over 900 *°C* from gasification, will produce the emmission were more environmental friendly gaseous outputs [18]. Char from gasification process is the result of rate-limiting step in the production of gaseous fuels from biomass [19].

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen, and it consists of three stages, namely moisture evaporation, devolatization, and char formation respectively [20], [21]. The gaseous products from pyrolysis process consist of H_2, CO, CO_2 and hydrocarbon gas having carbon number of less than 5 [22]. The pyrolysis technique conducts partial combustion which holds the temperature value lower than the gasification temperature to produce bio-oils as fuel for power generation [16]. The operational temperatures of these three thermochemical systems are 850 – 1200 *°C* for incineration process, 550 – 1600 *°C* for a gasification process, and 500 – 800 *°C* for pyrolysis process [23].

The biochemical-based energy conversion through anaerobic digestion technique requires microbes to break the organic waste into biogas such as CO_2 and CH_4. The methane gas (CH_4) is then converted to energy [24]. The methane gas can be formed at mesophilic temperature (32 – 42 *°C*) and thermophilic (50 – 58 *°C*) and with C: N ratio ranging from 20 – 30 [25]. The physical parameters play an essential role in the thermochemical and biochemical conversion system related to the municipal solid waste (MSW) characteristics as seen in Table 1.

Table 1. Critical parameters in the biomass energy development [26]

Waste Processing Method	Basic Principle	Key Parameter	Expected Range
Thermochemical Conversion:	Decomposition of organic substances through heat treatment	Moisture content	< 45 %
Incineration, pyrolysis, and gasification		Organic/volatile matter	> 40 %
		Fixed carbon	< 15 %
		Total inerts	< 35 %
		Calorific value (net calorific value)	> 1200 kcal/kg
Biochemical conversion:	Decomposition of organic substances through microbial action	Moisture content	> 50%
Anaerobic digestion (biomethanation)		Organic/volatile matter	> 40%
		C:N ratio	25 – 30

Some researchers have conducted experiments related to pretreatment related to organic waste treatment with the aim of reducing MSW waste generation. Opalinska et al. [27] develop a system for treating waste including hazardous waste, containing organic compounds which consist of two primary processes, namely: the pyrolysis of waste and the oxidation of the pyrolytic gas using The modular large-scale laboratory non-equilibrium plasma. This process recovering the desired components of solid residue after pyrolysis and the higher calorific value of waste causes the oxidation of the hydrocarbons that are contained in the pyrolytic gas to be more efficient. The thermal plasma pyrolysis process of the polymer treatment waste samples was conducted by Mohsenian et al. [28] to produce hydrogen-rich gases and high purity carbon black nanoparticles using treatment in a furnace fitted with a twin DC thermal plasma torch. The pyrolysis process through this method produces gas products consist of hydrogen and some hydrocarbons without any carbon monoxide.

An integrated waste treatment plant (IWTP) produces the compost and liquid fertilizer in a limited capacity to meet the requirement of fertilizer for the local garden, or for sale in a small amount. However, IWTP is an only preliminary system for waste treatment which cannot solve the main waste problem significantly. Moreover, there is no applied conversion system which uses wastes from Giwangan market as a raw material for energy harvesting. Therefore, this study proposes the waste-to-energy development by using an organic waste recycling system (OWRS). This OWRS method of organic waste processing consisted of a combination of two devices (Figure 1): 1—the dewatering machines that process the raw material and 2—the pyrolysis machine that process the solid product from dewatering process. The research focused on the results obtained from processes from this device.

2. Methodology

The initial stage of the research is sampling the waste from Giwangan traditional market, Yogyakarta Province, Indonesia to determine the total mass and composition of the organic waste. During the sampling process, the organic waste will be classified into three types of fruit and three types of vegetables as the representation of foods waste. Each sample was tested for the calorific value and moisture content before being processed through an Organic Waste Recycle System (OWRS) unit. Figure 2 shows the OWRS system process for experimental set-up.

Figure 1. The OWRS devices for Giwangan traditional market in Yogyakarta. (Left) Dewatering Machine. (Right) Hookway Pyrolysis

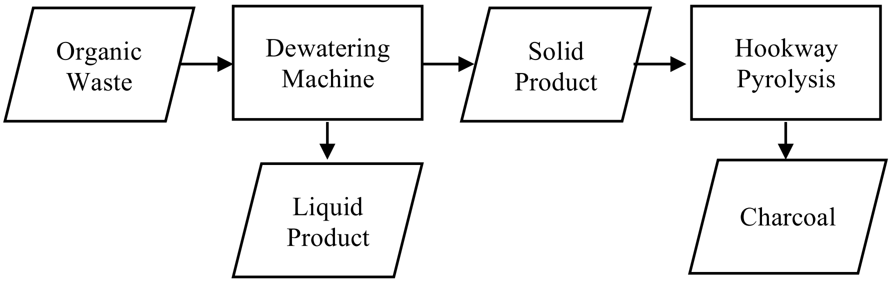

Figure 2. The Organic Waste Recycle System (OWRS) system process

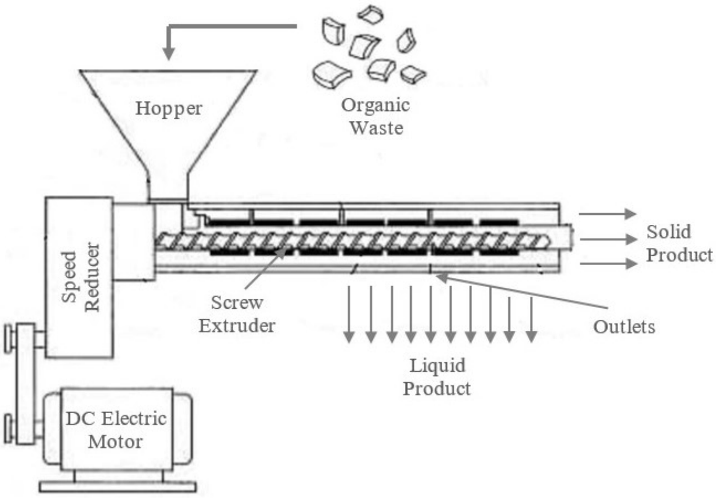

Figure 3. Schematic diagram of the dewatering machine

There are two principle equipment's utilized in the OWRS. The first is a dewatering machine in the form 1 HP electric motor (speed ratio 1:60) with the capacity of 3 kg/hour. Figure 3 shows the schematic diagram of the dewatering machine. Moreover, the second is hookway type pyrolysis machine with the capacity of 100 kg/batch. The Organic Waste Recycler System (OWRS) method as seen in Figure 2 separates the organic waste which has moisture content more than 70% to the solid and liquid organic material which is the raw material for pyrolysis, and gasification. OWRS technology utilizes an extruder machine explicitly designed to reduce the water content and separating the solid material with a liquid at the same time.

The liquid organic material is also conditioned so as not to inhibit the process of acidification and methanification on biogas production. The OWRS process helps to provide the proper raw materials for gasification and anaerobic digestion process so that synthetic gas and biogas production can be optimized. The solid and charcoal products from OWRS system are analyzed based on several parameters such as mass, calorific value, and moisture content. The calorific value and moisture content of solid material are measured by utilizing an adiabatic bomb calorimeter. The C:N ratio value is determined by calculating the ratio between the total of organic C elements and the total of N elements. These results are used to estimate the potential of energy from waste, as described in Table 2. The liquid product of OWRS is analyzed based on the C:N ratio, while the solid products are analyzed based on total mass reduction after OWRS process. The solid products obtained from OWRS process are then carbonized in the hookway pyrolysis unit charcoal products, and this charcoal is used for feed to mini gasifier reactor.

3. Results

3.1 Waste Composition Analysis

Investigations in this study show that the average amount of waste generated by the Giwangan market is 4.4 tons per day with the density of 0.3465 gr/cm^3. Meanwhile, the maximum capacity of Piyungan Landfill is 400 tons per day. Thus, Giwangan market contributes only 1.1% of the total waste production in Yogyakarta. Table 3 describes the composition of total wastes produced by Giwangan market every day.

Table 2. Methods for estimating the energy potential recovery from waste.

Parameter	Equation	Unit	Notes
Total waste quantity (W)		Tonne	The theoretical value based on waste generation data before being processed through OWRS. The empirical value is based on the amount of charcoal that enters the gasification reactor
Net Calorific Value (NCV)		kcal/kg	NCV theoretical value is NCV organic waste before using OWRS process. NCV empirical value is NCV of OWRS charcoal system product
Energy recovery potential (ERP)	NCV x W x (1000/860)	kWh*	[29]
Power generation potential (P)	ERP/24	kW	Operation time is assumed 24 hours
Conversion Efficiency (CE)	~25	%	Using internal combustion engine [30]
Electrical Power (P_{el})	**CE x P**	**kW**	

*) 1000/860 is a conversion factor of kcal for each tonne (1000 kg) to kWh

Table 3. The waste composition of Giwangan market during daily operation

No	Type of Waste	Composition (%)	Water Content (%)
1	Food waste	71.14	83.48
2	Wood	1.15	62.64
3	Garden (yard) and park waste	2.89	74.98
4	Paper and cardboard	3.61	34.83
5	Nappies (disposable diapers)	1.30	n.a
6	Textiles	1.15	1.11
7	Rubber and leather	n.a	n.a
8	Plastics	17.89	71.32
9	Metal	0.43	n.a
10	Glass	0.29	n.a
11	Other (e.g., ash, dirt, dust, soil, electronic waste)	0.14	n.a

Based on the information as seen in Table 3, the percentage of food waste reached 71.14% of the total waste in the Giwangan market. Moreover, the food waste has a water content of 83.48%. Food waste which dominates the composition of market garbage is majority derived from vegetables, fruits, rice, and meat. The second largest composition after food waste is plastic waste that is equal to 17.89% with a water content of 71.32% since the plastic material is commonly used as a feedbag. The organic waste recycler system involves only food waste as an organic material to get a liquid and solid product. Figure 4 shows the solid product of food waste as the result of OWRS implementation.

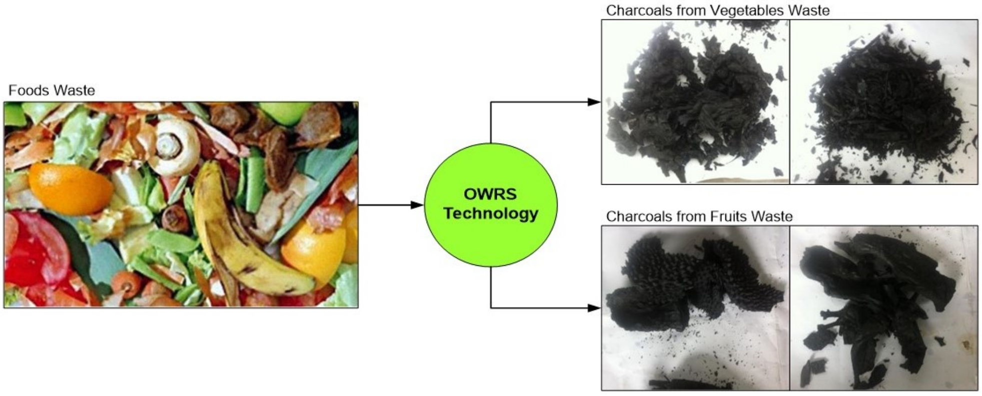

Figure 4. Foods waste to solid material transformation using the Organic Waste Recycler System (OWRS) method.

3.2 Physical Parameters Analysis

Observations on calorific value, water content, and C:N ratio are obtained from laboratory experiments. During the experiment, researchers use two types of food waste, namely fruit waste, and vegetable waste. The fruit waste consists of pineapple, jackfruit, and banana. While the vegetable waste consists of kale, cabbage, and mustard greens. Observation of net calorific value (NCV) is divided into three stages, namely before OWRS, after OWRS – dewatering process, and after the OWRS – pyrolysis process. The initial preparation process is to mix all the waste samples for each type of garbages with the same ratio, both type of fruit and vegetable waste. Figure 5 depicts the comparison of NCV value measurement from two types of food waste mixtures for the three observation conditions. The comparison results show that NCV rises significantly after the OWRS process (dewatering and pyrolysis). The NCV of fruit waste before the OWRS process is 723.12 kcal/kg and up to 6308.26 kcal/kg after the OWRS process (pyrolysis), showing an increase in the NCV by 8.7 times.

Similarly, the NCV of vegetable waste also increases to 9.1 times after OWRS process. The increase of NCV on solid products generated by the OWRS process reflects the amount of energy potential that can be harvested from the organic waste. The higher the NCV, the higher the potential energy that can be used.

In addition to NCV observations, researchers also observe a reduction in water content after the OWRS process. The figure 6 shows the comparison of water content measurements of the two types of mixed waste before and after the OWRS process. The comparison results show that the water content down significantly after the OWRS process (dewatering and pyrolysis). The water content of fruit waste before the OWRS process is 79.79% and down to 0.6% after the OWRS process (pyrolysis). The results show that the OWRS can remove the water content of fruit waste up to 99.25%.

Similarly, the water content of vegetable waste can also significantly reduced up to 99.06% after OWRS process. The decrease in water content determines the efficiency level of energy conversion. The lower the water content, the higher the energy conversion efficiency.

Similar research on pyrolysis of organic waste from the market conducted by Supakata et al. [31] using the same pyrolysis temperature as the pyrolysis system in OWRS which is 500 °C results in a lower calorific value of charcoal products and higher water content compared to OWRS charcoal products where using rice husk composition: cabbage is equal to 40:60 produces a calorific value of 4910.10 kcal/kg and water content of 3.64%. This proves that the OWRS system can increase the calorific value of charcoal products by 18.44% and decrease the water content to 81.32% when compared to using the pyrolysis system without the dewatering process.

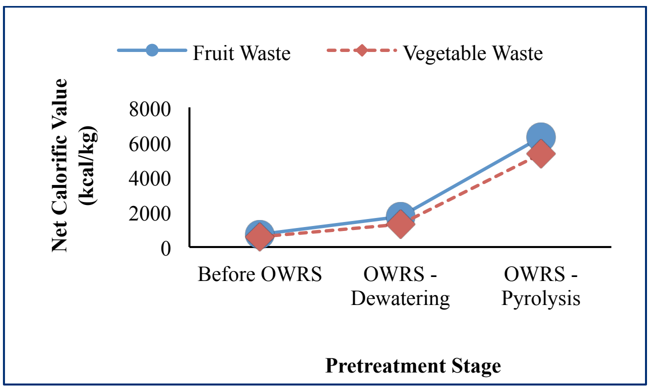

Figure 5. The comparison results of net calorific value (NCV) measurement based on three observation conditions.

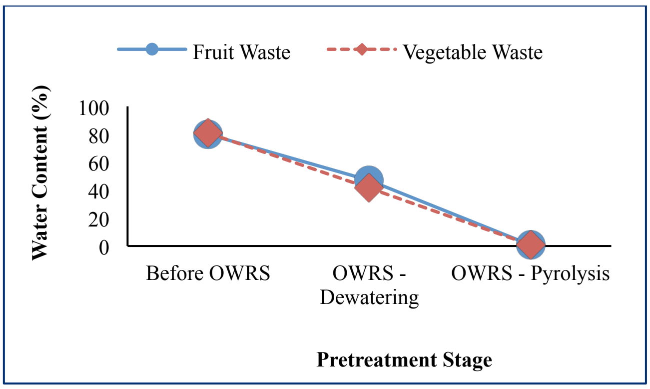

Figure 6. The comparison results of water content measurement based on three observation conditions

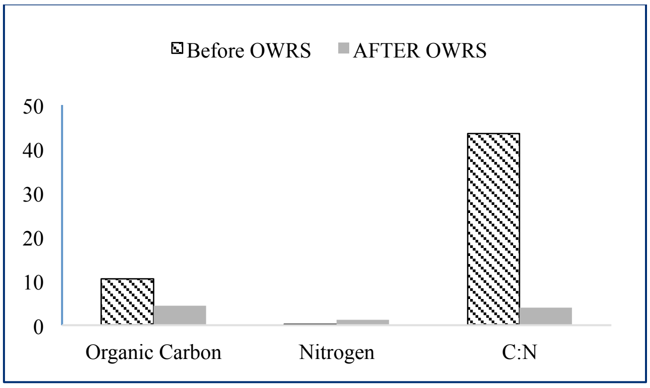

Figure 7. The composition of organic waste based on observations of carbon and nitrogen content in the laboratory.

The dewatering process on the fruit waste, the water content decreased by 32.95%, and 39.7% on the vegetable waste as shown in Figure 6. Based on the laboratory observation, the result shows the C:N value of the liquid waste produced after the dewatering process of 4.06 as shown in Figure 7. When compared with the minimum requirement of C:N which is suitable for biogas as stated in Table 1 (25 to 30), the liquid waste produced after the dewatering process cannot be used for biogas' raw materials due to the C:N value is far below minimum requirements. However, the liquid waste after the dewatering process still can be used as organic liquid fertilizer.

3.3 Empirical Results of OWRS Technology

During laboratory experiments, the water content of fruit and vegetable waste with a total weight of 48 kg will be reduced using a dewatering machine with a capacity of 6 kg/hour. Thus the engine operates for 8 hours. The dewatering process produces 10.3 kg of solid waste and 25.51 liters of liquid waste. Since the resulting liquid waste has a low C:N value as shown in Figure 7, all liquid waste is only used for organic fertilizer. Whereas, 10.3 kg of solid waste is used as raw material by pyrolysis machine for 5 hours, and produce 2.64 kg of charcoal. Table 4 shows the experimental results empirically in the Laboratory.

Table 4. Empirical result of OWRS process during Laboratory experiments.

No	Description	Value	Unit
1	Dewatering Capacity	6	kg/hour
2	Pyrolysis Capacity	50	kg/batch, 5 hours
3	Total Waste	48	Kg
4	Mass of dewatering results	10.22	Kg
5	Mass of the pyrolysis (charcoal) material	2.64	Kg

The charcoal material obtained from the pyrolysis process is the input for the gasification reactor. The gas produced during the gasification process is used for the operation of the electric generator. Since the capacity of the gasification reactor is 5 kg/hour, therefore the OWRS process requires twice the operational time to meet the capacity of the gasification reactor, i.e., 2 x 8 hours for dewatering process and 2 x 5 hours for pyrolysis process.

3.4 The Development of WTE using OWRS system

The results of laboratory analysis related to experiment on fruit and vegetable waste (i.e., calorific value, mass reduction, C/N ratio, water content) are used as a reference in designing OWRS-based Waste-to-Energy development. Table 5 shows the results of the raw material mass rate and the OWRS process mass rate.

Table 5. The mass rate simulation results of OWRS.

No	Description	Value	Unit
1	The Waste Mass of Giwangan Market	4397.95	kg/day
2	The Percentage of Food Waste	71.14	%
3	The Food Waste Mass	3128.70	kg/day
4	OWRS System (Dewatering and Pyrolysis Process):		
	Dewatering Process:		
	The Reduction of the Output Solid Material Mass	21.31	%
	Solid Material Output	666.73	kg/day
	Pyrolysis Process:		
	The Decrease of the Charcoal Output Mass	25.82	%
	Charcoal Output	172.15	kg/day

The total mass reduction of organic waste after OWRS process is 94.45%. Thus, food waste obtained from the Giwangan market of 3128.7 kg/day will produce charcoal products of 172.15 kg/day. Charcoal products are introduced to the gasification reactor to produce synthetic gas through the heating process. The Giwangan market contributes 4937.95 kg of waste per day, and the proposed OWRS technology is only capable of using food waste of 3129 kg per day. In theory, if the average calorific value based on laboratory test is equal to 635.9 kcal/kg, then the potential energy to be generated is 2378.9 kWh, and the potential of electrical power is 99.12 kW. Based on the results of the experiment, the power generation value is 48.50 kW whereas theoretically, the power generation potential is 99.12 kW, so the efficiency of the power generation for the OWRS system is 48.93%.

If the efficiency of the electric generator is 25%, then the potential for electrical power to be obtained is 24.78 kW. Based on the empirical test through the gasification reactor, the food waste converted to charcoal has an average calorific value of 5815.33 kcal/kg and provides an energy recovery potential of 1164.07 kWh or 48.5 kW of power generation potential. The gasification reactor used during the study has an efficiency of 11% so that the electric power generator can provide the electrical power of 5.14 kW. Table 6 describes the comparison between empirical and theoretical results during OWRS and gasification process.

Table 6. The comparison between the theoretical and empirical results of OWRS-based waste-to-energy development

Parameter	Equation	Theoretical Value	Empirical Value	Unit
Total waste quantity (W)		3.129	3.129	Tonne
Total Waste Dewatering-OWRS (TWD)	21,31 % x W		0.667	Tonne
Total Waste Charcoal-OWRS (TWC)	25,82 % x TWD		0.172	tonne
Net Calorific Value (NCV)		653.90	5,815.33	kcal/kg
Energy recovery potential (ERP)	NCV x W x (1000/860)	2,378.90	1,164.07	kWh
Power generation potential (PGP)	ERP/24 hour	99.12	48.50	kW
Conversion Efficiency (CE)		25	11	%
Net power generation potential (NPP)	CE * NPP	24.78	5.14	kW

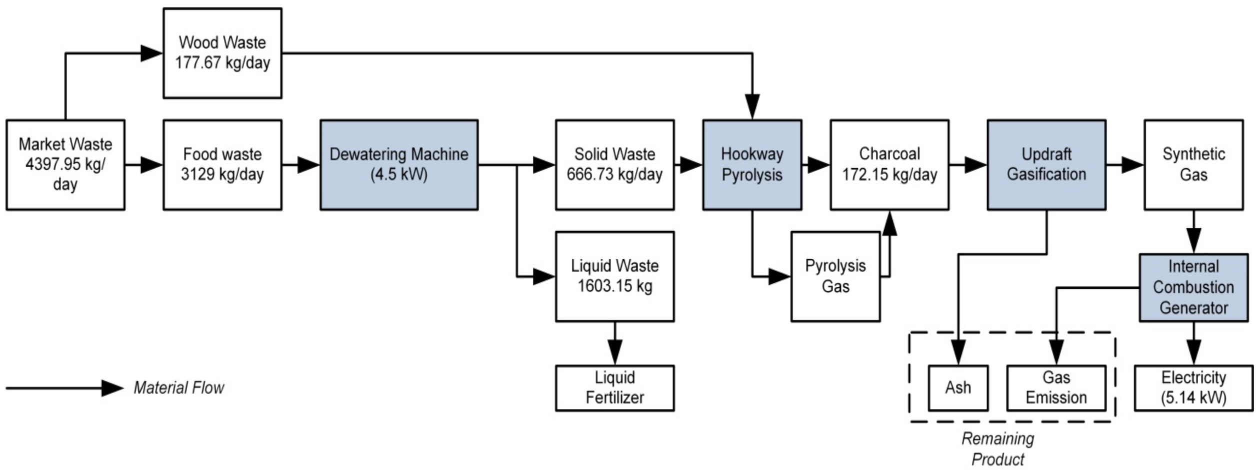

Figure 8. Process diagram for the development of the WtE system of Giwangan market organic waste using OWRS

Based on the amount of fuel used, raw materials and biomass products generated depicted in Figure 8 the energy balance for the waste-to-energy process using the OWRS system is shown in Table 7 with assumptions:

1) Dewatering unit processes 3129 kg of organic waste with a total of three machines. Each unit has a capacity of 200kg/hour and operates for 6 hours per day
2) Pyrolysis unit processes 667 kg of OWRS Solid Organic Materials with a total of seven Hookway Pyrolysis units. Each unit has a capacity of 100 kg/batch for 2 hours per day
3) Gasification unit processing 172 kg of waste charcoal requires three reactor units with a reactor capacity of 2.5 kg/hour for 24 hours per day
4) Fuel diesel heating value = 10341.6 kcal/kg with a density of 0.86 g/cm^3 with a conversion value of energy from kcal/kg to kWh = 0.00116.

Table 7. The energy balance of WtE development at Giwangan Market using OWRS

No	Unit Process	Type of Equipment	Type of Fuel	Total Fuel/ Day	Amount of Energy Consumed (kWh)	Amount of Energy Produced (kWh)
1	Dewatering	Diesel engine (8 Hp)	Diesel	31 Liter	322.78	-
2	Pyrolysis	Oil burner (2L/hour)	Diesel	27 Liter	275.14	-
3	Gasification	Blower (300 Watt)	Electric	-	172.15	123.34
			Total		770.07	123.34

The energy balance data above shows that the market organic waste based WtE process uses OWRS-gasification pretreatment system requiring the total energy of 770.07 kWh per day to produce electrical energy of 123.34 kWh per day. It means that the total energy balance value is -646.73 kWh. Although the balance energy is negative, the OWRS-gasification method is very beneficial regarding the environment, namely that it can reduce the amount of organic waste generated every day at Piyungan Landfill, so that CH_4 gas emissions from landfill waste generation can significantly be reduced. This system can also support the program of the DIY Provincial Government in increasing the energy mix in the renewable energy sector, especially biomass which is in line with the national energy policy targets.

4. Conclusion

OWRS technology produces solid products in the form of charcoals used by gasification reactor to produce synthetic gas. OWRS method runs two stages of foods waste processing, dewatering process, and pyrolysis process. Foods waste from Giwangan market of 3.129 tons per day is extracted through the dewatering process and produce solid material of 666.37 kg. Then the pyrolysis process converts the solid material into charcoal products of 172.15 kg to be fed into the gasification reactor. In this study, the liquid material produced during the dewatering process cannot be used as biogas material because the C:N value is lower than the minimum requirement. Therefore, the liquid product of OWRS serves as organic liquid fertilizer. The gasification reactor produces synthetic gas that fuels the electrical generator. Based on the experiment, the charcoal products from OWRS of 172.15 kg fed to the gasification system produce the electrical energy of 5.14 kW. Although the experimental results empirically show lower energy recovery potential values than theoretical calculations, the proposed OWRS technology can overcome the problem of accumulation of waste in the Giwangan market by converting organic waste into electrical energy.

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