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Analysis of the effect of initial moisture content variation on organic waste characteristics using biodrying process

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Abstract. The use of solid waste as an alternative energy can be a solution in demanding for environmental sound energy. However, this is limited by its high moisture content, especially in organic waste. This high moisture content decreases the heat value of the waste. Biodrying is a method of utilizing microbial activities assisted by air injection to decrease the moisture content. This study discussed the effects of wastes' initial moisture content on biodrying process. Food waste and garden waste were used as feedstock. This experiment used 3 reactors with volume of 168 dm^3. The initial moisture content of each reactors were varied into 51,07, 63,96, and 71,06 (%wt/w), and the air flow rate were 10 L/min.kg. After 21 days, it was shown that moisture among 3 reactors were significantly different with final moisture content were 21,92, 29,12 and 38,38 (%wt/w) while the volatile solids were identic. Also, FAS and heat value increased while C:N ratio decreased after the process. Different initial moisture content caused different duration of time needed to dry the organic waste until the moisture reaches <20% to use as an RDF. Reactor 1 took 22 days, reactor 2 took 25 days, and reactor 3 took 27 days.

1. Introduction

The production of energy from waste is not a new concept since various energy conversion technologies are available. However, they are based on the physical and chemical properties of the wastes both the type and quantity of the available waste feedstock and the form of energy required [1]. The availability of wastes which are easy to find and affordable make wastes one of the solution to meet the demand of alterative energy and to reduce the waste generation in landfill, at once.

The heat value of waste is affected by several factors, one of them is moissture content. For optimizing heat value of waste, several methods can be implied in many ways. One of the method is biodrying.

Biodrying, as the name implies, is a drying technique that relies on biological activities of microorganisms such as bacteria and fungi to reduce the moisture content of wet biomaterial waste [2]. Biodrying method assisted by the aeration system will provide mass and energy airflow to reduce the moisture content and to distribute the excessive heat transfer so that the heat will spread evenly across the entire surface. Moisture content is one of the most important parameter in biodrying because it affects the complexity of biochemical reactions which are related to microbial growth and biodegradation of organic waste that occur during the process [3] [4]. The bog organic fraction composition will speed up the biodrying process [5].

Generally, typical domestic wastes have a moisture content ranging from 15 – 40% [6]. Indonesia, a country with 2 seasons will certainly have a various moistre content of waste. The moisture content of municipal solid waste ranging from 70 – 80% [7] with 2-year old waste is 79,01% and 4-year old waste is 78,88% [8]. Other data showed that moisture content of waste in Jakarta is ab

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out 47,97% [9] and other studies mentioned moisture content of waste in TPA Cipayung, Depok is about 64,74% [10]. These differences in moisture contents are due to the different the season during the sampling occur and the rain intensity in several regions of Indonesia are different.

The initial moisture content is important because if it is too high, it will limit oxygen transport and microbial activities hence hindered and invalidated biodrying process [11]. On the other hand, if initial moisture content is too low, micorbial activities will be slow due to the lack of moisture which results in reduced drying performance.

Research on biodrying has been occured since approximately 15 years. According to the Villegas an Huilinir's [12], initial moisture content had a stronger effect than air flow rate by affecting temperature and increasing water removal. Another research conducted by Ma *et al*., (2016) mentioned that in biodrying process, initial moisture content showed significant influence based on statistical analysis.

This study will analyze the effect of initial moisture content variation to temperature, volatile solid, the change of moisture content during the 21 days of biodrying process. Three laboratory scaled reactors are used. Free air space (FAS), C:N ratio, and heat value parameters will be measured to compare the changes during biodrying process. At the end of the study, the 3rd order line equations were used to calculate the drying duration to reach final moisture content less than 20 (%wt/w) as an RDF standard.

2. Method and material

2.1. Feedstock preparation

Samples consist of organic waste with composition of garden dan food waste as feedstock. To obtain initial moisture content's variation, the percentage of garden waste (dried leaves and green leaves) and food waste were set so that the initial moisture content for each reactors are 50,71%, 63,96%, and 71,06%. Each reactor consists of 17 kg of mixed organic wastes.

2.2. Experiment and process operation

Biodrying is a combination of physico-chemical process with aeration system. There were three similar laboratory scaled reactors made from polystyrene as an insulator to diminish the heat loss during the biodrying process Three type of feedstock with different initial moisture content are used. Reactor 1, 2, and 3 consecutively had the initial moisture content of 50,71%, 63,96%, and 71,06%. The dimension of each reactor was 70 cm x 50 cm x 40 cm and the thickness of the styrofoam was 2-cm. The reactor was sealed by covering with the 2 cm sponge at the top of the reactor to avoid heat loss and condensation. The bottom of the reactor was made perforated so the leachate would drip to the leachate box of polystyrene foam with the dimension of 70 cm X 50 cm X 20 cm. At the top of the cover a thermocouple ETI Type K was installed and connected to thermologger ETI ThermaData logger type T. Aeration system was conducted by Multipro Mini Air Compressor MC-101-MPSG with capacity 80 L/min. The air hoses were perforated to distribute the oxygen. The air flow rate was set to 10 liter/minute and regulated by flow meter to adjust the incoming air supply before finally connected to the compressor. The compressor is set to be turned on every 15 minutes and then turned off for the next 30 minutes.

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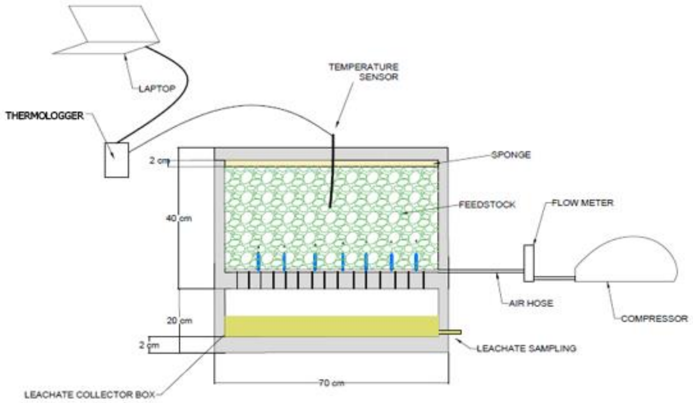

Figure 1. Reactor Design

2.3. Sample analysis

Several parameters will be analyzed during this study which are include C, N, free air space (FAS) and heat value. The temperature data were recorded every hour, while moisture content and solid volatile were analyzed by using Standard Method 2540 G with duplo system. C and N are analyzed using SNI 06-6989.28-2005 (Carbon) and Standard Method (1980) (Nitrogen), the heat value was measured using ASTM D5865-2004.

Data will be analyzed through statistical test which were ANOVA (Analysis of Variance) to analyzed the significance of the three reactors which was preceded by normality test, Pearson test was also used to know correlation between parameter and also regression test was used.

3. Result and discussion

3.1. Feedstock charcterisics

The initial and final feedstock characteristics are presented in Table 1 and 2:

Table 1. Initial feedstock characteritics

Characteristics	Reactor 1	Reactor 2	Reactor 3
Initial Moisture Content (%)	50,71	63,96	71,06
Volatile solid (% TS)	89,44	88,68	86,63
C (%)	76	70,6	79,2
N (%)	2,92	2,52	2,87
C/N Ratio	26,07	28,02	27,64
FAS	87,85%	85,84%	81,95%
NHV (kkal/kg)	1509	1386	1421

The premilinary characteristic test results in Table 1 showed the C/N ratio were in tha range suggested in biodrying process. C/N ratio was used by microbes to synthesize proteins, the required C/N ratio is about 20 – 30 to ensure that microorganisms have a balanced nutrient for their metabolic activities [2].

The free air space (FAS) with green leaves, dry leaves and food waste as feedstock had value in the range of 80% ensuring system with aerobic condition.

The initial heat value before the biodrying process, at reactor 1 showed the highest NHV value of 1509 kcal / kg. This result is ini line with previous study which mentioned LHV values of leaves waste ranging from 906.08 - 2000 kcal / kg [6].

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Table 2. Final feedstock characteritics

Karakteristik	Reactor 1	Reactor 2	Reactor 3
Initial Moisture Content (%)	21,92	29,12	32,39
Volatile solid (% TS)	75,532	75,274	76,721
C (%)	64,8	66,2	72,2
N (%)	2,79	2,45	2,77
C:N Ratio	23,21	27,07	26,09
FAS	95,12%	93,81%	91,61%
NHV (kkal/kg)	2707	2860	2793

The FAS after biodrying process were increased for each reactor indicating expansion of the space inside the feedstocks for air to flow. This is similar to the research conducted by Ma *et al*., (20116), the FAS value increased to 93.53%, 94.03%, and 92.62% influenced by the extent of water removal compared with organic degradation.

Carbon concentration decreased significantly in reactor 1 as 11,2% sincecarbon is used by microorganisms to form cells in the form of skeletons of all organic molecules carried by organisms to form an energy [13].

Nitrogen value decrease significantly in reactor 2 as 0,15% since nitrogen is required for the synthesis of amino acids, purines, pyrimidines, some carbohydrates, lipids, and enzyme cofactors. Amino acids, purines and pyrimidines are growth factors [13].

All of three reactors have C/N ratio between 20-30 so that the biodrying process can be lengthen for more than 21 days to obtain the expected final moisture content.

The NHVs are continuously increase during the biodrying process. The largest increase in NHV occurred in reactor 2 with an initial moisture content of 63.96% due to the high water removal at reactor 2 that is equal to 34,84%. Some researchers such as Velis et al. (2012) concluded that biodrying can increase LHV from 30% - 40% or even more by reducing the moisture.

3.2. Temperatur profile

Biodrying is a combination of physico-chemical process with aeration system. There were three similar laboratory scaled reactors made from polystyrene as an insulator to diminish the heat loss during the biodrying process Three type of feedstock with different initial moisture content are used. Reactor 1, 2,

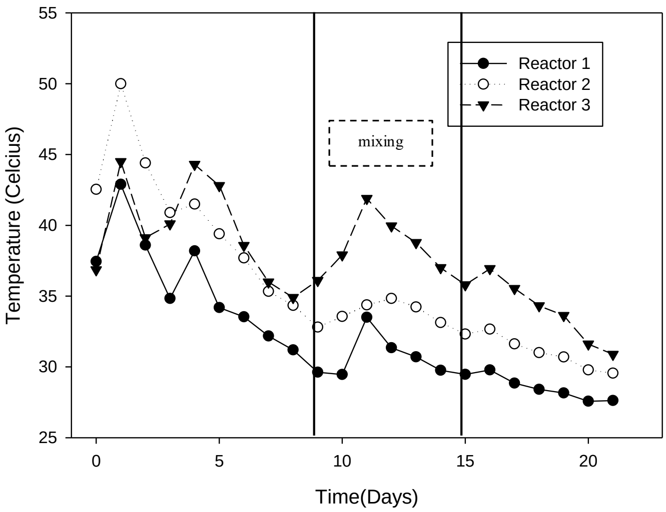

Figure 2. Temperature profile of each reactor

The ANOVA test results showed that the temperature profile among three reactors were significantly different. Reactor 1 with initial moisture content 50,71% reached the highest temperature on day-1 which

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was about 43^{0}C then decreased and increase again on day-4 which was about 38^{0}C. After the 4th day, the temperature decreased so wastes are mixed on the 9th day hence the temperature increase again in the 11th day. The second mixing conducted on the 15th day however the temperature only slightly increased and then continuously decreased until the 21st day at 27,62^{0}C.

At reactor 2 with initial moisture content 63,96%, the highest temperature reached on day-1 was 50^{0}C. Feedstock was mixed on day-9. On day-10, the temperature increased again until day the 12th. The second mixing was done again on the 15th day. The temperature has increased slightly and then continues to decrease until the 21st day (Figure 2).

The temperature in reactor 3 which initial moisture content was 71.06% had a different temperature profile compare to the other 2 temperature profiles. The highest temperature reached on day-1 which was about 44.5^{0}C then decreased. Mixing was done on day 9. On day-10, the temperature increased again until the 11th day which was about 41.9^{0}C. The second mixing was done on the 15th day and the temperature only slightly increased and then decrease until the 21st day. In reactor 3, the temperature was ranging from 44,50^{0}C - 30,88^{0}C.

Overall, the highest temperature reached by reactor 2, which is 50^{0}C and the lowest temperature occured in reactor 1 which is 27,57^{0}C. In the first 4 days, the temperature would be at its highest point. This similar result occurred in previous research of feedstock used, as explained by Ma *et al.*, (2016) if the food waste is used in the biodrying process it will show that the direct temperature rises drastically without going through the lag phase and has the second (from day 1 to day 4.5) and the temperature will decrease until the first mixing.

Higher biodegradable organic content will produce higher heat and temperature, which will also result in the degradation of organic matter [14]. The temperatures from day 1 to day 4 were high due to the hydrolysis stage and microorganism growth entering the exponential phase in which microoganism grows and multiplies itself constantly [13]. Non-elevated temperatures indicated that overall biological stability has been achieved after biodrying and microorganism activity has been retained, while temperatures have fallen due to the solubility of decomposing organic materials [15].

3.3. Moisture content

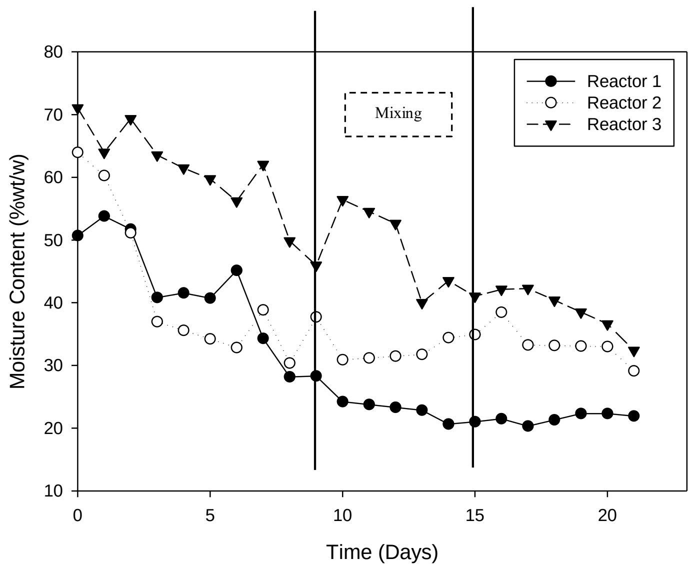

Figure 3. Moisture content profile of each reactor

The moisture content profile among three reactors were significantly different. Reactor 1 had a considerable decreased until day-to-10 with the final moisture content was 21.92% and water removal which was 28.79%. Reactor 2 had a significant decrease in the first 8 days with moisture content after 21 days reached 29.12% with water removal was about 34.84%. While, the condition of reactor 3 had the highest water removal which was 38,68% with the final moisture content reached 32,38%. The water removal caused by heat from waste through biodrying processes is not constant, but depends on the

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growth of microorganisms. The growth depends on the presence of water on the waste as happened in the composting **[16]**

In Figure 3, reactor 1 with initial moisture content 50.71% representing the reactor had a final water content of close to 20% among other reactors which is a parameter for an RDF. This might be happened because reactor 1 has the lowest initial moisture content of 50.71%. However, when returning to the main concept of biodrying which means biological-drying, then reactor 3 with the initial moisture content 71.06% had the highest water removal percentage which was about 38.68%..

Previous studies have been conducted on moisture reduction on biodrying. Zhang *et al*., (2008) conducted a study with the initial feedstock moisture content of 72%, then after the biodrying process it reached 50.5. Not much different from the research done by Shao *et al*., (2010) showed a decrease in moisture content from the biodrying process with an initial value of 73.0% to 48.3% after 18 days. Velis *et al*., (2009) did the same thing for 7 - 15 days and obtained water removal results of 25 - 30%. The same thing happened to reactor 1,2, and 3, until day 15, water removal ranging from 29% - 30%. The biodrying process will be slowing down when the moisture content was below 35% **[16]**. The statement is evident in the conditions of reactors 2 and 3 which had a small percentage of water removal when the moisture content reached 35%. In addition, the moisture content of microorganisms is well within the range of 40% -70% to maintain the active metabolic function of microorganisms because cell walls must remain permeable to the flow of nutrient-readily soluble nutrients by osmosis **[17]**. The process of removing moisture content was done in 2 (two) stages. First, water was evaporated from the biomass surface to the air sublayer that flows through the bed voids, then water vapor was carried from around the surface of the waste surface by convection airflow. This also made the sponge on the top of insulation became wet caused by evaporated water vapor **[18]**

3.4. Volatile solid

The volatile solid (VS) content in the biodrying process becomes an important parameter in conditioning the feedstock as an RDF. This is because the higher VS reduction can lead to lower energy content and resulting in lower quality for RDF **[15] [19]**.

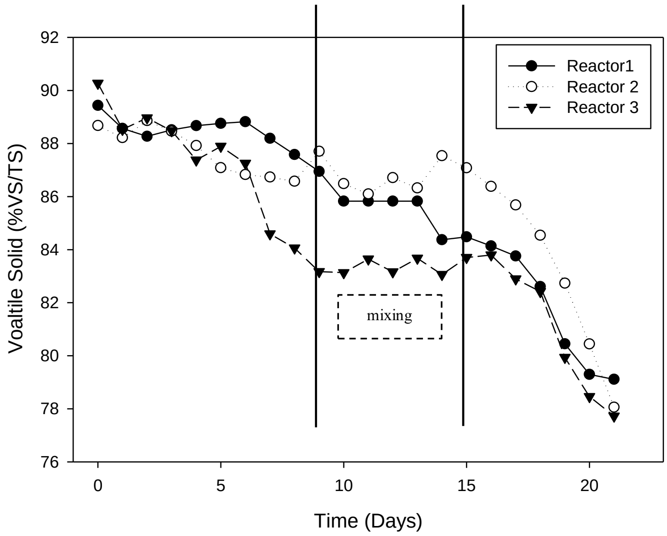

Figure 4. Volatile solid profile of each reactor

The results of the ANOVA test showed that the volatile solid profile among three reactors were identical (Figure 4). Reactor 1 had a volatile solid content of 89.44% on day 0 and on day 21 the volatile solid output in reactor 1 was 79.10%. So, the difference of volatile solid content in reactor 1 was 10,33%. In the reactor 2 volatile solid content was 88.68% on day-0. Volatile solid content were continuously decrease until the 21st day. The difference of volatile solid reduction in reactor 2 is 10,62%. While for reactor 3, initial volatile solid content was 90,27%. As reactor 3, volatile solid content showed decreasing trend until 21st day and reached 76,72%. So, the difference of volatile solid reduction in reactor 3 was 13,55%.

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Figure 4 shows that after the 15th day, the volatile solid content of all three reactors were highly decreased while the objective of biodrying is to keep the volatile solid content. The overall reactor shows that the volatile solid reduction ranging from 13% - 15% under different initial moisture content conditions and constant airflow. The difference in volatile solids reductions is similar with Villegas (2014) research with a reduction of volatile solid ranging from 1-19%.

3.5. The duration of biodrying process to an RDF

This study was conducted for 21 days, and all wastes in the three reactors have not reached the standard of moisture content for the RDF that is <20 (% wt /w). The equations have been developed using 3rd order line equation showed in table 3 to predict the final day that waste can reach 20% of the standard moisture content.

Table 3. Equation of 3rd Order for Moisture Content

Number	Line Equation	R^2
Reactor 1	$y = 0{,}0046x^3 - 0{,}0294x^2 - 2{,}8415x + 54{,}032$	0,9442
Reactor 2	$y = -0{,}0111x^3 - 0{,}4533x^2 - 6{,}2296x + 64{,}037$	0,9734
Reactor 3	$y = 0{,}0033x^3 - 0{,}1264x^2 - 2{,}9566x + 70{,}727$	0,9122

By using the 3rd order line equation with the values of R^2 are more than 0,9 which mean the influence between independent variables to the dependent variables are getting bigger, so the time which are required for final moisture content reach <20 (%wt/w) showed in table 5,

Table 0. estimated drying duration

Number	Days	Final Moisture Content (%wt/w)
Reactor 1	**22**	**19,83**
Reactor 2	**25**	**18,17**
Reactor 3	**27**	**18,09**

Those 3 reactors showed different duration, beacuse the higher the initial moisture content, the higher the amount of water removal that affect the duration of drying time. So, in order to reach <20 (%wt/w), biodrying procsss should be continued.

4. Conclusion

This study showed that initial moisture content generates significantly different temperature profiles for all three reactors. The highest temperature reached by the initial moisture content of 63.96% by 50^{0}C. The moisture content among three reactors were significantly different with the initial moisture content of 71.06% had the highest water removal percentage of 38.68%. The initial moisture content showed an identical volatile solid reduction among the reactors. The higher the initial moisture content will affect the higher volatile solid consumption caused by the increased activity of microorganisms.

The biodrying process gave different results on the heat value among three reactors. The highest NHV (Net Heating Value) reached 2860 kcal / kg was in reactor 2 with the initial moisture content of 63.96% which also became the largest percentage of increasing after 21 days of biodrying process which was about 107%.

The whole reactors have not reached the RDF parameter, with the calculation of equations of 3rd order equation, it was found that reactor 1 took 21 days, reactor 2 took 25 days and reactor 3 took 27 days to reach moisture content less than 20 (% wt/w).

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References

[1] T. Hamad, A. Agll, Y. Hamad and J. Sheffield, "Solid waste as renewable source of energy: current and future possibility in Libya," *Case Studies in Thermal Engineering Vol.4,* pp. 144-152, 2014.

[2] S. Sadaka, K. VanDevenderm, T. Costello and M. Sharara, "Partial Composting for Biodrying Organic Materials," *Agriculture and Natural Resources,* pp. 1-4, 2011.

[3] L. Cai, T.-B. Chen, D. Gao, G.-D. Zheng, H.-T. Liu and T.-H. Pan, "Influence of forced air volume on water evaporation during sewage sludge bio-drying," *Water Research,* vol. 47, pp. 4767 - 4773, 2013.

[4] J. Ryckeboer, D. D. Clercq, J. Mergaert, J. Coosemans, K. Vaes, H. Insam, S. Klammer and J. Swings, "A survey of bacteria and fungi occuring during composting and self-heting process," *Annals of Microbiology,* vol. 53 (4), pp. 349 - 410, 2003.

[5] F. Tambone, B. Scaglia, S. Scotti and F. Adani, "Effects of biodrying process on municipal solid waste properties," *Bioresource Technology,* vol. 102, pp. 7443 - 7450, 2011.

[6] G. Tchobanoglous, *Integrated Solid Waste Management,* New York: Mc. Graw Hill, 1993.

[7] Sudradjat, Mengelola Sampah Kota, Jakarta: Swadaya.

[8] G. A. Kristanto, H. Rialdi and I. Gusniani, "Nitrogen removal from landfill leachate via ex-situ nitrification and in-situ denitrification in laboratory scale reactor," *Procedia Engineering,* vol. 171, pp. 425-433, 2017.

[9] D. K. K. Jakarta, "karakteristik Sampah Jakarta," Jakarta Open Data, Jakarta, 2011.

[10] A. Juwita Sari, "The Potential of Solid Waste in TPA Cipayung as Refuse Derived Fuel (RDF) Raw Material," UI, Depok, 2008.

[11] S. Navaee-Ardeh, F. Bertrand and P. R. Stuart, "Development and Experimental Evaluation of a 1D Distributed Model of Transport Phenomena in a Continuous Biodrying Process for Pulp and Paper Mixed Sludge," *Drying Technology,* vol. 29, pp. 135 - 152, 2011.

[12] C. Huilinir and M. Villegas, "Simultaneous effect of initial moisture content and airflow rate on biodrying of sewage sludge," *Water Research,* pp. 1-11, 2015.

[13] Prescott, Harley and Klein, Prescott, Harley, and Klein's Microbiology, Seventh Edition, New York: Mc Graw Hill, 2008.

[14] B. Yang, L. Zhang and D. Jahng, "Importance of Initial Moisture Content and Bulking Agentfor Biodrying Sewage Sludge," *Drying Technology, 32,* pp. 135-144, 2014.

[15] F. Adani, D. Baido, E. Calcaterra and P. Genevini, "The influence of biomass temperature on," *Bioresource Technology,* pp. 173-179, 2001.

[16] Mendoza, Martinez, Prats, Izquierdo and Bovea, "Biodrying as a biological process to diminish moisture," *Environ Dev Sustain,* pp. 1013-1026, 2012.

[17] K. M. Frei, D. Cameron and P. R. Stuart, "Novel Drying Process Using Forced Aeration Through a Porous Biomass Matrix," *Drying Technology,* vol. 22, no. 5, 2004.

[18] A. Zawadzka, L. Krzystek, P. Storalek and S. Ledakowicz, "Biodrying of Organic Fraction of Municipal Solid Wastes," *Drying Technology,* vol. 28, pp. 1220 - 1226, 2010.

[19] Velis, Longhurst, Drew, Smith and Pollard, "Biodrying for mechanical-biological treatment of wastes: A review," *Bioresource Technology,* vol. 102, pp. 2747-2761, 2009.

ISBN : 978-602-99806-3-9

[20] T. C. Ogwueleka and F. Ogwueleka, "Modelling Energy Content of Municipal Solid Waste," *Iran. J. Environ. Health. Sci. Eng.,*, pp. 263-264, 2010.

[21] B. Adhikari, A. Tremier, S. Barrington and J. Martinez, "Biodegradability of Municipal Organic Waste:," *Waste Biomass Valor Vol. 4,* pp. 331-340, 2013.

[22] I. Petric, A. Sestan and I. Sestan, "Influence of Initial Moisture Content on the Composting of Poultry Manure with Wheat Straw," *Biosystems Engineering,* vol. 104, no. 1, pp. 125-134, 2009.

[23] C. Cimpan and H. Wenzel, "Energy implications of mechanical and mechanical–biological treatment," *Waste Management,* pp. 1648-1658, 2013.