Original Research Article

The effect of variations air discharge with the addition of biodryed Solid Recovered Fuel (SRF) in biodrying process of urban waste on Water Content Parameters and Calorific Value

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Abstract

Indonesia as the 5th position of the largest waste produce in the world contributes around 65,2 million tons of waste. From that number of wastes, most of the waste almost didn't manage nicely. Data from BPS shows that only 7% of waste is able to be recycled. Therefore, the concept of waste to energy must become a reality to answer critical problems in the solid waste management system in developing countries. Solid Recovered Fuel (SRF) is considered as the best option to reducing the bulk volume of the waste. SRF consists of non-hazardous waste fractions submitted to certain processing to obtain better quality fuel for commercialization and use in industry or combustion plants to produce energy. The quality of this SRF depends on calorific value, water content, temperature of the product etc. In this scenario, the best opinion to increase the quality of this SRF is biodrying process, where the biological heat energy is effectively channelized for drying purpose to reduce the water content of the waste and increase the calorific value of SRF product.

Keywords: Biodrying, Solid Recovered Fuel (SRF), Temperature, Calorific Value, and Water Content

1. Introduction

Waste production in Indonesia increases every year (Aziz and Gumilang, 2018). Indonesia occupies the 5th position in the world as the largest producer of waste. Indonesia contributes around 65.2 million tons of waste (Fahrurazy, 2021). Data from the Indonesian Plastics Industry Association (INAPLAS) and the Central Statistics Agency (BPS) shows that of the 69% of waste that goes to landfill, only 7% is recycled (Marpaung, 2023). This increasing waste problem encourages the search for sustainable alternatives. Waste to energy (WTE) technology has the potential to reduce the volume of the original waste by 90%, depending on its composition by reusing the energy (Beyene et al., 2018). One alternative technology for reducing the volume of waste to energy (WTE) is Solid Recovered Fuel (SRF). This waste to energy (WTE) concept can reduce the bulk volume of the waste in addition to Solid Recovered Fuel (SRF) production application (Tom et al., 2016).

Solid recovered fuel (SRF) as known as alternative to direct waste combustion and is produced from different sources of municipal waste and/or non-hazardous waste used in the thermal conversion process, has significantly different chemical and physical properties and is formed into fluff or pellets. SRF can be differentiated from alternative fuels such as Refuse Derived Fuel (RDF) using the CEN/343 (EN 15359) standard (Chen et al., 2022). Solid recovered fuels (SRF), like other solid fuels, contains non-flammable and non-volatile inorganic substances that remain as ash after the combustion process (Szydełko et al., 2022). Their composition contains a significant proportion (40-80& by weight) of biological compounds such as wood, paper and cardboard, combined with other polymeric residual materials such as plastics and textiles. The alternative energy from SRF can reduce dependence on fossil fuels and reduce the concentration of greenhouse gases in the atmosphere, thereby contributing for a better environmental management (Alves et al., 2021).

Waste that can be converted into alternative energy depends on the composition, density, and relative percentage of water content of the waste. Most of the waste in Indonesia is a wet waste with a lower calorific value, making it difficult to be burned. So that, utilizing waste by increasing the temperature and calorific value of waste in the biodrying process of Solid Recovered Fuel (SRF) production is the best and effective solutions for reducing urban waste (MSW (Municipal Solid Waste)) levels in these conditions (Soriano et al., 2020). In this scenario, the biodrying process where biological heat energy is channeled effectively for drying purpose so that muncipal solid waste containing a lot of water vapor is dried and it is energy value increases.

Biodrying is a high-impact convective removal process that reduces the water content of waste, with minimum aerobic degradation. The main difference between biodrying and composting is that the main goal is not to strengthen the degradation process of organic waste materials, but to degrade the waste so that it can produce biological heat to dry the waste (Tom et al., 2016). Biodrying is the decomposition of some organic substances by utilizing heat produced by microorganisms which are assisted by aeration. Biodrying is a technology that is used to reduce the water content of waste by using microorganisms that naturally increase the temperature in the decomposition process. During biodrying, large amounts of bioheat are produced from biodegradation of biochemical components, which results in dehydration of organic waste. Biodrying produces a product in the form of Solid Recovered Fuel (SRF) which is produced from partially degraded waste. During the biodrying process, temperature affects the degradation process. Temperature affects the biodrying process, which will also affect the biodrying product which is indicated by the water content value and the calorific value. The water content value of municipal solid waste is a very important factor that infuences the efficiency of combustion and the process of converting waste into energy conversion process (Tom et al., 2016)

It was found that the biodrying process increased the separation efficiency of municipal waste to 71% from the original value of 34%, and the conditions of the biodrying process were different for mixed and separated waste (Tom et al., 2016). A laboratory-scale biological drying studies were carried out on 3 kg of municipal waste mixed with an initial moisture content of 50%, which resulted in a maximum volume reduction of 32% and weight reduction of 50% at a temperature of 50 °C (Bilgin and Tulun, 2015). However, in the same study, heat was supplied using a water jacket to maintain the temperature at 50°C in the external drying process, and biological heat could be effectively used in the large-scale biological drying process, so the pilot-scale such a heat supply can be avoided in the reactor unit.

This study introduces an initial approach to optimizing the biodrying process of municipal solid waste by examining the impact of varying air discharge rates combined with the addition of biodried Solid Recovered Fuel (SRF). It analyzes key process parameters, including temperature, water content, and calorific value, before and after the biodrying process. This research aims to provide practical insights into enhancing waste management efficiency and energy recovery. The combination of biodried-SRF and air discharge variations offers a novel strategy to optimize the biodrying process.

2. Methods

The research method is a procedure for how a research will be carried out to solve problems This research is purpose to know the effect of variations air discharge on biodrying process with the addition of biodryed-SRF of urban waste on temperature parameter and calorific value. So that, data that needed on this research will be show on this table below

Table 1. Research of Operational

No		Data	Data Source	Method	Data collection tool
1.	Primary Data	Waste Composition	Weighing waste	scales	Stationary and digital scales
		Temperature	Mixed waste on the reaktor tank	Thermometer	Stationary and thermometer
		Water Content	Mixed waste on a tub reactor	Gravimetri	Stationary and laboratory tools
		Calorivic Value	Testing calorific value of mixed waste on a tub reactor	Bomb calorimetry and documentation.	Stationary and laboratory tools
2.	Secondary Data	University waste weight and waste weight percentage	Journal and book		

The variable which will be observed on this research are:

a. Independent variables are variables that influence or cause changes or emergence of the dependent variable. The independent variables in this study were variations in air flow (0, 2, 4, and 6 liters/minute).
b. The dependent variable is one influenced or a result of the independent variable's existence. The dependent variables in this research are temperature, water content, carbon and nitrogen content, hemicellulose content, and heating value.
c. A control variable is one controlled or made constant so that the relationship between the independent variable and the dependent variable is not influenced by external factors not studied. The control variables in this research are the initial water content before the process takes place (± 60%) and the addition of biodryed-SRF of 30%. The optimum water content for the biodrying process is 60% -65%, with a drinking water content of 40% because bacteria need water for their metabolism.

This study was carried out in the Environmental Engineering Greenhouse by testing the parameters in the Laboratory. This research and testing were done for 30 days (about 4 and a half weeks) from May 2018 to June 2018. This research was done by measuring temperature, testing water content, and heating value.

2.1 Research Planning

This research uses an experimental method to find the effect of x factor to the other factor. The parameters that will be examined in this study are temperature and calorific value. Waste composition consists of twigs and leaves, plastic, paper waste and food waste by comparison of each waste composition 64: 19: 15: 2. The mixed waste was then added with 30% Biodryed SRF. Samples from this study were done by taking a sample at the midpoint of the waste's height with the amount in accordance with needs for 30 days adjusting the study's duration.

A preliminary study will complement this research by focusing on temperature and wastewater content. It will be conducted over 15 days using a reactor with a controlled air discharge of 2 liters/minute and a water content of about 60%. This preliminary phase aims to establish baseline conditions and refine the methodology for the main experimental phase.

The main research will be carried out by 30 days with the following steps:

a. The biodrying reactor will be design with various kind of air discharge which are 0 l/m, 2 l/m, 4 l/m and 6 l/m.
b. The conditioning materials research that has been mixed and given add water until the water content of each piece of waste reactor by 60-65%.
c. Measurement of the temperature and water content was carried out every day for 30 days. A thermometer is used to measure the temperature of waste produced during the process on the reactor. Temperature measurement is done by plugging a thermometer into the center of the waste in the reactor to measure the temperature of the waste generated during the process. While the water content is measured using a calculation using formula
   Waste Water Content (%) $= \frac{b-c}{b-a} x\ 100\%$
d. Measurement of the calorific value were carried out on the sample on the 15th and 30th days.

3. Result and Discussion

3.1 Biodrying Process

Biodrying produces Solid Recovered Fuel (SRF). The main components of SRF are biological materials (40–80 wt%), with the remainder being plastic (Wu et al., 2018). In this study, adding SRF Biodryed intended as microorganisms' addition so that the lag phase in the biodrying process can be accelerated. Four tubular reactors were used and the test reactor was made of acrylic with a volume of 42 liters. The test reactors were filled with municipal waste and biodryed-SRF respectively. This process is carried out for 15 days. In this study, urban waste was used with a composition of 64% twigs and leaves, 2% food waste, 15% paper waste, and 19% plastic waste. Twigs and leaves waste was obtained from the front yard of the Undip TPST with trees growing including Mahogany Trees, Glodokan Tiang Pecut Trees and Angsana Trees. Reducing the size of twigs and leaves waste was carried out at the Undip TPST. For the food waste, it was obtained from Warung Makan Oishi on Jl. Banjarsari, Semarang. Paper waste is waste left over from photocopying business activities around the Diponegoro University of Semarang in the form of waste left over from binding products. Meanwhile, plastic waste is obtained from waste collectors on Jl. Waru Banyumanik Semarang with the main component being a plastic bag, reducing the size of the plastic waste is done manually using scissors.

Table 2. Result of Parameters

No	Parameters	Units	Day		
			0	2	15
1.	Temperature	°C	32.5	44	29
2.	Water Content	%	64.39	59.73	31.87

The initial moisture content of the waste being treated is 64.39%. After 15 days of treatment, the final water content of the waste treated in the form of SRF was 35.93%. While the maximum temperature reached during this treatment is 44 °C and the final temperature is 29 °C.

3.2 Parameter Analysis

3.2.1 Temperature of SRF

Temperature can cause metabolism by microorganisms and increase the population of microorganisms and is one of the factors that influence evaporation (Sen and Annachhatre, 2015). The initial temperatures of Reactor V, Reactor W, Reactor X and Reactor Y, respectively, were 31°C, 31°C, 32°C and 32°C. The biodrying process takes place at mesophilic temperatures (35°C-40°C) or moderate thermophilic temperature (40°C-°C) compared to thermophilic temperatures (55°C-70°C) (Ab Jalil et al., 2016). The reason is only thermophilic microbes can survive if the environmental temperature is too high (Yang et al., 2017). In this research, the temperature profile was monitored for 30 days and reactor temperature measurements were carried out every day to determine the temperature pattern of each reactor to air discharge.

In the biodrying process, the temperature is divided into three stages: heating stage, cooling stage and stablization stage. The peak temperature reached on the first day is due to the addition of biodrying SRF, which allows the presence of additional microorganisms in the waste matrix and shortens the duration of the induction phase (Song et al., 2017). Studies have shown that a mesophilic (35°C to 40°C) or moderately thermophilic (40°C to 45°C) phase is more effective in the biodrying process than a thermophilic (55°C to 70°C) phase. This is because temperatures above 60°C kill some microorganisms and only the thermophilic phase microorganisms can survive (Widarti et al., 2015).

On this biodrying process, the temperature on each reactor cannot reach thermophilic phase (up to 550C) because there was a high possibility that the waste pile will be buried, this will result in the heat that is formed not being retained for long in the waste pile.

After a rapid increase in temperature, the temperature in each reactor periodically decrased to 35°C from day 2 to day 5, indicating that the biodrying process had re-entered the mesophilic phase. On day 6, the temperature in each reactor increased again. However, the increase was not significant. This increase was due to the ambient or environmental temperatures reaching nearly 36°C. From day 7 until the end of the biodrying process, temperature fluctuations occurred in each reactor. However, the temperature fluctuations that occur between 29°C and 34°C are not that significant. The temperature is almost the same as the ambient temperature. The temperature of the biodrying process increases during the first two days and then slowly decreases to almost ambient temperature. Fluctuations that occur during the bio drying process are shown in this figure below

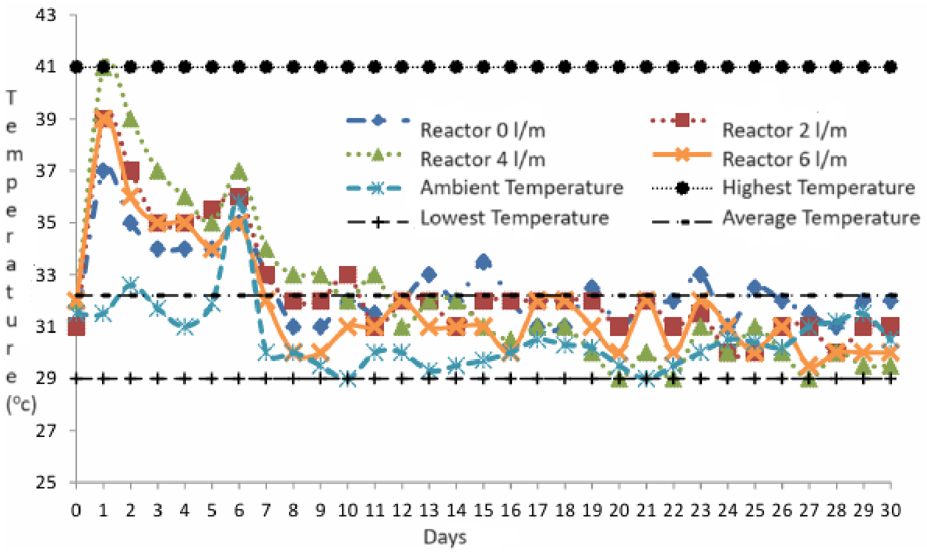

Fig. 1 Temperature Graph during The Biodrying Process

3.2.2 Moisture Content

One of the main important parameters in determining the success of the ongoing biodrying process is water content. It is because water content influences chemical reactions associated with microbial growth and the biodegradation process of organic substances during the process (Tom et al., 2016). At the beginning, water content is generally set in the range of 50% -75%. If the initial water content is too low, microbial activity will be slow because microbial metabolic processes require water. Too high of water content can cause the space in the matrix to be filled with water so that the distribution of air in the matrix will be hampered, with obstructed air distribution it will slow down the activity of aerobic microorganisms.

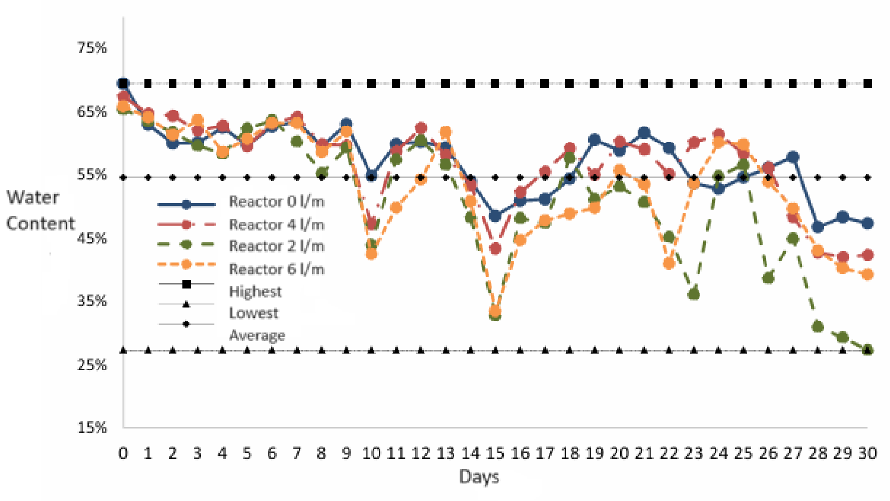

Fig. 2 Water Content Graph during The Biodrying Process

Moisture content data was collected for each reactor on the specified days during the 30-day biodrying process. The average water content on day 30 was 39% with a decrease of 41.92%. The water content in each reactor was found to vary up to day 30. The initial water content of reactor V, reactor W, reactor X, and reactor Y were 69%, 67%, 65%, and 66%, respectively.

During the first 5 days, the water content tends to decrease. The decrease was 10%, 8%, 7%, and 7% for each reactor V, W, X, and Y respectively. During the first two days, the water content will decrease in the form of leachate. Leakage of leachate is observed in reactor V. However, in the other reactors, leachate is only formed on the 30th day. This indicates that the water content in reactors W, X and Y decrease in the form of water vapor during the first five days.

After 10 days, the water content in each reactor decreased significantly. The largest decrease occured in reactor Y, which had a moisture content of 42%. The water content then increases slowly until the 13^{th} day, when it decreases again significantly on the 15^{th} day.

From day 16 to day 30, there was less fluctuation in water content. At this stage, the biodrying process enters the cooling phase. In this phase, evaporation occurs only through ventilation. With aeration, the evaporation rate of water is greater than the production rate, so that evaporation can still occur even though the activity of microorganisms begins to decrease. The most significant reduction in water content was observed in Reactor X, which achieved a reduction in water content of around 58.29% and had a final water content of 27.29%. A decrease in these microorganisms' activity is also indicated by temperatures approaching room temperature.

3.2.3 Calorific Value

Calorific value is an indicator to determine the energy content of a substance. The biodrying process can process urban waste into fuel that has high energy content by drying the waste to produce SRF products. Here was a HHV measurement on the 15th day and 30th day in biodrying process that will be shown on the table below.

Table 3 HHV test results and water content on days 15 and 30

Reactor (l/m)	HHV dry (cal/gr)		Water Content (%)	
	Days 15	Days 30	Days 15	Days 30
0	4.289,40	4.353,74	48.50	47.34
2	5.704,90	5.834,13	43.34	42.31
4	5.790,69	6.008,16	48.30	27.28
6	5.876,48	6.095,24	50.82	39.27

The table below is the result of HHV measurement at 1 grams of dried sample.

Table 4. The result of HHVdry, LHVdry, and LHVwet

Reactor (l/m)	HHV dry (Mj/Kg)		LHV dry (Mj/Kg)		LHV wet (MJ/Kg)	
	Days 15	Days 30	Days 15	Days 30	Days 15	Days 30
0	17.96	18.23	16.77	17.07	8.06	8.44
2	23.89	24.23	22.82	23.39	12.47	13.06
4	24.24	25.15	23.06	24.49	11.35	17.63
6	24.60	25.52	23.36	24.56	10.86	14.54

HHV is the combustion value obtained when there is air in the combustion product gas. The HHV value can be determined using a boom calorimeter or using the gaur and reed equation. When used, the calorific value is generally in MJ/kg units. The conversion of the results obtained was carried out using equations III-7 and III-8, so that the results presented in the table.

LHV is the combustion value obtained when there is steam in the combustion product gas. In the calculation, the LHV value is lower than the HHV value. The following shows the increase in calorific value on the 15th day and the 30th day in table below.

Table 5. Percentage Increase in Calorific Value

Reactor (l/m)	LHV Wet (Mj/Kg)		Increase in Calorific Value
	Days 15	Days 30	
0	8.06	8.44	4.7%
2	12.47	13.06	4.7%
4	11.35	17.63	55.3%
6	10.86	14.54	33.9%

From the table below it can be seen that the lowest LHVwet value was achieved on the 15th day in 0 l/m reactor, namely 8.06 Mj/Kg and the highest LHVwet value was achieved by the 4 l/m reactor, namely 17.63 Mj/Kg. According to Zhang et al.,2018, a decrease in high levels of lignocellulose can cause a decrease in calorific value (Zhang et al., 2018). However, this is not the case in the present study. The lowest hemicellulose reduction was achieved in the 0 l/m reactor, namely 50.3% and 85.31% in the 4 l/m reactor. LHV is also influenced by the fixed carbon content of the fuel. The higher heat value in the 4 l/m reactor is influenced by the fact that the final water content is reduced by the biodrying process and therefore less heat is required to evaporate the water. The high LHV value is due to plastics in the sample components, as other studies have stated that they generate high heat (Nasrullah et al., 2014).

From the results obtained, LHV 17.63 Mj/Kg can be classified as SRF class 3 with an LHVar specification of more than 15 Mj/Kg, while SRF class 2 has an LHVar content of 20 Mj/Kg (CEN/TC343, 2013). SRF with an LHV content of 17.63 Mj/Kg can be used in cement, hard coal, brown coal and fluidized bed combustion units.

3.3 Statical Analysis

Based on this research, data on water content and heating value were obtained as in the following table

Table 6 Water Content and Calorific Value

Reactor (l/m)	LHV wet (Mj/Kg)		Water Content (%)	
	Days 15	Days 30	Days 15	Days 30
0	8.06	8.44	48.50	47.34
2	12.47	13.06	43.34	42.31
4	11.35	17.63	48.30	27.28
6	10.86	14.54	50.82	39.27

From the table above, an air discharge of 4 l/m can produce SRF with the highest calorific value on day 30 of 17.63 Mj/Kg. At an air flow rate of 2 l/m it can produce SRF of 12.47 Mj/Kg which is the largest calorific value on day 15. SRF with a calorific value of 12.47 Mj/Kg is class 4 SRF and this SRF can be sold to the cement industry. The selection of an air flow rate of 2 l/m as the optimum air flow rate is based on the SRF that can be produced and the calorific value of 12.47 Mj/Kg which is close to the calorific value requirements that can be accepted by industries using air flow rates such as dry bottom boiler for hard and lignite coal and boilers from industries using fluidized bed combustion namely 13.5 Mj/Kg. Based on the study, using an air discharge of 4 l/m in the reactor and the same waste composition as this research but with the addition of a heat insulation layer on the walls and water absorbing material can produce a reactor with a water content of 18% on day 21 (Ziadati Husna, 2018). A greater reduction in water content can increase the heating value so that the quality of the SRF produced from a reactor with an air flow rate of 2 l/m can be increased by adding a layer of heat insulation and water absorbing material at the top of the reactor. Selecting an air flow rate of 2 l/m and an operating time of 15 days as an application recommendation because with low air flow it can save costs used for electricity consumption and more and more waste is processed.

To determine the optimum air discharge for biodrying urban waste with the addition of bidryed-SRF, data on water content and heating value were used during the research. A graph of the influence of air discharge on water content and heating value is presented in the image below.

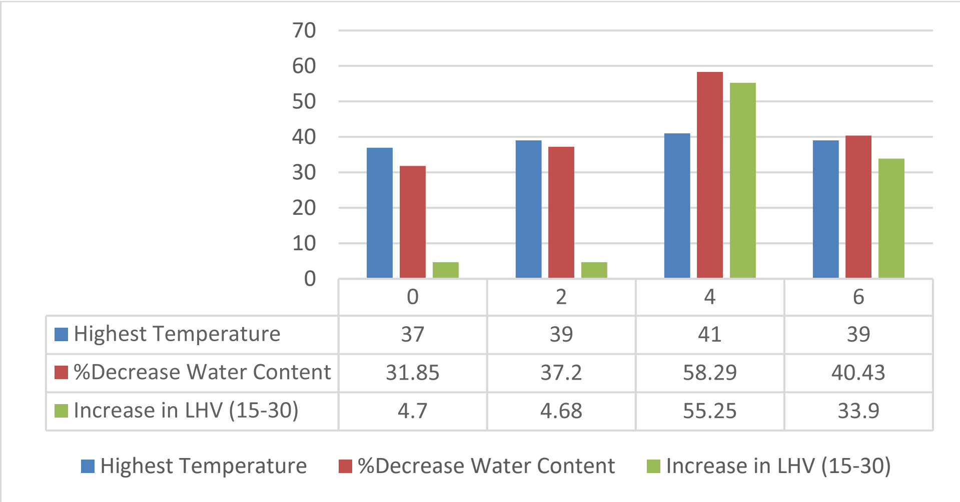

Fig. 3 Graph of the effect of air discharge on water content and heating value

In the data presented in the image above, it is known that an air flow rate of 4 l/m can reduce water content and increase the highest heating value with the analysis carried out in the previous subchapter. Additional analysis was carried out to strengthen the analysis based on the graph above, namely with statistical analysis and scoring. Induction statistical analysis is used to test inferences on a set of data originating from one sample. Statistical analysis in this study used SPSS software. The influence of the dependent variable on the independent variable tested using the regression test in SPSS software can be seen in the significance value. When sig. greater than 0.05, then there is no influence between variables. Meanwhile, if sig. smaller than 0.05, then there is an influence between variables. Apart from looking at the significance value, how close the relationship between variables is can be seen from the R2 value.

3.3.1 *Effect of Air Discharge on Water Content and Calorific Value*

In the table below, the SPSS test results for water content are presented

Table 7 Statistical Analysis Results of the Effect of Air Discharge on Water Content and Calorific Value
ANOVAa

Parameters	Model	Sum of Squares	Df	Mean Square	F	Sig.
	1 Regression	340.313	1	340.313	5.562	.033[b]

Parameters	Model	Sum of Squares	Df	Mean Square	F	Sig.
Water Content	Residual	856.625	14	61.188		
	Total	1196.938	15			
Calorific Value	1 Regression	2624287.493	1	2624287.493	13.724	.010[b]
	Residual	1147299.643	6	191216.607		
	Total	3771587.136	7			

a. Dependent Variabel: water content
b. Predictors: (Psomopoulos et al.): Air discharge

Table 7 presents the ANOVA results showing the effect of air discharge on water content and calorific value parameters. The regression test reveals that the air discharge significantly influences the water content parameter, as indicated by a sig value of 0.033 ($p < 0.05$). This significance is supported by an R^2 value of 53.3%, indicating a moderate relationship between air discharge and water content. It also confirm a significant effect of air discharge on the calorific value parameter, with a sig value of 0.010 ($p < 0.05$). The R^2 value of 69.6% demonstrates a strong relationship, suggesting that nearly 70% of the variations in calorific value can be attributed to changes in air discharge.

Analysis using scoring is used to determine the points for each variable, namely variations in aeration discharge based on the total parameter values, namely temperature, water content and heating value. For each parameter, you will get a score range from the difference between the highest value and the lowest value, then divided by four. The descriptive statistical method using scoring/weighting tables in determining optimum variables functions to provide an overview through population data of the objects to be studied. Scoring is carried out based on the results of the analysis. The table below contains all the results for each parameter that has been analyzed.

Table 8 Recapitulation Table of Air Discharge Results for Each Parameter

Debit	The Highest Temperature (°C)	% of decrease in water content	% of increase calorific value
0	37	31.85	4.70
2	39	37.20	4.68
4	41	58.29	55.25
6	39	40.34	33.90

Scoring calculations can be done using the formula (1):

Score range = (highest value – lowest value)/total scores.

Example of calculating the scoring range for water content:

$$\text{Score range} = (58.29-31.85)/4 = 6.61 \quad (1)$$

The results of calculating the scoring range and its values are displayed and the results of the scoring calculation are displayed in the following table.

Table 9 Biodrying Process Score Ranges with the addition of Solid Recovered Fuel

The Highest Temperature (°C)	% of Decrease Water Content	% of Increase Calorific Value
37-81 = 1	31,85-38,46 = 1	4,68-17,32 = 1
38-39 = 2	38,47-45,08 = 2	17,32-29,97 = 2
39-40 = 3	45,09-51,70 = 3	29,97-42,61 = 3
40-41 = 4	51,71-58,32 = 4	42,61-55,25 = 4

Table 10 Scoring Results Table Range of Biodrying Process Scores with the addition of Solid Recovered Fuel

Debit	Temperature	Water Content	Calorific Value	Total
0	1	1	1	7
2	3	1	1	6
4	4	4	4	13
6	3	2	3	9

With the scoring results based on the table above, Reactor X with an air flow rate of 4 L/minute shows the highest score with a score of 13 points. Meanwhile, the lowest score was Reactor W with an air flow rate of 2 L/minute which received a score of 6 points. This shows that the optimum air flow for this biodrying process is in Reactor X with a flow rate of 4 L/minute.

4. Conclusions

After analysis of the research results was carried out, it is shown that the variations in air discharge have a significant effect on the heating value (based on a simple linear regression test with a sig value <0.05) with an R2 of 69.6%. The optimum air discharge for calorific value is 7.14 liters/minute.kg dry (4 l/m) which produces SRF with a calorific value of 17.63 Mj/kg. The recommended air flow for application is 3.57 liters/minute.kg dry (2 l/m).

This study presents the impact of varying air discharge rates and the addition of biodried Solid Recovered Fuel (SRF) on the biodrying process of municipal solid waste. Unlike previous research, it focuses on using biological heat without external heating and examines key parameters such as temperature, water content, and calorific value. The combination of air discharge variations and SRF addition offers a new approach to improving the efficiency and energy recovery potential of municipal waste management.

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