Jurnal Teknik Industri, Vol. 26, No. 2, December 2024 DOI: 10.9744/jti.26.2.157-170
ISSN 1411-2485 print / ISSN 2087-7439 online

Design for Manufacturing and Assembly Optimization of Home-Scale Biodigester-Composter Using VDI 2222 and Finite Element Analysis Methods

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Abstract: This research focused on the Design for Manufacturing and Assembly (DFMA) optimization of home-scale biodigester-composter machines. The aim is to determine feasibility from technical-economic aspects. The technique was to design the machine's mechanical process, physical, and constituent components. There are two methods conducted on this research, VDI 2222 to optimize and Finite Element Analysis (FEA) to assess the optimal quality results of the machine design based on simulation analysis. This research ended with making a physical prototype of a home-scale biodigester-composter machine using the optimal design, then validating it with a working test of the machine. The results of the VDI 2222 method show an optimal design concept through the structure of the working mechanism. All its constituent components match with the ten target specifications and the machine manufacturing cost of IDR 2,393,000, as well as the assembly chart design for each constituent component. These results are also evaluated using the FEA method. The resistance value of the frame system to maximum Von Mises Stress is obtained at 128.75 MPa with a minimum value of 6.93e-04 MPa. It is concluded to be acceptable at withstanding normal and shear stresses effectively with a relatively small displacement value of 0 to 0.47 mm. The equivalent strain value results are 3.89e-09 ul to 5.83e-04 ul and safety factor value results are 1.93 to 15 ul. It can be concluded that the frame system design concept is safe.

Keywords: DFMA, Optimization, Biodigester-Composter, VDI 2222, FEA

Introduction

This research was conducted against the dynamics background of organic food waste in Indonesia. Current and proposed literature review-based research has provided a much deeper understanding for researchers of sustainable food waste treatment technology [1]. The results of previous research showed that each province in Indonesia generates around 20.8 million tons of food waste annually. Optimal plans, regulations, and applied technologies are required to accelerate the 70% strategic goal of food waste reduction by 2025. Bioconversion, biomass, biogas, composting, and other types of applied technology have all been examined for their potential. Thus, this previous research focuses on food waste processing methods using biodigesting and composting methods. This is reinforced by studies showing that the biodigesting method can produce biogas from organic waste, supporting the achievement of SDG goals [2]. Furthermore, biogas can improve social sustainability in Southeast Asian countries [3]. On the other side, the composting method can provide economic prosperity for its manager. [4]. In line with the biodigesting and composing method, the basis for strengthening decision-making in their application to support circular economic aspects has been studied [5]. Moreover, the technical implementation stages of these methods in processing food waste have been reviewed [6]. In Indonesia, a study uses a combination of the two methods to process palm oil waste using the Life Cycle Assessment (LCA) method [7]. The LCA method is also used to compare the effectiveness of biodigesting and composting methods in processing sewage sludge waste [8].

The research's issues are based on previous literacy studies. A high quantity of organic waste, such as food waste, has become a concern in Indonesia. This is because of the country's large population and people's purchasing abilities. On the other hand, the study about implementing applied technology in food waste processing is not fully linked. It is driven by the high cost of waste processing. Consequently, digesting and composting methods are preferred for economic and practical considerations. The research's urgency requires the development of appropriate technology for processing organic food waste that can be used optimally on a small scale, like residential households. In this case, biodigester or composter-based equipment has the potential to make waste into energy in compliance with the government regulation's plans to reduce organic waste and global emissions. The research's problem is based on literacy studies related to biodigester-composter combination technology that has not been realized. Therefore, the challenge is to create a machine for home use based on this combination of technology, along with the production and assembly process. The selection of appropriate components considering economic, security, and convenience aspects. The research aims to design a home-scale biodigester composter for food waste processing in Indonesian using the Design for Manufacturing and Assembly (DFMA) method. Also, to help accelerate the government's program to reduce 70% of food waste. The DFMA method is appropriately used for the technological design development process by considering the desired target specifications. The DFMA method integrates the Verein Deutscher Ingenieure (VDI 2222) method for the machine design optimization process and the Finite Element Analysis (FEA) method to assess the optimal quality results of the machine design based on simulation analysis.

Some prior studies on biodigester composter design have either been conducted or are currently progressing. There have been several past research on the biodigester composter's design. In 2013, a thermal evaluation was carried out on the concrete structure of the biodigester device [9]. In 2014, the biodigester was evaluated for financial and economic feasibility in residential household use [10] and residential kitchen waste as a biogas-producing media [11]. In 2016, biogas production studies were analyzed for rural areas and residential households in East Africa [12]. Also, the use of organic waste from residential households for biogas in Latin America [13]. The depth studies related to the design, fabrication, and research of small-scale portable biodigester in its use to meet residential gas needs [14]. In 2018, multi-criteria testing of residential-scale biodigester was conducted in rural areas [15]. In 2019, residential-scale biodigester was investigated for its ability to help reduce enteric viruses and bacteria in residential areas [16]. In 2020, biodigester technology was evaluated for its relevance in the district of Limpopo province of South Africa [17]. Critical factors of residential-scale biodigester technology in the Punjab province of Pakistan was also studied [18]. In 2021, the portable biodigester for residential kitchen waste has been studied for its effectiveness in providing energy in a decentralized manner [19]. The environmental, social, and health benefits of residential-scale biodigesters in rural areas have also been extensively studied [20]. At the same time, issues related to the placement of biodigesters in rural areas have been conducted in further detail using economic, social, environmental, and technical perspectives [21]. Waste utilization studies have been developed. This is not only limited to household waste but also includes utilizing organic waste sourced from household waste [22]. In 2022, the development of a biodigester using solar system heating has been examined for its social and economic benefits [23]. A study about developing a biodigester based on fiber-reinforced plastic (FRB) material has also been implemented using livestock manure and kitchen waste [24]. The feasibility of the biodigester continued to be explored regarding the public's willingness to pay for biodigester equipment in Madagascar's livestock farming systems [25], as well as studies in Bangladesh related to the factors that influence people having a residential-scale biodigester about sustainable development [26].

Several present research are currently progressing related to the design of the biodigester-composter. In 2023, the study on sustainable development explored the user's perspective of residential-scale biodigester technology [27]. The characteristics of kitchen waste and other organic waste from residential homes that can be used for biodigesters were also studied [28]. In 2024, an in-depth study regarding the dynamics of biodigester technology adoption was carried out in Uganda. This study aimed to understand the diffusion between application and innovation theory [29]. Furthermore, the biodigester technology innovation was also studied more deeply by comparing its implementation at residential and industrial scales [30]. Studies about the performance of household-scale biodigesters and greenhouse-related effects in Rwanda were also conducted [31]. In addition, there is a compilation of studies regarding the consideration of small-scale biodigester design for residential homes in terms of the operational and maintenance aspects in Asia [32]. Based on past and present research studies, it is possible to identify critical factors (see **Table 1**) in processing organic waste (food) into gas using biodigester and composter technology. These factors can serve as a reference in achieving target specifications of the design process. Using appropriate biodigester-composter technology will support a circular economy for society.

In this research, the design of a small-scale biodigester-composter machine for residential needs is based on the Design for Manufacturing and Assembly (DFMA). Optimized using the VDI 2222 method and the Finite Element Analysis (FEA) method for simulation test analysis. The FEA method references applied in several similar previous studies in simulation test analysis related to gas storage-based objects, including this method's ability to analyze LPG tanks in measuring bursting pressure [33], measuring fracture and exploded deformation of CNG tanks [34], measuring storage tank reliability [35] and analyzed the blast-resistant design of LPG tanks [36]. This method is also applied in integration with the QFD (Quality Function Deployment) method to test simulation-based tool designs [37], as field testing is impossible. Regarding the VDI method references, the VDI 2206 method is utilized to create designs for globally distributed self-organizing production systems [38]. The

VDI 2222 method is applied in designing the PBF-LB/M process related to developing an innovative machine concept [39]. It was implemented in Indonesia to design an environmentally appropriate technology for a solar-powered cocoa dryer [40]. Furthermore, in the present research, the VDI 2206 and VDI 2222 methods are integrated in implementing the combination design of additively manufactured joint assemblies [41].

The research's novelty is as follows: (a) unlike previous research that focused on communal biodigester-composter combination machines in community groups, this research focuses on designing the machine for households used in processing organic waste (especially kitchen and food waste); (b) previous research on the biodigester-composter machine was implemented to test aspects of the economic-environmental communal impact. This research delves into the design process of the tool in detail by examining technical-economic aspects for household purposes; (c) the design of the biodigester-composter machine with technical-economic aspect parameters is investigated using the Design for Manufacturing and Assembly (DFMA) approach for functional effectiveness and manufacturing cost efficiency; and (d) the DFMA approach was applied by implementing the VDI 2222 method and then tested by simulation using the Finite Element Analysis (FEA) method before being realized as a prototype, where the implementation of this method has not been carried out in previous research.

Selecting the VDI 2222 method involves process planning, analysis, and execution of product design, from idea to prototype. This method provides a systematic approach to the concept variations developing and designing technical systems and products. This makes it suitable for optimizing design results for DFMA. The advantages of this method include: (a) being able to provide several alternative design concepts for the system's design, products, devices, services, and work processes (based on a combination of concept variations). Then selecting the optimal design concept through adjustments between critical factors and variations in the constituent components; (b) using target design specifications as a control variable in determining variations of the selected concept; and (c) applying sensitivity analysis through efforts to readjust the combination of critical factors to component variations, ensuring the ideal design concept for the desired target specifications. The disadvantages of this method include: (a) as the number of critical factors, component variations, and concept combinations increases, it becomes challenging to find optimal concept variations; (b) the process of selecting optimal or ideal concept variations is carried out subjectively. So, it will produce a tendency of high bias values if it comes from assessments from inappropriate sources; and (c) if the assessment is carried out objectively with many critical factors and component variations, the testing process tends to be expensive as each concept variation must be tested individually.

Methods

This research covers the identified research gap results through literature studies from several previous and current studies related to understanding food waste processing methods within the from-waste-to-energy scheme. The orientation of this research is on the bio-digesting-based food waste processing method to become biogas and composting to become compost or biomass. This research aims to design a home-scale biodigester-composter machine based on the Design for Manufacturing Assembly (DFMA) approach. The following Figure 1 shows the flow of research activities.

The methods applied for the home-scale biodigester-composter machine design process are VDI 2222 and Finite Element Analysis (FEA). The VDI 2222 method focuses on the design and optimization of machines. It also determines the working mechanism of the machine's physical design, the components that make up the machine, and the optimal assembly design of the machine. The FEA method focuses on achieving optimal design results for further analysis, the aspects of reliability and safety in use, and understanding the machine's critical parts. These results can be used as a reference for future design development and preparation of Standard Operation Procedures (SOP) for machine operations and maintenance. This research was determined by constructing a physical prototype of a home-scale biodigester-composter machine. Further analysis was carried out to validate the suitability of the optimal design and actual realization.

Results and Discussions

Design for Manufacturing and Assembly (DFMA)

Additional information about customer needs was obtained through field observations from several sources. The information sources are from previous research results [9-32], from four community groups, forty owners and users of composters and biodigesters on a household scale, and from four expert vendors providing biodigester and composter equipment. This information was then used to determine the target specifications for the design concept of a household-scale biodigester-composter machine shown in Table 1.

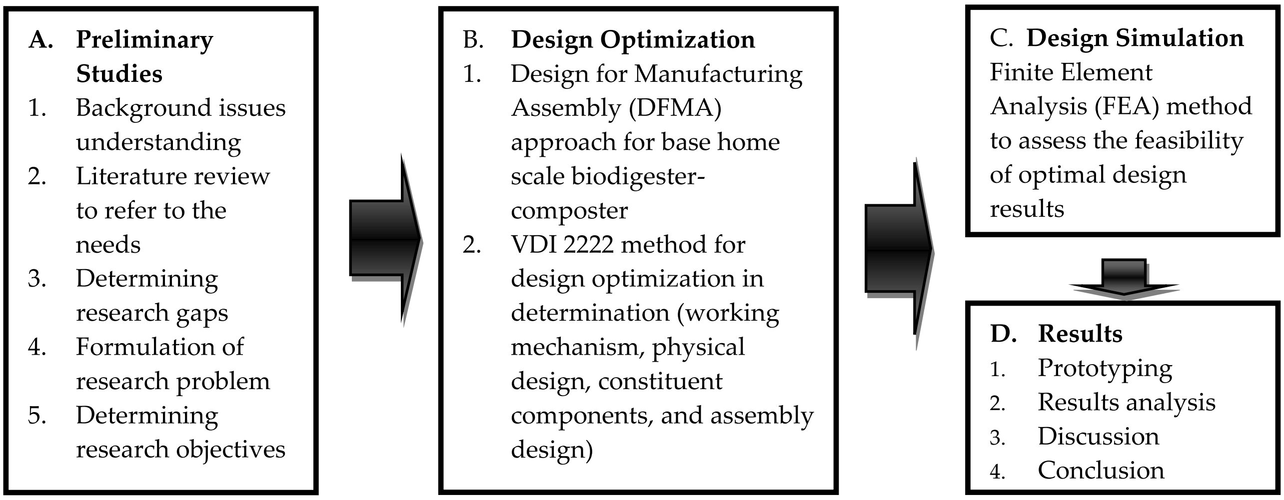


Figure 1. Research flow activities

Table 1. Target specifications of machine design concept

No.	Target specifications
1	Easy to use
2	Safe to use
3	Practical (without having to do it manually)
4	Quickly produces biogas and compost
5	Odorless
6	Not a source of pathogens
7	Easy to monitor
8	Durable and reliable
9	Economic
10	Compact and attractive design

The next stage is determining the optimal design for the manufacturing process. The VDI 2222 method is applied to identify the results of the optimal working mechanism of the home-scale biodigester-composter machine shown in Table 2. First, the result shows a Reverse Engineering process for the communal biodigesters (owned by community groups) and small-scale composters in the market. Second, determining the critical system mechanism as the working mechanism of the biodigester-composter machine design by comparing Reverse Engineering results. Critical results assessed by several biodigester and composter equipment manufacturing experts and several design and mechanical property experts. Meanwhile, in the second stage, seven important systems were formed as the working mechanisms of the biodigester-composter design concept. Third, mechanical properties studies should be conducted by observing commonly available machine work processes. This also deepens the evaluation results of several previous experts as alternative mechanism variations that can be applied. Fourth, the system mechanism variations are determined by ensuring the critical system mechanism results to fulfill the desired target specifications (see Table 1) by applying the VDI 2222 method. Meanwhile, in the fourth stage, a House of Quality (HOQ) was carried out regarding the availability of components and mechanisms that can form the critical system. Then, each component that makes up the system was evaluated by several biodigester and composter equipment manufacturing experts and several design and mechanical property experts. This evaluation serves for the purpose of utilizing the target specifications as control parameters.

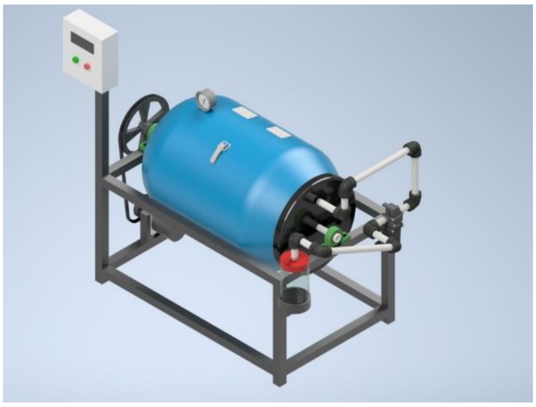
The results in Table 2 can be arranged into the following mathematical model.

$$Y = Y_{13} + Y_{22} + Y_{31} + Y_{42} + Y_{52} + Y_{61} + Y_{72} \tag{1}$$

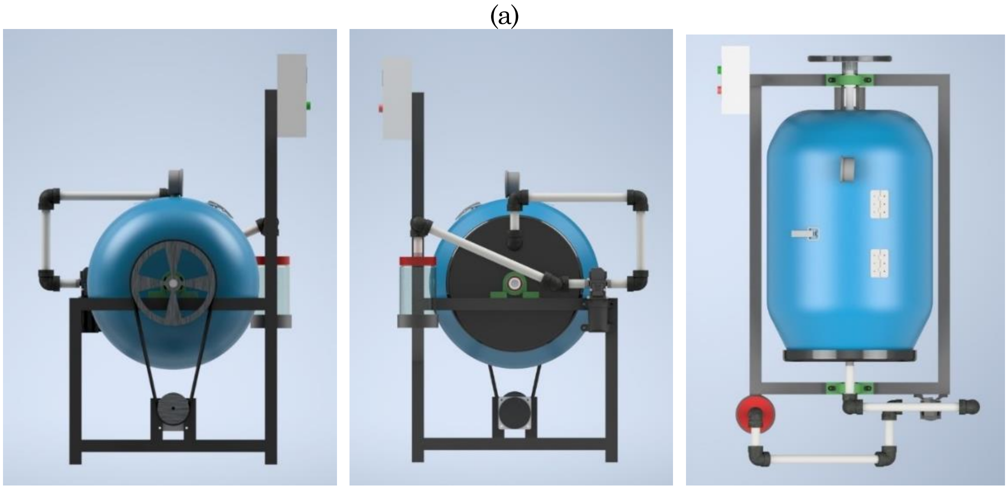
Next, a detailed physical design was created to determine the optimal working mechanism of the home-scale biodigester-composter machine. The machine design results are shown in Figure 2.

Table 2. Determining working mechanism of machine design concept

Critical system mechanism	Node	Mechanism variations			Target spec.
		1	2	3	
Mixer mechanism	Y_1	Manual	Rotary drum	Stirrer system	2, 3, 4, 9, 10
Drive mechanism	Y_2	Manual	Machine (non auto)	Full auto (otomation)	1, 3, 4, 9, 10
Input (organic waste)-Output (compost) Mechanism	Y_3	Manual	Machine (non auto)	Full auto (otomation)	3, 4, 5, 9, 10
Probiotic transfer mechanism	Y_4	Manual	Machine (non auto)	Full auto (otomation)	1, 3, 4, 5, 6, 9, 10
Control and monitoring system mechanism	Y_5	Manual	Sensor (monitoring)	Sensor (monitoring + control)	1, 3, 7, 9, 10
Biogas transfer control mechanism	Y_6	Manual (valve system)	Full auto (otomation)	-	2, 3, 9, 10
Frame system mechanism	Y_7	Vertical system	Horizontal system		3, 8, 9, 10



(a)



(b) (c) (d)

Figure 2. Physical design of the home scale biodigester-composter machine
(a) Overall view, (b) Left side view, (c) Right side view, (d) Top view

Using the results of the optimal critical system mechanism (see Table 2) and physical design realization (see Figure 2), the next stage is determining the optimal design for the assembly process. The VDI 2222 method is applied to determine the results of the optimal constituent components of the home-scale biodigester-composter machine shown in Table 3. In contrast, the constituent components are the outcome from an optimal breakdown of previously known system critical mechanisms. The function of the VDI 2222 method helps select optimal variations of constituent components based on predetermined specification targets. First, the constituent components are organized into the selected working mechanisms that make up each critical system of biodigester-composter machine design in Table 2, enhancing the results of the Reverse Engineering process and strengthening them with analysis from several biodigester and composter equipment manufacturing experts and several design and mechanical property experts. Second, component and material properties studies should be conducted through field observations related to commonly available machine work processes. The evaluation results of several previous experts should be deepened as alternative component variations that can be applied as constituent components. Third, component variations are determined by ensuring the constituent component of the critical system mechanism meets the desired target specifications (see Table 1) and applying the VDI 2222 method. Meanwhile, in this stage, a detailed House of Quality (HOQ) was carried out regarding the availability of components in the market to form the critical system. Then, several experts assessed each component that makes up the system while still considering target specifications as a general control parameter and investment costs (IDR) as a specific parameter.

Table 3. Determining constituent components of the biodigester-composter machine

System Mechanism	Constituent Component	Node	Component Variations			Cost (IDR)
			1	2	3	
Y_{13}	Stirrer	A_1	Paddle	Ribbon	Hybrid (paddle + ribbon)	315,000
	Bearing	A_2	Round shaft bearing	Pillow block bearing	Flange bearing	56,000
	Drum	A_3	Iron stel drum	Stainless steel drum	HDPE plastic drum	200,000
Y_{22}	Machine	B_1	Dynamo motor	Electro motor	Servo motor	450.000
	Drive	B_2	Full gear drive (gear box)	Chain gear	Belt pully	230,000
Y_{31}	Input-output gate	C_1	Single gate with hinge	Double gate with hinge		40,000
	Leakstripping	C_2	Foam strip	Rubber strip	Hybrid strip (rubber + foam)	15,000
	Locking	C_3	Reguler latch	Hook latch	Overpal	30,000
Y_{42}	Machine	D_1	Electric DC pump	Electric submersible pump	Diesel pump	100,000
	Container	D_2	Container box	Jerry cans	Water gallon	25,000
	Piping set	D_3	PVC pipe	PU hose	Nylon hose	57,000
	Sprayer nozzle	D_4	Cone nozzle	Polijet nozzle	Flat fan nozzle	75,000
Y_{52}	Gas pressure gauge monitor	E_1	EN 837-1 (6 bar) pressure gauge	EN 837-1 (10 bar) pressure gauge	EN 837-1 (16 bar) pressure gauge	80,000
	Electrical panel	E_2	Thermoplastic panel	Plate panel	Fibreglass panel	115,000
	Button	E_3	Push button	Selector switch		81,000
	Wiring set (cable, spiral hose, stecker)	E4	NYA	NYAF	AWG	82,000
Y_{61}	Piping and fitting set	F_1	PVC standard gas piping	Standard pneumatic hose and fitting	SAE 30 standard gas flex. hose with brass fitting	57,000
	Stop valve	F_2	PVC ball valve	Brass ball valve	Solenoid valve	30,000
	Safety valve	F_3	PRV	PSV		85,000
Y_{72}	Frame material	G_1	Coated steel hollow	Galvanized hollow	Stainless stel hollow	250,000
	Support	G_2	Fix system	Support leg	Wheel system	20,000

The results of determining the design concept of constituent components for the home scale biodigester-composter machine in Table 3 can be arranged into the following mathematical model.

$$Y_{13} = A_{11} + A_{22} + A_{33} \quad (2)$$

$$Y_{22} = B_{11} + B_{23} \quad (3)$$

$$Y_{31} = C_{11} + C_{22} + C_{33} \quad (4)$$

$$Y_{42} = D_{11} + D_{22} + D_{32} + D_{43} \quad (5)$$
$$Y_{52} = E_{12} + E_{21} + E_{32} + E_{42} \quad (6)$$
$$Y_{61} = F_{11} + F_{22} + F_{32} \quad (7)$$
$$Y_{72} = G_{11} + G_{22} \quad (8)$$

Referring to the results in Table 3, further analysis regarding the calculation of Total Cost (TC) in IDR for each system can be seen in the following results.

$$TC\ Y_{13} = 315{,}000 + 56{,}000 + 200{,}000 = IDR\ 571{,}000 \quad (9)$$
$$TC\ Y_{22} = 450{,}000 + 230{,}000 = IDR680{,}000 \quad (10)$$
$$TC\ Y_{31} = 40{,}000 + 15{,}000 + 30{,}000 = IDR\ 85{,}000 \quad (11)$$
$$TC\ Y_{42} = 100{,}000 + 25{,}000 + 57{,}000 + 75{,}000 = IDR\ 257{,}000 \quad (12)$$
$$TC\ Y_{52} = 80{,}000 + 115{,}000 + 81{,}000 + 82{,}000 = IDR\ 358{,}000 \quad (13)$$
$$TC\ Y_{61} = 57{,}000 + 30{,}000 + 85{,}000 = IDR\ 172{,}000 \quad (14)$$
$$TC\ Y_{72} = 250{,}000 + 20{,}000 = IDR\ 270{,}000 \quad (15)$$
$$TC\ Y = TC\ Y_{13} + TC\ Y_{22} + TC\ Y_{31} + TC\ Y_{42} + TC\ Y_{52} + TC\ Y_{61} + TC\ Y_{72} \quad (16)$$
$$= 571{,}000 + 680{,}000 + 85{,}000 + 257{,}000 + 358{,}000 + 172{,}000 + 270{,}000 = IDR\ 2{,}393{,}000$$

The calculation shows the results of the optimal cost in realizing the concept design of a home-scale biodigester-composter machine is IDR 2,393,000. Next, a detailed assembly design is conducted to select the optimal constituent components of the home-scale biodigester-composter machine. The assembly design results are shown in Figure 3.

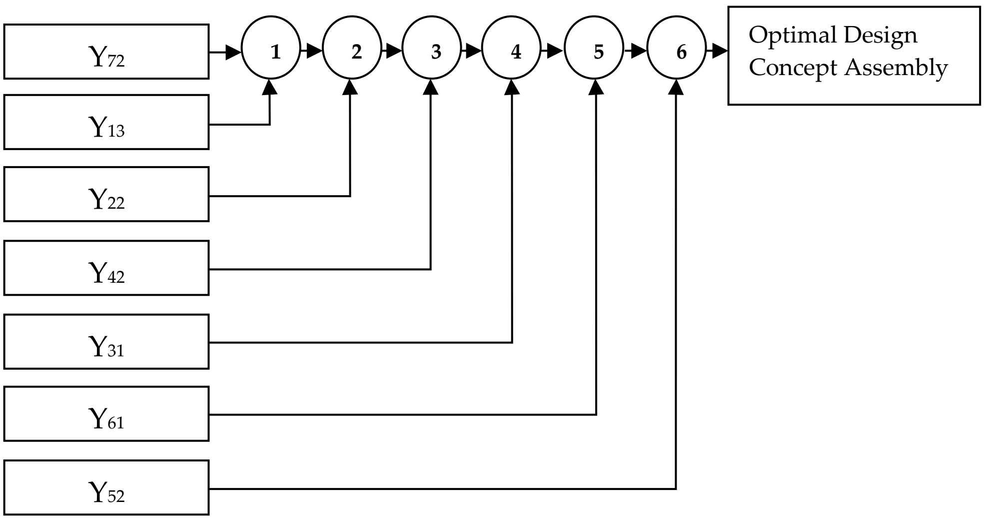


Figure 3. Assembly chart design of the home scale biodigester-composter machine

Finite Element Analysis (FEA)

Next, the FEA method is applied to test the optimal design results of the home-scale biodigester-composter machine determined through design simulation. It aims to measure the machine's technical feasibility. The FEA method can measure the design's performance without having to be physically implemented, reducing physical testing costs. The initial stage of implementing the FEA method is the meshing process related to the optimal design of the biodigester-composter equipment technology achieved from the previous VDI 2222 method, shown in the properties setting for frame test Table 4.

Based on the settings in Table 4, the meshing process quality for optimal design analysis of the biodigester-composter machine frame obtained 65,513 nodes with 32,923 elements. The number of nodes and elements is generated from the type of triangle mesh due to the maximum turn of the 60-degree angle setting, as shown in Figure 4. This research uses many test parameters in FEA analysis, including Von Mises Stress, principal stress, displacement, safety factor, equivalent strain, and principal strain. The testing process is carried out on the frame, which is a vital component of the machine because it withstands the tension of the load. The FEA analysis technique uses Autodesk simulation software. The results of the FEA simulation for Von Mises Stress analysis are shown in Figure 5.

Table 4. Frame properties setting

Section	Properties		Value
A	Mesh setting		
	Avg. element size (fraction of model diameter)		0.1
	Min. element size (fraction of avg. size)		0.2
	Grading factor		1.5
	Max. turn angle		60 deg
B	Material properties		
	Material		Steel ASTM A36
	General	Mass density	7.85 g/cm^3
		Yield strength	248.225 MPa
		Ultimate tensile strength	399.9 MPa
	Stress	Young's modulus	199.959 GPa
		Poisson's ratio	0.3 ul
		Shear modulus	76.9073 GPa
C	Operating conditions		
	Load type		Force 1
	Magnitude		674.427 lbforce
	Vector X		0.000 lbforce
	Vector Y		-674.427 lbforce
	Vector Z		0.000 lbforce
	Load type		Force 2
	Magnitude		200.000 N
	Vector X		0.000 N
	Vector Y		-200.000 N
	Vector Z		0.000 N

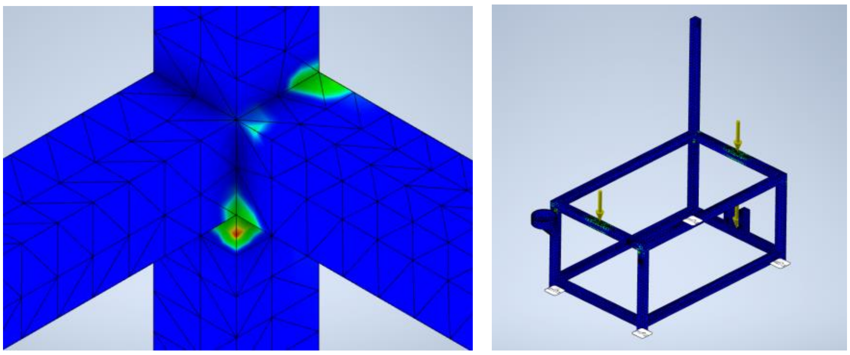


Figure 4. Frame meshing process quality

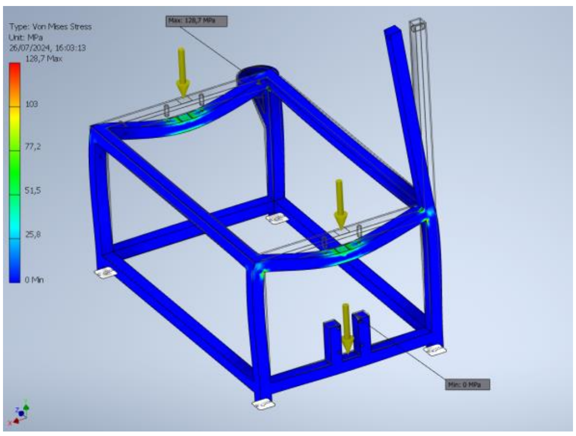


Figure 5. von Mises stress analysis of frame machine design

The von Mises Stress analysis in the FEA methods evaluates an object's normal stress (tensile and compressive) and shear stress when treated. This analysis can test the object's resistance to peak stress before deformation occurs. Figure 5 shows that the frame part is treated at the load-bearing fulcrum point (the part of the drum component that will later have a load). It can be seen from the results that the frame can withstand a maximum stress of 128.749 Mpa. All the components of the frame can withstand it well, as can be seen from the majority of blue color pattern on all parts of the frame with a little green at the fulcrum point (the bluer, the better and vice versa). Then, the analysis continues with equivalent strain analysis on the frame section shown in Figure 6 equivalent strain results.

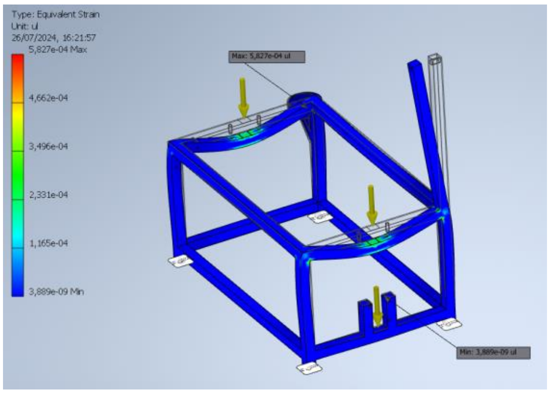


Fig 6. Equivalent Strain Test Analysis of Machine Frame Design

The simulation results in Figure 6 show that the frame is treated with a maximum strain of 0.000582699 ul. These results are decent because the blue color is all over the frame (see the color pattern), then the green color appears to be at the load fulcrum point (drum component). Then, a summary of the test simulation results using the FEA method is presented in Table 5.

Table 5. Summary of FEA simulation test results

Name	Minimum	Maximum
von Mises stress	0.000692564 MPa	128.749 MPa
1st Principal stress	-32.7244 MPa	123.24 MPa
3rd Principal stress	-149.177 MPa	17.8911 MPa
Displacement	0 mm	0.465518 mm
Safety factor	1.92797 ul	15 ul
Stress XX	-122.296 MPa	121.055 MPa
Stress XY	-55.002 MPa	43.3294 MPa
Stress XZ	-33.2878 MPa	30.5414 MPa
Stress YY	-128.688 MPa	52.3705 MPa
Stress YZ	-21.0378 MPa	20.0028 MPa
Stress ZZ	-59.7261 MPa	73.1333 MPa
X displacement	-0.0470144 mm	0.465047 mm
Y displacement	-0.346398 mm	0.00991599 mm
Z displacement	-0.0161149 mm	0.0181458 mm
Equivalent strain	0.00000000388886 ul	0.000582699 ul
1st Principal strain	-0.00000461958 ul	0.000618313 ul
3rd Principal strain	-0.000673599 ul	0.00000607616 ul
Strain XX	-0.00060904 ul	0.000602019 ul
Strain XY	-0.000357587 ul	0.000281699 ul
Strain XZ	-0.000216415 ul	0.00019856 ul
Strain YY	-0.000592287 ul	0.000220712 ul
Strain YZ	-0.000136774 ul	0.000130045 ul
Strain ZZ	-0.000182426 ul	0.00036746 ul

The simulation results from Figure 7 reveal that the safety factor level is categorized as good, with values in units (ul) ranging from 1.92797 ul (minimum) to 15 ul (maximum), none of which has a value of 0 or even minus. On the other hand, it can be seen from the blue color pattern that the majority is formed from the frame condition when tension is applied, and only a few are green at the load fulcrum point. Therefore, the machine frame's design is feasible regarding safety factors in its ability to withstand stress from a maximum load of 128.749 Mpa. It can be assumed safe for future use if the machine is realized as a prototype.

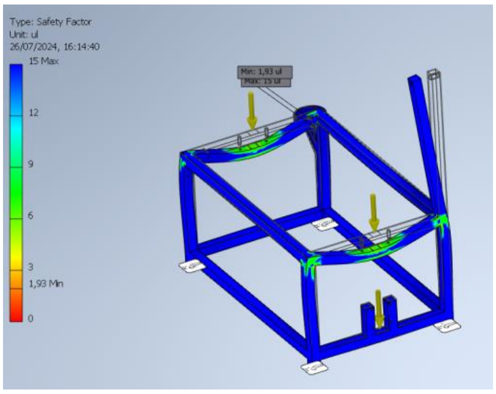


Figure 7. Safety factor test analysis of machine frame design

The safety factor (Sf) assessment is based on the frame design of the home-scale biodigester-composter machine. The implementation of ASTM A36 steel material and the yield strength value required by Joseph P. Vidosic are stated to have met the safety standards as shown in Table 6. The resulting safety factor value can be classified as adequate safe when compared to the material properties employed in the simulation.

Table 6. Safety factor analysis

Safety factor (Sf) value (ul)	Results	Analysis
1.25 – 1.5		Controlled conditions and working voltages can be known with certainty
1.5 – 2	Minimum (1.92797 ul)	For widely known materials under relatively constant operating conditions and easily determined loads
2 – 2.5		For general materials that are operated under normal conditions and are subjected to specified loads
2.5 – 3		For materials that are less tested or brittle under normal operating conditions and loads
3 – 4		For materials that have not been tested under normal operating conditions and loads
> 4	Maximum (15 ul)	For materials that have been tested under uncertain operating conditions and loads

Prototyping

Prototyping is the final stage in the research. The physical manifestation of the design is realized in a prototype according to the optimal design that has been produced. Figure 8 shows the physical prototype of the home-scale biodigester-composter machine.

(a) (b) (c) (d)

Figure 8. Prototype of the home scale biodigester-composter machine
(a) Overal View, (b) Top View, (c) Belt-Pulley with Electro Motor, (d) Paddle Stirrer

This research indicates that the target specifications can be efficiently achieved by developing an optimal design concept for a home-scale biodigester-composter machine. The use of two methods, the VDI 2222 method for the design concept development stage until prototyping and the FEA method for assessing the technical results design based on simulation analysis, makes this research successful.

Conclusion

Based on the research that has been carried out, it is concluded that the development of a home-scale biodigester-composter machine design concept based on the DFMA method can properly implement and integrate the VDI 2222 method to optimize the design concept and FEA method in testing and analyzing the optimal results of the design concept to measure feasibility from a technical aspect. The results of the VDI 2222 method obtained an optimal design concept through the structure of the working mechanism and all its constituent components, which was able to meet ten target specifications with a machine manufacturing cost of IDR 2,393,000 as well as an assembly chart design for each constituent component. Furthermore, using the optimal design concept through the FEA method, the resistance value of the frame system to maximum Von Mises Stress was obtained results 128.75 MPa with a minimum value of 6.93e-04 MPa, which was concluded to be quite good at withstanding normal and shear stresses effectively with a relatively small displacement value of 0 to 0.47 mm. The equivalent strain value minimum results are 3.89e-09 ul to 5.83e-04 ul maximum with safety factor value results ranging from 1.93 up to 15 ul, which can be concluded that the frame system design concept is safe.

As consideration for future research, the prototype resulting from the optimal design of this home-scale biodigester-composter machine can be further developed for (1) optimal machine settings (stirring speed, length of stirring time, interval between stirring times, type of probiotic used, volume probiotics sprayed per cycle, the volume of water mixed with probiotics and the volume of organic waste processed per cycle and several other possible factors) in processing kitchen and household organic waste to produce optimal (fast and high quality) biogas and compost fertilizer, (2) Carry out design development by integrating elements of digital technology (by installing digital sensors and controls) as well as Internet of Things (IoT) technology so that it can be integrated with networks and remote control, (3) Carry out machine learning technology development so that the machine can carry out processes work automatically and optimally. So, through this development, the design of a home-scale biodigester-composter machine can be more optimal by the target specifications and can become a modern industrial product in the field of household waste processing on a large scale, which provides added economic and environmental value.

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