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Design and manufacturing optimization of herbal drink crystallization machine using reverse engineering method

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ABSTRACT

This article explains the design and manufacture of a herbal drink powder crystallization machine at Menik Jaya MSMEs. The problem with this research stems from the large number of defective products produced in the form of herbal powder that is burnt and lumpy. This is because production staff still manually stir the process continuously without stopping, causing fatigue due to work and impacting the quality of the process. So that the optimal design and manufacture of the crystallization machine is obtained where the dimensions of the machine are 130 cm high, 100 cm long and wide, machine legs height is 62 cm, stove height is 87 cm from the base and the stove pan handle width is 12 cm. Regarding engine performance, the ideal electric capacity of the motor is 60 watts with a stirrer and pan made from a combination of wood and AISI 3195 stainless steel. The pully uses 2 types of sizes, if the volume of raw material is small then a 4 cm pully is used with 10 Rpm rotation speed and 0,052 Nm torque value, while for large volumes a 6 cm pully is used with 15 Rpm rotation speed and 0,038 Nm torque value.

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1. INTRODUCTION

Herbal medicine is a part of Indonesian culture. Considering Indonesia's rich with natural resources and research results, it is known that more than 50% of Indonesia's population regularly consumes herbal medicine. Herbal medicines offer a number of advantages, including reduced toxicity and minor negative effects. One of the recommendations for living a healthy life on a limited budget is herbal drinks [1]. One of his local MSMEs that manufactures herbal products is Menik Jaya MSMEs was established in 1998 to manufacture three types of traditional drinks: wedang uwuh, ginger alang-alang syrup, and traditional instant drinks. These MSMEs conduct their business activities from their homes and are based in Banyumanik Barat, Kota Semarang, Central Java. Traditional drinks that made daily production at around 800 to 1,000 pieces per day, while ginger alang-alang syrup and traditional instant drinks are only made when there is a consumer demand. Wedang uwuh is made with spices and powdered herbal medicines such as secang wood, cinnamon, cloves, pandan leaves, lime leaves, rock sugar, lemon grass and cardamom.

Research related to the product and crystallization process itself has been carried out on a domestic and international research scale. The implementation of research on the application of crystallization technology in the instant processing of herbal powder-based foods has been initiated with the aim of implementation in

Keren Bankirai village [2]. Research continued with the application of crystallization machines to produce instant herbal medicine powder containing items for MSMEs in East Ungaran District [3]. During the Covid-19 pandemic, research related to hedonic tests and formulation of powdered herbal drinks to maintain family immunity was conducted [4]. In the same year, we also conducted crystallizer design research to study the design, manufacturing, and performance testing of red ginger powder processing machines [5]. Then, targeting MSME Melati Losari, the use of instant herbal drink powder crystallizer was also implemented to maintain the taste quality and sterilize the drink ingredients [6]. A study on the design of a ginger crystallized product manufacturing machine with a semi-automatic mechanism was carried out with a process capacity of 5 kg [7]. A study on the technical analysis of the power and performance of the agitator of a ginger crystallizer was also carried out at a throughput of 5 kg/h [8].

Research related to crystallization that has been carried out on an international scale includes research related to the crystallization of yerba mate extract using sucrose and analysis of the microstructure of the mineral [9]. Then research related to the crystallization of dried mango fruit using sugar and understanding the effects of the resulting water activity [10]. Furthermore, research related to the crystallization of yerba mate was carried out again by understanding the level of stability of the anti-oxidants contained when stored [11]. Crystallization research on fruit was also carried out using pomegranates and tested chemically [12]. Research related to the crystallization process combined with gelatinization and its application was also carried out for wax-based gels in the food industry [13]. The crystallization process using sucrose media was carried out again for the Basella rubra extract and then an analytical study was carried out [14]. The use of sugar catalysts for crystallization was further investigated regarding the fat content in nougat cream production [15]. The use of this sugar was also investigated in the crystallization of Chilean raisin products [16]. Sucrose catalysis media was studied in its application for the crystallization process of propolis extract as a food ingredient [17]. Erythromycin extract has also been researched regarding its crystallization process using a sugar catalyst [18].

Further research regarding the crystallization process using a sugar catalyst has now been carried out on cocoa butter [19]. The use of sugar and organic acids as catalysts is now also being developed in the jujube slice crystallization process [20]. The use of sucrose sugar was also developed in the crystallization process of bioactive food capsules [21]. The food capsule crystallization process was also developed using securigera securidaca extract [22]. The use of lactose sugar in the crystallization process was also developed using panela cheese whey [23]. The process of analyzing the behavior of food product crystallization results was also carried out regarding their performance and grouping [24]. Crystallization has now also been carried out for fermented extracts of fresh coconut water related to uropathogenic, antioxidant and struvite [25]. Re-research regarding pomegranate peel was carried out to encapsulate it using a crystallization process [26]. The crystallization process can now also be carried out on types of peanuts and studied physically, texture and characteristics of the crystallization results [27].

In This research, Menik Jaya MSMEs carry out labor-intensive production activities by employing local people as labor and using conventional production tools in the production process. The high production rate, especially for the herbal product wedang uwuh, certainly means a heavy burden on the workers. From **Table 1**, we can see that the largest percentage of the workload is the stirring process, i.e. 35%. This is because the stirring process takes the longest processing time and still requires manual labor, which will affect the performance of the herbal powder and cause it to burnt and lumpy.

Research related to the application of reverse engineering methods has begun to be carried out to design cutting equipment on machines [28]. This method is also used in designing improvements to shaft components in machines [29]. Furthermore, this method is starting to be used in the design of composite materials [30]. Regarding performance measurement, this method can be used to measure milling machine processes [31]. In designing further components, the reverse engineering method can be used to create a spiral bevel type gear drive [32]. In addition, this method is stated to be able to measure consumer perceptions regarding cycling culture [33]. At the complex system level, the reverse engineering method can be applied to the design innovation process in the aviation industry [34]. This method can also be used in designing pedagogical processes for education in robotics in schools [35]. Regarding deeper research, this method can be applied to designing DNA origami at the nanostructure level [36]. The reverse engineering method can be integrated with multi-criteria decision-making methods in the classic car remanufacturing process [37]. Regarding medical research, this method can also be applied in prosthesis design [38]. Apart from that, in by-product implementation, this method can be used to design the structure of the dendrite layers [39]. Regarding re-

interrogation with the multi-criteria decision-making method, this method can be applied in testing consumer preferences regarding passenger vehicles [40].

Table 1. Herbal powder drink production process flow data

No	Process Activity	Number Worker	Cycle Time (Min)	Percentage (%)
1	Raw material cleaning	1	20	4%
2	Raw material shredding	1	15	3%
3	Raw material squeezing	1	30	6%
4	Stirring/crystallization process	1	180	35%
5	Sieving	1	20	4%
6	Powdering	1	10	2%
7	Instant herbal medicine packaging	1	20	4%
8	Material cutting for wedang uwuh	3	80	16%
9	Drying	1	50	10%
10	Wedang uwuh packaging	1	90	17%
	Total		**515**	**100%**

Through a literature review related to the reverse engineering method, it turns out that this method is able to perfect a previously existing system to become more optimal according to needs. Based on these reasons, the aim of the research carried out is to design and manufacture a powder crystallization machine with an automatic stirring component in it using the reverse engineering method, which is expected to be able to reduce the burnt and lumpy conditions that occur as a result of the process. Technically, the reverse engineering method will be applied to improve machines that already exist on the market, which apparently through observations are known to have several shortcomings, related to the price being quite expensive, vibrating when used, difficult to disassemble for cleaning, poor ergonomic design and safety, and so on. So, through this method it is hoped that we will be able to optimize the design and performance of the machine according to the wishes and needs of the user, in this case Menik Jaya MSMEs.

2. MATERIALS AND METHODS

This study identifies issues regarding the need for a crystallization machine, creates a design according to consumer needs, and applies reverse engineering method. The final stage of this research will develop a crystallization machine that can meet consumer needs and reduce the degree of burnt and lumpy.

2.1. Data Collection

a. **Observation**. We observed the flow of the production process in order to understand the work machine (machine and machinery) involved in the production process. The manufacturing process at Menik Jaya MSMEs was directly observed on site to identify and determine the problems faced by the workers.

b. **Interview**. Researcher interview sources are employee at the MSMEs center for herbal powder crystallization in Banyumanik, Semarang to obtain information about the research subject necessary to achieve the research objectives.

c. **Literature study**. Literature study is a data collection method that involves reading books, literature, or reports on a topic. This study reviews the literature on design using reverse engineering method.

2.2. Research Flowchart

This research flowchart is shown in Figure 1.

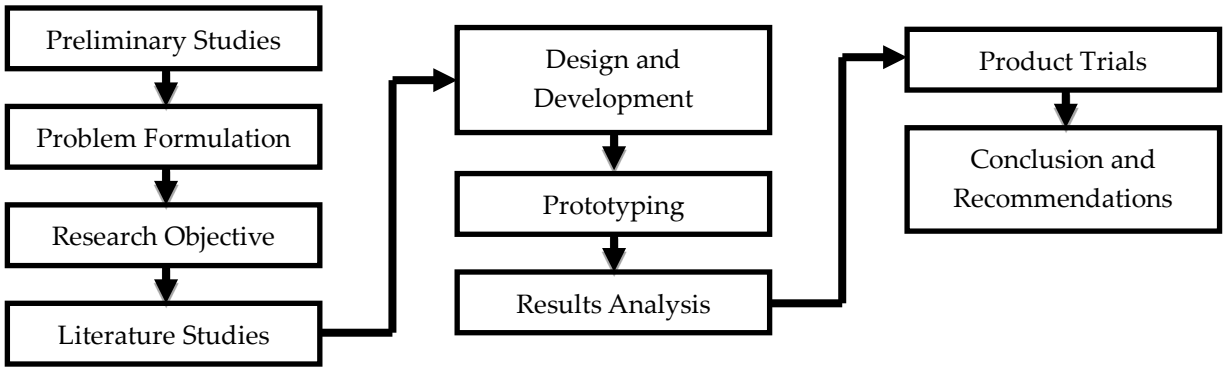


Figure 1. Research flowchart

a. Preliminary Studies. This is the initial stage where research carries out field studies to identify needs.
b. Problem Formulation. The second stage is where the research problem is formulated based on the background. The problem of this research is that the herbal powder drink product produced has product defects in the form of burnt and lumpy, because the cooking stirring process is still manual using human power which is limited in terms of stamina because the stirring process is non-stop and when it reaches the fatigue point, the quality of the process will decrease and results in product defects.
c. Research Objective. The third stage of this research is determining the research objectives. The aim of this research is to design and manufacturing a crystallization machine for herbal powder drink products with an automatic stirring system using the reverse engineering method.
d. Literature Studies. The fourth stage is developing studies with scientific literacy. This research uses a literacy study of scientific articles related to powder crystallization techniques, crystallization machines, and reverse engineering methods.
e. Design and Development. The fifth stage is to carry out the design and development process of a crystallization machine for herbal powder drink using the reverse engineering method based on the consumer needs that have been obtained. Apart from that, design optimization of the machine design was also carried out.
f. Prototyping. The sixth stage is to create a physical prototype of the crystallization machine based on technical measurements that are known from the results of design and development.
g. Product Trials. The seventh stage is to test the crystallization machine prototype to determine the machine's performance and validate the design optimization results.
h. Conclusion and Recommendations. This stage is the final stage where suggestions and conclusions are drawn from the results of design and development, prototyping and testing of the crystallization machine, and future research opportunities are also explained.

3. RESULTS

At this stage, data processing regarding consumer needs is performed, product specifications are determined and a crystallization machine is created for reduce the amount of burnt and lumpy products.

3.1. List of Consumer Needs

The development goals for the powdered herbal medicine mixer were based on data on consumer needs obtained from interviews. Table 2 shows list of consumer needs.

3.2. Determine Specification Goals

Before implementing the goals, we must first create a technical response mapping to consumer needs. Table 3 below shows technical response from consumer needs and Table 4 shows purpose of developing herbal drink crystallization machine.

Table 2. List of consumer needs

No.	Consumer Needs
1	Durable material
2	Easy to maintenance
3	Safe to use for operators
4	Easy to clean
5	Not easy to rust
6	Easy to use
7	Low maintenance costs
8	Comfortable to use
9	There is no vibration in the furnance
10	The machine does not vibrate when in use
11	Economical
12	Ergonomic
13	Not noisy when used
14	Easy to pour the ingredients to be stirred
15	Effective to use
16	Safe for foodstuffs
17	Fast processing time

Table 3. Technical response

No.	Consumer Needs	Technical Response
1	Economical	Using commonly used components
2	Safe to use for operators	
3	Low maintenance costs	
4	Not easy to rust	Using stainless steel material
5	Durable material	
6	Safe for foodstuffs	
7	There is no vibration in the furnance	There is no vibration in the furnance
8	The machine does not vibrate when in use	
9	Not noisy when used	
10	Easy to use	The stirrer and other machine components are easy to replace
11	Easy to maintenance	
12	Easy to clean	
13	Ergonomic	Machine design based on anthropometry
14	Comfortable to use	
15	Easy to pour the ingredients to be stirred	Has a system for pouring ingredients into the machine
16	Effective to use	Using a transmission with a pulley system so that the rotation of the stirrer can rotate constantly
17	Fast processing time	

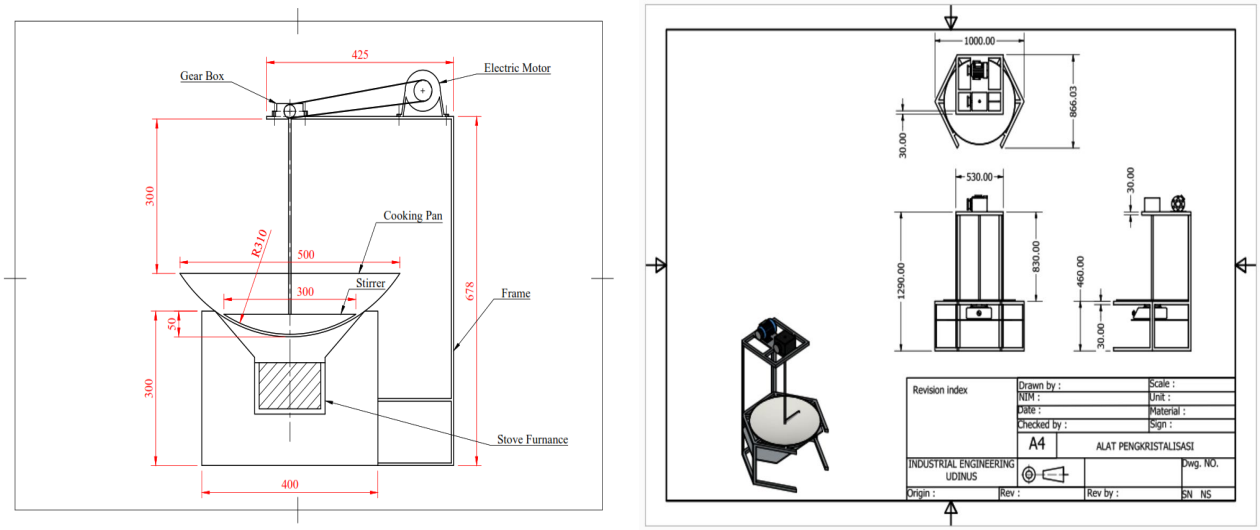
Table 4. Purpose of developing herbal drink crystallization process machine

Technical Response	Target Specifications
Using commonly used components	Pulley, electric motor, shaft, iron frame, v-belt and stirrer
Using stainless steel material	Stainless steel
There is no vibration in the furnance	Locks on two sides of the furnance
The stirrer and other machine components are easy to replace	Bolts and nuts for assembling components
Machine design based on anthropometry	Indonesian anthropometric data from https://www.antropometriindonesia.org.
Has a system for pouring ingredients into the furnance	The open frame on the furnance provides a rotating space for stirring
Using a transmission with a pulley system so that the rotation of the stirrer can rotate constantly	Transmission with pulley and v-belt

3.3. Reverse Engineering

a. Disassembly

At this stage, researchers dismantle products that are already on the market. Reference measurements from the crystallization machine used by researchers come from previous research that has been done and the proceeds from dismantling a crystallization machine belonging to some of the herbal MSMEs in Semarang which has been used for production, where the machine had problems that were explained in the previous introduction. The researcher focuses on the dimensions and size of the components, from the size of the frame, furnace, to the size of the stirrer from machines. Figure 2 below shows sketches in 2D crystallization machine which was redrawn by the researcher based on the results of disassembly and measurements of each constituent component (source: Model 1 from previous research that has been done [3] and Model 2 from non-brand crystallization machine owned by some MSMEs herbal powder producers in Semarang which was dismantled by researchers).The results of the disassembly of the above crystallization machine consist of a frame measuring 900 mm - 1000 mm of length, 400 mm = 800 mm of width, a fire furnace measuring 400 mm x 300 mm, a cooking pan with a diameter of 500 mm – 530 mm, a stirrer with a length of 300 mm and a radius of 310 mm, as well as an electric motor, van belt, and gearbox.



(a) (b)

Figure 2. (a) Sketch model 1 from previous research (b) Sketch model 2 of 2d non-brand crystallization machine owned by some herbal powder msmes in Semarang

b. Assembly

At this stage, researcher combine the components of the machine to be benchmarked, namely crystallization machines for herbal drinks already available on the market. Figure 3 below shows assembly chart crystallization machine.

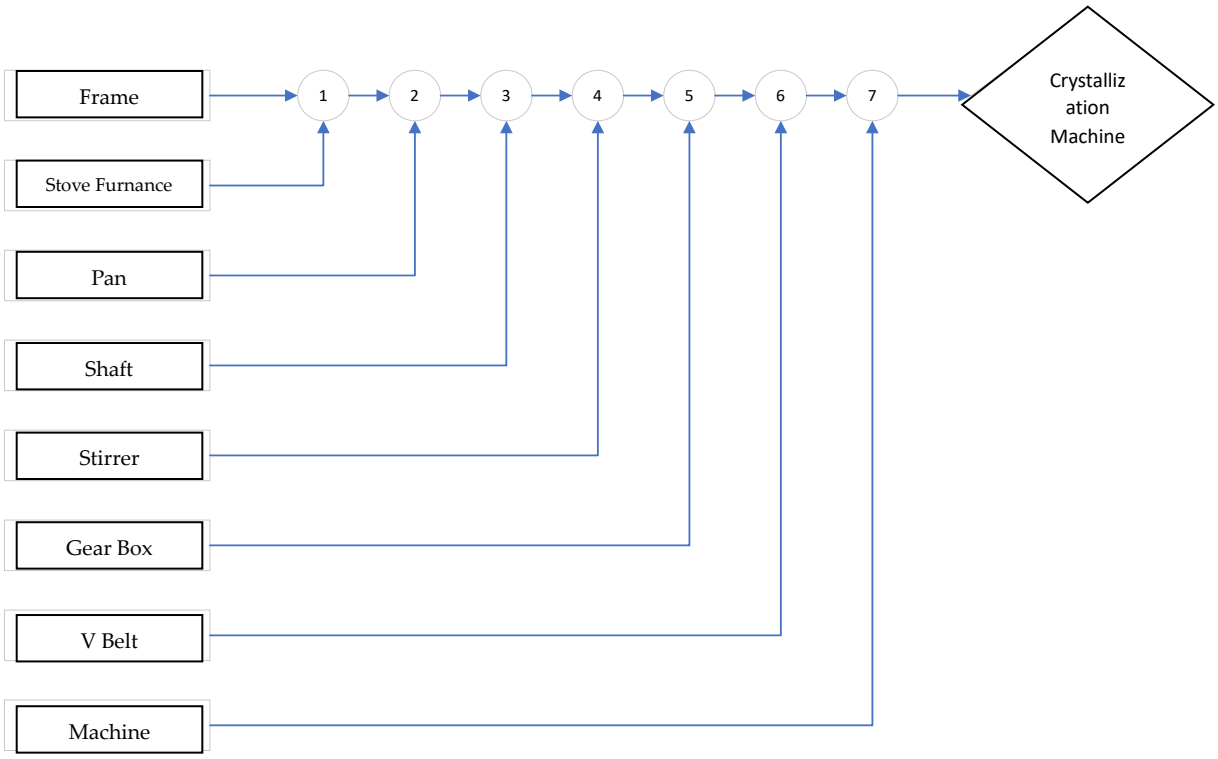


Figure 3. Assembly chart crystallization machine

c. Benchmarking

During this benchmarking stage, researcher directly observed commercially available powder herbal medicine crystallizers and compared the advantages and disadvantages of similar products. Figure 4 shows crystallization machine that existing on the market.

(a) (b)

Figure 4. Crystallization machine (a) Agrowindo (b) Tiga dara

d. Design of Herbal Drink Crystallization Machine

At this time, a machine was developed to crystallize herbal drinks. Product specifications are designed as stages below:

- **Product Structure**. This stage is the design detail stage using an assembly chart as in Figure 5.

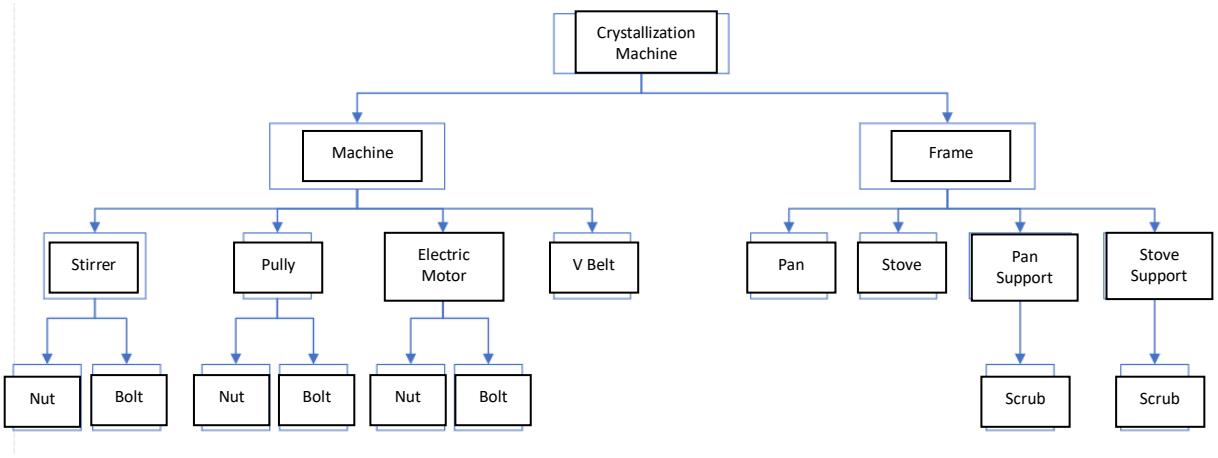


Figure 5. Assembly chart crystallization machine

- **Ergonomic Calculations**. In determining the target specifications for herbal powder crystallization machine, an ergonomic machine design is required. So in this stage an ergonomic analysis is carried out by applying anthropometric data of the human body as a reference for considering the dimensions of the machine. Table 5 shows the anthropometric data obtained.

Table 5. Anthropometric dimensions of each percentile in cm

Dimensions	Percentile			Standard Deviation
	5th	50th	95th	
Elbow height	89,36	97,09	104,82	4,7
Hand width	6,61	7,7	8,8	0,66
Knee height standing	42,41	47,71	53	3,22
Range length Hands forward	57,23	66,52	75,81	5,65
Standing shoulder height	121,04	128,51	135,99	4,54

One of the three existing percentiles is selected to be used as a design reference according to the desired design requirements based on this data. Table 6 shows the anthropometric dimensional analysis for the design of the powdered herbal drink crystallization machine.

- **Design Plan**. 3D models using reverse engineering methods with Inventor software, based on customer feedback. The researcher's design omits the gearbox as a drive transmission device and replaces it with a pulley because it is cost-effective. Figure 6 shows 2D design plan of herbal drink crystallization machine. Figure 7 below shows the 3D design of herbal drink crystallization machine.

e. Machine Calculation

Known: Power 60 Watts, Rotation 15 Rpm, Voltage 220 V.

Calculating rotation of the pulley with 4 cm drive diameter. n1=15 Rpm, d1=4 cm, d2=6 cm.

$$n2 = \frac{n1\ x\ d1}{d2} = \frac{15\ x\ 4}{6} = 10\ Rpm \quad (1)$$

Calculating rotation of the pulley with 6 cm drive diameter. n1=15 Rpm, d1=6 cm, d2=6 cm.

$$n2 = \frac{n1\ x\ d1}{d2} = \frac{15\ x\ 6}{6} = 15\ Rpm \quad (2)$$

Calculating torque with 4 cm pulley diameter. P=0,06 kW, N=10 Rpm.

$$T = \frac{0{,}06\ x\ 60}{2\ x\ 3{,}14\ x\ 10} = \frac{3{,}6}{68{,}2} = 0{,}052\ Nm \quad (3)$$

Calculating torque with 6 cm pulley diameter. P=0,06 kW, N=15 Rpm.

$$T = \frac{0{,}06\ x\ 60}{2\ x\ 3{,}14\ x\ 15} = \frac{3{,}6}{94{,}2} = 0{,}038\ Nm \quad (4)$$

Therefore, based on the mechanical design calculations, the electric motor used is 0,06 kW. Using a machine with a power output of 60 Watts, it is possible to stir herbal drink with a capacity of 10 to 15 kg, as demonstrated in a test scenario carried out by the researcher.

f. Product Manufacturing

At this stage, the herbal drink crystallization machine is made using the following stages.

- Stirring shaft manufacturing
  The specified distance between shaft and socket is 40 cm. Here, the diameter of the stirrer is 56 cm, and the stirring material is made of a stainless steel axle shaft and a wooden casing. Figure 7 shows brown wood covered with stainless steel. These two materials were chosen because stainless steel is rust-resistant and wood is safe from rubbing against the boiler. The thickness of the stainless steel axle is 20 mm. The stirrer is designed to evenly stir the entire surface of the pan and maintain circulation so that no part of the herb powder ingredients remain untouched. This overcomes the shortcomings of existing machines on the market and results in a design like Figure 8.
- Frame manufacturing
  Based on the 75 cm diameter of the frying pan, the width of the frame on which the frying pan will be placed will need to be 100 cm. The distance between the main shaft and the motor is pulley 1 type A1 6 inches, pulley 2 type A1 4 inches, and V belt type K-34. Therefore, the frame length is set to 100 cm. According to the crystallizer operator, the effective height of the frame is 130 cm.
- Based pan manufacturing
  The size of the pan used is 75 cm in diameter which corresponds to the size of the upper frame for supporting the pan.

Table 6. Ergonomic analysis of machine design

Dimensions	Function	Percentile	Purpose	Value (cm)	Design Size
Standing shoulder height	To determine the height of the tool	50th	To be comfortable for users with shoulder height	128,51 m	130 cm
Length of arm span forward	To find out the width of the tool	95th	To be comfortable for all users	75,81 cm	100 cm
Knee height standing	To find out where the fuel is from the new tool	95th	To be comfortable for knee height users when standing	53 cm	62 cm
Elbow Height	To determine the placement of the pan furnance	5th	To be easy for all users	89,36 cm	87 cm
Hand Width	To determine the width of the pan furnance handle	95th	To be comfortable for users with wide hands	8,8 cm	12 cm

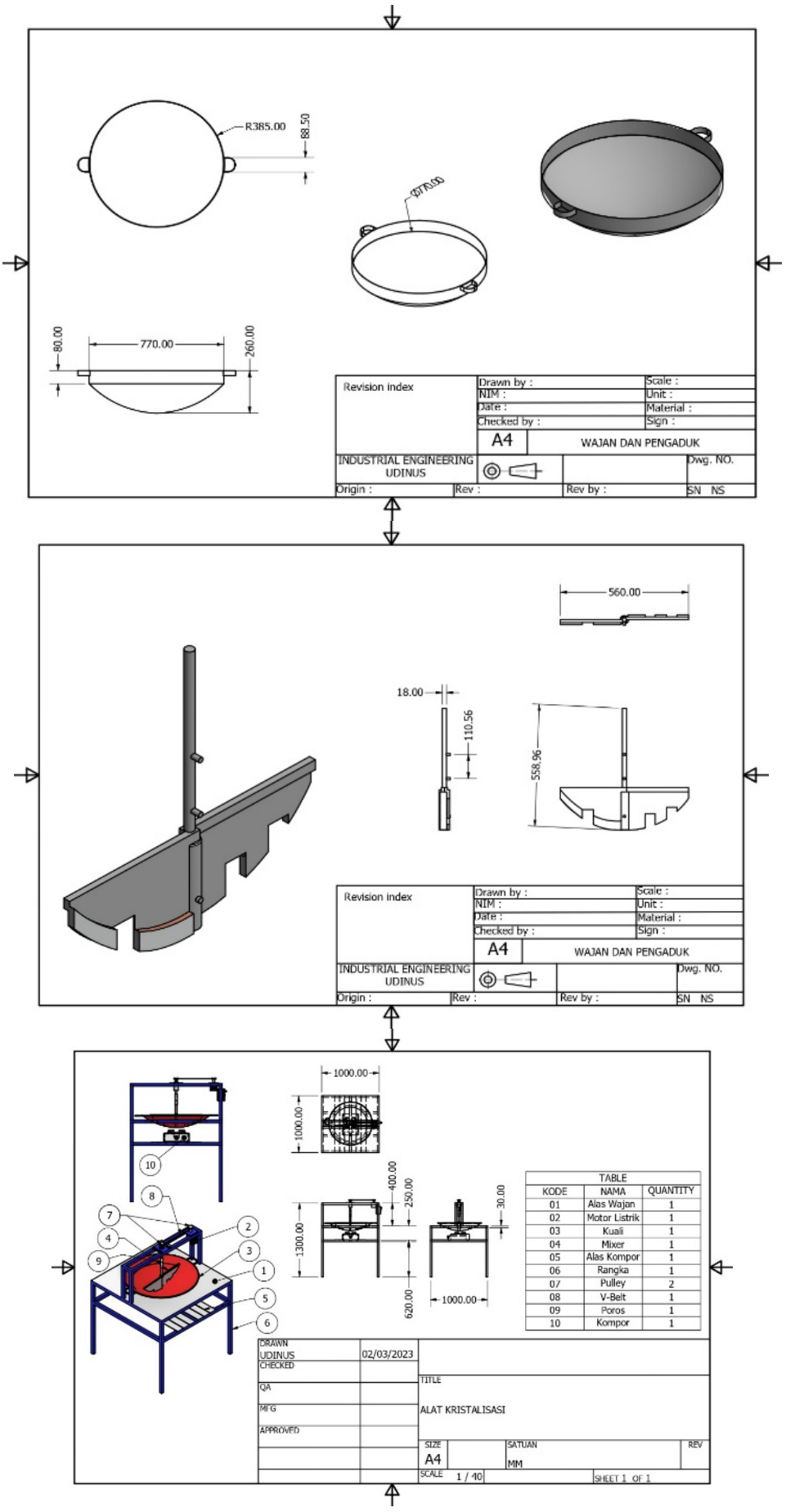


Figure 6. 2D Herbal drink crystallization machine design

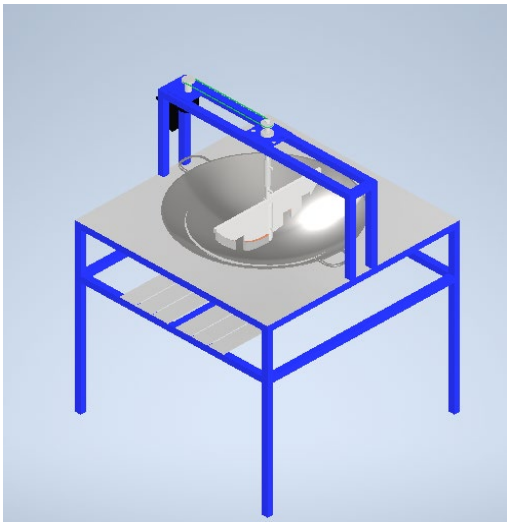


Figure 7. 3D Herbal drink crystallization machine design

- Stove base support manufacturing
  The width of the stove base or support on which the stove is installed is 25 cm from the base or support of the furnance. A 2 mm thick aluminum plate is installed on the furnace support according to ASTM 2017 standards.
- Main shaft manufacturing
  To determine the size of the main shaft, determine the height of main shaft pulley 2 and the height of the lower frame. Therefore, adjust these dimensions to determine the length of the shaft, which is 40 cm from the height of the frame to the diameter of the pan and uses AISI 3195 standardization.

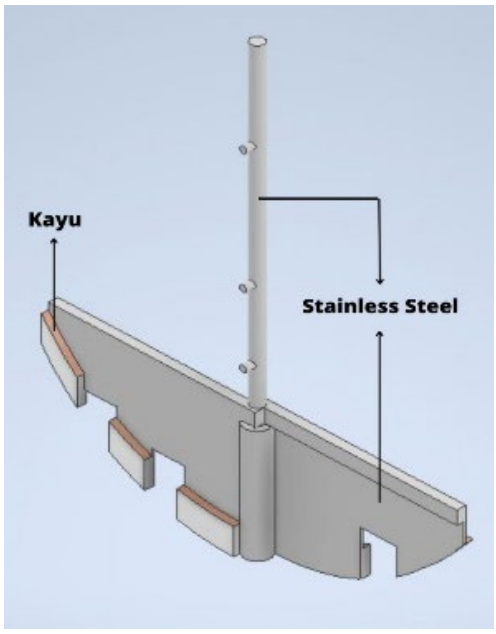


Figure 8. Stirrer shaft design

- Electric motor selection
  The crystallization machine uses an electric motor power of at least 10 Rpm, which already covers the required operating power for this crystallization machine, but the rotation of the electric motor created by the researcher is 60 Watts and the output is 15 Rpm.
- Pulley and v-belt selection
  The motor used in this crystallizer has a power output of 60 Watts and uses a K-34 type V-belt and 4 cm and 6 cm pulleys.

Figure 9. Herbal drink crystallization machine

Figure 9 shows picture final product of herbal drink crystallization machine. Table 7 below shows list of specification from herbal drink crystallization machine.

Table 7. Technical specification of crystallization machine

No	Items	Specifications
1	Capacity	15 Kg
2	Frame material	Hollow steel 30 x 30
3	Mixer material	Stainless steel AISI 3195
4	Shaft	Stainless steel AISI 3195
5	Alumunium plate	Thickness 2 mm ASTM 2017
6	Pan Furnance material	Stainless steel
7	Electric motor	60 Watt
8	Dimensions	100 cm x 100 cm x 130 cm
9	V-belt	Type K-34
10	Pully 1	Type A1 6 inch
11	Pully 2	Type A1 4 inch

g. Machine Trials

The test in purpose is to find out or check whether the herbal drink crystallization machine was successful or not. The mechanism of powder herbal medicine crystallization machine tested through multiple test scenarios is as follows:

- The researcher performed a test scenario of a crystallizer with a machine speed of 15 Rpm, with 0,2 cm distance between the stirrer and the pan or furnance and 5 liters capacity of liquid herbal drink. From 5 liters of liquid material, 3.237 grams of fine powder and 163 grams of powdered herbal drink were obtained. Figure 10 shows testing with 15 Rpm machine speed.
- The researcher tested the crystallization machine with a machine speed of 10 Rpm, with 0,2 cm distance between the stirrer and the pan or furnance and 2,5 liters volume of liquid herbal drink. From 2,5 liters of liquid material, the yield of herbal drink powder was 1.599 grams of fine powder and 101 grams of still lumpy powder. Figure 11 shows testing with 15 Rpm machine speed.

Figure 10. Process with 15 rpm machine speed

Figure 11. Process with 10 rpm machine speed

4. DISCUSSION

This research was able to identify 17 consumer need requirements for powdered herbal drink crystallization Machine, including durability, ease of maintenance, safe use and ease of cleaning. Based on consumer needs, target specifications for the machine are set, such as the use of common parts, the use of stainless steel and the presence or absence of furnance vibration. The design of the herbal drink crystallizer machine was created based on specifications derived from consumer needs, product data from the market and reverse engineering methods. The machine design includes components such as the pan, mixer, V-belt, frame, pulley, electric motor and stove furnance. Therefore, in this research, we used reverse engineering methods to successfully develop an automatic crystallization machine for produce herbal drink powder that meets consumer needs, such as durability, ease of maintenance, safe use and efficiency of the production process. Further research can be carried out to optimize machine settings with variable stirrer rotation speed and stove furnace heat level for each type of fruit to be crystallized, as well as other types of ingredients such as spices and herbs. Optimization variables can also be developed further with variable volumes of fruit, spice or herb raw materials, water and sugar as catalysts. Regarding optimization methods, you can use the Design of Experiment (DoE) approach or metaheuristic-based optimization methods. Regarding multi-parameters, you can use process time speed, production process costs and quality of crystallization results.

5. CONCLUSION

The conclusion obtained is that the reverse engineering method in the process of optimizing the design and manufacture of crystallization machines is able to refer to ergonomic aspects to obtain optimal machine dimensions and technical engineering aspects to obtain optimal machine performance. The optimal dimensions of the crystallization machine are 130 cm high, 100 cm long and wide, the machine legs are 62 cm high, the stove furnace height is 87 cm from the base and the pan furnace handle width is 12 cm. Regarding machine performance, the ideal motor electric capacity is 60 watts with the stirrer made from a combination of wood and AISI 3195 stainless steel to make it more food grade, the pan also uses stainless steel while the frame uses hollow steel to make it structurally stronger. Regarding the driving component, the pully uses 2 types of sizes, namely 6 cm and 4 cm, this is to accommodate the volume of raw materials used. If the volume is small, use a 4 cm pully with a rotation speed of 10 Rpm with a torque value of 0,052 Nm, while for large volumes use a 6 cm pully with a rotation speed of 15 Rpm and a torque value of 0,038 Nm.

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REFERENCES

[1] E. Pujiastuti, D. A. Palupi, S. Primadevi, D. Erliani, M. Sari, and L. Sugiarti, "Apoteker Kecil dan Budaya Minum Jamu," *Jurnal Pengabdian Kesehatan*, vol. 4, no. 1, pp. 71–77, 2021, doi: https://doi.org/10.31596/jpk.v4i1.108.

[2] E. Trinovit, Fatmaria, and F. D. Alexandra, "Penerapan Teknologi Kristalisasi dalam Pengolahan Produk Pangan Serbuk Herbal Instan di Kelurahan Kereng Bangkirai," *Jurnal Pengabdian Inovasi Lahan Basah Unggul*, vol. 1, no. 2, pp. 63–72, 2021, doi: https://doi.org/10.20527/ilung.v1i2.

[3] S. Purwantisari, S. N. Jannah, D. Handayani, M. E. Yulianto, and A. Ardiansari, "Produksi Serbuk Jamu Instan dengan Alat Kristalisasi di UMKM Kecamatan Ungaran Timur Kabupaten Semarang," *Jurnal E-DIMAS*, vol. 12, no. 3, pp. 527–532, 2021, doi: https://doi.org/10.26877/e-dimas.v12i3.7070.

[4] M. G. Miranti *et al.*, "Formulasi dan Uji Hedonik Minuman Herbal Serbuk Untuk Menjaga Imunitas Keluarga dalam Masa Pandemik Covid-19," *Jurnal KELUARGA*, vol. 7, no. 1, pp. 15–27, 2021, doi: https://doi.org/10.30738/keluarga.v7i1.8811.

[5] M. Yusuf, F. Yudhanto, and D. P. Purbajati, "Desain, Manufaktur dan Uji Kinerja Mesin Pengolah Serbuk Jahe Merah," *Quantum Teknika : Jurnal Teknik Mesin Terapan*, vol. 2, no. 2, pp. 87–92, Apr. 2021, doi: 10.18196/jqt.v2i2.11573.

[6] Pramono *et al.*, "Penerapan Mesin Kristalisasi Serbuk Minuman Herbal Instan untuk Menjaga Kualitas Cita Rasa & Sterilisasi Bahan Minuman UMKM Melati Losari," *Jurnal Karinov*, vol. 5, no. 2, pp. 80–84, 2022, doi: 10.17977/um045v5i1p80.

[7] F. A. P. Putra, Y. S. Pramesti, and M. M. Ilham, "Rancang Bangun Pemanas pada Mesin Produksi Jahe Kristal Semi Otomatis Kapasitas 5 Kg," in *Seminar Nasional Inovasi Teknologi*, 2022, pp. 113–119.

[8] Y. S. Pramesti, I. Setyowidodo, F. Rhohman, M. M. Ilham, and T. P. Arlana, "Analisis Gaya dan Daya pada Alat Pengaduk Mesin Kristalisasi Jahe dengan Kapasitas5 Kg/Jam," *Jurnal Mesin Nusantara*, vol. 6, no. 1, pp. 98–106, Jul. 2023, doi: 10.29407/jmn.v6i1.19929.

[9] L. Deladino, A. S. Navarro, and M. N. Martino, "Microstructure of minerals and yerba mate extract co-crystallized with sucrose," *J Food Eng*, vol. 96, no. 3, pp. 410–415, Feb. 2010, doi: 10.1016/j.jfoodeng.2009.08.015.

[10] N. Harnkarnsujarit and S. Charoenrein, "Effect of water activity on sugar crystallization and β-carotene stability of freeze-dried mango powder," *J Food Eng*, vol. 105, no. 4, pp. 592–598, Aug. 2011, doi: 10.1016/j.jfoodeng.2011.03.026.

[11] A. López-Córdoba, L. Deladino, L. Agudelo-Mesa, and M. Martino, "Yerba mate antioxidant powders obtained by co-crystallization: Stability during storage," *J Food Eng*, vol. 124, pp. 158–165, 2014, doi: 10.1016/j.jfoodeng.2013.10.010.

[12] G. Sun *et al.*, "'Two-dimensional' molecularly imprinted solid-phase extraction coupled with crystallization and high performance liquid chromatography for fast semi-preparative purification of tannins from pomegranate husk extract," *J Chromatogr A*, vol. 1505, pp. 35–42, Jul. 2017, doi: 10.1016/j.chroma.2017.05.033.

[13] C. D. Doan, I. Tavernier, P. K. Okuro, and K. Dewettinck, "Internal and external factors affecting the crystallization, gelation and applicability of wax-based oleogels in food industry," *Innovative Food Science and Emerging Technologies*, vol. 45. Elsevier Ltd, pp. 42–52, Feb. 01, 2018. doi: 10.1016/j.ifset.2017.09.023.

[14] A. V. Karangutkar and L. Ananthanarayan, "Co-crystallization of Basella rubra extract with sucrose: Characterization of co-crystals and evaluating the storage stability of betacyanin pigments," *J Food Eng*, vol. 271, Apr. 2020, doi: 10.1016/j.jfoodeng.2019.109776.

[15] S. S. Hubbes, A. Braun, and P. Foerst, "Sugar particles and their role in crystallization kinetics and structural properties in fats used for nougat creme production," *J Food Eng*, vol. 287, Dec. 2020, doi: 10.1016/j.jfoodeng.2020.110130.

[16] T. Truong, D. Dahal, P. Urrutia, L. Alvarez, S. Almonacid, and B. Bhandari, "Crystallisation and glass transition behaviour of Chilean raisins in relation to their sugar compositions," *Food Chem*, vol. 311, May 2020, doi: 10.1016/j.foodchem.2019.125929.

[17] Y. Irigoiti, D. K. Yamul, and A. S. Navarro, "Co-crystallized sucrose with propolis extract as a food ingredient: Powder characterization and antioxidant stability," *LWT*, vol. 143, May 2021, doi: 10.1016/j.lwt.2021.111164.

[18] N. Pawar, S. Moharkar, S. G. Agrawal, P. B. Dhamole, and R. N. Methekar, "Crystallization of erythromycin extracted using novel phase separation 'sugaring-out extraction': A combined modelling and experimental approach," *Chemical Engineering and Processing - Process Intensification*, vol. 169, Dec. 2021, doi: 10.1016/j.cep.2021.108616.

[19] S. Simoes, E. Lelaj, and D. Rousseau, "The presence of crystalline sugar limits the influence of emulsifiers on cocoa butter crystallization," *Food Chem*, vol. 346, Jun. 2021, doi: 10.1016/j.foodchem.2020.128848.

[20] H. Hou *et al.*, "Glass transition and crystallization of solid model system of jujube slice as influenced by sugars and organic acids," *Food Chem*, vol. 359, Oct. 2021, doi: 10.1016/j.foodchem.2021.129935.

[21] E. Chezanoglou and A. M. Goula, "Co-crystallization in sucrose: A promising method for encapsulation of food bioactive components," *Trends in Food Science and Technology*, vol. 114. Elsevier Ltd, pp. 262–274, Aug. 01, 2021. doi: 10.1016/j.tifs.2021.05.036.

[22] A. Behnamnik, M. Vazifedoost, Z. Didar, and B. Hajirostamloo, "Evaluation of physicochemical, structural, and antioxidant properties of microencapsulated seed extract from Securigera securidaca by co-crystallization method during storage time," *Biocatal Agric Biotechnol*, vol. 35, Aug. 2021, doi: 10.1016/j.bcab.2021.102090.

[23] V. E. Luján-Torres *et al.*, "Co-crystallization of lactose-flavonoids using Panela cheese whey," *J Food Eng*, vol. 357, Nov. 2023, doi: 10.1016/j.jfoodeng.2023.111598.

[24] S. Jia *et al.*, "Separation performance and agglomeration behavior analysis of solution crystallization in food engineering," *Food Chem*, vol. 419, Sep. 2023, doi: 10.1016/j.foodchem.2023.136051.

[25] D. Raj CT, V. Palaninathan, and R. A. James, "Anti-uropathogenic, antioxidant and struvite crystallization inhibitory potential of fresh and fermented coconut water," *Biocatal Agric Biotechnol*, vol. 47, Jan. 2023, doi: 10.1016/j.bcab.2022.102555.

[26] E. Chezanoglou, N. Kenanidou, C. Spyropoulos, D. Xenitopoulou, E. Zlati, and A. M. Goula, "Encapsulation of pomegranate peel extract in sucrose matrix by co-crystallization," *Sustain Chem Pharm*, vol. 31, Apr. 2023, doi: 10.1016/j.scp.2022.100949.

[27] W. Ke *et al.*, "Physical, textural and crystallization properties of ground nut oil-based diacylglycerols in W/O margarine system," *Food Chem*, vol. 433, Feb. 2024, doi: 10.1016/j.foodchem.2023.137374.

[28] A. P. Valerga, M. Batista, R. Bienvenido, S. R. Fernández-Vidal, C. Wendt, and M. Marcos, "Reverse Engineering Based Methodology for Modelling Cutting Tools," in *Procedia Engineering*, Elsevier Ltd, 2015, pp. 1144–1151. doi: 10.1016/j.proeng.2015.12.607.

[29] B. Engel and S. S. H. Al-Maeeni, "An integrated reverse engineering and failure analysis approach for recovery of mechanical shafts," in *Procedia CIRP*, Elsevier B.V., 2019, pp. 1083–1088. doi: 10.1016/j.procir.2019.03.257.

[30] K. Yanamandra, G. L. Chen, X. Xu, G. Mac, and N. Gupta, "Reverse engineering of additive manufactured composite part by toolpath reconstruction using imaging and machine learning," *Compos Sci Technol*, vol. 198, Sep. 2020, doi: 10.1016/j.compscitech.2020.108318.

[31] J. Che *et al.*, "A novel method for analyzing working performance of milling tools based on reverse engineering," *J Pet Sci Eng*, vol. 197, Feb. 2021, doi: 10.1016/j.petrol.2020.107987.

[32] I. Gonzalez-Perez and A. Fuentes-Aznar, "Reverse engineering of spiral bevel gear drives reconstructed from point clouds," *Mech Mach Theory*, vol. 170, Apr. 2022, doi: 10.1016/j.mechmachtheory.2021.104694.

[33] H. de Freitas Miranda, A. N. Rodrigues da Silva, and K. Geurs, "Reverse engineering cycling culture using stakeholders' perceptions of well-established examples – Insights from Enschede and Münster," *Case Stud Transp Policy*, vol. 14, Dec. 2023, doi: 10.1016/j.cstp.2023.101107.

[34] M. Rozesara, S. Ghazinoori, M. Manteghi, and S. H. Tabatabaeian, "A reverse engineering-based model for innovation process in complex product systems: Multiple case studies in the aviation industry," *Journal of Engineering and Technology Management - JET-M*, vol. 69, Jul. 2023, doi: 10.1016/j.jengtecman.2023.101765.

[35] X. Liu, J. Gu, and L. Zhao, "Promoting primary school students' creativity via reverse engineering pedagogy in robotics education," *Think Skills Creat*, vol. 49, Sep. 2023, doi: 10.1016/j.tsc.2023.101339.

[36] B. Shirt-Ediss *et al.*, "Reverse engineering DNA origami nanostructure designs from raw scaffold and staple sequence lists," *Comput Struct Biotechnol J*, vol. 21, pp. 3615–3626, Jan. 2023, doi: 10.1016/j.csbj.2023.07.011.

[37] A. C. Kyaw, N. Nagengast, C. Usma-Mansfield, and F. K. Fuss, "A Combined Reverse Engineering and Multi-Criteria Decision-Making Approach for Remanufacturing a Classic Car Part," in *Procedia CIRP*, Elsevier B.V., 2023, pp. 222–228. doi: 10.1016/j.procir.2023.02.133.

[38] A. X. Amal Rebin, A. Amal Krishna, A. Sharavana Kumar, and R. Christu Paul, "Design development and analysis of pylon prosthesis through reverse engineering," in *Materials Today: Proceedings*, Elsevier Ltd, 2023, pp. 150–155. doi: 10.1016/j.matpr.2023.05.249.

[39] Y. H. Lee *et al.*, "Byproduct reverse engineering to construct unusually enhanced protection layers for dendrite-free Zn anode," *Chemical Engineering Journal*, vol. 464, May 2023, doi: 10.1016/j.cej.2023.142580.

[40] I. Rhoden, C. S. Ball, M. Grajewski, S. Vögele, and W. Kuckshinrichs, "Reverse engineering of stakeholder preferences – A multi-criteria assessment of the German passenger car sector," *Renewable and Sustainable Energy Reviews*, vol. 181, Jul. 2023, doi: 10.1016/j.rser.2023.113352.