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Reverse Engineering to Design an Ergonomic Bio Briquette Packaging Machine

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ABSTRACT

Briquettes are solids that are produced through the process of compression and pressure application and if burned will produce a small amount of smoke. Briquette production is carried out using a hammer mill where the raw material for briquettes is charcoal which is then crushed into charcoal granules. The packaging process is still done manually using a shovel to fill the 50kg sack and then take it to the sewing machine. The worker's posture when using a shovel has a Rapid Entire Body Assessment (REBA) score of 12 so it has a high work risk of musculoskeletal disorders (MSDs) and requires immediate improvement. The working environment at the company produces pollutants, meaning that there is no capture container for the fall of charcoal grains from the hammer mill. Based on the existing problems, a redesign of the existing machine is needed. The proposed machine was designed using the Reverse Engineering method because the existing condition already uses the machine then the existing machine is decomposed to find out the components and functions of the existing machine to find alternative concepts. The ergonomic approach uses REBA and LBA to determine changes in worker posture and the forces acting in the human spine. The DEM approach was chosen to find out if the charcoal grains dropped from the hammer mill were successfully captured and to find out the flow of the charcoal grains. The results of the proposed machine design have a good impact on workers in the packaging process.

1. INTRODUCTION

Bio briquettes are solids that are produced through a process of compression and pressure and if they are burned, they will produce a small amount of smoke. Charcoal bio briquettes are charcoal that is processed with a pressing system and uses adhesive materials, so these briquettes can be used for daily purposes. Bio-charcoal is charcoal made from various kinds of biological materials or biomass, such as twigs, leaves, grass, straw, paper, and other agricultural waste that can be carbonated. This bio-charcoal can be processed into charcoal briquettes [4].

Briquettes in Indonesia are experiencing rapid development, especially in overseas sales. Indonesia's briquette exports already dominate the Middle East, European countries, Nigeria, and Brazil as stated in Figure 1. These countries are already customers of Indonesian briquettes which Indonesia can export no less than 6 million tons of briquettes monthly [3].

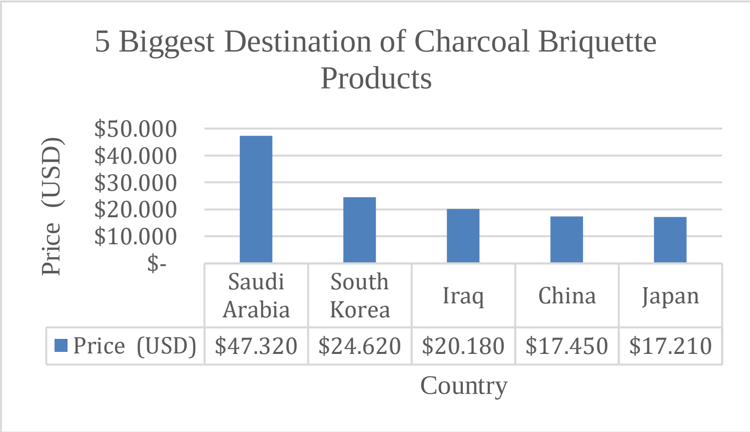

Figure 1 – Five Biggest Destinations of Charcoal Briquette Products

CV. XYZ produces briquettes using a hammer mill machine. This machine can also be used to carry out one of the briquettes manufacturing processes, for example: crushing charcoal into small granules before entering the mixing process as described in the following production process flow (Figure 2).

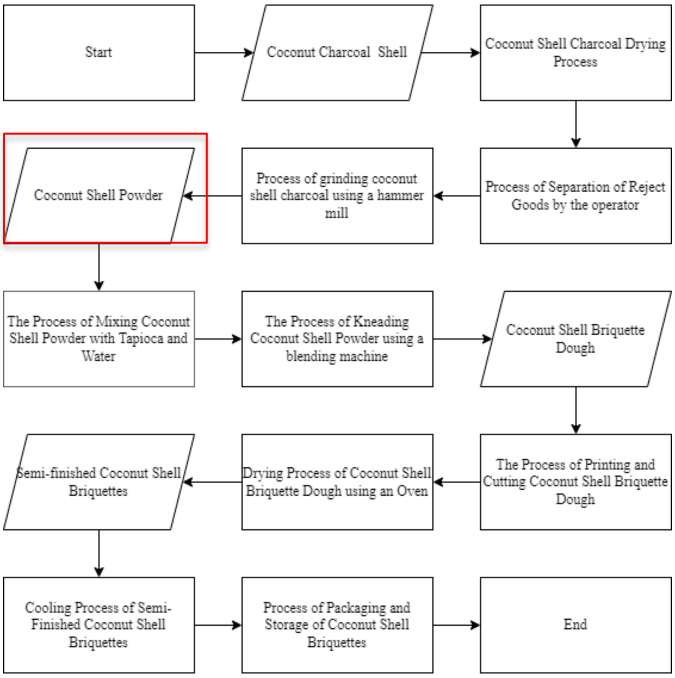

Figure 2 - Briquettes Production Process Flow

As shown in Figure 2, the briquette production process on CV XYZ begins with putting raw material into the hammer mill, in which the raw material is in the form of dried coconut shell charcoal. After the coconut shell charcoal is destroyed, it will enter the packaging and the charcoal grains will enter the sack. After the charcoal grains enter the sack, the next process is the mixing process, printing, and finally drying process. In the last process, they become a finished product, namely briquettes.

In the existing hammer mill machine, the results of charcoal grains that have been crushed will immediately fall to the ground, then the granules are put into a sack using a shovel by workers, and then the sack is sewn in the sewing machine. The process of crushing charcoal on the hammer mill followed by the suturing process is still not integrated, and the process of moving between the two processes still involves workers. In this process, workers need to carry out this process repeatedly over a long time so that workers have a high risk of experiencing work accidents due to the worker's non-ergonomic posture. The non-ergonomic posture of workers can cause musculoskeletal disorders (MSDs) which are the symptoms or disorders related to muscle tissue, tendons, ligaments, cartilage, the nervous system, bone structure, and blood vessels [14].

Figure 3 – Posture of Existing Workers

Figure 3 presents the process of inserting charcoal grains that are the result of a hammer mill into a 50kg sack using a shovel. In the process of transferring charcoal grains into sacks, the worker's posture is bent when inserting charcoal grains into the sack. Consequently, the posture is not ergonomic and needs improvement analysis to solve the issue. Rapid Entire Body Assessment (REBA) was used as the first measurement to get a score from the worker's posture. The results of the analysis of workers' posture using REBA obtained a score of 12. While the ideal condition of the worker's posture using the REBA score is 3 for the maximum and has a low risk.

After calculating REBA on the existing posture, a lower back analysis (LBA) was then carried out to evaluate the forces acting in the human spine and an assessment was carried out to get a value of 2212 N. LBA assessment was assisted by the application of Technomatix Jack to the existing posture. In the work environment, many produce pollutants, are caused by the absence of a charcoal grain capture container from the hammer mill so workers get easily cough from the flying charcoal grains because no one catches charcoal grains.

Based on the identification of the problem, the alternative solution is designing a packaging machine, since the existing conditions, the packaging process is still done manually. Redesigning is the most important factor because the existing machine does not have a packaging process that is conducted automatically. Hence, a packaging machine is needed to make the process easier for the operators as well as good for their postures [22].

2. METHOD

In this study, the reverse engineering method was used to carry out the design of the machine. Reverse Engineering is a method of product development by redesigning an existing product to produce the data needed for the design of the proposed product. This Reverse Engineering method is used to add non-existent functions and/or features of an existing product. Each system to be reverse engineered contains a limited number of components that work together to bring out system behavior. Some of these components vary i.e., they can be in more than one different state that affects system performance [12].

In the reverse engineering and redesign method, there are three different phases namely, reverse engineering, modeling and analysis, and redesign. These three phases are described in Figure 4. The previous three phases are further divided into several processes that must be carried out, namely in the reverse engineering phase including investigation, prediction, & hypothesis, and concrete experience. The modeling & analysis phase includes design models and design analysis. The redesign phase includes parametric, adaptive, and original design [15].

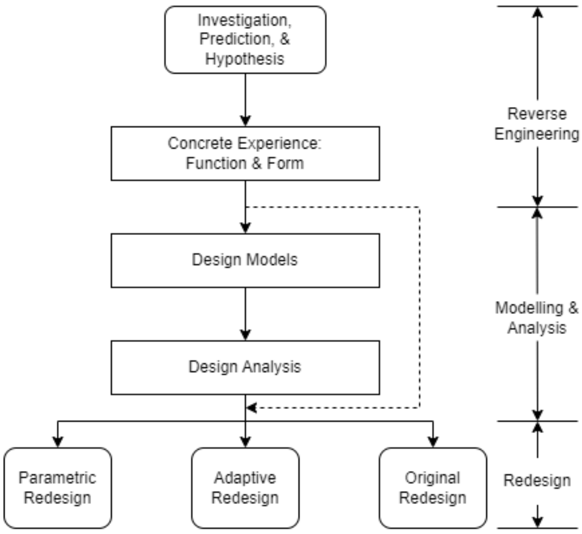

Figure 4 - Reverse Engineering Method Procedure

3. RESULT AND DISCUSSION

3.1 Investigation and Prediction

Identifying need statements is conducted based on interviews with CV XYZ workers. Interviews were done with workers on packaging machines. Interviews are used to get customer leveling to find out the needs of the customer [23]. Need statements are carried out to find out the guidelines that will be used to determine the functions and features of the product to be developed.

Table 1 - Need Statement

No.	Need Statement
1	A machine can reduce the risk of injury to workers
2	The machine can output into the sack
3	Filled sacks do not need to be transported to the sewing machine
4	The machine can reduce pollutants

After the list of need statements from the product is known from Table 1, which comprises 4 need statements, then the conversion of the need statement into product attributes is carried out.

Table 2 – Convert Need Statements to Product Attributes

Need Statement	Product Attributes
The machine can reduce the risk of injury to workers The machine can output into the sack	The machine has a charcoal granule conveying system to fill sacks
Filled sacks do not need to be transported to the sewing machine	The machine has a system that is integrated with the sewing machine
The machine can reduce pollutants	The machine has a capture container to reduce pollutants

After converting user needs to product attributes from Table 2, a functional analysis is carried out. Functional analysis is a functional prediction of the technical characteristics of the required design, which is described in Table 3.

Table 3 – Functional Predictions

Product Attributes	Function Predictions
The machine has a charcoal granule conveying system to fill sacks	The conveying system used is a screw conveyor Has a REBA score ≤ 3

Product Attributes	Function Predictions
The machine has a system that is integrated with the sewing machine	Integrated system with a sewing machine using a gravity conveyor
The machine has a capture container to reduce pollutants	The machine has a hopper for catching charcoal grains

3.2 Structural Decomposition Analysis

The analysis of the decomposition of the structure is divided into two parts, namely product decomposition and product experiments. Product decomposition is the process of knowing the details of the constituent components of the product along with the weaknesses of each component. The process of decomposition of the existing product is carried out after obtaining the level of importance and satisfaction of the product.

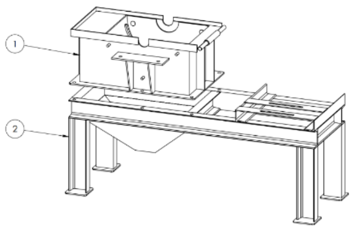

Figure 5 - Decomposition of Existing Products

Table 4 describes the Bill of Materials from the decomposition of existing products in Figure 5.

Table 4 - Bill of Material of Existing Products

Item No	Component Name	Total
1	Base Plate	1
2	Frame	1

In product experiments, revocation experiments are carried out on several components or sub-assemblies to determine the effect of change on the loss of these components.

Table 5 - Experimental Results of Existing Products

Sub-Assembly	Item No.	Component Name	Component Revocation Effect	Component Sub-Function Conclusion
Finished Material Production System	1	Base Plate	The finished material becomes scattered before exiting the frame	Place for storage of finished materials before exiting
	2	Frame	The base plate will fall, and the production of finished materials will be scattered	Mounting for Base Plate and finished material production

From the experimental results of existing products in Table 5, each sub-function of the components of the product can be obtained.

Table 6 - Component Sub-Functions

No.	Component	Sub-Functions Component
1	Base Plate	Place for storage of finished materials before exiting
2	Frame	Mounting for *Base Plate* and finished material production

Based on Table 6 there are two components of the existing machine, and the function of each component is based on what happens if the component is revoked.

3.4 Technical Specifications

The technical specifications of the product are determined from the needs of the user that have been obtained at the investigation and prediction stage. The first thing to do on technical specifications is to determine the technical characteristics. Getting the technical characteristics of the product can be done by scanning the product attributes so that each product attribute has a valuable characteristic.

Table 7 – Technical Characteristics of Proposed Machines

Product Attributes	Technical Characteristics
The machine has a charcoal granule conveying system to fill sacks	Charcoal grain conveying mechanism REBA score
The machine has a system that is integrated with the sewing machine	Has a gravity conveyor for sacks to the sewing machine
The machine has a capture container to reduce pollutants	Has a hopper for catching charcoal grains

After collecting the technical characteristics of the proposed machine from Table 7, the next step is to determine the target picture to be achieved for these technical characteristics. A target picture needs to be created so that the proposed machine specification target can be known. This process is displayed in Table 8.

Table 8 – Technical Characteristics Target Overview

Technical Characteristics	Target
Charcoal grain conveying mechanism	Screw Conveyor
REBA score	≤ 3
Has a gravity conveyor for sacks to the sewing machine	Gravity Conveyor
Has a hopper for catching charcoal grains	Hopper

3.5 Product Morphological Analysis

Product morphological analysis is a process of figuring out alternative concepts of design. Product morphological analysis is divided into two parts, namely the product morphological map and function compatibility. A product morphological map is an arrangement of several alternatives from a complete design and then combined to obtain an alternative product design concept. After obtaining several alternative product design concepts, one of the alternative design concepts will be chosen as the final solution to the proposed product design. The alternatives contained in the morphological map of this product are taken from benchmarks against products on the market.

Table 9 – Proposed Product Morphology Map

Functions	Alternative		
	Option 1	Option 2	Option 3
Charcoal grain conveying mechanism	 Screw Conveyor	 Belt Conveyor	 Bucket Conveyor
Integration system with a sewing machine	 Gravity Conveyor	 Chute Conveyor	
Charcoal grain catcher container	 Hopper	 Manual with shovel	

Based on Table 9, there are three main functions in the proposed product. Of the 3 main functions of the product, there are two of them that are not available in products that can meet user needs. Two functions that are not present in existing products are obtained from the attributes of user needs. The number of combinations produced from this morphological map is calculated using multiplication between all possible alternatives in each function for example the first function has 3 alternatives; the second and the third function has the same number from the alternatives which is 2 then the possible combination is 3 x 2 x 2 = 12 concepts.

Table 10 – Alternative Combinations

Combinations	Conveying Mechanism	Integration System	Catcher Container
A	Screw Conveyor	Gravity Conveyor	Hopper
B	Screw Conveyor	Gravity Conveyor	Manual with shovel
C	Screw Conveyor	Chute Conveyor	Hopper
D	Screw Conveyor	Chute Conveyor	Manual with shovel
E	Belt Conveyor	Gravity Conveyor	Hopper
F	Belt Conveyor	Gravity Conveyor	Manual with shovel
G	Belt Conveyor	Chute Conveyor	Hopper
H	Belt Conveyor	Chute Conveyor	Manual with shovel
I	Bucket Conveyor	Gravity Conveyor	Hopper
J	Bucket Conveyor	Gravity Conveyor	Manual with shovel
K	Bucket Conveyor	Chute Conveyor	Hopper
L	Bucket Conveyor	Chute Conveyor	Manual with shovel

Based on Table 10 presents 12 alternative concepts where the concept is obtained from the morphology map. At the stage of compatibility of functions, concept screening is carried out. Concept screening is a method to reduce or filter all existing concepts into one best alternative concept. it is carried out by assessing the concept based on the selection of criteria from product attributes. To carry out the concept screening process, existing products are used as a reference to be compared with alternative concepts then proceed with the assessment process.

Table 11 - Concept Screening Assessment

Criteria of Choice	Concept												
	Existing	A	B	C	D	E	F	G	H	I	J	K	L
The machine has a charcoal grain conveying system to fill sacks	0	+	+	+	+	-	-	-	-	0	0	0	0
The machine has a system integrated with the sewing machine	0	+	+	-	-	+	+	-	-	+	+	-	-

Criteria of Choice	Concept												
	Existing	A	B	C	D	E	F	G	H	I	J	K	L
The machine has a capture container to reduce. pollutant	0	+	-	+	-	+	-	+	-	+	-	+	-
Sum (+)	0	3	2	2	1	2	1	1	0	2	1	1	0
Sum (0)	3	0	0	0	0	0	0	0	0	1	1	1	1
Sum (-)	0	0	1	1	2	1	2	2	3	0	1	1	2
Final Score	0	3	1	1	-1	1	-1	-1	-3	2	0	0	-2
Rank	6	1	3	3	9	3	9	9	13	2	6	6	12
Continue?	No	Yes	No	No	No	No	No	No	No	No	No	No	No

Based on the results of the concept screening calculation of existing products from Table 11, the best concept is concept A. Concept A is the best concept because the highest final value is three, where the value of three can be interpreted as the concept all criteria exceed that of the existing product so, concept A becomes a realized concept.

With the selection of the concept in the previous stage as the concept of the proposed tool design, a final specification can be made for the packaging machine, which is described in Table 12.

Table 12 - Final Specifications

No	Technical Requirements	Value	Unit
1	Designing machine	Yes	Binary
2	May reduce pollutants	Yes	*Binary*
3	REBA score	≤ 3	Skor
4	Screw conveyor length	3791	mm
5	Screw conveyor width	550	mm
6	Screw conveyor height	3251	mm
7	Filling bulk rotary valve length	2070	mm
8	Filling bulk rotary valve width	890	mm
9	Filling bulk rotary valve height	2400	mm

The 3D design is made from the tools according to the final specifications. The design is created with the Autodesk Inventor application (Figure 6).

Figure 6 – Proposed Machine Design

After the proposal tool is made with the Autodesk Inventor application. Analysis of the worker's posture was carried out on the proposal tool using REBA and LBA assessments (Figure 7). Posture simulation is done with the Technomatix Jack application.

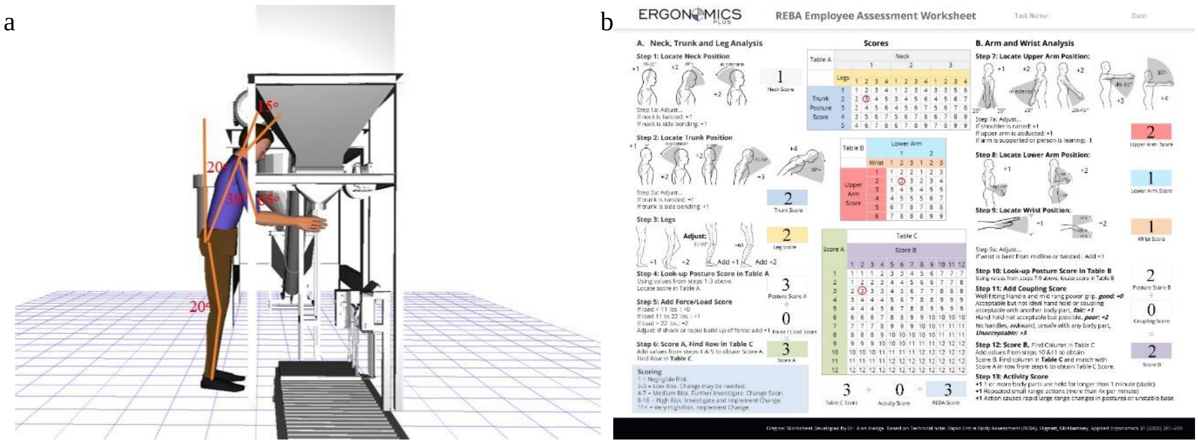

Figure 7 – (a) Worker Posture; (b) REBA Calculation

Based on the REBA assessment in Figure 8, it was found that the proposed REBA score was three. Furthermore, the LBA analysis was carried out after the worker's posture on the proposed tool was simulated. This analysis uses the Technomatix Jack application. After entering the design of the proposal tool and adjusting the posture of the proposal tool, then an LBA analysis was carried out which was directly carried out.

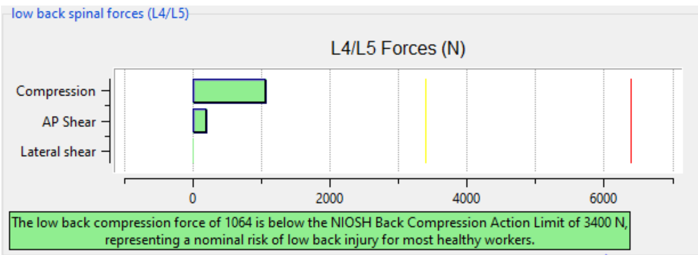

Figure 8 – LBA Analysis Result

The result of the LBA analysis is that the compression force of the lower back produced is 1064 N, where the LBA value in the proposed tool is below the maximum safe limit value. In the pollutant analysis, a simulation of the fall of charcoal grains was carried out in the proposed tool using the EDEM application. As depicted in Figure 9, the simulation in this application is carried out by including the design of the proposal tool, the adjustment of particles from the charcoal grains, and the movement of the proposed tool.

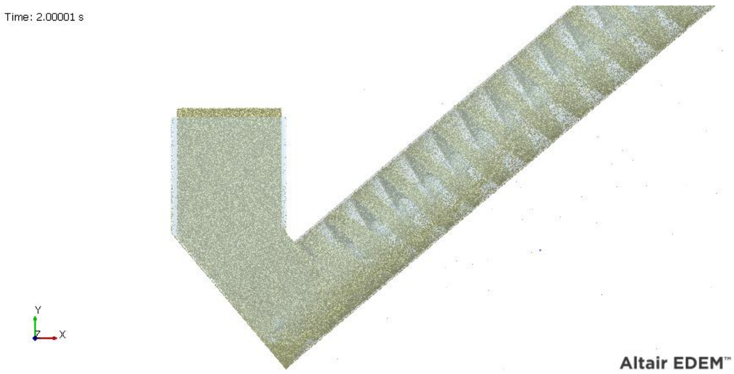

Figure 9 – EDEM Simulation Result

This simulation was carried out for two seconds and it can be known that the charcoal grains that came out, were 30kg and all of them were successfully captured by the hopper.

The DEM analysis conducted in this study is a comparison of the mass of charcoal grains entering and being captured by the hopper with the mass of charcoal grains coming out of the screw conveyor for two seconds using the EDEM application.

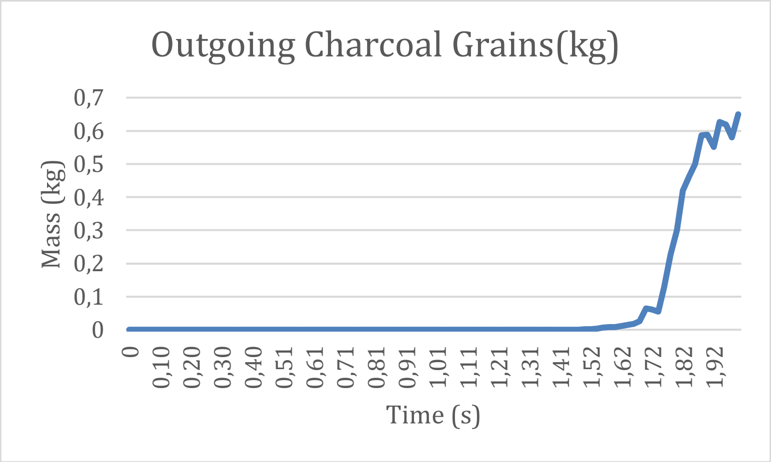

Figure 10 – Outgoing Charcoal Grain

Based on the comparison chart in Figure 10, it can be concluded that the number of charcoal grains that come out of the proposed machine in seconds is 1.39 seconds and continues to grow where the total charcoal grains that come out the amount to 21.72% of the 30 kg of incoming charcoal grains, where the rest are still in the proposed machine waiting to be pushed out with a *screw conveyor*.

4 CONCLUSIONS

Based on research that has been carried out by observing CV XYZ and designing proposal tools and simulations of proposal tools, this research can be concluded that packaging machine design using the Reverse Engineering method can reduce the risk of work accidents such as musculoskeletal disorders for workers in the packaging process. The results of the worker's posture analysis of the proposed tool using REBA and LBA showed a significant change in the condition of the existing worker's posture. This change is indicated by the REBA and LBA values on the proposed tool being smaller than the REBA and LBA values under the existing conditions. The results of the analysis of the presence of pollutants due to the fall of charcoal grains from the hammer mill were carried out with the application of EDEM where for two seconds all charcoal grains falling from the hammer mill were successfully captured by the proposed tool. The results of the DEM analysis using the EDEM application in the form of total charcoal grains coming out of the screw conveyor are 21.72% of the total number of charcoal grains entering the screw conveyor, where this simulation with 1000 rpm rotation is run for two seconds. Based on the results of this study, there are suggestions for further research for example designing the layout for the proposal tool so that it can find out the ideal layout for the company and conduct research on other processes that possibly can be improved.

Disclaimer

The authors whose names are written certify that they have no conflict of interest

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