Designing carbon dioxide absorbent and detector products using the Quality Function Deployment (QFD) method

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Abstract. Global warming is defined as an increase in the average temperature of the earth's surface caused by an increase in the amount of greenhouse gases in the earth's atmosphere. The largest contributor to greenhouse gases on earth is carbon dioxide (CO₂). It is hoped that this CO₂ detector and absorber tool can solve the problem of harmful gases generated from existing industries. This tool is silver with a size of 30 x 30 cm, and the material used is aluminum and has an additional function in the form of a coil cable. The design of this tool uses the method of brainstorming techniques and sampling techniques by means of open and closed questionnaires to determine the type of product. After that, a market survey is conducted using sampling techniques and determining the validity and reliability of the product with competitor I, competitor II and competitor III. The stages from problem to sub problem are determined to classify the goals that will be made in designing the product. Sub-problem to sub-solution steps are carried out to determine the Quality Function Deployment (QFD) of the product.

1. Introduction

The progress of human civilization causes activities in the industrial sector to be faced with tough challenges, every business actor who wants competition will pay full attention to the quality of the products produced. The quality of the product produced is a very important factor in determining a company. Products are said to be of quality to meet the needs and desires of customers [1]. A high quality product will require high costs and consumers may not necessarily need a product that is too high quality. This view is what makes companies oriented towards consumer needs so that they can provide products according to consumer desires and low prices [2]. Consumers still exist but their purchasing power is still limited, as a result, consumers are becoming more careful in making purchases and determining a product they want [3]. One of the human factors is always trying to create something both tools and other objects to help activities. In the embodiment of these objects, a design or product design is needed [4]. Design is an activity or engineering design that starts from design innovation ideas, or the ability to produce works and creations that can truly describe market demand due to technological research and development [5]. The combination of several functions in one product is often the main focus for managers of product research and development departments to produce product design concepts today [6].

Global warming causes erratic climate change. Global warming is generally defined as an increase in the average temperature of the earth's surface caused by an increase in the amount of greenhouse gases in the earth's atmosphere. The largest contributor to greenhouse gases on earth is carbon dioxide (CO₂) [7]. Increasing the temperature of the earth's surface will result in extreme climate changes on...
earth. This can result in disruption of forests and other ecosystems, thereby reducing their ability to absorb atmospheric carbon dioxide. Global warming results in melting of icebergs in arctic regions which can cause sea levels to rise. The greenhouse effect will also result in an increase in sea water temperature so that the sea water expands and the sea level rises, which results in an archipelagic country that will have a very big influence [8]. The increase in the concentration of greenhouse gases also causes the height of the infrared radiation emitted by the earth to decrease, so that the amount of infrared emitted into space decreases, while the sun continues to shine. As a result, there is a change in the amount of incoming and outgoing radiation energy in the tropopause layer of the atmosphere, which is expressed in radiative forcing [9]. The most abundant gas produced from each change (oxidation) process is carbon dioxide. Therefore, the CO$_2$ produced from this transformation process is in the form of a gas, so the earth's atmosphere is a container that will accommodate all this CO$_2$ waste [10]. Various activities in urban areas such as transportation, households, hotels, industry, and other activities require propulsion and heating energy, most of which are obtained from burning fossil fuels. The process of burning fossil fuels produces carbon dioxide (CO$_2$) [11]. With the development of industry, more and more harmful gases are produced that can threaten the cleanliness of the air, especially for the health of our bodies. These gases will pollute the air in the environment so that it will unconsciously be inhaled and enter the body, then gradually the body will feel the impact. CO$_2$ gas is odorless and invisible, therefore humans will not know about the presence of these gases around, humans can only know when they have felt the impact, then a tool is made that can help measure gas in an industrial environment. This tool is expected to solve the solution to the problem of hazardous gases generated from existing industries [12].

The purpose of this research is to design a CO$_2$ detector and absorber that can measure carbon dioxide levels and will check the carbon dioxide levels which represent the detected CO$_2$ levels, which are detected to be above predetermined limits, the tool will automatically reduce CO$_2$, so that it will reduce CO$_2$ and provide benefits to the existing environmental health and can reduce the increase in the amount of greenhouse gases in the earth's atmosphere.

2. Materials and method

2.1. Data Collecting
This research uses a questionnaire instrument. The questionnaire used is based on the establishment of open and closed questionnaires [13] and market surveys conducted to find out the information needed related to the product design of CO$_2$ detection and absorber.

2.2. Data Processing
Brainstorming. Brainstorming is a form of discussion in order to gather ideas, opinions, information, knowledge, experiences from all participants to generate ideas and most of the ideas will be discarded to choose the best idea [14]. From the results of brainstorming, 10 attributes were obtained which were then made in the form of questions for making open questionnaires [15].

Nigel Cross Method. The stages in the product design process with Nigel Cross by classifying objectives, determining functions, compiling needs, determining characteristics, determining alternatives, evaluating alternatives and communication.

Sampling was done using probability sampling, namely simple random sampling. Simple random sampling is a sampling method where each element that makes up the population is given the same opportunity to be selected as a sample [16]. This method is done when members of the population are considered homogeneous. This technique can be used when the number of sampling units in a population is not too large [17]. Through this sampling method, the number of samples was determined, then made open questionnaires, closed questionnaires, and AHP questionnaires. The questionnaire was designed to determine what kind of tools are expected in the product design process. Then after the questionnaire was recapitulated, validity and reliability tests were carried out which were useful for determining CO$_2$ detection and absorber tools.
Questionnaire. A questionnaire is a research or survey tool consisting of a series of written questions, which will be distributed to appropriate respondents, with the aim of obtaining answers or opinions from certain groups of people through personal interviews or in the form of a list of questions [18]. Analytical Hierarchy Process (AHP) is a General Theory of Measurement for finding discrete scale comparison and continuous pair comparison. AHP breaks down complex multi-factor or multi-standard problems into hierarchical arrangements. Hierarchy is defined as an expression of a complex multi-layer structural problem, where the first level is the goal, the second level is the factors, conditions, sub-conditions, etc. Until the last level of alternatives. By using a hierarchical structure, complex problems can be broken down into groups which are then arranged into a hierarchical form so that the problem will appear more structured and systematic [19].

The application of the quality function (QFD). QFD is a way to improve the quality of goods or services, understand what consumers want and relate it to technical characteristics to produce goods or services at each stage of the manufacture of goods or services produced [20]. This QFD provides a strong framework to consider customer expectations and production capabilities quantitatively so that the target specifications for a particular product or service can be in line with what the customer expects. QFD is a quality system that can guarantee satisfaction to customers within the scope of total quality management. In this case, the application of the quality function aims to produce better products [21]. Then, classify the objectives and product determination functions. For sub-problems, the determination of needs, is a way to compare the results of brainstorming and attributes to form a questionnaire recapitulation. Next is to determine product characteristics using QFD based on a questionnaire containing customer needs or an investigation of customer satisfaction with products related to technical characteristics [22].

Then in order to find solutions to any problems arising from the manufacture of the product, steps are determined to generate alternatives, evaluate, and improve detail. From all these steps, it can be determined the characteristics of the manufacture of the product at an appropriate cost.

3. Results and discussion
The result of designing this product is a CO₂ detector and absorber that is efficient, effective, ergonomic and affordable that can be used by workers to reduce CO₂ levels in the room. The design problems contained in the design of this CO₂ detector and absorber include product composition, assembly time, length of assembly, length of soldering, length of measurement and thickness of CO₂ detector and absorber equipment.

3.1. Classification of Purpose, Function, and Determination of Needs
To find a solution to the above problems, there are 3 steps needed so that the problem will be divided into sub-problems, namely the classification of objectives, functions, and determination of needs. The conclusion of the 3 steps in designing a CO₂ detector and absorber product is:

- List of objectives for the design of CO2 detection and absorber tools consisting of Color Detection Tool and CO₂ Absorbent, Size of CO₂ Detectors and Absorbers, Color Indicator for CO₂ Detection and Absorbers, Position of CO₂ Detector and Absorbent Switches, Material for CO₂ Detection and Absorption Equipment, Base material for CO₂ detection and absorber, Inner Material of CO₂ Detector and Absorbent Equipment, Has a cabel winder holder, Material from the cable winder, Color of cable winding material. The Purpose Tree Diagram can be seen in figure 1. below.
The division of functions into essential sub-functions consisting of the sub-function design of the CO2 detector and absorber, MQ135 sensor design sub-function, The sub-function of the design of the base section of the CO2 detector and absorber, Sub function of cable reel design CO2 Detector and Absorbent Equipment.

Determine the level of generality to operate which consists of products having a lightweight, comfortable and ergonomic design. The product has a low electrical power (12 volts). The product does not need special care.

3.2. Determination of Characteristics
In this section, the sub-problem of the CO2 Detector and Absorbent Equipment specification will be found a sub-solution with the steps from the Nigel Cross design, to determine product characteristics. House of Quality CO2 Detector and Absorbers can be seen in Figure 2 below.
The conclusion from the QFD image of the CO₂ detector and absorber in figure 2, namely:

- The attributes of the carbon dioxide detector and absorption device based on the results of the questionnaire according to consumer desires are as follows: Silver Color, Material of Aluminum, Size 30x30 cm, Indicator Color Red, Cross-sectional Base Material of Wood, Fabric of the Inner Layer, Position of the Switch on the Wall, Additional Functions of Cable Winders, Additional Function Materials made of Plastic, Additional Function Color is Black.

- Degree of Interest: soldering is quite important. The assembly time, equipment weight, soldering time and measurement time are all important, while product composition, assembly time, and material thickness are all very important.

- Estimated Cost: all technical characteristics are cheap except for expensive assembly.

3.3. Sub-Result

The sub-solution is the solution to each problem that occurs, including the selection of attributes for CO₂ Detection and Absorbers which is carried out by using Nigel Cross steps, while maintaining the advantages that are owned and improving the quality of the product.

In this section, there are 3 steps taken so that sub-solutions become solutions, namely generating alternatives, evaluating alternatives, and improving details. Following are the conclusions of the three steps in the process of designing a CO₂ detector and absorber.

3.3.1. Alternative Generation. The alternative generation stage aims to collect as many alternatives as possible that can be used to solve problems in designing CO₂ detection and absorber products, so that the best solution or alternative is then sought. This is done by using the Morphological Charts method with the following steps:

- Make a list of functions or goals that are important to the product.
- Make ways to achieve essential functions.
- Identify a combination of design solutions that can applied.
- Identify the feasibility of a combination of sub-solutions.
The Morphological Chart shows all possible solutions or alternative relationships that can be used in the design of CO₂ detection and absorber tools as shown in the Morphological Chart for CO₂ Detection and Absorbing Equipment products shown in the form of a 10 x 3 matrix, where there are 10 functions that must be achieved and there are 3 possible alternatives. The combination formula used is:

\[ 3^{10} = 59,049 \]

So the total possible combination to achieve these alternatives is 59,049 ways. The Morphological Chart of CO₂ Detection and Absorption Equipment can be seen in Table 1 below.

**Table 1. Morphological Chart**

| No | Characteristic    | How To Achieve Function | 1  | 2  | 3  |
|----|-------------------|-------------------------|----|----|----|
| 1  | Color             |                         | Silver | Blue | White |
| 2  | material          |                         | Aluminum | Iron | Plastic |
| 3  | Size              |                         | 30x30cm | 30x20x20cm | 15x100x8cm |
| 4  | Indicator Color   |                         | Red | Red yellow green | Red yellow blue |
| 5  | Baha Cross-section|                         | Wood | Plate | Aluminum |
| 6  | Inner Lining Material |                    | Fabric | Plastik | Aluminum |
| 7  | Switch Position   |                         | Wall | Beside the socket | Beside the product |
| 8  | Additional Functions |                    | Cable roll | Fire extinguisher | Alarm |
| 9  | Additional Function Material |    | Plastic | Iron | Wood |
| 10 | Color Additional Functions |                 | Black | Red | White |

3.3.2. **Alternative Evaluation.** Alternative evaluation aims to compare the utility values of alternative product designs that are made or made on the basis of performance on the basis of weighted objectives, where the results of the alternative generation step will be evaluated by re-examining the alternatives to be selected so that the best alternative is produced. The method used is the weighted objective method with the AHP scale.

Rating ratings are carried out using Pair Wise Comparison and AHP scale, with data obtained from the importance value for each attribute in QFD. Level I is a Pairwise Appeal Matrix between Primary Attributes, Level II is a Pairwise Appeal Matrix between Design Secondary Attributes, and Level III is a Pairwise Appeal Matrix between Secondary Attributes of Materials and Additional Functions. After the paired appeal matrix is carried out with the AHP scale then weighting is carried out for each level. Weighting for each attribute is needed to determine how the influence of these attributes in product design. Weighting is done by dividing the ranking value of each attribute to the total value of the ranking itself and determining the performance parameters of each attribute. The following performance parameters can be seen in Table 2 below.
Table 2. Performance parameters of each attribute

| Characteristic | Parameter            | 5                | 4                | 3                | 2                | 1                |
|----------------|----------------------|------------------|------------------|------------------|------------------|------------------|
| Color          | Contrast             | in stark contrast| Contrast         | enough contrast  | lack of contrast  | not in contrast  |
| Size           | Size                 | 30x30 cm         | 30x20x20 cm      | 15x100x8 cm      | 20x100x50 cm     | 15x100x80 cm     |
| Color Indicator| Contrast             | in stark contrast| Contrast         | enough contrast  | lack of contrast  | Kurang baik      |
| Switch Position| Conformity           | very good        | good             | pretty good      | Kurang baik      | not good         |
| Color Indicator| Contrast             | in stark contrast| Contrast         | enough contrast  | lack of contrast  | not in contrast  |
| Switch Position| Conformity           | very good        | good             | pretty good      | Kurang baik      | not good         |
| Material       | Quality              | very good        | good             | pretty good      | not good         | not good         |
| Cross-section  | Material             | very good        | good             | pretty good      | not good         | not good         |
| Material       | Quality              | very good        | good             | pretty good      | not good         | not good         |
| Inner Lining   | Material             | very good        | good             | pretty good      | not good         | not good         |
| Additional     | Function Material    | very good        | good             | pretty good      | not good         | not good         |
| Additional     | Function Material    | very good        | good             | pretty good      | not good         | not good         |
| Additional     | Conformity           | very good        | good             | pretty good      | not good         | not good         |

3.3.3. Improve Detail. The final stage of the design process aims to increase product value for consumers and reduce costs incurred by producers. This can be done by using the Value Engineering method. The steps in improving details are as follows:

- List the product components and identify the function of each component as in Table 3 below.

**Table 3. Data on the components of CO₂ detection and absorption equipment products**

| Component         | Function                                      |
|-------------------|-----------------------------------------------|
| Aluminium         | As a case / product frame material            |
| Sensor MG811      | As a CO₂ sensor                               |
| Mini Arduino      | As a microcontroller from the AP.PENKO system|
| fabric            | As an isolator                                |
| Monitor Running Text | CO₂ level percentage indicator screen    |
| Tombol on-off     | Switch to turn on and off AP.PENKO            |
| Wood              | As AP.PENKO's foundation on the wall          |
| Bolt              | The lock between the components and the frame|
| Mur               | The lock between the frame and the base       |
| Cable             | As a connection between each component        |
| mini fan          | As an air regulator                           |
• Determines the value of the identified function. 
Based on the functions that have been identified, the values are determined based on consumer perceptions. The values of each function assessed based on the suitability of the design against the desires of the upper consumers are as shown in table 4.

| No | Function | Score | Information |
|----|----------|-------|-------------|
| 1  | Design   | good  | AP. PENKO has a simple design, with a size that is not too big, light, and easy to move, besides that this tool is also designed ergonomically and practically making it easy to use. |
| 2  | ingredient | good | AP. PENKO uses tools that are light and easy to find and assemble such as aluminum, cloth, wood, as well as the main tool in the form of a CO2 sensor and its energy source, namely electrical energy. |
| 3  | dimensions | good | In this AP.PENKO, the dimensions of the length of the tool, the length of the wooden base, the length of the cable, and the number of bolts and nuts to be used are determined. |
| 4  | Multifunction | good | AP.PENKO is designed with the main function of detecting CO2 in the room, and the additional function is a cable rewinding theme that can make it easier to use. |

• Calculate the cost of each component.
The prices of the main raw materials, additives, and auxiliary materials for the manufacture of the product have been estimated beforehand to determine the selling price of the resulting product. The component prices are assumed as shown in table 5.

| Component | Component Prices (IDR) | Number of Components Required | Total price (IDR) |
|-----------|------------------------|-------------------------------|------------------|
| Aluminium | IDR 80.000,00          | 1 sheet                       | IDR 80.000,00    |
| Sensor MG811 | IDR 300.000,00       | 1 unit                        | IDR 300.000,00  |
| Mini Arduino | IDR 100.000,00       | 1 unit                        | IDR 100.000,00  |
| fabric     | IDR 15.000,00         | 1 sheet                       | IDR 15.000,00   |
| Monitor Running Text | IDR 150.000,00 | 1 unit                       | IDR 150.000,00  |
| On-off button | IDR 10.000,00       | 1 unit                        | IDR 10.000,00   |
| Wood       | IDR 50.000,00         | 1 unit                        | IDR 50.000,00   |
| Bolt       | IDR 2.500,00          | 16 unit                       | IDR 40.000,00   |
| Nut        | IDR 1.000,00          | 8 unit                        | IDR 8.000,00    |
| Cable      | IDR 3.000,00          | 2 m                           | IDR 6.000,00    |
| **Total**  | **IDR 859.000,00**   |                               |                  |
3.4. Design Prototype

Prototype is a description or initial model of the product that you want to design on a CO2 detector and absorber. The results of the prototype CO2 detector and absorber device that have been designed can be seen in figure 3 below.

![Prototype Image]

Figure 3. Carbon dioxide detection and absorbing equipment

4. Conclusion

The characteristics of the CO2 detector and absorber products obtained from the design objectives are silver color with a size of 30 x 30 cm, and the material used is aluminum and has an additional function in the form of a cable coil. For the attributes of this tool product can be divided into several parts. The primary attributes of the CO2 Detection and Absorbent Equipment product are design, materials and additional functionality. The design attributes are divided into secondary attributes, namely color, size, indicator color, switch position, and additional function color. Material attributes are divided into secondary attributes, namely material, cross-sectional base material, inner layer material and additional function materials. Function attributes are divided into secondary attributes, namely additional functions of cable winders. For QFD, it was found that all the technical characteristics were classified as very difficult except for the relatively difficult assembly time, for the degree of importance that soldering was found to be quite important. The assembly time, equipment weight, soldering time and measurement time are all important, while product composition, assembly time, and material thickness are all very important. and in the estimated product cost, the technical characteristics are classified as cheap except for the expensive assembly. Based on the value engineering step through improving details, it was found that from the existing alternatives there is the best alternative with a total cost of IDR. 895,000.00.

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