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# Analysis of Pressure Laboratory Scale Swing Adsorption (PSA) Varian Design using Zeolite 13X as Adsorben Medium

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**Abstract**

*The demand of high quality of oxygen increases, moreover in the pandemic of covid -19. In another hand, there are demands of technology and material usage to improve the quality of oxygen. Those two main reasons encourage us to conduct a study which aims to obtain the best variant on concept design analysis of pressure swing adsorption (PSA) which utilizes adsorption material of synthetic zeolite 13x. The method used was Quality Function Deployment (QFD) which is an information collecting about the need and the expectation of users. The steps carried out to obtain the best variant design concept of pressure swing adsorption are as follow: requirement list determination, priority scale determination, house of quality making, PSA specification determination, design concept and the best variant determination. The result was that the best variant was selected, the 10 variants, because it fulfilled the requirement of the specification list. It was because this variant used in PSA is single column type with the capacity of zeolite of 13X 2 – 2,5 kg, it was equipped with manual valve so that it needs no automatic control system, the electricity source was from PLN and need no accumulator and the product of $O_2$ using 1 single tank which makes it considerably simpler.*

***Keywords****: Variant, design concept, PSA, zeolite 13X*

## 1. Introduction

Oxygen is one of the most abundant elements and it also has an important function on earth and life, where oxygen is found in nature in its pure element and in the form of $O_2$ compounds. For various purposes, such as the current Covid-19 pandemic, it is necessary to carry out oxygen purification with the aim of improving the quality of oxygen, which can be used by COVID-19 patients with moderate or severe symptoms who experience shortness of breath or difficulty breathing. To produce good air quality is to do the air purification. Among the methods that can be used for air purification are adsorption and cryogenics. In this study, the adsorption method was used, because adsorption is the most frequently employed, cheapest and easiest to use method because it uses zeolite adsorbent media which is easy to obtain and easy to synthesize [1]. Zeolite is a porous silica mineral with a large surface area and a certain size, which is 3-10 [1], so that zeolite has a function as an adsorbent that has good adsorption ability [2] and zeolite is also able to separate gases which have a size different [3]. Zeolite consists of 2 types, namely natural zeolite and synthetic zeolite [4]. Natural zeolite is easy to obtain because it is spread in several areas [5] and has also been widely used, which requires obtaining a silica source that can be useful for the characterization of synthetic zeolite [6]. Most natural zeolites have a low Si/Al ratio, due to the absence of organic matter that is important for the formation of silica [7]. Synthetic zeolite is purer than natural zeolite. Synthetic zeolites can be grouped according to the ratio of the levels of Al and Si components in the zeolite [8]. In contrast to natural zeolites, synthetic zeolites in Indonesia are still few in terms of ready-to-use raw materials [9].

Adsorption is the change of molecules of solids from the fluid phase which is a spontaneous attraction phenomenon called adsorbent. While the adsorbent is a substance that has pores, and it also has a surface area per unit mass. The interaction with the adsorbent surface will be different, this is because the molecules are different and will separate them. Equilibrium will be reached at a certain time when the adsorbent is in contact with the fluid phase. The time required to reach the equilibrium may also be important, especially when the pore size of the adsorbent is close to the size of the molecules to be adsorbed [10]. Molecular geometry of zeolites can be described by considering the bond distance, bond angle, and van der Waals radius [11]. The adsorption refrigeration cycle is one of the adsorption technologies that is well known to have benefits in various applications [12]. The technology that can be used to separate and purify gas, capture nitrogen and $CO_2$ [13] is Pressure Swing Adsorption (PSA) [14]. The oxygen concentrator used a Pressure/Vacuum Swing Adsorption (PVSA) prototype with an adsorption column with diameter of 3 cm and a column length of 20 cm. The adsorbent used was zeolite nanosize 13X. The adsorption pressure used is 1.79 barg and the desorption pressure is -0.82 barg. The analysis was carried out by comparing the experimental and simulation results [15].

Analysis of the design of the Pressure Swing Adsorption (PSA) device should consider about pressure equalization, vacuum swing adsorption, particle size, cleaning volume, layer size, adsorbent selection and layer configuration [16]. The performance of the PSA device, especially related to heat and mass transfer, must also consider about the large variations in the surface wave of the falling film [17]. In addition, the design stages of the PSA Pressure Swing Adsorption (PSA) tool also include the stages of determining the base design, preparing the conceptual design, and calculating the PSA column design [18]. In PSA, the adsorbent media commonly used is synthetic zeolite, namely 13X zeolite because 13X zeolite has a good nitrogen adsorption ability compared to synthetic zeolite 5A. (PSA) because this zeolite has a high ability to adsorb nitrogen. The nitrogen adsorption capacity of zeolite is 13X higher than that of synthetic zeolite, namely zeolite 5A [19].

Considering the above conditions, namely the need for oxygen quality, and the importance of using technology and materials to improve the oxygen quality, this study analyzed the design concept of a laboratory-scale Pressure Swing Adsorption (PSA) device with 13X zeolite adsorbent media.

## 2. Methods

The method used in the analysis of the design concept of the Pressure Swing Adsorption (PSA) tool is the Quality Function Deployment (QFD) method [20], which is collecting information on the needs and desires of users. The steps taken to get the best variant design concept on the Pressure Swing Adsorption (PSA) tool are as follows: determining the requirements list, determining the priority scale, making a house of quality, determining PSA tool specifications, design concepts and determining the best variant.

## 3. Result and Discussion

### 3.1 Determination of Requirement List

In preparing requirements list it is important to outline the objectives and circumstances under which it must be met in the manufacture of PSA. The resulting list of requirements must be identified as either demands or wishes. Demands are requirements that must be met on the PSA under all circumstances in other words, if one of these requirements is not fulfilled the solution is unacceptable [21]. Wishes are requirements that should be considered in PSA tools whenever possible. The requirements list in the following table:

*Table 1. Requirement list of PSA*

| Requirement List | Description | Demands = D Wishes = W |
|---|---|---|
| Functional | Able to adsorb $N_2$ and produce $O_2$ | D |
| Geometry | *single bed* type with *cylindrical shell & ellipsoidal head* shape | D |
| | Dimension optimal and economical | W |
| Energy | Optimal operational pressure | W |
| | The source of air pressure is from air compressor | D |
| Material | Able to retain load of equipment when operating | D |
| | Adsorbent was zeolite 13X | D |
| | Product was $O_2$ ± 90% purity | W |
| Production | Equipment component is easy to find in market | W |
| Operation | Can be operated by 1 operator | D |
| | Low level of noise | W |
| Safety | The equipment does not harm the operator | D |
| Maintenance | Maintenance can be done by 1 person | D |
| Cost | Low component and equipment production cost | W |

### 3.2 Determination of Priority Scale

After determining the requirements list on the PSA tool, then based on the requirement list, a priority scale of wishes (wishes) on the PSA tool is made, which is in the following table:

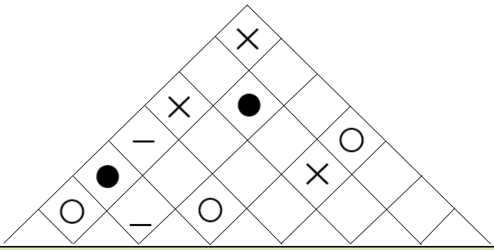
*Table 2. Priority scale of PSA*

| Requirement List (wishes) | Correlation Matrix | Sum | % | Rank |
|---|---|---|---|---|
| Optimal & economical | 1 1 1 1 1 | 5 | 33.3 | 1 |
| Optimal Operational | 0 1 1 1 1 | 4 | 26.6 | 2 |
| Product of $O_2$ ±90% | 0 0 1 1 1 | 3 | 20 | 3 |
| Easy to find in market | 0 0 0 1 1 | 2 | 13.3 | 4 |
| Low noisy level | 0 0 0 0 0 | 0 | 0 | 6 |
| Low component cost | 0 0 0 0 1 | 1 | 6.67 | 5 |
| Total | | 15 | 100 | - |

### 3.3 House of Quality

In the Quality Function Deployment (QFD) method, a quality house or also known as a House of Quality (HoQ) is used which systematically supports user orientation of the product and process planning. User requirements are translated into technical requirements which will then be translated into organizational processes and production requirements. Based on the specified requirements list, a House of Quality can be made in the following table:

*Table 3. House of Quality (HoQ) of PSA*



| Line | Customer Requirements | Technical Requirements | weight | Compressor power | Operational pressure | Air feed volume flow rate | Adsorbent capacity | Noisy level | Oxygen level | cost |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Colom | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | | Units | | kW | bar | L/min | kg | dB | % | Rp |
| | | Targets | | 1,1 | ≥7 | 32 | 1.5-2 | 80 | ±50 | - |
| 1 | Functional | Able to adsorb $N_2$ and produce $O_2$ | 1 | 1 | 9 | 9 | 9 | 1 | 9 | 3 |
| 2 | Geometry | Cylindrical shell & ellipsoidal head | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| | | Dimension is optimal and economical | 5 | 1 | 3 | 3 | 2 | 1 | 1 | 9 |
| 3 | Energy | Optimal pressure | 5 | 3 | 9 | 1 | 1 | 1 | 9 | 1 |
| | | Air compressor | 0 | 9 | 3 | 3 | 1 | 1 | 1 | 3 |
| 4 | Material | Can retain load when operating | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 |
| | | The adsorbent was zeolite 13X | 1 | 1 | 1 | 1 | 9 | 1 | 3 | 3 |
| | | The product was $O_2$ ≥50% | 5 | 1 | 9 | 1 | 3 | 1 | 9 | 1 |
| 5 | Manufacturing | Easy to find in market | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 3 |
| 6 | Operation | Can be operated by 1 operator | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | Low level of noise | 1 | 3 | 1 | 1 | 1 | 9 | 1 | 1 |
| 7 | Safety | Equipment doesn't harm the operator | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | Maintenance | Maintenance can be done by 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | Cost | Low component & production cost | 5 | 3 | 1 | 1 | 1 | 1 | 1 | 9 |
| | | Score | | 185 | 293 | 193 | 258 | 91 | 263 | 253 |
| | | Percentage (%) | | 12 | 19 | 12 | 16 | 5 | 17 | 16 |
| | | Rank | | 6 | 1 | 5 | 3 | 7 | 2 | 4 |

## 3.4 Determination of PSA tool specifications

At this stage, which is to determine product specifications in the form of a laboratory Sakla PSA device with an adsorbent in the form of 13X zeolite based on the House of Quality and priority scale, PSA equipment specifications have been obtained, namely as follows:

1. Maximum operating pressure 7 bar
2. O2 product purity ±50%
3. Absorber capacity 1.5 - 2 kg
4. Optimal and economical dimensions

## 3.5 Design concept

This stage explains the design concept of the function of the laboratory-scale PSA tool. There are three functions of the tool which is a description of the function of the first level in the form of the function of the tool in general. For each of the first-level functions, there is a description of the second-level functions in the form of tool functions in more detail.

The description of the function of the first level is that air is introduced, then separated and then exhaled. For the description of the second level function, the air was compressed and then filtered (filtered) and then the flow rate is adjusted. The second level function was that nitrogen was adsorbed and oxygen gas was removed. The next second level function was that oxygen was accommodated and the adsorbed nitrogen was released into the surrounding air.

1. First-level function description

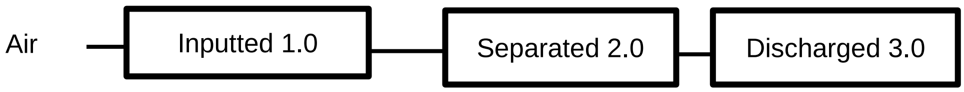



*Figure 1. first level function*

2. Level 2 function description

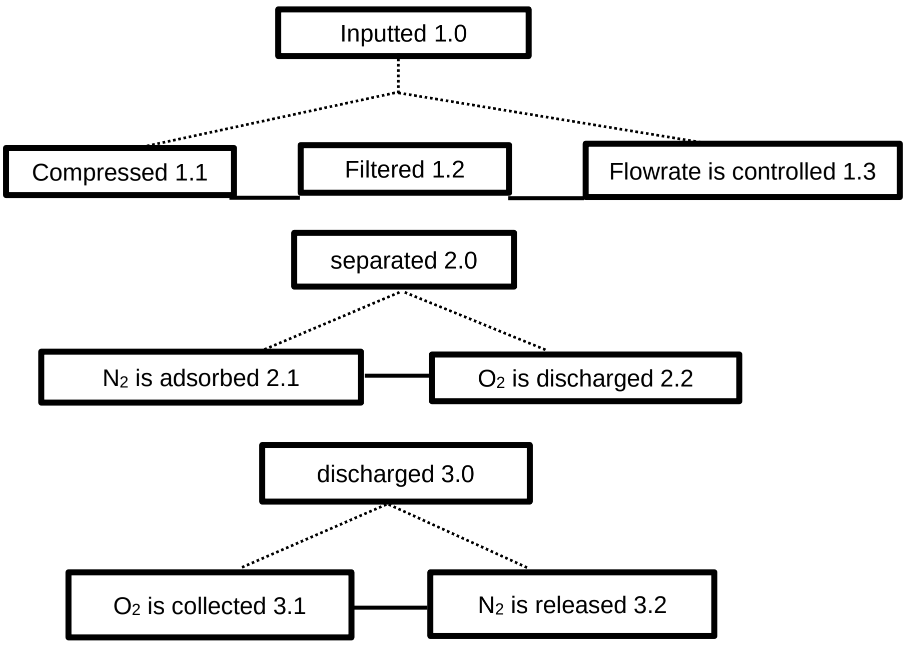



*Figure 2. Second level function*

### 3.6 Determination of the best variant

At the stage of determining the best variant, the variants that can be applied to the PSA tool are described where several components have variants that have advantages and disadvantages. Therefore, it is necessary to describe several variants of the components used as well as several variants of the form. The number of variant categories is 4 categories with each having 2 different variants. Here are some variants of the PSA tool, namely:

*Table 4. Variant of PSA*

| No | Variant | A | B |
|---|---|---|---|
| 1 | Bed or column type | *Single bed* | *Double bed* |
| 2 | *Valve* mechanism | Automatic | Manual |
| 3 | Electricity source | PLN electricity | Accumulator |
| 4 | Product $O_2$ tank | 2 tanks of $O_2$ | 1 tank of $O_2$ |

From various variant determined, they were combined to obtain the best variant. The variant combinations are as follow:

*Table 5. Variant combinations of PSA*

| Variant | Description |
|---|---|
| Varian 1 (1A-2A-3A-4A) | *Single bed* – Automatic –PLN electricity – 2 tanks of $O_2$ |
| Varian 2 (1B-2A-3A-4A) | *Double bed* – Automatic – PLN electricity – 2 tanks of $O_2$ |
| Varian 3 (1A-2B-3A-4A) | *Single bed* – Manual – PLN electricity – 2 tanks of $O_2$ |
| Varian 4 (1A-2A-3B-4A) | *Single bed* – Automatic – Accumulator – 2 tanks of $O_2$ |
| Varian 5 (1A-2A-3A-4B) | *Single bed* – Automatic – PLN electricity – 1 tank of $O_2$ |
| Varian 6 (1B-2B-3A-4A) | *Double bed* – Manual – PLN electricity – 2 tanks of $O_2$ |
| Varian 7 (1B-2A-3B-4A) | *Double bed* – Automatic – Accumulator – 2 tanks of $O_2$ |
| Varian 8 (1B-2A-3A-4B) | *Double bed* – Automatic – PLN electricity – 1 tank of $O_2$ |
| Varian 9 (1A-2B-3B-4A) | *Single bed* – Manual – Accumulator – 2 tanks of $O_2$ |
| Varian 10 (1A-2B-3A-4B) | *Single bed* – Manual – PLN electricity – 1 tank of $O_2$ |
| Varian 11 (1A-2A-3B-4B) | *Single bed* – Automatic – Accumulator – 1 tank of $O_2$ |
| Varian 12 (1B-2B-3B-4A) | *Double bed* – Manual – Accumulator – 2 tanks of $O_2$ |
| Varian 13 (1B-2B-3A-4B) | *Double bed* – Manual – PLN electricity – 1 tank of $O_2$ |
| Varian 14 (1B-2A-3B-4B) | *Double bed* – Automatic – Accumulator – 1 tank of $O_2$ |
| Varian 15 (1A-2B-3B-4B) | *Single bed* – Manual – Accumulator – 1 tank of $O_2$ |
| Varian 16 (1B-2B-3B-4B) | *Double bed* – Manual – Accumulator – 1 tank of $O_2$ |

After compiling the combination of variants in table 6, there were 16 variants on the PSA which must be chosen as the best. The variants are selected through the following table:

*Table 7. Variant solution of PSA*

**The selection of the best variant of PSA**

decision

Solution was evaluated using:
(+) Yes
(–) No
(?) Insufficient information
(!) reconsidered (check *requirements list*)

(+) solution is proceed
(–) solution is rejected
(?) collect more information
(!) reconsidered

Variants

Specification list

Compatible for overall function
Fulfill specification need
Principally can be implemented
*Safety*
Simpler
Sufficient information

| Variants | A | B | C | D | E | F | Description | Decision |
|---|---|---|---|---|---|---|---|---|
| V1 | + | + | + | + | – | ? | High dimension and lack of information for automatic *valve* | – |
| V2 | – | – | + | + | – | ? | Is not suitable as the specification and the dimension is too big | – |
| V3 | + | + | + | + | – | + | Big Dimension | ! |
| V4 | + | + | ? | ? | – | ? | Too difficult to be implemented, the dimension is too big, and the component cost is high | – |
| V5 | + | + | + | + | – | ? | Lack information of automatic valve | – |
| V6 | – | – | ! | + | – | – | not suitable to specification and the dimension is too big | – |
| V7 | – | – | ? | ? | – | ? | not suitable to specification, difficult to be implemented, dimension is too big and the component cost is high | – |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| V8 | – | – | + | + | – | ? | not suitable to specification and dimension is big | – |
| V9 | + | + | + | + | – | + | The dimension is too big | ! |
| V10 | + | + | + | + | + | + | Selected variant | + |
| V11 | + | + | ? | ? | – | ? | Difficult to be implemented dimension is too big | – |
| V12 | – | – | ! | + | – | – | Not suitable to specification and dimension is too big | – |
| V13 | – | – | ! | + | – | – | Not suitable to specification and dimension is big | – |
| V14 | – | – | ? | ? | – | ? | Not suitable to specification, dimension is big and difficult to be implemented | – |
| V15 | + | + | + | + | – | + | dimension is big | ! |
| V16 | – | – | ! | + | – | – | Not suitable to specification and dimension is too big | – |

From table 7 the variant solutions on the PSA have taken several main decisions, namely, variant 3 used 2 tubes of $O_2$ so that it can store more $O_2$ products resulting from the air separation process. However, the drawback of variant 3 was that it did not meet the specifications list because it used 2 tubes of $O_2$ so that the PSA was not simple and produces large tool dimensions and requires additional costs for $O_2$ tubes. Variant 9 used 2 tubes of $O_2$ so that it can store more $O_2$ from the air separation process and the tool was more portable because it used an accumulator power source. However, the drawback of variant 9 was that it did not meet the specifications list because it used 2 tubes of $O_2$ and used an accumulator power source so that the PSA was not simple and produced tool dimensions that are too large and require additional costs for accumulator components. Variant 15 used an accumulator power source so that the tool was more portable. However, the lack of variant 15 was because it did not meet the specifications list because it used an accumulator power source so that the PSA tool was not simple and produced large tool dimensions and required additional costs for accumulator components. While variant 10 had met the specification list because the variant used in the PSA is a single bed type for a zeolite capacity of 2 – 2.5 kg, the valve mechanism was conducted manually so there was no automatic control system component, the electricity source was from PLN and do not require accumulator components and used 1 tube of $O_2$ which made it simpler. In addition, the 10 variants did not require additional costs for accumulator components, automatic control systems or additional $O_2$ tubes. However, the drawback of variant 10 was that it did not work in continuous process because the valve was still manual and used a single bed type. Therefore, from the 4 variants above, an analysis and consideration had been carried out that the best variant chosen was variant 10 because it met the list of specifications and existing parameters.

## 4. Conclusion

By using the Quality Function Deployment (QFD) method, the best variant on the laboratory scale Pressure Swing Adsorption (PSA) design concept (specification: capacity 2 – 2.5 kg, oxygen concentration 82%, pressure 20 Psi, flow rate 20 L/minute) with 13X zeolite adsorbent media is variant 10 because it meets the specification list because the variant used in the PSA device is the bed or column type. used is a single bed with a zeolite capacity of 13X 2 – 2.5 kg, the valve mechanism uses a manual so there is no need to use an automatic control system, the source of electrical energy is PLN electricity and does not require an accumulator, and the O2 product tube uses 1 O2 tube so it is simpler.

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