Mechanical Strength Design Analysis of Molecular Sieve Vessel of Helium Purification Systems in RDE

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Abstract. Experimental Power Reactor (RDE) uses a type of pebble bed fuel and helium gas as the primary coolant. In order to maintain the quality of helium as a coolant in accordance with the established requirements, the helium purification system is designed. One part of the main components of this helium purification system facility that absorbs CO2, CH4, and H2O is a molecular sieve vessel. The purpose of this study is to determine the ability of mechanical strength of a molecular sieve vessel through simulation testing using Computer Aided Three-dimensional Interactive Application (CATIA) software. The steps taken in analyzing the mechanical strength of molecular sieve designs include: built a 3-dimensional model, entering data on the mechanical properties of the material used, and simulating the operation at a test pressure of 30 bar and a temperature ranging from 50 °C to 250 °C. At a pressure of 30 bar and a temperature of 200 °C, the mechanical voltage result was 2.13 x 109 N/m2 that exceeded the yield strength of 304 Stainless Steel material at 1.7 x 109 N / m2. Furthermore, the smallest translational displacement was 0.218 mm.

Keywords: helium purification system, molecular sieve vessel, RDE, translational displacement

1. Introduction
The developments in the sectors of technology, industry and information that are increasingly rapid in Indonesia, have resulted in increased energy consumption, especially electricity. The amount of this need is not accompanied by the supply of energy provided, so that the energy crisis will continue to
occur. Therefore, it is necessary to develop new renewable energy to reduce the energy crisis. BATAN as a nuclear energy research and development institute plans to develop non-commercial Experimental Power Reactors (RDE). In the construction of RDE, Pebble Bed Reactor technology is chosen with the consideration that it is very safe, functions for cogeneration, has fuel flexibility, has been tested, competitive prices, multipurpose, can be developed in all regions of Indonesia, and to meet the needs of electricity supply.

As primary coolant in RDE uses helium gas and secondary cooling using water. The heat of the primary coolant is transferred to the secondary coolant via a steam generator. The purity of helium in the primary coolant must always be maintained to a certain extent so that the impact on the system, structure and components is minimal. To meet the desired purity requirements for helium in RDE primary coolers, a helium purification system is needed. This system must be designed to purify helium from solid and gas impurities. The accumulation of graphite dust impurities will have an impact on the reduction of the heat up process. Gas-shaped impurities if carried in the coolant flow will trigger the carburization and decarburization process in the material. The carburizing process in the SSK will make the material more fragile [1] while the decarburization process will reduce the carbon concentration in the material and prevent the formation of an oxide layer on the surface so that the corrosion process is easy.

The main components used in the Helium Power Plant Reactor Purification System are filters, CuO oxidation vessels, condensers, molecular sieve vessels and very low activated carbon vessels. Based on the experience of operating HTGR reactors on China (HTR-10) and Japan (HTTR) the principle of cleansing CO₂, CH₄ and H₂O impurities is to use molecular sieve [2]. Several studies on cleaning of gas impurities using molecular sieve have been carried out by several researchers including Myrlla et.al conducted a study to study the dynamic behavior of molecular Zeolite 4A to reduce CO₂ impurities in natural gas at high pressure using Aspen Adsim software simulation [3]. Xiaojing et.al Conducted experiments for molecular sieve characterization at several sizes to absorb hydrogen at 100 Pa, 200 Pa, and 0.2 MPa. The results show that molecular sieve 5A-2 can effectively absorb hydrogen quickly [4]. Ahmed et.al Performs theoretical and experimental calculations for the separation of propane from a mixture of methane, ethane, and propane using zeolite molecular sieve 4A as an adsorbent. The experimental results showed that the propane purity obtained was 98% and the productivity was 0.413 mmol/minute [5].

The parameters that determine the efficiency of the cleaning process in molecular sieve are the length of gas contact with molecular sieve and the type of molecular sieve used. To get the optimal cleaning process efficiency, in addition to using the type of molecular sieve that is suitable then the dimensions of the column/bed molecular sieve are right. Incorrect dimensions of the molecular sieve column design have an impact on the cost so that it is economically unfavorable.

This study aims to determine the ability of the molecular sieve vessel design in terms of mechanical strength through simulation testing using Computer Aided Three-dimensional Interactive Application software (CATIA). Mechanical strength includes mechanical stress and translation displacement in a molecular sieve vessel due to load, in the form of pressure and temperature. The steps taken in analyzing the mechanical strength of molecular sieve vessel include making a 3-dimensional model of molecular sieve vessel, collecting data on the mechanical properties of molecular sieve vessel material used and simulating mechanical strength [6]. By comparing the magnitude of the mechanical stress experienced by the molecular sieve vessel to the yield strenght of the material used, the mechanical strength of the molecular sieve vessel can be known, and it is expected that the translation displacement will be very small. This software has also been used to analyze the structure of channel experiment facilities and heating source device support [7, 8].

2. Methodology
The design of the molecular sieve vessel is shown in Figure 1, consisting of components of the lid and body vessel.

![Figure 1. Design of Molecular Sieve Vessel](image)

Molecular sieve vessels are designed using Stainless Steel 304 material with dimensions and shapes as shown in Figure 2 below.

![Figure 2. Dimensions and Forms of Molecular Sieve Vessel](image)

The mechanical properties of the Carbon Steel AISI 1040 material are as follows;

| Mechanical Properties | Stainless Steel 304 |
|-----------------------|---------------------|
| Young Modulus         | $1.93 \times 10^{11}$ N/m² |
| Poisson Ratio         | 0.29                |
| Density               | 7800 kg/m³          |
| Thermal Expansion     | $1.72 \times 10^{-5}$ 1/K |
Yield Strength \( 1.7 \times 10^9 \text{ N/m}^2 \)

By using 3-dimensional modeling of a molecular sieve vessel design and mechanical properties of Stainless Steel 304 as input data on CATIA software. So by testing the simulation it can be seen the mechanical strength includes mechanical stress and translational displacement in the design of molecular sieve vessels.

Stages of simulation testing carried out in analyzing mechanical strength are as follows;

1. Preparation of 3-dimensional models.
   At this stage, a 3-dimensional vessel molecular sieve model is made with reference to the design. The model is equipped with material properties used in the design as input data.

2. Load
   The maximum load given to the molecular sieve vessel is in the form of pressure and temperature with a constant pressure of 30 bar and temperatures varying from 50 °C to 250 °C.

3. Restrain
   Restrain simulates a 3-dimensional body model and support in static conditions. Restrain must be given to the model so that the simulation can be done.

4. Mechanical stress testing and translational displacement
   The 3-dimensional model is given input in the form of material properties, load and restrain. Then a simulation is performed to determine the amount of mechanical stress and translational displacement that occurs. The magnitude of the mechanical stress is compared to the yield strength of the material used so that the mechanical strength of the design of the molecular sieve vessel can be known.

3. Result and Discussion
The simulation test was carried out on a molecular sieve vessel design with the simulation results obtained as follows:

1. Determination of the mechanical stress in a vessel of molecular sieve.
   The simulation test on the body with a pressure load of 30 bar and a temperature of 100 °C is shown in Figure 3.

![Figure 3. Mechanical stress that occurs in the design of a molecular sieve vessel.](image-url)
The greatest mechanical stress occurs in the output of a molecular sieve vessel with a mechanical stress of $9.45 \times 10^8 \text{ N/m}^2$. This happens because the output pipe (bottom) is attached to the support (clamp) which keeps the vessel's position as a static molecular sieve. So that the part is the weakest part of the load in the form of pressure and temperature.

2. Determination of the large translational displacement that occurs in the design of a molecular sieve vessel.

In this test aims to determine the occurrence of changes in shape, in the design of a molecular sieve vessel. If the test results obtain a very large translational displacement compared to the size of a molecular sieve vessel design, there has been a change in the design of the molecular sieve vessel.

![Figure 4. Translational displacement that occurs in the design of a molecular sieve vessel](image)

The results of translational displacement testing on a molecular sieve vessel design produce the largest translational displacement at the top of the body (the part connected to the lid) is 0.581 mm. in the simulation test with a pressure of 30 bar and a temperature of 100 °C as shown in Figure 4. The results of simulation tests that have been carried out by varying temperatures ranging from 50 °C to 250 °C and a fixed pressure of 30 bar are obtained as follows:

| No. | Tekanan (bar) | Temperatur (°C) | Tegangan Mekanik ($\text{N/m}^2$) | Translational Displacement (mm) |
|-----|--------------|----------------|----------------------------------|---------------------------------|
| 1   | 30           | 50             | $3.51 \times 10^8$               | 0.218                           |
| 2   | 30           | 100            | $9.45 \times 10^8$               | 0.581                           |
| 3   | 30           | 150            | $1.54 \times 10^9$               | 0.945                           |
| 4   | 30           | 200            | $2.13 \times 10^9$               | 1.310                           |
| 5   | 30           | 250            | $2.73 \times 10^9$               | 1.680                           |

The simulation results show that at a pressure of 30 bar and a temperature of 200 °C the resulting mechanical stress is $2.13 \times 10^9 \text{ N/m}^2$ has exceeded the yield strength of Stainless Steel 304 at $1.7 \times 10^9 \text{ N/m}^2$. These results are obtained by the design of a molecular sieve vessel in the piping section of the input and output static clamps. So that there is no vertical shift in the design to overcome the magnification of mechanical stress that occurs. At the operating pressure and temperature the
mechanical stress that occurs is $9.45 \times 10^8 \text{N/m}^2$, smaller than the yield strength of Stainless Steel 304 and in elastic material. So even though the design of a molecular sieve vessel with input and output piping conditions static clamps are safe to operate at a pressure of 30 bar and a temperature of 100 °C. It is recommended that the molecular sieve vessel design be changed with the input piping conditions (the top) clamped by giving freedom to shift vertically to overcome the magnified mechanical stress. Translational displacement that occurs in the design of a molecular sieve vessel is very small (the largest 1.680 mm) so that it does not result in a change in the design of a molecular sieve vessel.

4. Conclusion
Design of a molecular sieve vessel using 304 Stainless Steel material and statically clamped on the input and output piping. Through simulation testing using software CATIA obtained at a pressure of 30 bar and a temperature of 200 °C the resulting mechanical voltage is $2.13 \times 10^9 \text{N/m}^2$, has exceeded the yield strength of 304 Stainless Steel materials at $1.7 \times 10^9 \text{N/m}^2$. Translational displacement that occurs in the design of a molecular sieve vessel is so small that it does not result in a change in shape in the design of a molecular sieve vessel.

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