Two-stage Anaerobic Reactor Design of SS 316 Material with Application of Penetrant Test Method (NDT)

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Abstract-- *Anaerobic reactors are essential in processing organic waste, biomass, and wastewater into desired end products through a dark fermentation process. This process involves bacteria decomposing organic matter without light or oxygen, producing hydrogen gas, and other by-products. In this study, the design, manufacture, and testing of a two-stage anaerobic reactor of stainless steel 316 material were carried out carefully, considering dimensions, and material specifications. The device design process involved design simulation using SolidWorks, while the manufacturing stage involved material preparation, component forming, welding, and device installation. Testing was conducted using Nondestructive testing (NDT) methods to detect surface defects, and ensure the structural integrity of the reactor. This study provides an in-depth overview of the manufacturing process of a two-stage anaerobic reactor, including material preparation, welding, and NDT testing, hoping to contribute to developing more effective, and sustainable organic waste treatment technologies.*

Keywords: *Two-stage Anaerobic Reactor, Dark fermentation, Nondestructive Test (NDT), Stainless steel 316*

1. INTRODUCTION

Anaerobic reactors are used to process organic waste, biomass, and wastewater, and convert them into desired end products. This process is known as dark fermentation, where bacteria break down organic matter in the absence of light, andoxygen, producing hydrogen gas, and other by-products. At this stage, the reactor's acid, acetogenic, and methanogenic processes occur [1] [2].

During anaerobic digestion, complex organic matter is converted into biogas, and digestate. The initial stage involves the hydrolysis of large, complex organic molecules such as proteins, lipids, and polysaccharides. The resulting monomers, such as amino acids, fatty acids, and simple sugars, transform easily digestible fatty acids. Evaporate through acidogenesis. These volatile fatty acids are then converted in the process of acetogenesis, producing acetic acid, carbon dioxide, and hydrogen. Finally, methanogenic reactions occur, where organic acids from the previous stages are utilized to produce methane, and carbon dioxide [1].

Factors that influence the dark fermentation process in anaerobic reactors, namely substrate composition, and quality, temperature, pH, organic matter content, bioreactor design, and microbial community dynamics, and interactions, play a crucial role in optimizing the fermentation process [3][4], so these factors must be optimized for maximum energy production.

Designing, and building a reactor tool is important because it is very influential in the production process in the industry [5], such as selecting the type of material used, installing the tool according to standards, and testing or inspecting the tool before use.

Stainless steel is an iron (Fe) alloy with a minimum Cr content of 12%. Reaction oxidation between oxygen (O_2), and chrome (Cr) forms a protective layer (corrosion protection layer) [6], so the selection of materials in the manufacture of anaerobic reactor tools must be rust, and corrosion-resistant before the tool manufacturing process is carried out. Anaerobic Reactor Equipment is generally the same as a pressure vessel that experiences internal pressure in the form of gas produced from the dark fermentation process. In design, the vessel (pressure vessel) is calculated manually (hand calculation) with a formula from the ASME standard (American Society of Mechanical Engineers) or computer analysis (Software)

Reactor equipment that has been designed, and installed needs to be tested or inspected to detect leaks or failures in welding. One of the methods used is the Liquid Penetrant Test Method (dye penetrant), which is an NDT method that has the speed, and accuracy in detecting defects, and even leaks on the surface of both metals, and non-metals;

the material will be seen more clearly by looking at the indications on the surface of the test object after spraying the developer which is then sketched to be used as a work report which will later be translated for acceptance criteria [7].

Several previous studies have been conducted related to single-stage reactors, and two-stage reactors for fermentation processes with different materials, and end products, such as Biohydrogen plants [8], Batch bioreactors [9], Pyrolysis reactors [10], Anaerobic digestion [11], Reactor for disproportionation process [12], Fermentation Laboratory [13], Reactor for Biodiesel production [14], and Review of batch, and continuous reactor comparison [15].

In this study, a two-stage anaerobic reactor will be designed, and made for the dark fermentation process with 316 Stainless steel material, and installation using ASME BPVC Section VIII standards. After that, it is tested or inspected using the penetrant test method to maximize the two-stage anaerobic reactor tool for safety before use.

2. METHODOLOGY

2.1 Design Stage

In the anaerobic reactor design process, it is important to take into account the dimensions of the anaerobic digester, which are suitable to support efficiency in processing organic waste into desired end products, such as hydrogen gas, and other useful gases.

Therefore, the following is a breakdown of the design data for the anaerobic reactor that has been compiled:

Table 1. Two-stage Anaerobic Reactor Design

Two-Stage Anaerobic Reactor Design	
Material Type *Stainless ste*	*l* 316
Volume: Height: Diameter	7 liters: 40 cm: 15 cm
Wall thickness (sheel)	2 mm
Thick *Head & Bottom* 2.4 m	m
Design Internal Pressure	5 - 10 bars
Pressure Design Temperature	40 - 60 Celsius (Thermophilic)
Corrosion Factor	0.5 mm/year
Head Type Flat *(flange slip*	*on)*
Bottom Type *Torispherical*	
Stirrer (Impeller) Paddle/Str	ight

The proposed reactor has a total volume of 7 litres, with dimensions of 40 cm in height, and 15 cm in diameter. The thickness of the shell wall, which is the central part of the reactor structure, is 2 mm, while the thickness of the head, and bottom is 2.4 mm.

The reactor is designed to, handle internal pressures between 5 to 10 bar, and operational temperatures between 40 to 60 degrees Celsius, considering the thermophilic nature of the processes to be carried out.

In terms of corrosion resistance, the corrosion factor considered is 0.5 mm/year, which is essential in maintaining the integrity of the material during the reactor's operational life. The Head Type selected is Flat (slip-on flange), while the Bottom Type used is Torispherical. The impeller selected is a Paddle/Straight type to ensure optimal mixing in the reactor.

2.2 Design Stage

In this stage, the tool's design will be simulated using SolidWorks, starting with 2-dimensional, and 3-dimensional models, and ending with technical drawings ready for the manufacturing stage.

The tube frame was first designed to house the anaerobic reactor.

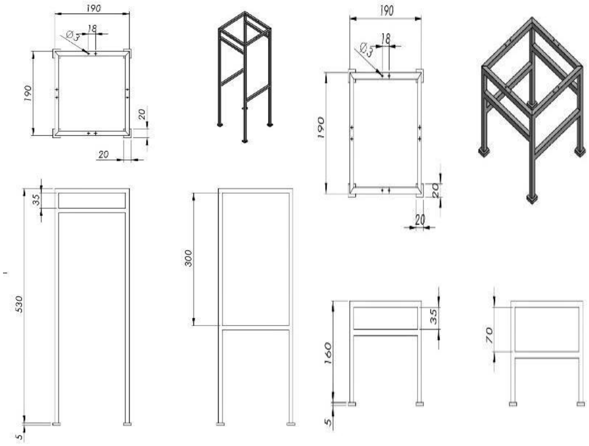

Figure 1. Reactor Frame

Then, the anaerobic reactor tube, and lid are designed according to the required size.

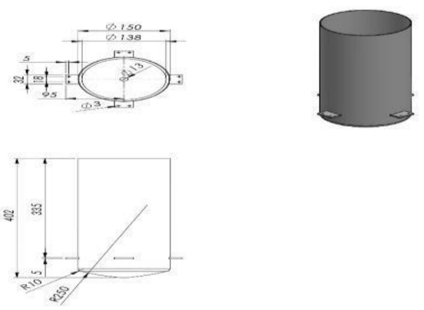

Figure 2. Reactor Tube

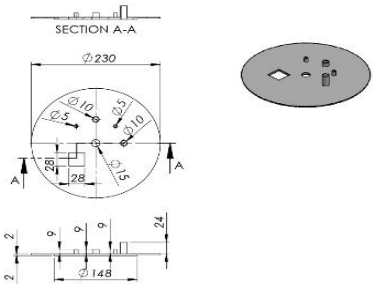

Figure 3. Tube cap

The two-stage anaerobic reactor is designed with a complete model, and can proceed to the manufacturing stage.

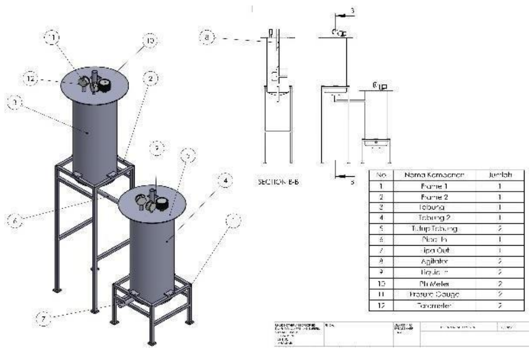

Figure 4. Two-stage anaerobic reactor design

2.3 Stage of Manufacture

Anaerobic reactor manufacturing is an essential stage in implementing a pre-planned design. This stage involves a series of processes, including material preparation, component forming, welding, device installation, and final refinement.

Here are the steps in making a two-stage anaerobic reactor:

1. Prepare SS 316 Plate for roll
2. Roll Plate SS 316
3. Tube Welding Process by GTAW or TIG method
4. Tube *Finishing* Process
5. Laser manufacturing of tube *flangeCutting*
6. Manufacture of *304 stainless steel hollow* tube frame
7. Tube Frame Welding
8. Making Tool Holders on *Flanges*: a stirrer, DC motor, Thermometer, *Pressure Gauge*, pH meter, and inlet are made, and installed on the *flange*.
9. Manufacture of *stirrer* (*impeller)* type Paddle/straight
10. *Gasket Packing* Manufacture for Lid *Flange*
11. Pipe Line Construction from reactor 1 to reactor 2
12. Installation indicator measurement on the reactor

2.4 Testing/Inspection Stage Using NDT

At this stage, tests were conducted on the anaerobic reactor using the Nondestructive test method to inspect the welding results, and detect possible surface defects such as cracks, uneven bonding, or potential leaks.

A liquid penetrant with a red colour seeps into the discontinuity. The liquid penetrant is removed from the discontinuity using a developer liquid (developer) whose colour contrasts with the liquid penetrant (white). The detection of discontinuities is by the appearance of red spots (liquid penetrant) that come out of the discontinuity [16].

3. RESULTS AND DISCUSSION

The results obtained in this study show that the two-stage anaerobic reactor tool ss 316 material has been installed with indicators equipped on it. such as Thermometer, pH meter, *Pressure gauge,* and a DC motor to stir the drive.

Furthermore, the test results on the anaerobic reactor equipment using the NDT method were also obtained, and the results showed no defects or severe leaks.

3.1 Two-stage Anaerobic Reactor Apparatus

The following are the results of the reactor tool that has been designed, designed, and made with ASME BPVC SECTION VIII installation standards.

Figure 5. Two-stage anaerobic reactor apparatus

Indicators are fitted, and installed on the apparatus to understand reactor performance, and its implications in organic waste treatment.

Tabel 2. Two-stage Anaerobic Reactor Indicator

Thermometer	-10ºC - 110 ºC
pH meter	*Digital Soil Survey Instrument 4 in 1*
Pressure Gauge	10 Bar/150 psi
DC motor	100-200 rpm
Heater Plate	*Heater Plate* 600W
Stirrer (Impeller) speed	20-200 rpm

Indicators such as thermometers, pH meters, pressure gauges, DC motors, plate heaters, and impellers play a key role in monitoring, and controlling the reactor's operational process. For example, thermometers measure temperature accurately, while pH meters provide an overview of the reactor's acidity level.

In addition, a pressure gauge monitors the pressure in the reactor, while a DC motor, and impeller maintain a consistent stirring speed. Plate heater, with appropriate power, keeping the reactor'soperational temperature stable.

3.2 NDT Testing Analysis

Testing or inspection of two-stage anaerobic reactor equipment is carried out using Magnaflux Set brand liquid penetrant consisting of Cleaner/remover (SKC-S), Red penetrant (SKL-SP2), and Developer (SKD- S2), which functions to check for cracks in moulding or welding results.

Three stages of testing are carried out as follows:

1. Cleaner/Remover (SKC-S) is the first step in the penetrant testing process. Its function is to clean the surface of contaminants such as dirt, oil, or dust thatmay prevent the penetrant from penetrating cracks or defects in the surface. SKC-S is applied by spraying or rubbing the surface to be inspected, then cleaned with a cleancloth or tissue.
2. Red Penetrant (SKL-SP2): used in penetrant testing. This penetrant has capillarity properties that allow it to seep into cracks or defects in the metal surface. Once the surface is clean of contaminants, and dry, SKL-SP2 is applied to the surface, and allowed to penetrate for some time according to the test procedure.
3. Developer (SKD-S2): Developer is the final step in the penetrant testing process. It absorbs the penetrant that has seeped into the crack or defect, clarifies, and magnifies the detected indications, and helps distinguish between the absorbed penetrant, and the surface background. SKD-S2 is applied in spray form, and allowed to dry for some time before the results are evaluated.

The following are the results of the Inspection Report carried out on the two-stage anaerobic reactor tool:

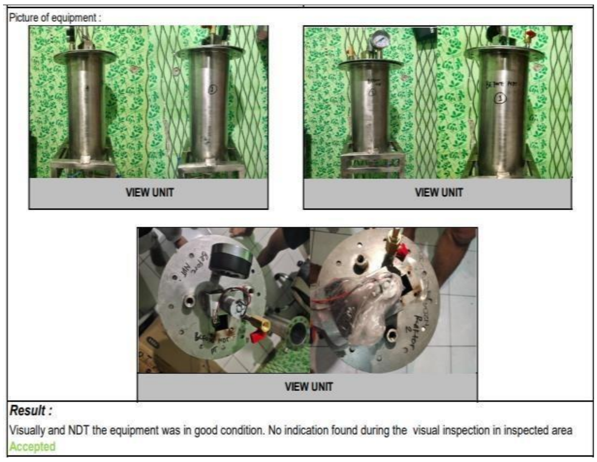

Figure 6. *Inspection Report*

After that, here are the results of the *penetrant test examination report*that has been carried out:

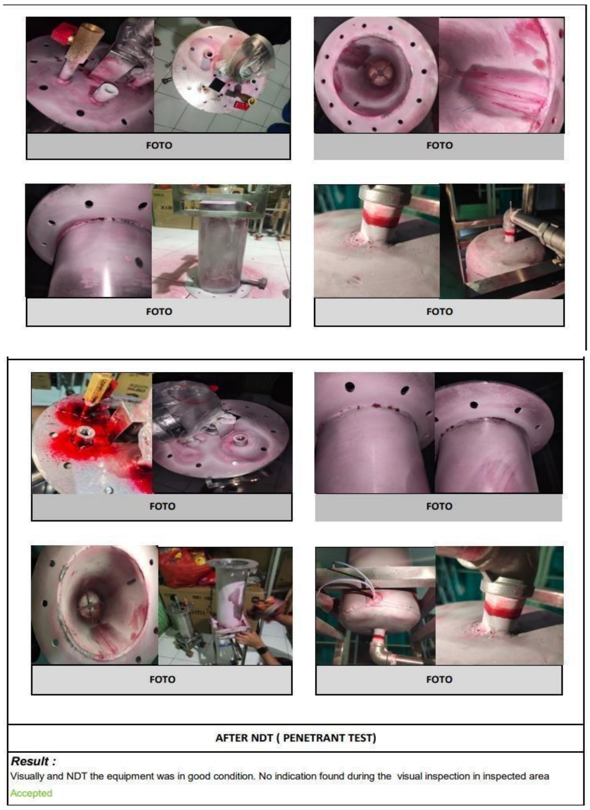

Figure 7. Penetrant test examination report

Penetrant test examination report notes the results of the penetrant test process using a red penetrant, and developer on the anaerobic reactor equipment are then carefully noted (visually) if there are defects or leaks in the welding area.

The test report also includes recommendations for action Corrective or preventive measures are required based on the penetration test findings.

Based on the results of visual, and Nondestructive Testing (NDT), the two-stage anaerobic reactor was in good condition, and no indications of damage or defects were found during visual inspection of the inspected areas. Therefore, the equipment is acceptable, and meets the standards set.

4. CONCLUSIONS

1. The design, and manufacture of a two-stage anaerobic reactor made of Stainless Steel 316 have been carried out. Dimensions, and material specifications, such as wall thickness, design pressure, and operational temperature, have been carefully considered so that the anaerobic reactor can be made according to the needs of dark fermentation.
2. The Penetrant Test Method (NDT) is applied in the manufacturing process to ensure the safety, and structural integrity of the reactor. This method aims to detect, and analyze any surface defects that may occur during the manufacturing process so that no gas leaks occur when the device is used.
3. This study provides an in-depth overview of the manufacturing process of a two-stage anaerobic reactor using stainless steel 316 material. The tool design data, and manufacturing steps, such as material preparation, welding, and NDT testing, have been explained in detail.

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