Hydrogen has been recognized as an ideal energy source that is environmentally friendly and widely used in various industries. Hydrodynamic factor is one of the important factors affecting the bio-hydrogen production processes involving multiphase system. Therefore, this research aims to study the influence of hydrodynamic factor that is off-bottom clearance (position of the impeller from the bottom of the tank) influence to the hydrogen production process by fermentation. Off-bottom clearance is one of the important hydrodynamic factors because it can affect the flow pattern and then can affect on mass transfer of hydrogen gas from liquid phase to the gas phase. The reactor used is a stirred tank equipped with a single impeller, 45°-6 blades, Pitched Blade Turbine (PBT) type at constant rotation speed of 200 rpm. While off bottom clearance was varied 0.25 H, 0.5 H and 0.75 H. The results showed that at the same impeller speed, impeller position does not affect to the speed of consumption of glucose by bacteria that are used as a carbon source for metabolism, but the position of the impeller effect on the capacity of hydrogen gas. A lower off bottom clearance provides better performance in an effort to increase the hydrogen production capacity. The highest yield was 0.0029 mol H₂/mol glucose, which was obtained at impeller position 0.25 H.

**Keyword:** hydrodynamics, biohydrogen, off bottom clearance, pitched blade turbine

**Introduction**
Bio-hydrogen production is a complex process involving chemical, biological and physical processes. Physical characteristics such as hydrodynamics factors affecting biohydrogen production efficiency is still rarely studied. Therefore, the purpose of this research is to study the influence of hydrodynamics factor that is off-bottom clearance (position of the impeller from the bottom of the tank) influence to the hydrogen production process by fermentation.

Hydrodynamics study in a bioreactor can be conducted experimentally and computationally. Computational approach is needed because it more economic, faster, can give a good approximation to predict the hydrodynamic in a system and can be used to visualize detailed flow phenomena (Wang et. al., 2010).

**Methodology**
Medium, *Enterobacter aerogenes* NBRC 13534, from Prof. Hiroyasu Ogino, Osaka Prefecture University, Japan was grown on potatoes dextrose agar (PDA) medium. The fermentation was conducted in two stages. The first stage is the stage of acclimatization in a container was filled to 2 L of solution containing the following components (in 2 L of distilled water): 40 g of glucose, 10 g of OHLY yeast extract, C₆H₁₂FeO₁₄ 250 mg, MnSO₄ 0.2 mg, CuSO₄ 0.2 mg. The second stage is the stage of fermentation in the bioreactor with a working volume of 14.5 L (consisting of per L of distilled water; glucose 2% w/v and OHLY yeast extract 0.5% w/v).

**Reactor system**
The reactor was employed for batch fermentation with a working volume of 14.5 L. Inside diameter (T) of 0.21 m and height (H) 0.45 m and it was equipped with a stirring system made of 6-blade 45° Pitched Blade Turbine (PBT). The dimensions of the impeller is diameter (D) of 0.072 m. In order to determine the influence of hydrodynamic on the hydrogen production, the clearance (C) was varied that is 0.25 H, 0.5 H, and 0.75 H with the direction of rotation is pumping down. The pH was kept on 5.5 – 6.5 by adding NaOH 4 M and the temperature was maintained constant at 37 °C. Schematic of the reactor and dimension of the impeller used in the present study can be seen in Figure 1.

**Computational Approach**
The bioreactor has analyzed with a computational three dimensional mesh. The meshes of bioreactor were created in the ANSYS Design Modeler and exported into the ANSYS Fluent 12.1. Computational approach used to predict and visualize the flow pattern of fluid (assumed as water) and the gas tracking that assumed as hydrogen gas only in the bioreactor. Hydrogen was considered as spherical particles with a constant diameter of 1 mm which injected in the bioreactor at ten points with maximum number of step of 500000.

**Results and Discussions**
**Effect of Clearance on Gas Volume Produced**
Position of the impeller from the bottom of the tank affect the flow pattern in the stirred reactor (Figure 2). Differences on flow patterns also influence the volume of gas that formed, as shown in Figure 3. The reduction in total gas volume which is formed also followed by the reduction in the volume of H₂ produced. It can be seen that at 0.25 H clearance, the volume of gas produced of 4229.6 ml, 462 ml at 0.5 H
and at 0.75 H increase to 660 ml. Enhancement of gas volume at the clearance of 0.75H can be caused by the impeller position was closer to the liquid surface so the influence of the flow of the upper impeller is smaller than at 0.5 H. Therefore, the gas that formed will be discharged from the liquid phase easier than at clearance of 0.5 H.

The experiment result can be supported by the simulation of H\(_2\) particle tracking where it shows the same result that at clearance of 0.25 H, residence time H\(_2\) particles in reactor is shorter than the other clearances that is about 16.8–64.6 seconds. It means H\(_2\) gas is more easy to escape from liquid phase and then leave the reactor, therefore the H\(_2\) gas volume increased. The residence time of H\(_2\) gas at clearance of 0.5 H and 0.75 H are 12.6–155.8 seconds and 12.6–170.5 seconds, respectively. Based on that data, residence time of H\(_2\) at 0.5 H is shorter than at 0.75 H but at clearance of 0.5 H, not all H2 particles are injected can be escaped from the reactor. Based on the simulation result, there are eight particles only that can be escaped. The different phenomena are shown at clearance of 0.75 H. All particles are injected can be escaped although the residence time H\(_2\) in reactor is longer than at clearance of 0.5 H. Therefore the gas volume that released is more than gas volume at 0.5 H.

**Effect of Clearance on Hydrogen Gas Yield.**

The highest hydrogen yield obtained at the clearance of 0.25 H that is 0.0029 mole H\(_2\)/mole glucose converted and the lowest is 0.00042 mole H\(_2\)/mole glucose converted at the clearance of 0.5 H. It is related to the total gas volume produced.

**Conclusion**

At the same impeller speed, off-bottom clearance give significant effect on the residence time of gas in reactor that can be influenced the capacity of H\(_2\) gas. A lower off-bottom clearance provides better performance in an effort to increase the hydrogen production capacity since it can influence the turbulence intensity. The highest yield was 0.0029 mole H\(_2\)/mole glucose, which was obtained at clearance of 0.25H.

**References**
