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Mathematical Modelling and Statistical Approach to Assess the Performance of Anaerobic Fixed Bed Reactor for Biogas Production from Piyungan Sanitary Landfill Leachate

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Abstract

Sanitary landfill method to treat solid waste offered cheaper operational cost but created environmental problems, one of which was leachate accumulation. Treatment of leachate to meet the environmental standard for disposal to the water bodies was mandatory by regulation. One way to treat leachate is using anaerobic bioreactor to digest the leachate and to produce biogas besides cleaner water to be disposed. To achieve stability in the bioreactor performance, zeolite was as microbial immobilization media. Zeolite was proven to be useful in stabilizing the growth of the microorganism and reducing the inhibitors in the leachate. The growth behavior of the microorganism before and after the zeolite addition was identified through the mathematical modelling and the statistical approach.

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Keywords: leachate; anaerobic fixed bed reactor; mathematical modelling; immobilization; zeolite; statistical approach

1. Introduction

The modernization of lifestyles, continuous development of industry, and commercial growth in economic sector has been accompanied by rapid increases in both the municipal and industrial solid waste production. The sanitary landfill method for the final disposal of solid waste material continues to be widely accepted and used due to its economic advantages. Comparative studies of the various possible means of eliminating solid urban waste (landfilling, incineration, etc.) have shown that the cheapest, in term of exploitation and capital costs, is landfilling [1]. Unfortunately, this method results in the

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undesirable side product, which was leachate. Leachate is defined as the aqueous effluent generated as a consequence of rainwater percolation through wastes, biochemical processes in waste's cells and the inherent water content of wastes themselves. The leachate generated from a landfill site containing organic, inorganic, and heavy metal compounds (Zn and Hg) has a complex mixture with a foul odour. The flow rate and the composition of the sanitary landfill leachate vary depending on site, season, and age of the landfill [2]. Leachate generated from Piyungan Sanitary Landfill, Yogyakarta, Indonesia contains high organic load (sCOD 2,800-3,500 mg.L^{-1}), high volatile fatty acid (VFA) content (970-1,000 mg.L^{-1}), and high ammonia content (500 – 800 mg.L^{-1}).

Leachate treatment using anaerobic digestion offers some advantages [3] and also the barrier which was the slow growth of microorganisms so that the using of conventional anaerobic digester needed huge volume of digester which was not economical. Besides, *wash out* often happened at the conventional anaerobic digester due to the high flowrate. The solution for stabilizing and maximizing the microorganism's growth in line with preventing the *wash out* problem is to use media to immobilize the bacteria [4,5]. By using fixed bed anaerobic digester, the possibility of the bacteria to be *washed out* can be minimized. One potential material as the immobilization media is natural zeolite. Natural zeolite's pore diameter was 3-10 Å, with the average surface area is 24.9 m^2/g approximately, and the void volume is about 29 – 39% [6]. The attachment of the microorganisms to the zeolite surface to form biofilm is supported by the nature of natural zeolite which is rich in Na^+, Ca^{2+}, and Mg^{2+} cation concentration [7].

Nomenclature

μ_{m1}	[day^{-1}]	maximum specific growth rate of acidogenic cell
μ_{m2}	[day^{-1}]	maximum specific growth rate of methanogenic cell
K_{SX1}	[mg sCOD/mg acidogenic cell]	half-saturation constant associated with sCOD
K_{SX2}	[mg VFA/mg methanogenic cell]	half-saturation constant associated with VFA
$Y_{X1/sCOD}$	[mg acidogenic cell/mg sCOD]	yield of cell formation per mg sCOD reduction
$Y_{X2/VFA}$	[mg methanogenic cell/mg VFA]	yield of cell formation per mg VFA reduction
$Y_{CH4/X2}$	[mL CH_4/g $sCOD_o$]/[mg methanogenic cell/L]	yield of cumulative CH_4 formation per cell formation
$Y_{VFA/X1}$	[mg VFA/mg acidogenic cell]	yield of VFA formation per mg acidogenic cell
K_I	[mg VFA/L]	inhibition constant associated with VFA

The reactor performance was studied by varying the weight of zeolite used inside the fixed bed. Afterward, the both mathematical and statistical approaches were required to scale-up the process in the bioreactor design in the future. Contois and Haldane kinetics were used in the mathematical approach to simulate the behaviour of the microbial growth rate because these equations were commonly used in the wastewater treatment systems [5,8,9]. In the statistical approach, Pearson correlation coefficient (Eq. 1) was chosen as the tool. From each weight of zeolite used in the fixed bed, there would be some constants derived from the mathematical equations. The correlation between the zeolite additions to the reaction kinetic can be identified from the Pearson correlation coefficient. This work aimed to identify the correlation between the various weights of natural zeolite as the immobilization media in the anaerobic fixed bed digester with the reactor performance and the Contois's and Haldane's kinetic constants.

$$r = \frac{n.\sum x.y - \sum x.\sum y}{\left\{\left(n.\sum x^2 - \left(\sum x\right)^2\right)\left(n.\sum y^2 - \left(\sum y\right)^2\right)\right\}^{0,5}} \quad (1)$$