Potential Use of Locally Available Filter Media in a UAFB Reactor Coupled with Natural Treatment in Soybean Industry Wastewater Treatment

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Abstract. Many food industries in developing countries cannot afford proper wastewater treatment and directly discharge their wastewater into surface water bodies causing several problems such as aesthetical, health and environmental problems. A new approach for low-cost wastewater treatment which is reliable, allows nutrients and energy recovery should be promoted. One of the alternative wastewater treatment technologies is anaerobic wastewater treatment which offers a number of advantages such as low energy requirement, low production of sludge and the possibility of energy recovery. As one of the disadvantages of using anaerobic method is that the effluent usually does not meet the authority’s regulation to be discharged directly into water bodies, to further treat the effluent in order to meet the standard, the up flow anaerobic fixed-bed reactor will be coupled with a ‘natural treatment’. This paper presents preliminary results of a research which has the main goal to examine the of several locally available materials as packing media in UAFB reactor and the appropriate vegetations for constructed wetland and/or macrophyte pond. Additionally, potential energy recovery from soybean wastewater is also calculated.

1. Introduction

Many food industries in developing countries fail to provide an adequate wastewater treatment installation and directly discharge their wastewater into surface water bodies such as creeks, rivers or lakes. This practice causes several problems such as aesthetical problems (odour nuisance, turbid water, etc.), health problems (skin infection, diarrhoea, etc.) and environmental problems (damage to surface or ground water, eutrophication, etc.). A new approach for wastewater treatment which is reliable and sustainable but requires low-cost and allows recovery of valuable nutrients and energy should be promoted. Selection of wastewater management systems depends on local environmental conditions, socio-economic situation, perceptions and cultural community as well as wastewater treatment technologies available.

In Indonesia, soybean products play a very important role in the dietary of the people. Since the protein of soybean is equal to the quality of protein found in meat and milk products, soybean products such as tofu (\textit{tahu}), tempe (fermented soybean), or soya milk can substitute the need of protein requirement [1]. As a consequence of increasing number of soybean industries, wastewater volume resulting from soybean industry activities is also increasing. Similar with other wastewater generated by food processing plants, wastewater from soybean industries generally contains organic materials such...
as starch (carbohydrate), fat (lipids) and proteins. This type of wastewater, which mostly is a by-product of the soybean steaming process, has a typical COD content of 2,000 to 12,000 mg/l and a total nitrogen content of up to 100 mg/l [2, 3]. Therefore, this type of wastewater is considered as high-strength wastewater that has to be treated before it is released to the environment.

Wastewater treatment plants are designed to create optimum conditions for the enhancement of the rate of the natural processes. According to Van der Steen et al. [4], the main feature of sustainable wastewater treatment systems is aimed at recycling of nutrients, water and energy. Since there is no mechanical oxygen input is required, anaerobic microbiological processes for organic removal are preferred in sustainable wastewater treatment systems. In aerobic microbiological processes, the oxygen for process is supplied by photosynthesis (algae, plants) or natural re-aeration. Although the application of anaerobic processes for industrial and domestic wastewater treatment has been intensively investigated since more than 40 years ago [5], only very few studies reported the application of anaerobic process for wastewater treatment in soybean industries [6]. Compared to the aerobic wastewater treatment process, anaerobic wastewater treatment offers a number of advantages. Among them are low energy requirement, low nutrient requirement, production of only little excess microbial biomass and the possibility of energy recovery in the form of methane. However, beside these advantages, the anaerobic process still has some limitations (such as its high cost) to be considered.

One of the most widely used anaerobic reactor is upflow anaerobic fixed bed (UAFB) reactor. It is a bioreactor in which the anaerobic organisms grow as a biofilm on the surface of non-moving supporting material. The population of microorganisms in this reactor take the substrates and nutrients from and releases the product to the medium that flows over the film. The reactor is classified as an open system since the biomass is retained on the surface of supporting material until it reaches its maximum thickness. When this condition is achieved, the biofilm will loose its adhesiveness and it will be washed out through the effluent, therefore, this system does not require a biomass recirculation [6, 7].

One of the most important part in a UAFB reactor is its packing media or supporting materials. The high cost of a UAFB reactor is the contribution of media packing price. The media packing materials that have been examined in several researches include: plastic media packing [8], blast furnace cinders, polyurethane foam and crushed stone [9], charcoal [10], polystyrene and expanded clay [11], and clay ceramic particles [12].

The UAFB reactor has also been applied to treat several types of wastewater either in full-scale reactor or in laboratory-scale reactor. These wastewater include: whey [7], pharmaceutical-containing wastewater [8], coffee bean industry [9], winery [13], landfill leachate [14], slaughterhouse wastewater [15] and phenolic wastewater [16].

Considering the aforementioned background problems, the main goals of this study was to examine the suitability of several local materials as packing (filter bed) media, either by physical/biological properties and economic considerations. In this study, several different packing materials have been evaluated and compared. The most suitable packing media will be used in the laboratory-scale upflow anaerobic fixed-bed reactors treating wastewater from soybean industry. Furthermore, several vegetations were also examined in order to find the most suitable method to enhance the quality of the UAFB effluent using “natural treatment” in the form of constructed wetland or macrophyte pond.

2. Materials and methods

The first step of this research is to examine the suitability of several locally available materials as packing material in an UAFB reactor. In order to determine which materials should be further examined, literature review and survey were conducted. The same procedure was also applied to find the suitable plants for constructed wetlands/macrophyte pond. The schematic diagram of laboratory-scale UAFB reactor coupled with “natural treatment” is shown in figure 1.
**2.1. Selection of locally available filter media**

Before conducting material selection to find the suitable materials, this study set-up a criteria matrix in order to evaluate the materials. The material selection method is a way of ranking so that the top ranking of the six materials will be used as media packing in the laboratory scale reactors. The matrix was based on literature study and previous experiences which resulted in several requirements that become the focus of the suitable packing media material determination. These requirements include:

1. It should be locally available and also must be easily found in abundant reserve,
2. The price of the packing media material should be cheap for cheaper construction of UAFB,
3. The weight of the material should be light in order to have lighter construction which will lead to a cheaper construction since it does not need to use very high-quality materials to build the reactor,
4. The surface area of the material must be large enough to provide a place for the living microorganisms (biofilm), which will be in charge to reduce the pollutants,
5. The material is non-toxic and can provide a good environment for the growth of microorganisms that will form a biofilm on the surface of the filter media,
6. If possible, a recycled material so as to reduce the burden on the environment and prevents unused material to be discharged into the environment.

From several pre-surveys and observations that have been made, there are several potential materials to be used as packing media. These materials are (see also figure 2): *bantak* of Merapi (Merapi lava stone), woven bamboo ball that contains smaller diameter of *bantak*, bamboo ring, clay roof-tile fragments, clay ring, and irregular clay ball.

**2.2. Selection of vegetation for constructed wetland/macrophyte pond**

Similar to the selection of packing materials, before conducting surveys to find the suitable vegetation, this study set-up a criteria matrix in order to evaluate the potential vegetation for constructed wetland/macrophyte pond. The requirements to determine appropriate vegetation include:

1. Should be locally available with abundant reserve on the location of the reactor,
2. Should have cheap price for procurement,
3. Does not require complex and expensive treatment,
4. Should have a function to supply oxygen to the microorganisms that reduce the organic pollutant,
5. When the vegetation is harvested, it should have an economic value (could as animal feed or handicraft material)
The vegetation to be assessed are: bulrush/cattail (*ekor kucing*) and water bamboo for constructed wetland, duckweed (*lemna*) and *eichhornia* (*eceng gondok*) for macrophyte pond (see figure 3).

![Figure 2](image1.png)

**Figure 2.** Selected materials to be observed as potential material for packing media in a UAFB. From top-left, clockwise: woven bamboo balls, bamboo rings, rooftile fragments, and *bantak*.

![Figure 3](image2.png)

**Figure 3.** Selected plants to be observed as potential vegetation to be used for constructed wetland or macrophyte pond. Top, left-right: cat-tail and water bamboo, both for constructed wetland. Bottom, left-right: duckweed (*lemna*) and *eichhornia* (*eceng gondok*), both for macrophyte pond.
3. Results

3.1. Assessment results of filter media selection

Adapted from the requirements criteria, a weighing matrix is developed to search rankings of the materials. A value of 1 was given to the material with least compliance with the criteria and value 4 to the material with most suited with the criteria. The summary of the assessment and ranking of the potential packing materials is presented in Table 1.

| Criteria                        | 1   | 2   | 3   | 4   | 5   | 6   |
|---------------------------------|-----|-----|-----|-----|-----|-----|
| Availability in nearby local/volume | 4   | 3   | 3   | 2   | 2   | 2   |
| Material price                  | 4   | 3   | 3   | 2   | 2   | 2   |
| Weight (specific gravity)       | 1   | 4   | 4   | 2   | 2   | 2   |
| Surface area                    | 3   | 3   | 4   | 3   | 3   | 4   |
| Non-toxicity                    | 4   | 4   | 4   | 4   | 4   | 4   |
| Recycled material               | 3   | 3   | 3   | 4   | 3   | 3   |

Table 1. Assessment and Ranking of the Potential Packing Materials

Description of the type of material:
1. Bantak of Merapi (Merapi lava stone)
2. Woven bamboo ball that contains small diameter of bantak
3. Bamboo ring
4. Roof-tile fragments
5. Clay ring
6. Irregular clay ball

Based from the above assessment (on the best ranking basis), the materials will be used as packing media in the laboratory scale reactors are: woven bamboo balls containing small diameter bantak and bamboo rings. The price difference of among chosen materials with the one of more sophisticated product from western industries is very large. The most sophisticated media packing from industry will cost about USD 1,000/m$^3$ media while bamboo rings and woven bamboo balls cost about USD 150/m$^3$ and USD 250/m$^3$ respectively. Therefore, the use of this locally available materials as filter bed in the reactor will reduce the construction cost and at the same time give economic improvement opportunity to the community by enabling new workplace.

According to Joo-Hwa et al. [17], media roughness and pore size were more important over surface area on the reactor performance. Within the same media porosity, pore size plays a more significant role than surface area in term of organic pollutant removal efficiency. The study indicates that the ability of a support medium to retain biomass either as suspended growth entrapped in the void space, or by attachment to the media surface is a significant consideration in an UAFB reactor.

3.2. Assessment results of vegetation selection

Aquatic plant systems (macrophyte pond) are shallow ponds with floating or submerged aquatic plants. These systems include two types based on the dominant plant types. The first type uses floating plants and is distinguished by the ability of these plants to derive their carbon-dioxide and oxygen needs from the atmosphere directly. The plants receive their mineral nutrients from the wastewater. The second type of system consists of submerged plants and is distinguished by the ability of these plants to absorb oxygen, carbon-dioxide, and minerals from the water column. Submerged plants are easily inhibited by high turbidity in the water because their photosynthetic parts are below the water.

With the same method applied for packing material selection, bulrush/cattail (ekor kucing) and water hyacinth were selected as vegetation for constructed wetland and macrophyte pond (see also Table 2).
Table 2. Assessment and Ranking of the Potential Vegetation

| Criteria                          | Type of vegetation |
|----------------------------------|--------------------|
|                                  | 1   | 2   | 3   | 4   |
| Availability in nearby local     | 3   | 2   | 4   | 4   |
| Vegetation price                 | 2   | 2   | 4   | 4   |
| Treatment complexity             | 4   | 3   | 4   | 3   |
| Environment disturbance potential| 4   | 4   | 3   | 2   |
| Potential oxygen supply          | 4   | 4   | 4   | 3   |
| Economic value                   | 4   | 4   | 4   | 2   |
| **Total score**                  | 21  | 19  | 23  | 18  |

Description of the type of material:
1. Bulrush (cattail)
2. Water bamboo
3. Water hyacinth (*Eichhornia*)
4. Duckweed (*lemna*)

Cattail, easily recognizable by their tall leaves and brown pistillate spike, is a common wetland plant. Cattails provide shelter for birds and mammals, shade water to cool fish, and their energy-rich rhizomes and shoots are a nutritious food source for many animals including humans [18]. With its high growing rate [19], *Eichhornia* is an excellent source of biomass which can be used for animal feed, energy sources and fertilizer/soil conditioner [20]. Several researchers also examined the potential use of *Eichhornia* as herbicide [21] and its use for medicinal use, e.g. its activity against human cervical cancer [22].

3.3 Methane production and potential energy recovery

The potential of a substrate to be converted to biogas during anaerobic treatment is essential to determine the suitability of a substrate as a feeding in anaerobic digester. The higher methane potential owned by a substrate the more attractive the substrate as a feeding, since it will give the higher energy recovery rate in the form of biogas. The biogas production potential of biodegradable solid wastes depends on the content of digestible carbohydrates, lipids and proteins, as well as on the content of more resistant cellulose, hemicellulose and lignin. According several researchers, COD elimination efficiency of UAFB reactors reached a range of approximately 60 - 90% with a range organic loading rate (OLR) of 1.5 – 4.6 kg COD/m³.d [8, 23, 24]. This data will be used to predict the potential biogas production of soybean industry wastewater and also to calculate the energy balance of the treatment.

Assuming that the soybean wastewater has a COD content of 8,000 mg/l and applying an average hydraulic retention time (HRT) of 5 days, a reactor volume of 250 m³ should be provided to treat wastewater from the semi-centralized (clustered) soybean industry. In this paper, it is assumed that COD removal is about 60%. With this assumption, 240 kg COD can be removed daily from wastewater by UAFB reactors. Using assumption that each kilogram of COD removed can produce 0.4 m³ methane, the reactors can produce 96 m³ biogas daily. It is equal to 57.6 m³ methane daily as it is assumed that 60% of methane is pure methane. If the energy content of methane is assumed 50.1 kJ/g CH₄ and methane density at 35°C is 0.6346 g/l [25], total energy recovered from wastewater would be 503.8 kWh/day. In Indonesia, electricity is sold for 0.065 USD/kWh in 2014. If the electricity produced by UAFB reactor is sold to the National Electricity Company (the PLN), it means that energy recovery activity from soybean industry wastewater can generate money of 11,951 USD per annum. See also Table 3 for the calculation of reactor dimension and potential energy recovery.
Table 3. Reactor dimension and potential energy recovery

| Parameter                                           | Unit | Value  | Remarks                      |
|-----------------------------------------------------|------|--------|------------------------------|
| Wastewater production/household - industry          | m³/d | 5      |                              |
| Number of household - industry/cluster               | HH   | 10     |                              |
| Wastewater production                               | m³/d | 50     |                              |
| Designed HRT                                        | d    | 5      | COD: 8.0 kg/m³               |
|                                                     |      |        | OLR: 1.6 kg/m³/d             |
| Active reactor volume                                | m³   | 250    | Removal efficiency:          |
|                                                     |      |        | 60%, each kg COD removed    |
|                                                     |      |        | produce 0.4 m³ biogas       |
| Daily biogas production                              | m³   | 96     |                              |
| Daily methane production                              | m³   | 57.6   | Methane content: 60%         |
| Energy recovered                                     | MJ   | 1,812.1| Each m³ methane: 31.46 MJ    |
| Energy recovered                                     | kWh/day | 503.8 | 1 MJ: 0.278 kWh              |
| Potential benefit                                    | USD/year | 11,951.8 | 1 kWh: USD 0.065         |

4. Conclusion

UAFB reactor can be constructed from locally available materials. The use of this kind of materials will reduce the cost of construction and make this technology affordable for developing countries. Moreover, from the above calculation simulation and prediction of energy recovery, it can be concluded that the application of UAFB reactor with locally available materials to treat wastewater from soybean industries has a very good prospect. This application can reduce the environmental risk of wastewater discharge and in the same time give the opportunity to recover energy from wastewater.

5. References

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