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Emergy analysis of cassava vinasse treatment

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ABSTRACT

Vinasse has great pollution to the environment. A number of technologies have been explored for reducing the pollution of vinasse. Sustainability has become an important factor when discussing wastewater treatment techniques. Emergy analysis was used to evaluate the treatment of cassava vinasse in this paper. Cr (emergy consumption ratio) as a new emergy index was proposed to measure the impact of waste treatment to the society. Centrifugal solid–liquid separation, UASB (up-flow anaerobic sludge bed), and SBR (sequencing batch reactor activated sludge process) are used in the treatment process. The emergy indices for cassava vinasse treatment system were as follows: EYR (emergy yield ratio) was 6.20, ELR (environmental loading ratio) was 5.81, ESI (emergy sustainability index) was 1.07, and Cr was 4.60E+12 sej/m^3. The emergy of coal electricity accounts for 46% of all purchased inputs. It is necessary to improve the treatment technology to reduce the electricity used.

Keywords: Emergy analysis; Vinasse; Sustainability

1. Introduction

The industrial production of ethanol through fermentation results in the discharge of large quantities of wastewater generally called stillages, distillery slops or vinasses, which have caused serious environmental concern. On an average 8–15 L of vinasse is generated for every liter of alcohol produced (Saha et al., 2005). Vinasse from cassava based ethanol production are moderately acidic (pH 4–5), have a high organic content, high ash content, and high concentration of mineral salts. Cassava vinasse consists of different organic compounds such as acetic acid, lactic acid, glycerol and various reducing sugars (Yavuz, 2007). Further, its dark color hinders photosynthesis by blocking sunlight and is therefore deleterious to aquatic life (FitzGibbon et al., 1998).

A number of technologies have been explored for reducing the pollution load of vinasse. Biological treatment of vinasse is either aerobic or anaerobic, but in most cases a combination of both is used. Various physicochemical methods such as adsorption, coagulation–flocculation, and oxidation processes like Fenton's oxidation, ozonation, electrochemical oxidation using various electrodes and electrolytes, nanofiltration, reverse osmosis, ultrasound and different combinations of these methods have also been practiced for the treatment of vinasse. These processes are employed generally after the primary anaerobic treatment in order to further reduce the COD and color.

At present, sustainability has become an important factor when discussing wastewater treatment techniques. Many different approaches have been used by different authors to assess sustainability of wastewater treatment. Sustainability of wastewater treatment has been discussed from a life cycle analysis perspective by Bengtsson et al. (1997), and Muñoz et al. (2006), from an exergy perspective by Hellström and Kärrman (1997), and Celma and Cuadros (2009), from an economic perspective by Breaux et al. (1995), and Benedetti et al. (2008), and from an emergy perspective by Björklund (2000) and Geber and Björklund (2002). Each method mentioned above has its own advantages that help us understand the sustainability of the wastewater treatment from a special perspective.

Analyses which do not regard human labor, environmental work and quality differences between different natural resources, scarcely deal with environmental impacts at substantially different places and times, or with the trade-off between them. Such studies are, therefore, not sufficient to

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rely on when discussing ecological sustainability on larger time and spatial scales (Björklund et al., 2001). The emergy-based analysis can be used as a supplement to conventional money-based accounting by unifying the value of free environment inputs, goods, services and information in a common unit, as well as avoiding the shortage of traditional energy analysis (EA) through consideration of both energy quality and energy used in the past, therefore provided a more feasible approach to evaluate the status and position of different energy carriers in the universal energy hierarchy (Odum, 1996).

The treatment of cassava vinasse was evaluated by emergy analysis in this paper. Emergy analysis has many indices to evaluate the system, and it is possible to provide insight into the present and future performance and sustainable development of vinasse treatment technology.

2. Methodology

2.1. *Emergy theory*

To integrate the value of free environment investment, goods, services and information in a common unit, an ecological evaluation approach based on a novel concept of emergy in terms of embodied energy was first presented in 1983 by Odum. Solar energy is used as the common denominator through which different types of resources (energy or matter) can be measured and compared.

Solar emergy is the baseline of this study. All the inputs along the production process such as mass quantities (kg) or energy quantities (J) are converted into solar emergy (sej) by multiplying a transformation coefficient, namely transformity or specific emergy. Transformity is the solar emergy required, directly or indirectly, to make 1 *J* or kilogram of a product or service. The more energy transformations there are contributing to a product, the higher the product's transformity, and the product therefore occupies a correspondingly higher position in the energy hierarchy (Odum, 1996). Therefore, transformity can be used as energy scaling ratio to indicate energy quality and the hierarchical position of different energy sources in the universal energy hierarchy (Rydberg and Haden, 2006).

Money payments can also be converted into emergy units by multiplying the emergy/dollar ratio. The emergy/dollar ratio is the ratio of total emergy use of a state or country to gross national product (GNP) for the national economy. It varies in different countries and has been shown to decrease each year, which is an index of inflation.

2.2. *Emergy indices*

Emergy analysis has many evaluation indices, which can provide a better insight into particular cases and distinguish the renewable and non-renewable components of the total emergy that drives the process, as well as the "natural" and economic inputs. The sustainability, renewability and efficiency of the system can be clearly analyzed through a series of emergy-based ratios and indices. The indices such as EYR (emergy yield ratio), ELR (environmental loading ratio), and ESI (emergy sustainability index) are often used.

2.3. *Cr (emergy consumption ratio)*

In the previous theory of emergy, waste produced accompany with the product, was thought to have the same emergy with the product. But the waste is harmful to our environment, and it is not what we need. Additional emergy was consumed in the treatment of waste.

Therefore, the waste has not transformity was first put forward in this paper. Cr (emergy consumption ratio) was also first proposed in this paper. Cr is the ratio of emergy consumed in the treatment to the amount (mass or volume) of the waste. It can be used to measure the impact of waste treatment to the society from the perspective of emergy consumption. The higher ratio means larger impact of waste treatment to the society, and lower efficiency of the treatment technology.

2.4. *Emergy evaluation procedure*

Emergy accounting is organized as a top down approach where system diagrams of processes are drawn to organize evaluations and account for all inputs and outflows from processes. Tables of the actual flows of materials, labor and energy are constructed from the diagrams and all flows are evaluated. The different units for each flow are multiplied by transformities to convert them to solar emergy. Comparison between flows of different materials and energies are possible once expressed in emergy units. In fact, the different inputs to a process can be summed to evaluate the total emergy requirement, which is then divided by the energy of the product to yield the transformity of the product (Ulgiati and Brown, 2002).

First, the system diagram was drawn to make the system processes clear. A system's diagram is drawn using the symbols of the energy language of systems ecology to graphically represent system components, emergy sources and flows and the circulation of money through the system (Odum, 1994, 1996). The components and subsystems are connected with arrows that indicate energy, feedstock and information flows (Odum, 1996). Second, emergy evaluation tabulation is made to list the numerical value and the units of each flow mentioned in the diagram. To obtain the emergy value of each input, the raw data of input such as joules, grams or dollars are multiplied by their transformities. Finally, various emergy-based indicators are calculated to assess the eco-efficiency, environmental impact and the sustainability of the studied system.

3. The studied system

The cassava vinasse treatment in an alcohol production factory of Shandong province in China was studied. The amount of vinasse treatment is 300 m^3 per day. Centrifugal solid–liquid separation/UASB/SBR are used in the treatment process. According to the data provided by the factory, the quality of the influent and effluent wastewater is shown in Table 1.

The flow chart of vinasse treatment process is shown in Fig. 1. Cassava vinasse were collected by collecting basin, and then pumped to the solid–liquid separator. The solids could be used as the feed additives. Neutralizers were added into the liquids to modulate pH value between 6.8 and 7.2 in regulation pond. Biogas was produced in UASB reactor, and the wastewater went through UASB reactor into settling tank to remove the sludge. Then the sludge was put to the drying field. The wastewater from settling tank went through coagulation and floatation to remove the light SS and colloids. After going through SBR reactor, the wastewater was discharged.