Design of baffle in upflow anaeorobic engineering essay

The Upflow Anaerobic Sludge Blanket process was developed by Lettinga in the Netherland during the early 1980s, as a relatively simple wastewater treatment system, in which no moving parts are present(Lettinga et al, 1980). It was first proposed for the treatment of high strength industrial waste, but soon research for its application also within domestic sewage treatment was initiated. The UASB reactor is now becoming a popular treatment method for industrial water, because of its effectiveness in treating high strength wastewater. From the Seghezzo et al. (1998), the features which make UASB reactor to be popular:

High efficiency. Availability of granular or flocculent sludge, allowing it to achieve high chemical oxygen demand (COD) removal efficiencies without the need of support material. Furthermore, the natural turbulence caused by caused by rising gas bubbles which buoy the sludge, provides efficient wastewater and biomass contact.

Simplicity. The construction and operation of the reactor is relatively simple.

Flexibility. Anaerobic treatment can easily be applied on either a very large or a very small scale. Besides, due to the granulation/blanketing in a UASB reactor, the solids and hydraulic retention time can be manipulated independently and effectively, thus permitting the design to be based upon the degradative capacity of the biomass, resulting in the reduction of treatment times from days to hours. (Hickey et al. 1991)

Low energy consumption. As far as no heating of the influent is needed to reach the working temperature and all plant operations can be done by gravity, the energy consumption of the reactor is almost negligible. Moreover, energy is produced during the process in the form of methane.

Low sludge production. The sludge production is low, when compared to anaerobic methods, due to the slow growth rate of anaerobic bacteria. The sludge is well stabilized for the final disposal and has good dewatering characteristics. It can be preserved for long periods of time without a significant reduction of activities, allowing its use a inoculums for the start-up of new reactors.

Low nutrients and chemical requirement. Especially in the case of sewage, an adequate and stable pH can be maintained without the addition of chemicals.

The UASB has been successfully used in the recent past to treat a variety of industrial as well as domestic wastewater. The applications for this technology are expanding to include treatment of chemical and petrochemical industry effluent, textile industry wastewater, landfill leachates, as well as applications directed at conversions in the sulfur cycle and removals of metals. Furthermore, in warm climates the UASB concept is also suitable for treatment of domestic wastewater.

1. 2 PROBLEM STATEMENT

The design and optimization of Upflow Anaerobic Sludge Blanket (UASB) reactor units required knowledge of bio kinetics, mixing, chemical reaction and else. However, the hydrodynamics within a UASB reactor is a critical importance to the performance of the system. Current wastewater treatment design methods make assumptions of the mixing conditions and it is therefore difficult to predict how vessel design for example, position of inlets, baffles or dimensions which could affects hydrodynamics, hence overall performance. Besides, the applications of the experimental techniques to investigate flow fields and mass concentration fields are extremely costly and also highly limited in application. Thus, an appropriate factor which is design of baffles had been chosen; and investigated the influences of hydrodynamics and performances of UASB reactor in this study.

Computational Fluid Dynamics (CFD) provides a mathematical method for prediction of the effect that wastewater treatment process design features on the hydrodynamics from a fundamental level. Advances in CFD have provided an efficient, economical and time saving tool to investigate the hydrodynamics and reaction conversion occurring in a UASB reactor.

OBJECTIVES

The thesis has two main objectives; firstly is to conduct the performance study of the designed Upflow Anaerobic Sludge Blanket (UASB) reactor which can be applied to full scale systems. The Computational Fluid Dynamics (CFD) model presented here has the ability to model multiple phases (in this case the sludge mixture with water and air). Besides, the CFD model was developed and applied for the construction of real scale model.

The second objective is to study the effects of baffles to the hydrodynamics for example the fluid mixing pattern, flow field, coupling and of the 3 phases (liquid, solid and air) of waste water treatment process. In this study, the experiment would conduct with baffled UASB reactor and the other is un-baffled UASB reactor to further study the influences to the hydrodynamics and overall performances.

CHAPTER 2

LITERATURE REVIEW

2. 1 TREATMENT PRINCIPLE OF UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR

The Upflow Anaerobic Sludge Blanket (UASB) process consists of an upflow of wastewater through a dense sludge bed with high microbial activity. In the reactor, the solids profile varies from very dense and granular particles with good settle ability close to the bottom (sludge bed), to more dispersed and light sludge particles close to the top (sludge blanket).

The UASB reactor can be divided into four components: sludge bed, sludge blanket, gas-solid-liquid separator and secondary compartment above the separator. The sludge bed is situated at the bottom of the reactor and consists of a dense sludge with exceptional settling characteristics; it is therefore kept in the reactor. Above the sludge bed is the sludge blanket, with solid presenting lower concentration and settling velocities. The sludge blanket consists of sludge particles in a mixture with the biogas formed, and is thus held in suspension. It is in these two compartments, the sludge bed and the sludge blanket, that the incoming wastewater is biologically degraded (Chernicharo, 2007).

Biogas

Sludge particle

Gas bubbles

Baffle

Sludge Blanket

Sludge bed

Digestion Compartment

Settling Compartment

3-phase separator

Figure 1 UASB reactor

The wastewater flows upward in a vertical reactor through a blanket of granulated sludge and bacteria in the sludge break down organic matter by anaerobic digestion, transforming it into biogas. The biogas-production and the influent flow cause natural turbulence in the reactor, which provides a good wastewater-biomass contact in the UASB reactor system (Heertjes al., 1978). The upflow regime and the motion of the gas bubbles allow mixing without mechanic assistance. To avoid sludge washout, the 3 phase separator is installed in the upper part of the reactor. The gas formed is separated from the liquid, which allow sludge retention and return. Above the separator, a gas free zone is formed which is settling compartment, for sedimentation of solid particles, and most of the particles that have entered this zone will settle back to the reactor, whereas the smallest particles will be washed out with the effluent (Angelidaki et al, 2007). Baffles at the top of the reactor allow gases to escape and prevent the outflow of the sludge blanket.

The 3-phase separator, or the gas-liquid-solid (GLS) separator, enables a high retention capacity of large amounts of high-activity biomass in the reactor. Through this feature, a solids residence time (SRT) much higher than the hydraulic retention time can be achieved. Consequently, the maintenance of high SRT is the major point of interest in practical application of UASB process. This ability to develop and maintain high-activity sludge within the reactor is the most important aspect of the UASB concept (Chernicharo, 2007).

2. 2 ANAEROBIC PROCESS IN THE UASB REACTOR

In UASB reactor, anaerobic microorganisms in the sludge blanket digest the organic pollutants in the incoming wastewater. Anaerobic digestion produces biogas (a mixture of methane CH4, carbon dioxide CO2 and traces gases). After some weeks of maturation, granular sludge forms and this is the main prominent characteristic of UASB reactor named phenomenon of granulation. The formation of granules is very important because bacteria in granules are more efficient for biogas production than the flocculated biomass (Wendland2008).

The anaerobic granular sludge consists of microbial communities, with millions of microorganisms per gram biomass. Usually the granules are grouped densely together and have excellent settling ability. The size wise each granule ranges from 0. 1to 5mm. The microstructure of each granule will be dictated by the substrate characteristics of the influent, for simple substrates only methanogens are needed for complete degradation. For complex substrates, generally the different bacterial populations will group together selectively in layers on top of each other (Tiwari et al, 2006).

The granular sludge enables the retention of a very high number of microorganisms in the reactor, which means that a rapid degradation of organic matter can be obtained. In turn, a large volume of waste can be treated within a volume that takes up only small amount of spaces. Besides, anaerobic sludge has or acquires good sedimentation properties, and is mechanically mixed by the upflow forces of the incoming wastewater and gas bubbles being generated in the reactor. For that reason, mechanical mixing can be omitted from an UASB reactor and thus reducing capital and maintenance costs. This mixing also encourages the formation of sludge granules.

2. 3 DESIGN CONSIDERATIONS OF UASB REACTOR

The UASB reactor can be designed as circular or rectangular. It is necessary to select proper range of operating parameters for design, such as organic loading rate (OLR), SLR, superficial liquid upflow velocity and hydraulic retention time (HRT).

Generally, there are two ways to design UASB reactor which are based on HRT or OLR. In the case of low strength wastewater, such as sewage, it is the HRT rather than the OLR that determines the design method of UASB reactor. In view of the rather low organic loads that can be applied in the treatment of dilute wastewater, and the lower mixing resulting from the gas production, it is apparent that more inlet points are needed, in comparison with the same reactor under high organic loading rates condition (Lettinga et al, 1983).

2. 3. 1 Low strength wastewater – Hydraulic Retention Time

For low strength wastewater with COD input less than 5000mg/l, the design method should be calculated based on the HRT which can be controlled by volumetric hydraulic load. It is note that HRT means the measure of the average length of time that a soluble compound remains in the reactor. Anaerobic digestion depends on the biological activity of relatively slowly reproducing methanogenic bacteria. These bacteria must be given sufficient time to reproduce, so that they can replace cells loss with the effluent sludge, and adjust their population size to follow fluctuations in organic loading. If the rate of bacteria loss from the digester with the effluent slurry exceeds the growth rate of the bacteria, the bacterial population in the digester will be “ washed out” of the system. This washout is avoided by maintaining a sufficient HRT for ensuring that the bacterial cells remain in optimal concentration within the digester. The longer a substrate is kept under proper reaction conditions the more complete its degradation will become. However, the reaction rate will decrease with increasing HRT. Thus, the amount of wastewater applied daily to the reactor, per unit volume, is termed the volumetric hydraulic load:

(2. 1)

where:

VHL = volumetric hydraulic load (d-1)

Q = flow rate (m3/d)

V = total volume of reactor (m3)

The hydraulic retention time (HRT), given in days, is expressed as

(2. 2)

which gives that,

(2. 3)

For tropical climates and subtropical climates experimental results showed that a HRT of six hours was sufficient to achieve satisfactory results in a one compartment UASB. In table 1 presents some guidelines for the establishment of HRTs in design of UASB reactors treating domestic wastewater.

Table 1: Applicable Hydraulic detention time for raw domestic wastewater in a 4m tall UASB reactor at various temperature ranges. (adopted from Lettinga et al, 1991)

Sewage temperature (°C)

HRT(h)

Daily Average

Minimum (during 4 to 6 h)

16-19

> 10 – 14

> 7 – 9

20-26

> 6 – 9

> 4 – 6

> 26

> 6

> 4

2. 3. 2 High strength wastewater – Organic load rate

In the COD input between 5000 – 15000mg/l or more, the design method should be calculated based on OLR. Bacteria have a maximum production rate depending on the type of reactor and substrate. The OLR is one of parameters used to describe this production rate. Bacteria and microorganisms have their specific growth rate that will achieve a maximum production rate when they degrade substrate. Thus, different OLR give different impacts to the reaction rate and efficiency as well. By definition, the volumetric OLR is the amount of organic matter applied daily to the reactor, per volume unit:

(2. 4)

where:

OLR = organic loading rate (kgCOD/m3d)

S = influent substrate concentration (kgCOD/m3)

COD treatment efficiency can be calculated by:

(2. 5)

For COD concentration in the range of 2 to 5g/L. the performance of the reactor depends on the hydraulic loading rate and is independent of influent substrate concentration. For COD concentration greater than 5g/L it is recommended to dilute the wastewater to about 2g COD/L during primary start up of the reactor. Once the primary start – up of the reactor is over with the granulation of sludge, loading rates can be increased in steps to bring the actual COD concentration of the wastewater. The loading above 1-2kg COD/m3d is essential for proper functioning of the reactor.

2. 3. 3 Upflow velocity, reactor height and volume

Higher upflow velocity, favors better selective process for the sludge and improve mixing in the reactor. However, too high upflow velocity may causes the incolumn get washed out during start up. Besides, during normal operation granules may get disintegrated and the resulting fragments can easily be washed out from the reactor. Thus, design the optimum liquid upflow velocities resulting favorable for granule growth and well fluid mixing with the activated sludge. The upflow velocity, v , is calculated from the relation between the influent flow rate and the cross section of the reactor:

(2. 6)

where:

v = upflow velocity (m / h)

A = cross sectional area of the reactor (m2)

Alternatively, the upflow velocity can also be calculated from the ratio of the height and the hydraulic retention time :

(2. 7)

where:

H = height of the reactor (m)

The choice of appropriate height of the reactor depends on the required performance and economic considerations. Another important aspect is the position of the bottom of the reactor, relative to ground level. Construction costs can be reduced if the reactor bottom can be placed at such level that no pumping system of influent is required. The reactor height also has importance for the efficiency of the organic matter removal, as the upflow velocity must not exceed the limit where the sludge washed out. The upflow velocity, and reactor height are closely related in Equation 2. 7.

Based on the higher suitable value of OLR, for given COD concentration, the volume of the reactor required is to be worked out as:

(2. 8)

The volume of sludge should be less than 50% of the reactor volume, worked out based on OLR, to avoid overloading of the reactor with respect to SLR. If the volume is not meeting the requirements, the OLR can be reduced to increase the volume.

2. 3. 4 Influent Distribution System

It is of vital importance that the influent substrate is evenly distributed in the lower part of the reactor. Otherwise a close contact between biomass and substrate cannot be obtained. The gas production will always contribute substantially to the mixing of the sludge bed, and therefore the mixing within the digestion compartment will typically be hindered when treating wastewater. Poor mixing can lead to the creation of preferential pathways through the sludge bed. For example, hydraulic short circuits, which in the long term will give a shorter sludge bed height and the formation of dead zones in the sludge bed (Lettinga et al, 1991). To avoid this problem, the influent should be introduced at several points from the reactor bottom. A special influent distribution system can guarantees equal distribution over the entire reactor surface area. Thus, the influent then passes a dense and expanded anaerobic granular biomass bed and the biological treatment efficiently.

The number of distribution pipes needed depend on the area of the cross section of the reactor. Chernicharo (2007) suggests that Equation 2. 9 be used to determine the number distribution pipes:

(2. 9)

where:

Nx = number of distribution tubes

A = area of cross section of the reactor (m2)

Ax = influence area of each distributor (m2)

2. 4 Fluid Mixing In UASB Reactor

The flow pattern in the UASB reactor is one of the most important factors to be considered for design to facilitate an efficient treatment. The efficiency of all bioprocesses is closely connected with mixing and transport phenomena, as an even mixing pattern will provide good conditions for substrate transport to and from the microbial aggregates. Thus, the conversion of organic matter in the UASB reactor is governed by not only the performance of the microbiological processes, but also the hydrodynamics of the reactor. However, the behavior of the UASB process is not fully understood.

The mixing inside a UASB reactor is related to several parameters, such as the type of influent-feeding device, upflow velocity and biogas production rate, and different studies have used different models to describe its hydrodynamics. Heertjes et al (1978) assumed the flow to be completely mixed within the sludge bed and sludge blanket, although the sludge bed could also have dead spaces and returning flows.

The more accurate models of the UASB hydraulics where recently highlighted by both Zeng et al (2005) and Lou et al (2006), stating that the existing mathematical models of anaerobic digestion in UASB reactors largely assume ideal mixing, thus neglecting concentration gradients. To create a more correct model of the reactor hydraulics, Zeng et al (2005) instead used a two-compartment model, with the sludge bed and liquid zones described by a two-zone axially dispersed system. The study showed that in a UASB reactor there is a strong dependence of the dispersion coefficient on both reactor height and upflow velocity.

2. 4. 1 Computational Fluid Dynamics (CFD)

With appearance of general purpose codes, such as FLUENT, CFX and others, Computational Fluid Dynamics (CFD) has become increasingly popular in environmental technology. CFD codes also can be used to visualize detailed flow phenomena, a significant benefit for the measurement of parameters such as pressure, velocity, phases volume fraction and else. The work mentioned above mainly concentrated on applying CFD codes to obtain UASB reactor hydrodynamics data, thus making beneficial suggestions for UASB reactor design and optimization. The models used were simplified two phases or single phase systems. Related UASB reactor simulation based on gas-liquid-solid three phase models and flow process related reaction kinetics models widely studied. For the first time, the focus lies on establishing hydrodynamics-reaction kinetics coupled model of a gas-liquid-solid three phase waste water treatment system using CFD simulation followed by experimental verification in this paper.

Although UASB reactor has been used in environmental technology applications for many years, lithe research has been published on UASB reactor modeling. The principal objectives of this study are to develop an easy to use of CFD model of the significant process parameters, based on fundamental science and to validate the model by use of experiment results. Due to not much researching on baffled UASB reactor, our coupled model was applied and validated on a waste water treatment process and investigate the overall performance. Once developed and assessed with the full-scale trial results, the model can be employed to analyze the effect of waste water quality characteristics on the performance of the process. It is expected that this study will prove useful in applying UASB technology.

CHAPTER 3

METHODOLOGY

3. 1 Computational Fluid Dynamics (CFD) simulation

The commercial Computational Fluid Dynamics (CFD) code ANYSYS FLUENT was used to simulate the two and three dimensional flow field before construction of the Upflow Anaerobic Sludge Blanket (UAB) reactor. A conceptual model was developed by the software and this proposed CFD model is composed of the core hydrodynamics model for the liquid and gaseous phases, and coupled with the sludge. CFD simulation helps to describe flow of the liquid and gas components of the multiphase flow. The continuous phase is the wastewater and sludge and the dispersed phase is air or biogas. The assumptions made for the dispersed phase are:

The bubbles are spherical

The bubbles have constant diameter

No collisions, coalescence or break-up of bubbles

The gas phase physical properties for example density and viscosity were air properties. For the liquid phase, the density was considered to be that of water, while in terms of viscosity.

3. 1. 1 Eulerian-Eulerian model

This model is help to solve a set of momentum and continuity equations for each phase. Applications of Eulerian multiphase model include bubble column, risers, particle suspensions and fluidized beds (Saurel and Abgrall 1999; Mathisesen et al. 2000). In this study, two dimensional Eulerian-Eulerian three phase fluid model has been employed to describe the flow behavior of each phase, so the biogas, wastewater and sludge granules are all treated as different continua, with wastewater as a primary phase, and the gas and sludge granules as the secondary phases. This model was chosen because of the high proportion of gas bubbles and granules particulates (Bin et al. 2003).

3. 1. 2 Species Transport and Reaction model

CFD codes can model the mixing and transport of chemical species by solving conservation equations describing convection, diffusion and reaction sources for each component species (Sivertsen and Djilali, 2005). Multiple simultaneous chemical reactions can be modeled, with reactions occurring in the bulk phase (volumetric reaction), on inside wall of the reactor or particle surfaces.

3. 1. 3 Numerical solution

The complete geometry of the UASB reactor have analyzed by a computational two-dimensional mesh. For efficiency use of computational time, simulation of the UASB reactor exploits the symmetric geometry of the reactor in a two-dimensional surface. The meshes were created in the ANYSYS Fluent as a preprocessor program and exported into the ANYSYS

Fluent CFD flow modeling software package to solve the continuity and momentum equations.

In Eulerian-Eulerian model, each phase was assumed incompressible. The wastewater was regarded as mixed liquid, initially containing pure water and some chemical wastes and the density was determined by using a volume weighted mixing law. The sludge granules took up about 35% of the volume in the bed region and were considered to be 1mm diameter spherical solid granules. The biogas was assumed to have a density by the incompressible-ideal-gas law (FLUENT 6. 0 Users' guide, 2001). The gas phase volume fraction was related to gas production in reaction and the gas bubbles were assumed to have a diameter of 0. 1 mm.

The simulation results vary little with grid density so truncation errors in the numerical simulation can be neglected. An analysis independent of the grid was performed to eliminate errors in simulation accuracy, numerical stability, convergence and computational steps related to grid coarseness (Ait-Ali-Yahia et al. 2002; Lu et al, 2009).

3. 2 Experimental Design

The research is conduct with two different types of UASB reactor model which are baffled and un-baffled to further study the influences of fluid mixing pattern in the reactor. Figure 1 shows the schematic diagram with dimensions of 1m x 0. 2m.

C: UsersKok FaiDesktopUASB. png

Figure 2: Schematic Diagram of the UASB reactor model. All units are in meter.

Table 2: Main feature of the UASB reactor model

Parameter

Value

Design liquid flow rate (l/h)

Hydraulic retention time (h)

Total Height (m)

Water depth (m)

Sludge depth (m)

Internal diameter (m)

Internal cross sectional area (m2)

Organic load (kg COD/m3/d)

Table 3: composition of waste water

Incoming waste water

Value

Total BOD (mg/l)

Total COD (mg/l)

Chloride (mg/l)

Sulfate (mg/l)

–

–

–

One of the UASB reactors is baffled and the other one is un-baffled. Both of these reactors operated with the same hydraulic retention time, organic load and composition of waste water which are the constant variables in this experiment. The differences of the chemical waste substances removal efficiency between both reactors would be the result of this study.

3. 2 Sampling and Analysis

Composite sample of the reactors influent and effluent were collected on a daily basis and analyzed for COD, BOD, sulfate and others chemical waste substances. Sludge sampling was carried out through side ports in the sludge zone of the reactor. The flow rate was control by the valve and continuously regulated by a pump.

3. 2. 1 BOD test

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen by aerobic biological organisms in a body of water to breakdown organic material present in a given water sample at certain temperature. BOD also can be used as gauge of the effectiveness of UASB reactor. The procedure of the BOD test:

The dilution water was prepared by 1ml each of phosphate buffer, magnesium sulfate, calcium chloride, ferric chloride solution into 1L distilled water.

1ml wastewater sample was added into a 500ml beaker.

Dilution water was added up to 300ml into same beaker.

The pH value was adjusted to 6. 5 to 7. 5 by added acid or alkali.

300ml dilution water was prepared as control.

All prepared samples and control put in 300ml-incubation bottle.

The DO for each sample was measured by using Dissolved Oxygen Meter.

All the bottles put in BOD incubator for 5 days. The temperature was set at 20°C.

The BOD5 was calculated according to the formula below:

Where:

D1 = DO value in initial sample

D2 = DO value in final sample

P = decimal volumetric fraction of sample used

Or;

Dilution factor = Bottle volume (300ml) / sample volume

3. 2. 2 COD test

The chemical Oxygen Demand (COD) test measured the oxygen equivalent consumed by organic matter in a sample during strong chemical oxidation. It can help to predict the oxygen requirements of the effluent and is used for monitoring and control of discharges, and for accessing reactor performances. The test method:

The wastewater sample was oxidized by digesting in a sealed reaction tube with sulphuric acid and potassium dichromate in the presences of a silver sulphate catalyst for 2 hours at a temperature of 150°C.

The amount of dichromate reduced is proportional to the COD.

A reagent blank was prepared for each batch of tubes in order to compensate for the oxygen demand of the reagent itself.

Over the range of the test a series of colors from yellow through green to blue are produced. The color is indicative of the chemical oxygen demand and its measured by using photometer.