ENHANCING OF UASB EFFICIENCY BY MIXING THE SEEDING SLUDGE WITH CLAY MINERALS

S. Bayoumi, K. Ewida and D. Saad El-Din

Environmental Engineering Department, Faculty of Engineering,
Zagazig University, Egypt

ABSTRACT

One of the main challenges facing wastewater treatment reactors remains the enhancement of its design and/or operation. In recent years, numerous designs and/or configurations of these reactors have been developed to optimize the anaerobic treatment of wastewater. The ability of clay minerals to create a favorable environment for the growth of microorganisms as well as to work as a catalyst of the reactions and degradation of organic compounds has been addressed for long time.

The present study investigated the influence of mixing the seeding sludge with clay minerals on the efficiency of raw sewage treatment in a pilot-scale model simulating UASB reactor. Kaolinite and montmorillonite are utilized in the present work as clay minerals, while organics (BOD and COD) and solids (SS and DS) are selected as assessment parameters of the treatment process. While the two UASB models constructed and operated within the work-frame of the present work are identical and operated under the same operation conditions and scenario, one of them was seeded with a mixture of sludge and kaolinite and the other was seeded with a mixture of sludge and montmorillonite. Different mixing ratios (weight-basis) of clay minerals and sludge (Wc:Ws) ranged from 0% to 80% have been investigated in the present study.

Among the results obtained from the experimental program executed within the scope of the present work is that montmorillonite enhances the UASB efficiency regarding the removal of organics and solids from raw domestic wastewater better than kaolinite. The enhancement reached 20%, 30%, and 25% in the % removal of BOD, COD, and SS respectively upon mixing the sludge seeded to the UASB with montmorillonite at a mixing ratio (Wc:Ws - weight-basis) of 40%. While mixing ratios higher than 40% doesn’t rise the gained enhancement that much amount, the mixing ratios lower than 40% yield a considerable enhancement.

Keywords: UASB, Domestic Wastewater, Clay Minerals, Kaolinite, Montmorillonite.

INTRODUCTION

In recent years, numerous designs of reactors have been developed to optimize the anaerobic treatment of wastewater. One of the major successes in the development of anaerobic treatment of wastewater was the introduction of high-rate reactors in which biomass retention time and liquid retention time are uncoupled (Lettinga, 2001).

The upflow anaerobic sludge blanket (UASB) reactor is one of the simplest anaerobic treatment systems that have been ever known. The dominating advantages of UASB reactor are the simplicity of construction, low construction and operating cost, the absence of expensive support media, low production of excess sludge, short retention times, low energy demand, production of biogas and no need for electromechanical equipment (Weiland and Rozzi, 1991).

However, UASB reactors are very efficient in removing suspended solids (SS) and organic material (BOD and COD) from wastewater, when they are operated in regions with a tropical or subtropical climate **(Paula, 2003)**. Although numerous designs and/or configurations of wastewater treatment reactors have been developed in recent years to optimize the anaerobic treatment of wastewater, one of the main challenges remains the enhancement of these designs and/or operations.

Clay minerals usually activate a wide variety of organic leading to transformation and/or decomposition of the adsorbed species. Clay minerals tend to stick things together and slow the movement of air and water through the mixture. These characteristics are related to the small size of clay crystals. In addition, clay minerals stimulate the microorganisms to grow and use the organics as a food and energy source by creating a favorable environment for them **(Mifsud et al., 1970).**

The ability of clay minerals to take up certain organic substances has been known for long time. One of the early attempts to elucidate mechanisms underlying the clay-organic interaction was by **Frissel and Bolt (1962**). They studied the up-take from an aqueous environment of some 14 organic herbicides by montmorillonite and kaolinite as a function of pH and electrolyte concentration**.** Their observation indicated that these compounds are adsorbed as the uncharged species in the neutral and basic range of pH and as the corresponding cations under acidic conditions.

Several mechanisms are involved in the adsorption of organic substances by clay minerals. Adsorption caused by Van der Waals forces can be of considerable importance in the adsorption of neutral polar and non polar molecules, particularly those, which are high in molecular weight **(Stevenson 1982).** Since organic anions are normally repelled from negatively charged clay surfaces, adsorption of humic and fulvic acids by clay minerals such as montmorillonite occurs only when polyvalent cations are present on the exchange complex. The polyvalent cations act as a bridge between two charged sites. For a long chain organic molecule, several points of attachment to the clay particle are possible **(McBride 1989).**

The main objective of this study is to investigate the influence of mixing the sludge seeded to UASB reactor with a clay mineral on the efficiency of this reactor in direct treatment of raw sewage in Egypt. It was among the specific goals of this paper to determine the favorable clay mineral (kaolinite or montmorillonite) can be utilized as well as the appropriate % of clay mineral shall be mixed with the seeding sludge.

A pilot-scale UASB has been built and operated according to an experimental program that was designed and executed during the frame-work of the present study. The description of the pilot-scale UASB as well as the executed experimental program shall be delineated in the following subsections. However, the enhancement in the UASB efficiency in treating raw sewage was assessed, experimentally, via comparing its efficiency in removing BOD, COD, SS, and DS when the utilized seed was a mixture of sludge and clay minerals to the corresponding efficiencies in removing the same pollutants when the seed was only sludge.

MATERIALS AND METHODS

Sewage:

The source of the sewage utilized in this research was Kawmeya Sewage Pumping Station receiving sewage coming from a combined sewer system collecting the sewage originated from west bank zone of Zagazig city, Egypt. Raw sewage from that source was fed to the pilot-scale model simulating the UASB reactor directly using a submersible pump and via a storage constant head feeding tank. Samples of the sewage influent to the model as well as from its effluent were collected and transported to the Environmental Engineering Department Laboratory, Faculty of Engineering, Zagazig University, Egypt to be characterized and/or analyzed by measuring such parameters as BOD, COD, pH, Temperature, Suspended solids (S.S), Dissolved Solids (D.S), Total Solids (TS), Dissolved Oxygen (DO), and NH_4. The results of these analyses are shown in Table (1). All analyses were carried out according to the American Standard Methods for Examination of Water and Wastewater, 18th edition **(APHA/AWWA/WEF; 1992)**.

Seeding Sludge:

The sludge utilized for inoculation in this study was collected after the gravity thickener of a wastewater treatment plant located at Safour village, Diarb Nigm Markaz, Sharkia Governorate, Egypt. Such characteristics as color, odor, pH, temperature, total solids, dissolved solids and volatile matter were determined in the same mentioned laboratory. The results of these tests are presented in Table (2).

Clay Minerals:

Two clay minerals; namely: kaolinite and montmorillinite were utilized in this study and mixed with the inoculated sludge at different mixing ratios and applied as a seed in the UASB model. Kaolinite and montmorillonite are those produced by Sinia Manganese Company. The chemical analysis of these minerals is presented in Table (3).

Table (1): Raw Sewage Characteristics

Characteristic	Value	
	Range	Average
BOD (ppm)	297-812	480
COD (ppm)	420-1200	739
pH	7-7.5	7
Temp. ^{o}C	17-27.5	21
S.S (ppm)	170-410	290
D.S (ppm)	490-837	630
T.S. (ppm)	553-993	610
D.O (ppm)	0.7-4.8	1.9
NH_4 (ppm)	29-75	55

Table (2): The physical properties of the sludge

Property	Description / value
Color	Dark brown to black
Odor	Like hot tar and musty
Temperature	(24°C-28°C)
pH	(7-7.5)
Total Solids (mg/l)	3010-3400
Total volatile solids (mg/l)	1860-1900
Total dissolved solids(mg/l)	1000-1100

Table (3): Chemical analysis of kaolinite and montmorillonite*

Chemical Compound	Percentage (%)	
	Kaolinite	Montmorillonite
SiO_2	58-60	49-55
Al_2O_3	25-30	20-24
Fe_2O_3	0.7-0.9	2.5-6
L.O.I	9.5-11	9-11
CaO	0.2-0.4	2-4
MgO	0.06-0.08	0.5-2
Na_2O	0.06-0.1	1.1-2.4
K_2O	0.01-0.04	1.2-1.4

*From Sinai Manganese Company, Mining and Refractory Holding Company

EXPERIMENTAL SET-UP AND PROGRAM

Within the frame-work of the present study, two identical pilot-scale models simulating UASB reactors are designed and constructed from PVC pipes, 200 mm diameter and 2500 mm height. The main features of the design and construction of the models are furnishing the model with the appropriate influent, effluent, and gas collection arrangements as well as the compatibility between the raw sewage and the reactor material. Sampling ports all-over the reactors height are arranged as well. Each reactor has an effective volume of 66 L and is furnished with 6 sampling ports equipped with valves and spaced uniformly at 400 mm all-over its effective height as shown in Figure (1).

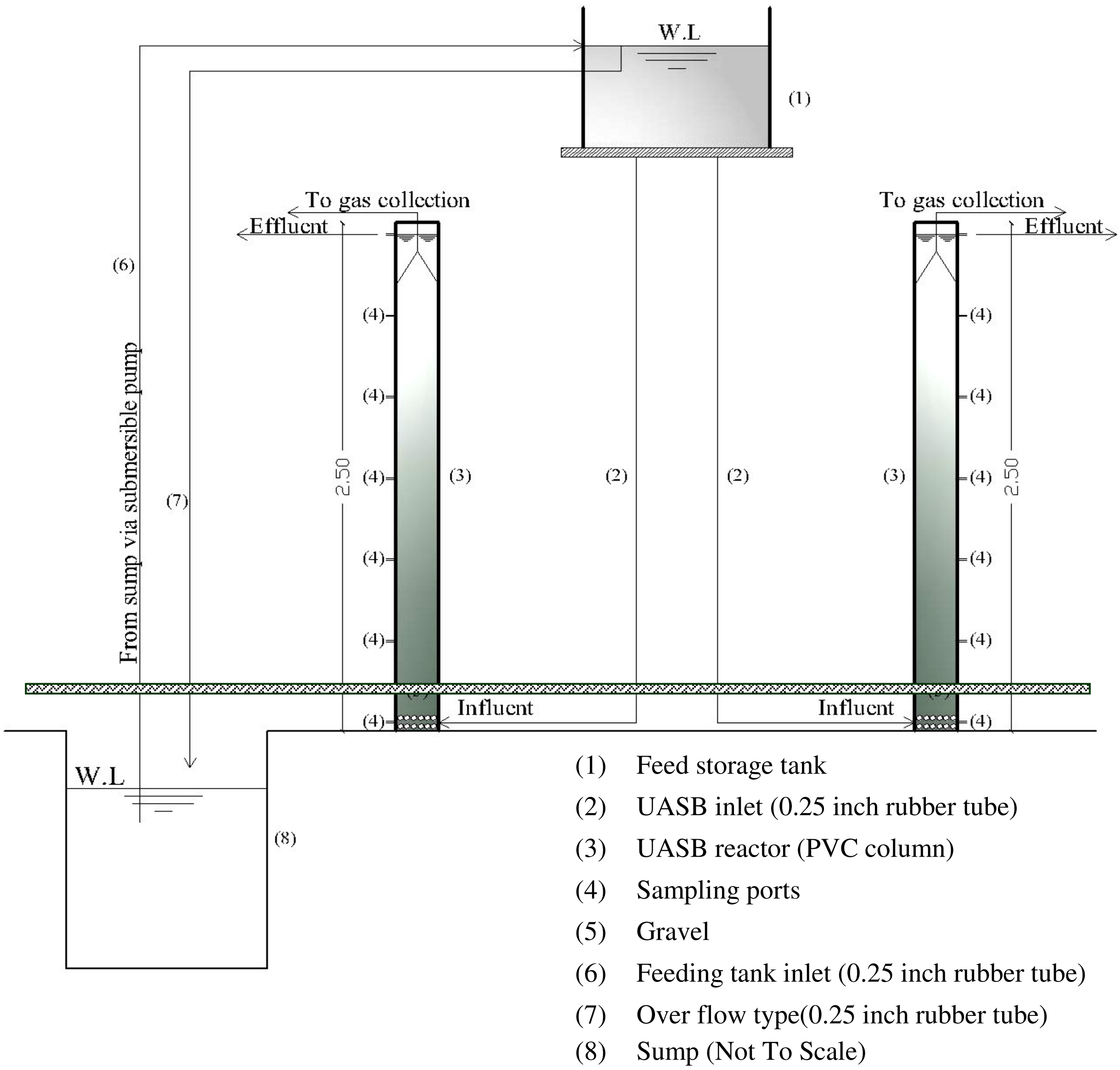

Figure (1): Schematic Diagram of the UASB Reactors Pilot-Scale Models

The pilot-scale models were built at Kawmeya Sewage Pumping Station that receives sewage coming from a combined sewer system collecting the sewage originated from west bank zone of Zagazig city, Egypt. Using a submersible pump, raw sewage was left from the sump of the mentioned pumping station to a constant head holding feeding tank located above the level of the UASB models. The contents of the holding feeding tank were continuously gently mixed to homogenize the UASB models influent. From the bottom of that constant head holding feeding tank, the two UASB models were continuously fed, by gravity, under constant head. On the other hand, the models effluent was drained directly to the sump of the pumping station.
Samples of the sewage influent to the model as well as from its effluent and sampling ports were collected and transported to the Environmental Engineering Department Laboratory, Faculty of Engineering, Zagazig University, Egypt to be characterized and/or analyzed.

The experimental procedure started with inoculating one of the two reactors with 16 L (about 24% of the reactor volume) of kaolinite-sludge mixture while the other one was inoculated with the same volume of montmorillonite-sludge mixture. Then the two reactors were filled with wastewater (batch flow basis) and left for 15 days to improve the Methanogenic activity. After that, the two reactors were fed continuously for 60 days with raw wastewater from the same source described above at the same hydraulic retention time, up velocity and average value of other operating parameters shown in Table (4) that are kept constant during all runs.

Table (4): Operating Parameters Utilized in the present Study

Parameter	Value
Hydraulic Retention Time (HRT), (h)	12
Feeding Rate, (L/hr)	6.54
Influent Concentration, (mgCOD/L)	739
Organic Loading Rate (OLR), (kgCOD/m^3.d)	1.23
Up-flow Velocity, (v_{up}), (m/hr)	0.175

However, the experimental program designed and executed in this study included five runs. In these runs, the seeding sludge was mixed with either kaolinite or montmorillonite at different mixing ratios. The utilized mixing ratios (clay to sludge - weight basis) were 0%, 20%, 40%, 60% and 80%. After the preparation period (15 days) described above, the pilot-scale UASB reactors were continuously operated for 60 days of which the first 45 days were lasted to reach the "steady-state" condition. The reactors behavior during the "steady-state" periods met the criteria for steady-state set by Noyola et al., (1988), who considered the "steady-state" of an anaerobic reactor treating domestic sewage to be achieved after an operation period of 10 times the HRT with a minimum of 2 weeks. So, the assessment of the enhancement of UASB performance upon mixing the seeding sludge with clay minerals was based on the results obtained during the last two weeks of each experimental set run at certain mixing ratio of specific clay mineral.

RESULTS AND DISCUSSIONS

In the following subsections, the obtained results as well as the main findings related to the enhancement of UASB efficiency in terms of removal ratio of (1) organics (BOD and COD), and (2) solids (SS and DS), upon mixing the seeding sludge with either kaolinite or montmorillonite at different mixing ratios (Wc:Ws - weight-basis) shall be presented and discussed.

Organics Removing:

The concentrations of BOD and COD influent to and effluent from the pilot-scale models simulating UASB reactors have been measured during the "steady-state" period of the time span of each experimental set that run at a certain mixing ratio of specific clay mineral. Consequently, the efficiency of the modeled UASB in removing BOD and COD at the different applied clay-sludge mixing ratios; namely: 0%, 20%, 40%, 60%, and 80% of the utilized clay minerals; namely: kaolinite and montmorillonite has been determined and plotted in Figures 2 and 3.

The obtained results shown in Figures 2 and 3 reveal that the modeled UASB achieved substantial enhancements in their efficiencies in removing BOD and COD up on mixing the seeding sludge with clay minerals. Also, it is noticed that montmorillonite is better than kaolinite in enhancing the efficiencies of the modeled UASB in removing BOD and COD especially at a mixing ration of 60%. At this mixing ratio, mixing the seeding sludge with kaolinite and montmorillonite achieved efficiencies in removing BOD and COD of 77% and 83%, respectively compared with 62% at a mixing ratio of 0%. Then, a decrease in the enhancement amount occurred upon increasing the montmorillonite-sludge mixing ratio to 80% while it continued increasing upon increasing of the kaolinite-sludge mixing ratio.

On one hand, the enhancement in the efficiencies of the modeled UASB in removing BOD and COD up on mixing the seeding sludge with kaolinite may be attributed to the acceleration of the reaction and degradation of organic compounds due to the catalyst effect of Kaolinite. This catalyst effect increases the ion exchange and the adsorption of the organic compounds by the kaolinite crystals due to the unsatisfied bonds of the kaolinite crystals which yield negative charge attracts the positive ions of the organic compounds. On the other hand, the superior enhancement in the efficiencies of the modeled UASB in removing BOD and COD up on mixing the seeding sludge with montmorillonite may be attributed to the large hydrateable surface of montmorillonite and consequently the higher acceleration of the reaction and degradation of organic compounds due to the greater catalyst effect.

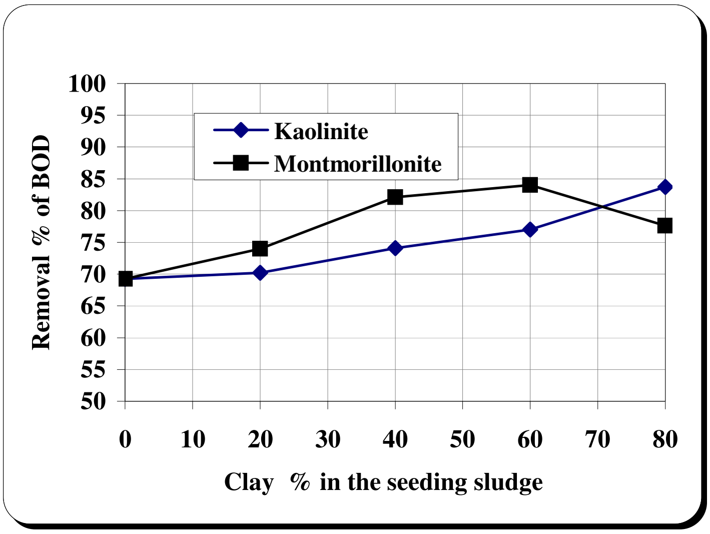

Figure (2): Influence of mixing the seeding sludge with clay minerals on the % removal of BOD.

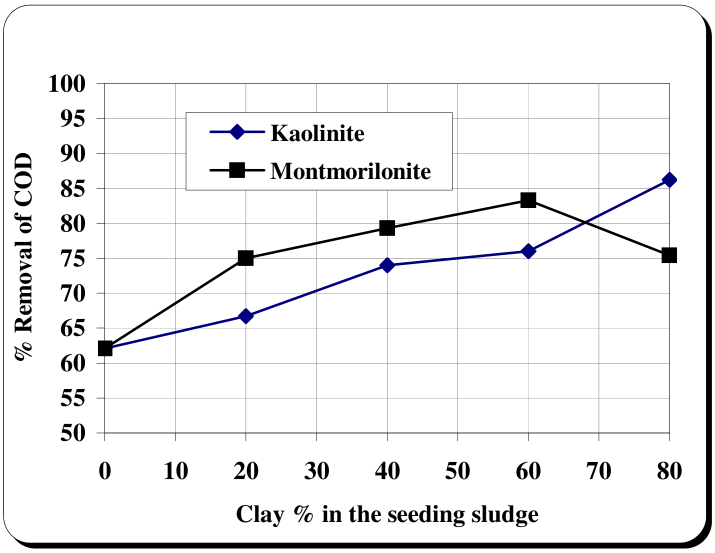

Figure (3): Influence of mixing the seeding sludge with clay minerals on the % removal of COD.

Last but not least, the decrease in the enhancement amount that occurred upon increasing the montmorillonite-sludge mixing ratio to 80% may be attributed to the movement of ions and organic molecules between the sheets of the clay crystals when montmorillonite adsorb water. This make the clay expands and tends to close the pores in the mixture, and consequently, the bacteria could not find its food. Hence, the degradability of the organic matter (BOD and COD) decreases (Fouad, 2001).

Solids Removal:

The concentrations of solids (SS and DS) influent to and effluent from the pilot-scale models simulating UASB reactors have been measured during the "steady-state" period of the time span of each experimental set that run at certain mixing ratio of specific clay mineral. Consequently, the efficiency of the modeled UASB in removing solids at the different applied clay-sludge mixing ratios; namely: 0%, 20%, 40%, 60%, and 80% of the utilized clay minerals; namely: kaolinite and montmorillonite has been determined and presented in Figures 4 and 5. On one hand, the obtained results shown in Figure 4 reveal that the modeled UASB achieved substantial enhancements in their efficiencies in removing SS up on mixing the seeding sludge with clay minerals. Also, it is noticed that montmorillonite is better than kaolinite in enhancing the efficiencies of the modeled UASB in removing SS especially at a mixing ration of 40%. At this mixing ratio, mixing the seeding sludge with kaolinite and montmorionite achieved efficiencies in removing SS of 74% and 81%, respectively compared with 69% at a mixing ratio of 0%. Then, a decrease in the enhancement amount occurred upon increasing the montmorillonite-sludge mixing ratio to 60% while it continued increasing upon increasing of the kaolinite-sludge mixing ratio. On the other hand, it is noticed from Figure 5 that clay mineral type and mixing ratio have no effect on the efficiency of the modeled UASB in removing dissolved solids (DS).

While the above behavior of the modeled UASB in removing solids may attributed to the same mechanisms contribute to organics removing, the decrease in the enhancement amount occurred upon increasing the montmorillonite-sludge mixing ratio to 60% may be attributed to the increase of the amount of the released gas that may wash out and/or violate the SS. Also, the weak bonds of the montmorillonite structure yield an easy disjointing of this structure and look like gelatinous mixture upon adsorbing water (Mitchell, 1992).

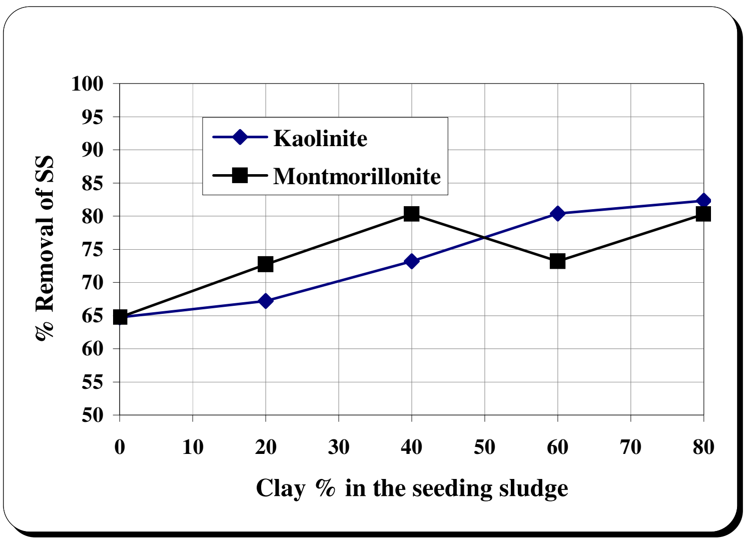

Figure (4): Influence of mixing the seeding sludge with clay minerals on the % removal of SS.

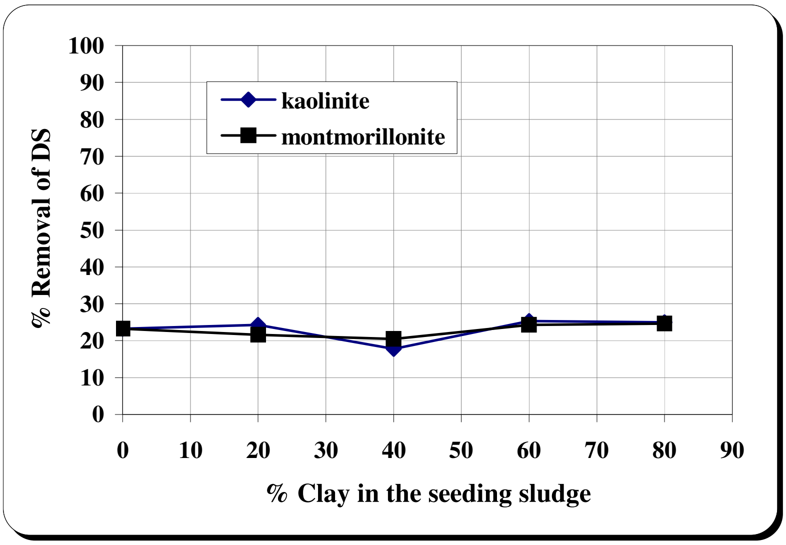

Figure (5): Influence of mixing the seeding sludge with clay minerals on the % removal of DS.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained from the experimental program executed within the scope of this paper and limited to the conditions under which the experimental runs had been run, it is found that mixing the seeding sludge with clay minerals enhances the efficiency of removing organics and solids from raw domestic sewage directly treated using UASB. Also, it is noticed that the amount of enhancement is highly related to the utilized clay mineral as well as the applied ratio at which it is mixed with the seeding sludge. In other words, montmorillonite is better than kaolinite in enhancing the UASB efficiency regarding the removal of organics and solids from raw domestic wastewater. Also, the best enhancement has been reached when montmorillonite was mixed with the seeding sludge at a mixing ratio ranging between 20% and 40% (Wc:Ws - weight-basis).

However, the following specific conclusions regarding enhancing the efficiency of the UASB upon mixing the seeding sludge with clay minerals may be drawn:

- Mixing the sludge seeded to the UASB with montmorillonite at a mixing ratio (Wc:Ws - weight-basis) of 40% yields an enhancement of 20% and 30% in the % removal of BOD and COD, respectively.
- Compared to the mixing ratio of 40%, increasing the mixing ratio of the montmorillonite and the seeding sludge to 60% increases the % removal of BOD and COD with only 3% and 6%. On the other hand, more increase in the mixing ratio (80%) doesn't yield any increase in the % removal of BOD and COD.

- Mixing the sludge seeded to the UASB with montmorillonite at a mixing ratio (Wc:Ws - weight-basis) of 40% yields an enhancement of 25% in the % removal of SS.
- Compared to the mixing ratio of 40%, increasing the mixing ratio of the montmorillonite and the seeding sludge to 60% increases the % removal of SS with only 7%. On the other hand, more increase in the mixing ratio (80%) doesn't yield any increase in the % removal of SS.
- Clay mineral type and mixing ratio didn't have a distinguishable effect on the efficiency of the modeled UASB treating raw domestic wastewater regarding the % removal of dissolved solids (DS).
- As mixing the sludge seeded to the UASB with montmorillonite at a mixing ratio (Wc:Ws - weight-basis) of 20% yields an enhancement of organics and solids about 90% of that achieved upon utilizing a mixing ratio of 40%, it does worth to consider that in specifying the best mixing ratio can be applied either 20% or 40%.

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