Anaerobic Pre-Treatment of Strong Sieved Sewage in a UASB Reactor

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المعالجة الاولية لمياه الصرف الصحي القوية المنخلة بواسطة المفاعل اللاهوائي الصاعد

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This thesis was prepared under the main supervision of Prof. Dr. Nidal Mahmoud and has been approved by all members of the examination committee.

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Dedication

For my beloved country Palestine

To my dear father's soul

To my great mother,

To my wonderful wife and children

To my dear brother and sisters

To all friends

All love, appreciation and gratitude

Thaer Issa Hammada

February, 2022

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List of Abbreviations

Abbreviation	Abbreviation Caption
atm	Atmospheric
AVR	Average
BOD	Biochemical Oxygen Demand
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
HRT	Hydraulic Retention Time
NKj	Kjeldhal Nitrogen
nm	Nanometer
OLR	Organic Loading Rate
R1	Reactor with Hydraulic Retention Time 12 hours
R2	Reactor with Hydraulic Retention Time 24 hours
SRT	Sludge Retention Time
STD	Standard Deviation
SVI	Sludge Volume Index
UASB	Upflow Anaerobic Sludge Blanket
VFA	Volatile Fatty Acids
Vup	Upflow Velocity
WWTP	Wastewater Treatment Plant
µm	Micrometer

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Abstract

The adoption of efficient and low-cost wastewater treatment technologies will enable providing the wastewater treatment infrastructure to a wider range of people in Palestine and worldwide. The up-flow sludge blanket (UASB) reactor is the most efficient low-cost high-rate anaerobic reactor. High-rate anaerobic sewage treatment in Palestine is limited because sewage is very concentrated, and is characterized by large temperature fluctuations due to the prevailing Mediterranean climate.

The previous research of the UASB reactor performance revealed limited COD removal in the range of 50- 70%, and frequent occurrence of operational problems like the formation of thick scum layers. Therefore, further technical modifications are still needed, in order to apply the UASB reactor in Palestine. Indeed, the integration of physical- and biological system to maximize the potential of the latter might represent a breakthrough in technology development and innovation to treat sewage up to secondary level.

The overall objective of this research is to assess the process performance, and to optimize the design criteria of the UASB reactor for the pre-treatment of sieved concentrated sewage under the Mediterranean climate that prevails in Palestine.

The UASB reactors will be operated in parallel at hydraulic retention time (HRT) 12 hour (R1) and 24 hours (R2) at ambient temperature treating sieved domestic sewage, each installed at Al Tireh wastewater treatment plant (WWTP), and were fed with sieved influent of 2 mm pore size that exists in Al Tireh WWTP.

Both of the UASB reactors were run for a period of five months, at ambient air temperature varying in the range 25-36 ºC with average value 30 ºC, the average sewage temperature during experiment was 25 ºC, the wastewater in this research was characterized high concentration of COD_{tot}, COD_{sus}, COD_{col}, and COD_{dis} with average value 1058 mg/l, 571mg/l, l93mg/l and 295mg/l respectively, and high TSS and VSS with average value 658mg/l and 525 mg/l, respectively and BOD_5 of 494 mg/l.

The obtained effluent concentrations and the calculated removal efficiencies for the reactor treating sieved wastewater over the whole period of operation are 717 mg/l (22.2%),319 mg/l (44.2%),138 mg/l (28.5%) and 259 mg/l (12.2%) of COD_{tot}, COD_{sus}, COD_{col}, and COD_{dis} respectively, and 501 mg/l (23.9%),402 mg/l (23.4%) of TSS, VSS respectively, and 356 mg/l (28%) BOD_5.

The performance of the two UASB reactors, R1 which had been studied during the research period are 336 mg/l (68%), 113 mg/l (80%),76 mg/l (60%), 147 mg/l (50%) and 153 mg/l (69%) of COD_{tot}, COD_{sus}, COD_{col}, COD_{dis} and BOD_5 respectively, and 194 mg/l (71%), 94 mg/l (82%) for TSS and VSS, and R2 are 259 mg/l (76%), 91mg/l (84%), 55 mg/l (72%), 116 mg/l (61%) and 153 mg/l (69%) of COD_{tot}, COD_{sus}, COD_{col}, COD_{dis} and BOD_5 respectively, and 137mg/l(79%),73mg/l(86%) for TSS and VSS.

The result indicted the potential performance of sieved that decrease the high concentration of parameter exist the UASB reactor. That allow to better treatment and give high performance of UASB. R2 (HRT=24 hours, Q=354m^3/d) is more performance than R1 (HRT=12Hours, Q=177m^3/d) which enhance the HRT in UASB

الملخص

إن اعتماد تقنيات معالجة مياه الصرف الصحي الفعالة ومنخفضة التكلفة سيمكن من توفير البنية التحتية لمعالجة مياه الصرف الصحي لمجموعة واسعة من الناس في فلسطين وجميع أنحاء العالم. يعتبر مفاعل UASB أكثر المفاعلات اللاهوائية منخفضة التكلفة. إن معالجة مياه الصرف الصحي اللاهوائية ذات المعدلات العالية في فلسطين محدودة لأن مياه الصرف الصحي شديدة التركيز، وتتميز بتقلبات كبيرة في درجات الحرارة نتيجة مناخ البحر الأبيض المتوسط السائد.

أظهر البحث السابق لأداء مفاعل UASB إزالة محدودة لـ COD في نطاق 50-70 ٪، وتكرار حدوث مشاكل تشغيلية مثل تكوين طبقات رغوة سميكة. لذلك، لا تزال هناك حاجة لمزيد من التعديلات التقنية، من أجل تطبيق مفاعل UASB في فلسطين. في الواقع، قد يمثل تكامل النظام الفيزيائي والبيولوجي ل تحقيق أقصى فعالية لمفاعل UASB طفرة في تطوير التكنولوجيا والابتكار لمعالجة مياه الصرف الصحي حتى المستوى الثانوي.

الهدف العام من هذا البحث هو تقييم أداء العملية، وتحسين معايير تصميم مفاعل UASB للمعالجة المسبقة لمياه الصرف الصحي المركزة المنخل تحت مناخ البحر الأبيض المتوسط السائد في فلسطين. تم تركيب مفاعلين UASB، كل منهما بحجم عمل يصل إلى 140 لترًا، في محطة معالجة مياه الصرف الصحي بالطيرة، وتم تغذيتهما بمنخل بحجم مسام 2 مم الموجود في محطة معالجة مياه الصرف الصحي في الطيرة. سيتم تشغيل مفاعلات UASB بالتوازي عند زمن مكوث هيروليكي 12 و24 ساعة عند درجة حرارة الغرفة لمعالجة مياه الصرف الصحي المحلية المنخل. هذا البحث ممول من برنامج التعاون الفلسطيني الهولندي. بلدية رام الله وجامعة دلفت التقنية / هولندا شركاء في المشروع. سيكون موقع إعداد البحث في محطة معالجة مياه الطيرة / رام الله.

تم تشغيل كلا المفاعلين UASB لمدة خمسة أشهر، في درجات حرارة الهواء المحيط متفاوتة في المدى 25-36 درجة مئوية بمتوسط قيمة 30 درجة مئوية، وكان متوسط درجة حرارة الصرف الصحي أثناء التجربة 25 درجة مئوية، واتسمت المياه العادمة في هذا البحث بارتفاع تركيز CODtot وCODsus وCODcol هو بمتوسط قيمة 1058 مجم / لتر و571 مجم / لتر و93 مجم / لتر و295 مجم / لتر على التوالي وTSS وVSS مرتفع بمتوسط قيمة 658 مجم / لتر و525 مجم / لتر على التوالي وBOD5 من 494 مجم / لتر.

كانت فعالية اداء المنخل بحجم مسام 2 مم وتركيزات المخلفات السائلة التي تم الحصول عليها وكفاءة الإزالة المحسوبة للمفاعل خلال فترة التشغيل والموجود في محطة معالجة مياه الصرف الصحي في محافظة الطيرة قبل وصوله إلى مفاعل. بأكملها 717 مجم. / لتر (22.2٪)، 319 مجم / لتر (44.2٪)، 138 مجم / لتر (28.5٪) و259 مجم / لتر (12.2٪) من CODtot وCODsus وCODcol

وCODdis على التوالي، و501 مجم / لتر (23.9٪)، 402 ملليجرام / لتر (23.4٪) من TSS، VSS على التوالي، و356 ملليجرام / لتر (28٪) BOD_5.

كان أداء مفاعلي UASB، مع زمن مكوث هيدروليكي لمدة 12 ساعة (R1) والتي تم دراستها خلال فترة البحث هي 336 مجم / لتر (68٪) ، 113 مجم / لتر (80٪) ، 76 مجم / لتر (60٪) ، 147 مجم / لتر (50٪) و 153 مجم / لتر (69٪) من CODtot و CODsus و CODcol و CODdis و BOD_5 على التوالي و 194 مجم / لتر (71٪) و 94 مجم / لتر (82٪) لـ TSS و VSS و مع زمن مكوث هيدروليكي لمدة 24 ساعة (R2) هي 259 مجم / لتر (76٪) و 91 مجم / لتر (84٪) و 55 مجم / لتر (72٪) و 116 مجم / لتر (61٪) و 153 مجم / لتر (69٪) من CODtot و CODsus و CODcol و CODdis و BOD_5 على التوالي و 137 مجم / لتر (79٪) و 73 مجم / لتر (86٪) لـ TSS و VSS.

أظهرت النتيجة فعالية لا باس بها للمنخل الذي يقلل من التركيز العالي CODtot، CODsus, CODcol، CODdis، TSS, BOD_5 وVSSالموجود في مفاعل UASB. مما يسمح ذلك بمعالجة أفضل وإعطاء أداء عالٍ لـUASB . كان أداء R2مع زمن مكوث هيدروليكي (24 ساعة) افضل من R1مع زمن مكوث هيدروليكي (12 ساعة) لمفاعل UASB.

Chapter 1

Introduction

1.1 Background

Water quality deterioration and global warming are the major environmental crises of the world at the beginning of 21st century, caused by massive growth of population, food production, high-pressure on elevating living standards and lack of water use strategies (PWA, 2020). The lack of the successful management of wastewater is the main influential factor on biological variability of the underwater ecosystems, regardless the balance of life natural curing systems, upon which a large number of fields depend such as development of urban areas, industry, and food production. Wastewater management is a core issue of integrated environmental protection that operates across sectors and borders (Latif *et al*., 2011; PWA, 2020).

In Palestine, infrastructure of wastewater management is increasingly expanding, though still not adequate (Mahmoud and Yasin, 2013). Nowadays, 30% of the household connected to sewer network in West Bank, while only about 10% is served with wastewater treatment plants (Amous *et al.*, 2020). In the non-sewered areas of the West Bank, domestic and industrial wastewater are collected for a far extent in cesspits. Due to the lack of adequate wastewater treatment plants, the emptied septage from the cesspits by the vacuum trucks is disposed into open fields, though septage characteristics do not comply with the Palestinian environmental requirements.

In addition to the social and political issues, it is a big obstacle for the Palestinian Water Authority to provide contentious services of wastewater management, is to facilitate the initial capital cost and operational service costs (Al- Sa` ed, 2010).

Anaerobic treatment of sewage offers big potential to participate in solving the global challenge of sewage treatment, especially in the less fortunate countries (Lettinga *et al.*, 1993; Zeeman *et al.*, 2000; Al-Shayah and Mahmoud, 2008; Tessele and van Lier 2020). Anaerobic technology wastewater treatment has advantages over all other wastewaters treatments. First, the minimization of fossil energy consumption to convert the chemical energy in the organic non-eco-friendly compound (van Lier, 2008; Ersahin *et al.*, 2011; Moussa and Mahmoud, 2019; Tessele, & van Lier 2020). Anaerobic wastewater treatment technologies, do not require external energy source, on the contrary they produce energy in the form of methane gas. High-rate anaerobic treatments depend on the uncoupling between SRT and HRT. The high SRT is an effect of high sludge retention, specifically that enabled by the natural immobilization of anaerobic sludge, granular or flocculent (Al-Shayah and Mahmoud, 2008; Tessele, & van Lier 2020).

The application of anaerobic sewage treatment using UASB reactor is common in tropical countries such as Brazil, Columbia, and India. In these countries, the atmospheric temperature is warm ranging between 20 and 30 °C all throug the year and sewage is diluted to a low-medium strength. (Von Sperling and Chernicharo, 2005; Aiyuk *et al.*, 2006). The development challenge of anaerobic reactor technology for sewage treatment is adapting systems to treat concentrated sewage, particularly at low temperatures. In Palestine and Jordan, for example, sewage contains high concentrations of chemical oxygen demand (COD) exceeding 1000 mg/L, as well as a high amount of suspended COD (COD_{sus}) (70 %), and the sewage temperature fluctuates between summer and winter in the range of 15–25 °C. (Mahmoud *et al*., 2003; Halalsheh *et al*., 2005; Mahmoud, 2008).

According to Leitaõ et al (2006), understanding the use of UASB reactors for the treatment of concentrated sewage with high COD content is critical for improving the overall trustworthiness of anaerobic processes.

The use of high-rate anaerobic sewage treatment in Palestine is not wide because sewage concentration is very high due to shortage in water sources which comes as a result of large temperature fluctuations due to the fluctuating Mediterranean climate between dry hot summer and rainy cold winter. The results obtained so far in Palestine and Jordan revealed limited COD removal in the range of 50-70%, and frequent occurrence of operational problems like the formation of thick scum layers. However, based on the work done, the UASB reactor carries big potential for sewage pre-treatment. However, further technical modifications are still in need, in order to apply this technology in Palestine.

A UASB reactor of 64 m^3 set up for anaerobic sewage treatment in in Jordan showed the possibility to run the reactor in Jordan and Palestine. The findings of the Jordanian pilot UASB reactor revealed that when used in Jordan and Palestine, the one stage UASB reactor should be operated at an extended hydraulic retention time (HRT) greater than 22 hours. (Mahmoud *et al*., 2004b; Halalsheh *et al*., 2005). As a modification to the single stage UASB reactor, (Mahmoud *et al*. 2004) investigated in the Netherlands a pilot-scale combined system, namely UASB-digester system that consisted of a highly loaded UASB reactor and a digester. In that system, a parallel digester is integrated to the UASB reactor so as to enhance the gene of active methanogenic sludge in the digester and to be recirculated to the UASB reactor. The initial findings of the UASB-Digester system were promising to be applied in Palestine and Jordan in comparison with the performance of the one-stage UASB reactor. Later on, the integrated UASB-Digester system was operated in Palestine so as to test the system under real challenging conditions of concentrated sewage and fluctuating sewage temperature, for which it was indeed initially developed. The UASB reactor was operated at an HRT of 10 hr, and the incorporated digester was operated at 35 °C.

In addition to the above-mentioned technical modifications on the conventional UASB reactor to treat domestic sewage in Palestine, sieving of raw sewage for large removal of big solids ahead of the UASB reactor will be tested. The removal of suspended solids could reduce the required imposed HRT of the UASB reactor, and might improve its performance and stability. Therefore, this research investigated the performance of the UASB reactor treating sieved sewage under the climatic conditions and sewage characteristics in the West Bank/Palestine.

1.2 Wastewater characteristics

In Palestine sewage water contains high levels of COD above the limit of 1000 mg/L, increased level of suspended COD (COD_{sus}) as high as 70%, and temperature variations range between summer and winter (15–25 ºC) (Mahmoud, 2008). The high concentration of sewage could be due to water scarcity that results in less water use, and behavior of people (Mahmoud *et al*., 2003; Al-Atawneh *et al*., 2016; Amous *et al*., 2020).

The wastewater management requires suitable collection, treatment, disposal of processed effluent. The practical management strategies for this sector in Palestine only focus on the collection of wastewaters by sewage networks and cesspits. Wastewater management in Palestine apparently lost importance since the beginning of the Israeli occupation before the Palestinian Authority control in 1995. During which only a fifth of the Palestinians were provided with public sewage collection systems, and less than 5% of the transported sewage in networks were treated physically and partially biologically (Mahmoud, 2017). Wastewater collection and treatment services been restricted from investment during the years of Israeli occupation when investments were dropped in the sector of wastewater networks and any expansion projects for wastewater treatment infrastructure development (World Bank, 2009).

However, and since 1999, there was noticeable development in sewage water networking. According to the PCBS, a development in in the connections range of households increased from 39.3% in 1999, to 52.1% in 2009 and to 53.9% for the year 2015 (PCBS, 2015). Wastewater collection networks have been implemented only in the big Palestinian cities and camps. Unluckily, the situation of wastewater management infrastructure in Palestine is still far from being considered adequate. Due to the poor wastewater infrastructure, the Palestine environment is in a serious stress since sewage might infiltrate and pollute underground water resources unless adequate environmental interventions are implemented (Amous *et al*., 2020). Table 2.1 presents data about current status of wastewater management in the West Bank of Palestine.

There are significant hazards from application of collection and discharge of septage over land or into valleys. Thus, shortage in the originally restricted water resources is polluted by wastewater, and wasting opportunity to use treated effluent in agricultural irrigation (Kramer, 2008; Saak *et al*., 2009; Halalsheh *et al*., 2018).

The challenges consideration the wastewater management had further rise by the multiplicity of non-governmental and governmental plants in water sector, and consequently to institutional shatter and lack of cooptation. Moreover, there is no clear comprehension of the performance and activities of each plant in wastewater treatment. Till now, the municipalities are taking the responsibility of wastewater management, but most of these institutions' shortage financial stability and

Table 1.1 Status of municipal wastewater treatment in the main districts of the West Bank/ Palestine (MoA and PWA, 2020)

District	**Served locality**	**Treatment Technology**	**WWTP Capacity (m^3/day)**
Ramallah and Al-Bireh	Al-Tireh	MBR	1500
	Rawabi	Activated Sludge	120
	Rihan	MBR	150
	Rammun	Rotating Biological Contactor (RBC)	100
	AL-Bireh	Activated Sludge	6500
	Bani Zeid (Al-Gharbiyeh)	UASB reactor followed by horizontal Flow Constructed Wetlands	100
Jenin	Jenin	Aerated Ponds	2000
	Anza	Activated Sludge	100
Qalqilya	Hajja	Wetland	80
Jericho	Jericho	Activated Sludge	1200
Hebron	Aroob	Activated Sludge	1200
	Nuba	Wetland	157
	Kharas	UASB	120
	Deir Samit	Septic Tank - Anaerobic Upflow Gravel Filter	13.5
Nablus	Western Nablus	Activated Sludge	14000
	Beit Hassan	Wetland	100
	Sara	Wetland	270
	Beit Dajan	Activated Sludge	100

Table 2.2 demonstrates wastewater collection systems distributed among the Palestinian localities in percentage. PCBS (2015c) issued that 38.4 % of Palestinian areas in the West Bank were served with sewage networks, 43.3%

with porous cesspits and 17.1% with tight cesspit (septic tanks). Moreover, in the Gaza, 83.5% of households were connected to sewage networks, 9.8% to cesspits and only 6.7% are connected to tight cesspit. Using all these numbers, the porous cesspits are the mostly used collection systems in the West Bank. Moreover, it is a serios issue concerning the enormous list of wastewater pollutants (heavy metals, pharmaceuticals, disinfection by-products, etc.) can gradually accumulate in the groundwater sources which is the drinking water source to almost all Palestinian communities.

Table 1.2 Distribution of household's wastewater disposal method (%) in Palestine according to region, and locality type (ARIJ, 2015)

Region and Locality Type	**Wastewater Disposal Method**			
	Tight Cesspit	**Porous Cesspit**	**Wastewater Network**	**Others**
Palestine	13.5	31.8	53.9	0.8
Urban	11.1	28.1	60.0	0.8
Rural	29.3	61.5	8.0	1.2
Camp	2.6	4.2	93.2	0.0
West Bank	17.1	43.3	38.4	1.2
Urban	13.5	39.4	45.8	1.3
Rural	29.3	61.9	7.6	1.2
Camp	5.1	8.7	86.2	0.0
Gaza Strip	6.7	9.8	83.5	0.0
Urban	7.1	10.0	82.9	0.0
Rural	29.5	55.9	14.6	0.0
Camp	0.9	0.9	98.2	0.0

1.3 Problem Definition

High rate anaerobic sewage treatment in Palestine is limited because sewage is very concentrated due to water shortage, and is characterized by large temperature fluctuations due to the prevailing Mediterranean climate with hot dry summer and cold rainy winter. The results obtained so far in Palestine and Jordan revealed limited COD removal in the range of 50-70%, and frequent occurrence of operational problems like the formation of thick scum layers. However, based on the previous work, the UASB reactor carries big potential for sewage pre-treatment. However, further technical modifications are still needed, in order to apply the technology in Palestine.

1.4 Research Question

The main question of this research is how to increase the efficiency of Upflow Anaerobic sludge Blanket (UASB) Under the weather conditions in Palestine and the high concentration of wastewater?

The specific research questions are:

- Is adding the sieve a sufficient solution to increase the efficiency of UASB?
- What the standard HRT for designing UASB?
- What the characteristics of raw and sieved domestic wastewater in study area?

1.5 Objectives

The overall goal of this MSc research is to examine the process efficiency and to optimize the design conditions of the UASB reactor for the pre-treatment of sieved concentrated sewage under the Mediterranean climate that prevails in Palestine. The specific objectives of the research are to:

1. Examine the UASB reactor performance for treating sieved concentrated domestic wastewater of Palestine under the prevailing Mediterranean climate. The performance of the UASB reactors were examined on the concentration basis of selected parameters in both the influent as well as the effluent of the reactors and the achieved removal efficiencies, mainly COD_{tot} and COD fractions, ammonia, Kjeldhal, and phosphate, and the produced biogas quantity, sludge build up in the reactors and wash out, sludge quality identified as TS and VS concentrations and VS/TS ratio.
2. Determine comparatively a recommended HRT for designing the UASB reactor, when fed with sieved sewage.
3. To determine sieved and raw sewage characteristics generated from domestic wastewater in Al Tireh area.

1.6 Thesis Structure

Chapter One provides a background on research issues, wastewater characteristics, problem definition, research questions and objectives. Chapter Two reviews the previous studies related to the research topic. Chapter Three talks about the methodology that which followed in this research. Chapter Four presents the results and discussion, and Chapter Five conclusions and recommendation

Chapter 2

Literature review

2.1 Anaerobic treatment

Anaerobic wastewater treatment stands for utilizing anaerobic microorganisms for biodegradation of organic matter that are ultimately converted to methane (CH_4) gas and inorganic products, including PO_4^{3-}, CO_2, H_2S, N_2 and NH_3 (McCarty, 1986). Anaerobic treatment of both domestic and industrial wastewater has been applied since more than 100 years (McCarty and Smith, 1986; Tessele, & van Lier 2020). Many advantages of the anaerobic processes exist mainly, methane production, which might form an energy source in the West Bank from waste. Also, the operating energy is less than that of aerobic treatment.

Anaerobic process efficiency is highly affected by the environmental conditions as pH, temperature, nutrients level, suspended solids content and Carbon to Nitrogen (C/N) ratio. The rate decomposition of organic material highly increases with higher temperatures (near the optimal mesophilic conditions of decomposition, 32- 39 ºC), optimum C/N ratio within 20–30:1 range, and in the favorable Methanogenesis pH ranges 6.8 -7.2.

2.1.1 Advantages of anaerobic wastewater treatment

Anaerobic wastewater treatment has several advantages as follows:

1. The optimum removal efficiency (%) could occur even at low temperatures and high loading rates.

2. The reactors’ assembly and operation are easy and involve low requirements for outer import of material due to possible local construction and production of material, and a negligible maintenance cost.
3. Anaerobic treatment is applicable on large or small scales.
4. At high loading rates, the reactor's required area is small, lowering the overall capital cost
5. In the absence of heath for the influent to work, the optimum temperature and all operations are only affected by gravity, making the reactor's energy consumption passive. Furthermore, methane gas is generated which is an energy source.
6. Low demand for external (fossil) energy supply and in-process energy generation. As a result, CO_2 emissions are reduced.
7. Because of the energy input for treating wastewater is transformed to bound energy in gaseous matter; thus, providing low amount of energy for new cells, namely bio-solids or sludge, production, waste generated is significantly less than that in the aerobic process.
8. Because anaerobic bacteria grow at a slower rate, sludge production is lower than in aerobic methods. The sludge is mostly preserved and reused until it is discharged, and it has a beneficial dewatering property. It can be used for a long time without losing activity, allowing it to be reused for the repetitive initiation of new reactors. In anaerobic wastewater treatment, organic shock loads could be managed perfectly.

9. Anaerobic treatment requires nutrients and chemical demand specifically of sewage, a stable suitable pH can be achieved without the need to add chemicals.
10. The availability of the beneficial macro-nutrients, nitrogen and phosphorus, and micro-nutrients in sewage during anaerobic treatment.

2.1.2 Disadvantages of anaerobic wastewater treatment

Despite the clear advantages of anaerobic wastewater treatment, some disadvantages might be argued as follow:

1. With the exception of helminth eggs trapped in the sludge bed, pathogenic microorganisms are rarely removed. Furthermore, nutrient removal is less effective in meeting discharge standards, and the output necessitates post-treatment.
2. Since the growth rate of methanogenic organisms is slow, long start-up period is needed before the treatment operation to start, if sludge quantity is not adequate.
3. During the anaerobic process, Hydrogen Sulphide is produced specifically at high concentrations of sulfate in the influent.
4. Suitable temperature control (15-35 ºC) is much needed in colder countries.

2.1.3 High-rate anaerobic systems

Sewage treatment by high-rate anaerobic systems has been widely reported over the last two decades. High-rate anaerobic treatment is an attractive process for domestic sewage because of its low construction, operation and maintenance costs, small land requirement, low excess sludge production, and opportunity of biogas production.

The high-rate processes have the ability to separate hydraulic and solid retention times effectively, relatively low hydraulic retention times are allowed due to the accumulation of a high biomass concentration in the system, and however wastewater treatment with high-rate anaerobic systems, has indicated significant benefits in reducing the cost and energy (Gomec, 2010).

Seghezzo *et al*. (2004) reported that the upflow anaerobic sludge blanket (UASB) reactor is the most effective anaerobic treatment system for reduced strength such as sewage. (Mahmoud, 2008) reported a good efficiency in high concentration depend mostly on temperature and solids retention time.

2.1.4 Upflow of anaerobic sludge blanket (UASB) reactor

Figure 2.2 depicts the classical UASB reactor, which was described first by Lettinga in the 1970s. To create a vertical upflow, wastewater is introduced into a reactor through a layer of anaerobic sludge at the reactor's bottom via a distribution system. The wastewater is then directed through the layer of sludge (called a "digestion zone") after being evenly distributed across the bottom side of the reactor. This process is synchronous with the decomposition of the organic compounds of the substrates and a development of gaseous outcomes. In addition to feeding the reactor, the continuous upflow limits the capacity of the sludge layer to from clogging, and remain afloat. On contrast, the upflow draws out the loose biomass, i.e., microorganisms that did not form small flocs/granules. The liquid layer above the sludge bed (referred to as the "settling zone") serves as a vertical settler and/or coagulation column to initiate the biomass and contribute to solids retention prior to the actual separation step. The segregation process takes place in the Gas–Liquid–Solids Separator (GLSS), which is a three-phase separator. The GLSS is located at the top of the reactor column and begins with a baffle-shaped structure in its lower part that serves to accumulate and re-direct the gas output to the gas collection component, not allowing gas bubbles flowing with the effluent out of the reactor.

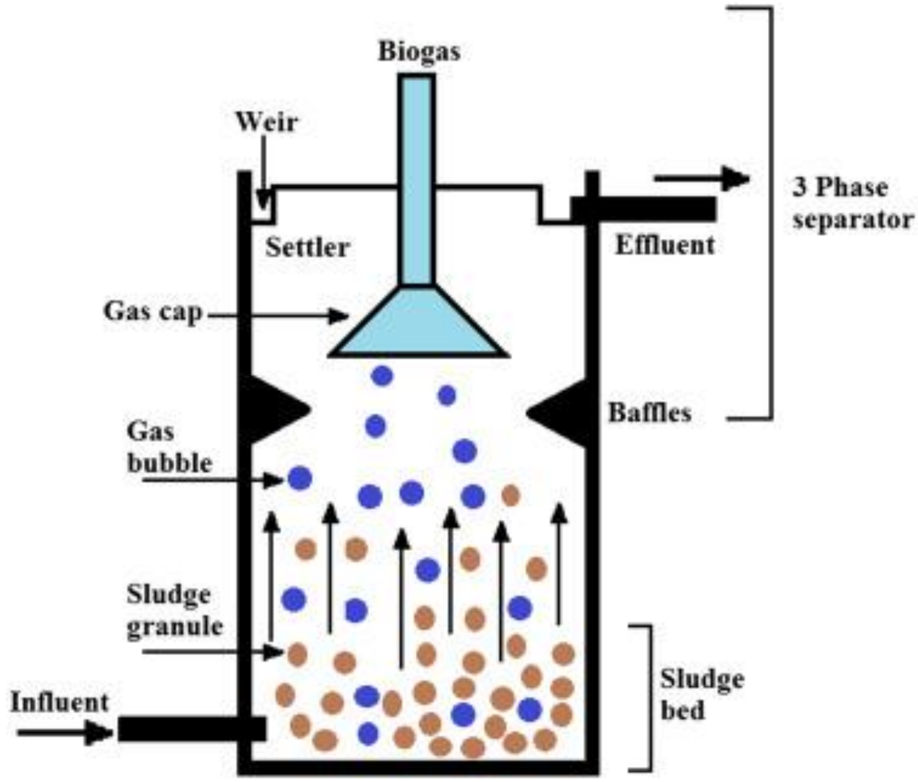

Figure 2.1. UASB reactor

Figure 2.1 demonstrates the classical model of the GLSS, where it's assembled by narrowing the outlet of the reactor with baffles, which are also mentioned in the literature as deflectors or collar. Narrowing the reactor outlet creates local velocity gradient called shear velocity, which slightly improves the of granulated particles' formation, as well as separation from the liquid medium and precipitating again to the bottom of the reactor. Above the deflectors, the gas collecting container is within the GLSS (Pereva *et al*., 2020). The liquid is pumped to stream through the distribution lines in between the lower end of the gas collector and the deflectors, to leave the reactor at the effluent gutter.

UASB reactors – comparing to other designs of anaerobic reactors- have the advantage of being stable without the need of stabilizing media for the attached biomass's growth. This is a focal point in the treatment of wastewaters with influent of high level of suspended solids. The biological reaction zone and the sedimentation zone are the two basic zones of any UASB reactor. In the influent, the organic compounds are degraded to produce carbon dioxide and methane gases in the reaction zone. The GLSS mediates the step of separation of the produced gas and the sludge buoyed by entrapping gas bubbles from the effluent.

2.2 Working of UASB

A UASB reactor as shown in Figure 2.2 is composed of four main parts which are sludge bed, sludge blanket, gas-solid separator and settlement compartment. The biomass generated at the lower part of reactor is the sludge bed while sludge blanket fixing the sludge bed where the biological reaction plants the suspended matter. Gas-solid separator is found at the reactor's upper part, for the separation of gas and solids and it traps the discharge of scum. The settlement compartment in which settlement of solids towards the sludge blanket takes place (Lin and Yang, 1991). First, the UASB reactor is fed with inoculums such as digested, anaerobic, granular, flocculent and initiated sludge. Wastewater is pumped from the lower part of the reactor which is in contact with the inoculums and the biological reaction takes place through the sludge bed and sludge blanket (Chong *et al*., 2012).

UASB reactor application on domestic wastewater treatment scale is typically restricted to tropical areas due to the lower COD level and high particulate matter levels (Sperling and Oliveira, 2009; Khan *et al*., 2011; Lew *et al*., 2011). This requires a preliminary pre-treatment stage called the hydrolysis to degrade the particulate matter and convert it to soluble effluent specifically at low temperatures or the particulate matter will accumulate in UASB reactor and stops the anaerobic treatment.

Recently, during the past few years, applying UASB reactor as the direct process for domestic sewage treatment is verified to be as effective and suitable treatment process for many countries like India, Brazil, Colombia, Mexico, Egypt, etc. This method has a superiority concluded with its lower practical costs and sustenance expenses, lowering the sludge production and safe and free generation of energy (as biogas, methane). On the other hand, UASB reactor is rarely considered as a pre-treatment method; since the treated sewage (the output) still has undigested organic particles, nutrients and variable count of pathogenic bacteria, and to avoid all these obstacles there is a wide demand of post-treatment system to purify the effluent particulates to match with the effluent standards set by Pollution Control Boards.

Worldwide sector of researches and studies issued that UASB reactor can be used easily for domestic sewage treatment. By contrary, it needs an efficient post-treatment to comply with the discharge standards (Vashi, 2019).

Table 2.2 Differences between UASB reactor and other wastewater treatment technologies according to (Daud *et al*., 2018)

Parameter	UASB reactor	Activated Sludge Process (ASP)	Trickling Filters (TF)	Waste stabilization pond (WSP)	Moving Bed Bioreactor (MBBR)
BOD removal, %	75–83	85–90	80–90	75–85	85–95
COD removal, %	70–80	80–95	85-90	70–85	85–90
TSS removal, %	70–80	85–90	75–85	70–85	85–95
Overall HRT	4–10 hrs	12–14 hrs	13-14 hrs	8–15 days	8–12 hrs
Average applied OLR for sewage treatment	1.0–2.0 KgCOD/m^3·day	0.3–0.55 KgBOD/m^3·day	1.5 to 2.0 KgCOD/m^3·day	50–450 kgBOD/ha·d	4–30 gCOD/m^2·day
Average area required (m^2/mld)	1450	1820	1620	8000	450
Biogas generation	0.05–0.25 (m^3/Kg COD removed)	Nil	Nil	0.05 to 1.5 m^3/Kg BOD_5 (infrequently collected)	Nil
Economic life in years	30	30	30	30	30

2.3 UASB reactor use in Palestine

The UASB reactors have been applied in domestic wastewater pre-treatment scale in Latin America and India, of tropical climates with hot and constant wastewater temperature of more than 20 ºC (Mahmoud, 2008). But the application of UASB reactor countries with high sewage strength and low temperature or temperature fluctuation, like in Palestine and Jordan, is still challenging (Mahmoud *et al.*, 2003). In these countries, Mediterranean climate domains with cold winter, and sewage is characterized with high fraction and concentration of suspended solids. These specific climate conditions and wastewater characteristics lead to operational challenges like scum layer formation, solids accumulation, low sludge methanogenic activity and so low methane gas production (Al-Jamal and Mahmoud, 2009).

The design and performance of the UASB reactor is widely affected by the SRT and wastewater characteristics, of mainly wastewater temperature, biodegradability and suspended solids (Mahmoud, 2008). These features are elaborated hereafter.

2.4 Effects of SRT and temperature

In biological wastewater treatment process, the selected Solids Retention Time (SRT) has big effects on the performance of the process, production of sludge, and oxygen demand. (Wastewater: control of solids retention time in waste water treatment process) . Therefore, SRT is certainly the most important parameter that influences the degradation of organic compounds. The SRT have a main role in anaerobic treatment, precisely for methanogenic bacteria at low process temperature (Mahmoud, 2002; Halalsheh *et al*., 2005). The solids retention time (SRT) needs to be long enough to maintain the existence and minimum activity of methanogens. Methanogenesis process takes place at SRT between 5-15 days on 25 °C and 30-50 days on 15 °C (Halalsheh *et al*., 2005); but it becomes very dependent on of the feeding materials characteristics.

The relationship between operating temperature and SRT is indirectly proportional. For lower wastewater temperature, longer SRT is needed for designing UASB reactors so as to be able to degrade the entrapped solids due to reduced rates of the hydrolysis and methanogens steps of anaerobic degradation (Zeeman and Lettinga, 1999). Therefore, for each wastewater temperature, a specific SRT is required based wastewater characteristics. Once the proper SRT is identified, the suitable HRT can be obtained by using the following model (Zeeman and Lettinga, 1999):

$SRT = \frac{X}{X_p}$............................ (eq. 1)

$X_p = OxSSxRx(1-H)$ .... (eq. 2)

$HRT = \frac{C}{O}$ ....……. (eq. 3)

$HRT = \left(\frac{CxSS}{X}\right) xR(1-H)xSRT$ … (eq. 4)

Where:

X: reactor’s sludge concentration (g COD/l); with 1 gVSS = 1.40 gCOD

Xp: biosolids (Sludge) production (g COD/L.d)

O: OLR (kg COD/m^3. d)

$SS = COD_{sus} / COD_{inf}$

R: removed fraction of COD_{sus}

C: COD concentration in the influent (kg/m^3)

HRT and SRT: Hydraulic and sludge retention times, respectively (d)

H: fraction of removed solids that are hydrolyzed

Based on the model calculations, Mahmoud *et al.* (2003) affirmed that an HRT of more than 22 hours is needed to design a UASB reactor for sewage treatment in Palestine. The calculated long HRT is assumed sufficient to overcome the cold winter period, calculated on the basis of a minimum 75 days SRT that is needed at a 15 ºC average sewage temperature in winter. For wastewater temperatures less than 5 ºC, a SRT of more than 100 day is needed to obtain sludge bed active methanogens (Zeeman and Lettinga, 1999).

2.5 Effects Hydraulic retention time (HRT)

Hydraulic retention time (HRT) is one of the most important parameters influencing reactor performance, particularly in the case of municipal wastewater. The upflow velocity () is proportional to HRT and plays an important role in the entrapment of suspended solids. A decrease in results in an increase in HRT, which improves the system's suspended solids (SS) removal efficiency. The COD removal efficiency of a UASB reactor decreases as upflow velocity increases because it reduces the contact time between sludge and wastewater, as well as smashing of sludge granules and, as a result, higher solids washout. (Daud et al., 2018)

1.6 Effect of Organic Loading Rate

OLR is the main indicator that has a significant impact on microbial ecology and the operation of the UASB process. In the case of sewage, OLR is typically applied in the range of 1.0–2.0 KgCOD/m3day. The UASB reactor is preferred because of its ability to treat wastewater with low suspended solids content while producing a higher methane yield. Reactors seeded with granular activated sludge can provide high performance in a short period of time and can also adapt quickly to increases in OLR. The effect of OLR on the performance of a UASB reactor is determined by a number of factors, some of which have a dissimilar, if not contradictory, effect on the performance of the UASB reactor. (Chen et al.,2010). (Farajzadehha et al.,2012) have found that increasing the OLR of high-rate anaerobic reactors increases their efficiency. However, that increase is limited to a certain OLR, beyond which sludge bed flotation and excessive foaming in the gas-liquid-solids separator (GLSS) occur; thus, an optimum OLR range is usually recommended for a given temperature range and wastewater.

1.7 Effect of PH

The pH of an anaerobic reactor is especially important because the methanogenesis process can only proceed at a high rate if the pH is kept between 6.3 and 7.8. Because of the buffering capacity of the acid-base system (carbonate system), the pH of domestic sewage naturally remains in this range, and chemical addition is not required. The pH and buffering capacity of UASB reactors used for sewage treatment in tropical and subtropical countries have been reported to be extremely stable. When treating domestic wastewater with an anaerobic reactor, both hydrolysis and acidogenesis rates improve, and pH 7 provides an optimal working environment for anaerobic digestion, resulting in more than 80% TOC and COD removal (Rizvi et al.,2015).

1.8 Effect of Granulation

Long HRTs have been found to be detrimental to the development of granular sludge in UASB reactors. In contrast, very short HRTs result in biomass washout. Both scenarios are unacceptable for achieving the best possible results from the UASB reactor. Despite the fact that granulation has been thought to be necessary for successful treatment of domestic wastewater in UASB reactors, these reactors have been found to be effective even without granules. The formation of granules during startup aids in the reduction of startup time. The UASB reactor's high performance is based on the formation of an active sludge in the lower part of the reactor. The formation of a sludge bed is caused by the accumulation of incoming suspended solids and bacterial growth under specific conditions, as a result of natural bacterial aggregation in flocs and the evolution of granules in the form of a layered structure (Daud et al., 2018).

1.9 Effect of Mixing

Mixing allows microbes and wastewater to have more effective contact time, reduces mass transfer barriers, slows the growth of repressive by-products, and provides uniform environmental conditions. If mixing is not done properly, pockets of substrate at separate digestion stages will impede the main process rate, resulting in pH and temperature changes at each stage. Mechanical mixing or recirculation of methane gas or slurry can be used. A number of researchers have discovered that significant mixing has an impact on the operation of anaerobic reactors. Mixing improved the efficiency of anaerobic systems treating wastewater with high COD concentrations; additionally, slurry recirculation outperformed biogas recirculation and impeller mixing mode (Kaparaju et al.,2008).

2.10 Cases of sewage treatment in upflow reactors

Two anaerobic full-scale reactors of the same configuration, total volume 14.6 m^3 and total height of 2.57 m, were studied both and were operated with an HRT up to 16-hour and subjected to OLR less than 2.7 kgCOD/ (m^3.d) (Amaral *et al.*, 2019).

UASB reactor is a well- known process for sewage treatment in India since it has a significantly low energy- requirements. On the other hand, UASB system has many limiting factors as the nutrients removal, accumulation of carbon and pathogens growth. This poses the application of a post- treatment stage after UASB that obligatory should meet the international quality standards of the treated-water. The modern treatment processes of waste water accredited the post-treatment of anaerobic treatment of sewage, specifically the full-scale UASB reactors in Surat, as well as the Indian. Two full-scale wastewater treatment institutes with many forms of UASB post-treatment processes have entered wastewater treatment sector.

Prolonged Aeration and Moving Bed Biological Reactor (MBBR) have been studied thoroughly. Pilot research was held out on a full-scale wastewater treatment plant (WWTP) focusing on the Sequential Batch Reactor (SBR) for post-treatment of a UASB reactor effluent over three months of study and research. Inlet and outlet characteristics that were studied are BOD, COD, TSS for polishing the effluent UASB reactor. The application of the SBR technology was shown to be much beneficial as comparing to all the studied technologies (Vashi *et al*., 2019).

El-Seddik et al. (2018) designed a Fractional Order Model (FOM) of UASB reactor treatment of wastewater of high-strength substrate biodegradation. The model was built to measure the biogas production (methane gas and Carbone dioxide) and the exact growth rate of bacteria with more degree of freedom, as well as the study of the hereditary influence of the present biomass on substrate degradation, biomass concentration is tested in reactor under the influence of many factors. A development in the performance was referred to FOM ability to influence on the biomass accumulation in the reactor.

UASB reactor was applied to process preserved wastewater to examine the effect of the anaerobic treatment's time on COD, pH, turbidity, SS, conductivity, absorbance, and decolonization rate of preserved wastewater. Under the optimum parameters of anaerobic treatment's time, the COD removal rate, turbidity removal rate, pH, conductivity, SS removal rate, absorbance, and decoloration rate of the wastewater were, in sequence, 49.6%, 38.5%, 5.68, 0.518×10^4, 24%, 0.598, and 32.4%. So that, the UASB reactor could be utilized as a limiting factor for the preserved wastewater (Zhang *et al*., 2016).

Anaerobic Filter (AF) and UASB was embedded in series in the design of an anaerobic treatment system that was then ran to examine its role in domestic wastewater treatment with considerable suspended solids fraction in the Jordan's ambient temperatures of 25 ºC for summer and 18ºC for winter. The apparatus was run in the period time of Sept, 2003 to April, 2004. The system's Hydraulic Retention Time (HRT) was 4 hours for phase (1) and AF of 8 hours for the phase (2) UASB reactor. Average COD_{tot} was 58% and COD_{sus} removal efficiencies was 81% of the AF-UASB on the study time period. The results of the first stage AF showed efficient discharging suspended solids. Also, hydrolysis, acidification and methanogenesis occurred in the first stage AF that was supportive to the second UASB reactor to state that AF-UASB system is efficient in processing concentrated sewage with high content of suspended solids (Sawajneh *et al*., 2010).

Two UASB-septic tanks were run on-site in parallel for more than 6 months under two different hydraulic retention times (HRT) as 2 days for R1 and 4 days for R2 at 24°C sewage temperature. The sewage had a considerable amount of COD_{tot} level of 1189 mg/L, and a large level of COD_{sus} as 54%. The removal efficiencies of both tanks as COD_{tot}, COD_{sus}, BOD_5 and TSS were 56%, 87%, 59% and 81%" and ''58%, 90%, 60% and 82%" consequently. The COD_{col} and COD_{dis} were also 31% and 20%, and 34% and 22% for both systems. Finally, the reactor can be operated perfectly at 2 days HRT (Al-Shayah and Mahmoud, 2008).

A study in which UASB reactor (96 m^3) was ran for 30 months with variable operational parameters to evaluate the utility of intense sewage treatment (COD_{tot} = 1531 mg/l) at 18 ºC average ambient temperature in winter and 25 ºC in summer. The reactor was operated as a two-stage system during the first year at OLRs of 3.6-5.0 kg COD/m^3. d at first stage and on 2.9-4.6 kg COD/m^3. d in the second one. The findings of the first UASB reactor showed average removal efficiencies of 51% COD_{tot} and 60% COD_{sus}. By the second year, results of treatment process demonstrated a 62% removal efficiency for COD_{tot} during summer, and 51% during winter. The results demonstrated no significant advancement in the performance especially the COD_{tot}, and a single-stage UASB reactor at longer HRT is preferred more than the two-stage system at the environmental conditions of the research (Halalsheh *et al*., 2005).

Two UASB-septic tanks fed with black water of high concentration at 15-25 ºC were tested for a year, where he discharges efficiencies of COD_{tot} and COD_{sus} in a $UASB_{ST}$ at 25 ºC were 70% and 92% respectively. The major fraction of effluent nitrogen and phosphate was in a soluble form of ammonium and phosphate, making the product of digestion attractive for nutrient recovery and reuse. Inoculation of the reactor ensures its faster start-up. The accumulation of the sludge bed was slow implying that sludge withdrawal does not take place often. Heavy metals content was below the standard for irrigation while the E. Coli count in the effluent of UASBST does not fully match with the agricultural reuse

Table 2.3. Overview of domestic wastewater treatment in UASB reactors

Reactor	**Temperature** (ºC)	**HRT** (Hours)	**OLR** kgCOD/ (m^3.d)	**Removal efficiency COD %**	**References**
UASB (compact anaerobic reactors)		16	Less 2.7	57.4	Amaral *et al*. (2019)
UASB SBR		12		93	Vashi *et al*. (2019)
UASB MBBR		12		90	
UASB EA		12		90	
	8-40	8	0.57-6.35	65-85	Khan *et al*. (2015)
UASB AnMBR	15	8		86	Petropoulos *et al*. (2019)
UASB	25-30	4	7.67	55	Moharram *et al*. (2016)
Septic tank-UASB-sand filter	19	6		93	Lohani *et al*. (2020)
UASB-digester	12.5-20	6	2.5 (g COD/L d)	60	Zhang *et al*. (2018)

Chapter 3

Materials and Methods

1.10 Location

This investigation was carried out in Ramallah city in the mid of the West Bank that the most important administrative center and the seat of the Palestinian government. Ramallah is the Palestinian city of commerce and services, with a variety of industrial facilities on varying scales. According to the most recent Palestinian Central Bureau of Statistics (PCBS) census, the population of Ramallah is 38,660 people. The average daily water consumption in Ramallah is 115.3 L/c.d., and sewage is collected in sewers that serve approximately 75% of the population (Mahmoud, 2017). Sewage was collected for this study from the Al-Tireh treatment plant via a pilot plant that was built there.

1.11 Experimental setup

Two UASB reactors with 140 L working volume for each one, were installed at Al-Tireh wastewater treatment plant (WWTP), and were fed with sieved influent of 2 mm bore size that exists in Al Tireh WWTP. Al-Tireh WWTP is composed of an aerobic MBR system that treats sieved influent. The UASB reactors were operated in parallel at 12 and 24 hr HRT at ambient temperature treating sieved domestic sewage (Fig. 1). Two peristaltic pumps were used to feed wastewater into the two UASB reactors. Biogas was continuously measured using gas maters (Ritter, Milligas Counter MGC-1 PMMA). Along the UASB reactor, sampling ports were installed. The influent was pumped into the reactors via a Polyvinyl chloride (PVC) tube with four outlets 5cm from the reactor base. The beginning of the practical application of the research, involving wastewater variables and recording ambient air temperature and recording of daily produced biogas, facilitated daily monitoring. Approximately 2-3 times per week, grab samples of sieved sewage and reactor effluent values were collected (1 L for each). For each collected sample, the temperature of the wastewater was measured in the field. The volume of biogas produced and the temperature of the surrounding air were measured on a daily basis.

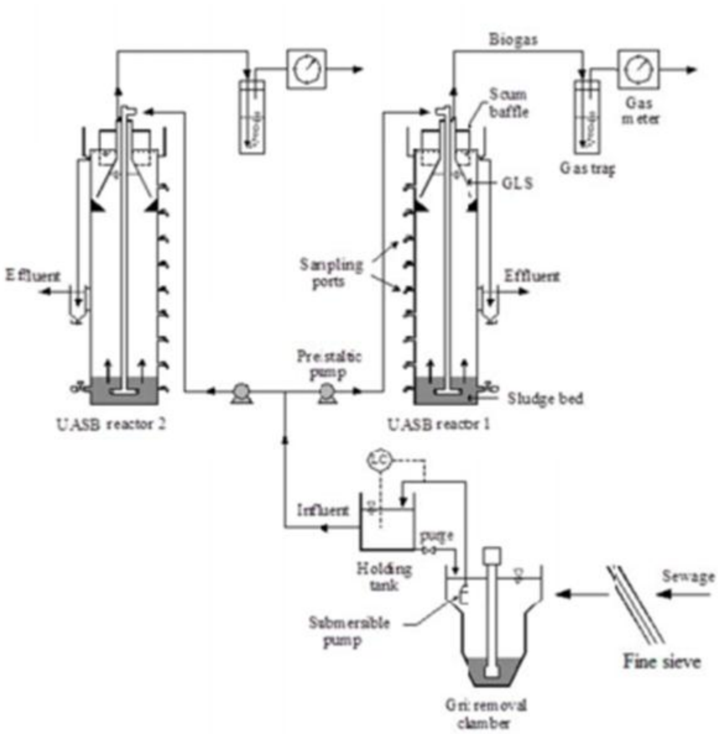

Figure 3.1. The UASB reactors pilot research setup

1.12 Reactor’s sewage feeding

A preliminary treatment of raw sewage was provided at Al-Tireh WWTP composed of fine sieves and grit removal chamber. Before it had been pumped to a feed interception tank from where both of the UASB reactors were fed. An automatic controlled submersible pump, used to pump the wastewater from the girt removal chamber to a distribution box (500 L tank made of plastic) where wastewater was fed to the UASB reactors using adjustable flow pumps. The distribution box was beneficial for reducing the pumping distance to the UASB reactor. Moreover, the distribution box served as a balancing tank, where the UASB reactors' influent preliminary treated wastewater was sampled.

1.13 UASB reactors operation

The UASB reactors were operated starting in March, 2020. The UASB reactors were run in parallel simultaneously at atmospheric air temperature that fluctuated in the range of 15 ºC to 34 ºC. The two UASB reactors had been designed and ran at HRTs of respectively 12 and 24 hours for UASB (R1) reactor and UASB (R2) reactor, for a six months period. The UASB reactors design and operation parameters are summarized in Table 3.1.

Table 3.1**.** Design parameters and operation condition of the two UASB reactors

Parameter	Unit	UASB (R1)	UASB (R2)
Flow rate	L/d	177	354
HRT	d	1	0.5
Height	m	2.50	2.50
Diameter	m	0.30	0.30

The system was temporarily suspended from April to July 2020 due to the Corona virus.

1.14 Sampling

Sampling was performed of raw sewage sample after the preliminary treatment units; UASB 1 (R1) and UASB2 (R2) effluent were sampled twice to thrice weekly (1 liter volume for each sample). The collected samples were kept inside ice box at around 4 ºC till being transported to the lab. An alcohol thermometer was fixed at the Al-Tireh WWTP and measured sewage and ambient temperature daily. The pH was measured in *situ* using EC pH meter (HACH). Gas production was monitoring and recorded daily.

Samples were analyzed for COD_{tot}, COD_{sus}, COD_{col}, TSS, VSS, NH_4^+, Nkj, total P, *ortho* PO_4^{3-} and SO_4^{2-}, all according to standard methods (APHA, 2005). Moreover, sludge samples were analyzed for TS, VS tests were also done for the effluent samples from the reactors.

1.15 Analytical Methods

The analytical methods used for characterizing influent and effluent wastewater are presented hereafter.

1.15.1 Chemical analysis

The influent and effluent wastewater were analyzed for these parameters: Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Kjeldhal Nitrogen (NKj-N), Ammonia (NH_4^+-N), Sulfate (SO_4^{2-}), Total Phosphorous (Total P) and Ortho-Phosphate (PO_4^{3-}). The parameters were analysed according to APHA (2005).

1.15.2 COD

To measure total COD (CODtot), 4.4 µm folded paper-filtered (Schleicher and Schuell 5951/2, Germany) samples were used, as were 0.45 µm membrane-filtered (Schleicher and Schuell ME 25, Germany) samples for particulate CODp and 0.45 µm membrane-filtered (Schleicher and Schuell ME 25, Germany) samples for dissolved COD (CODdis). CODsus (suspended COD) and CODcol (coloidal COD) were calculated as the difference between CODtot and CODp, and CODp and CODdis., respectively. The COD test was performed using the closed reflux method. (APHA, 2005).

1.15.3 BOD

DOD_5 was measured for the influent and effluents of the two reactors (APHA, 2005).

1.15.4 NH_4^+-N

Ammonia was measured by the Nesslerization method for paper filtered samples with spectrophotometer at absorbance of 425 nm wavelength (APHA, 2005).

1.15.5 SO_4^{-2}

Sulfate from paper-filtered samples was measured with spectrophotometer at absorbance at 420 nm wavelengths (APHA, 2005).

1.15.6 Total P and PO_4^{3-}

The concentration of total P was measured after digesting the wastewater samples and the *ortho*-phosphate after filtering wastewater samples through membranes using spectrophotometer at absorbance of 880 nm wavelengths (APHA, 2005).

1.15.7 Physical analysis

The measured physical parameters included: Total solids (TS), total suspended Solids (TSS), total volatile solids (VS) and volatile suspended solids (VSS), pH, temperature, and atmospheric pressure.

1.15.8 Total and suspended solids

Total solids and suspended solids were monitored by drying in an oven at 105 ºC as described by APHA (2005). For measuring the suspended solids, glass micro-fiber papers [GF/C 125mm, CATNO 1822 122 Whatman] were used.

1.15.9 Volatile solids and volatile suspended solids

Volatile solids and volatile suspended solids were measured by combustion in a furnace at 550 ºC according to the procedure described in APHA (2005).

1.15.10pH

pH was measured by EC/pH device (HACH).

1.15.11Temperature

Wastewater and ambient air temperatures were measured in Al-Tireh treatment plant using alcohol thermometer.

1.15.12Atmospheric pressure

The atmospheric pressure at the location of the pilot plan was measured using barometer pocket device.

1.16 Computations

1.16.1 Efficiency

Eq (3.3) was used to calculate the parameter removal efficiencies.

Removal Efficiency (%) = [(Influent concentration – Effluent concentration) *100%] / Influent concentration.......... (3.3)

Where:

Influent and effluent concentrations stand for the of a specific parameter in mg/L.

1.16.2 Statistical data analysis

Microsoft Excel 2010 was used to calculate the descriptive statistics (mean, range, and standard deviations) of the measured parameters. The t-test was performed using the SPSS software release 23.0.0 SPSS for the comparison of the two reactors, R1 and R2 removal efficiencies. "Compare Means," "Paired Samples t-tests," and "Type confidence interval 95 percent" are all options. If the *p* value is less than 0.05, the difference between the means of the two groups is considered significant ($p < 0.05$).

Chapter 4

Results and Discussion

1.17 Introduction

The raw and sieved sewage characteristics are given in Table 4.1 between 22nd March and 22nd October 2020. The given findings revealed that the from Al-Tireh neighborhood/ Ramallah city's wastewater is domestic, while the raw if of "high strength", and the sieved is of medium strength according to Metcalf and Eddy sewage strength (2013). Likewise, the COD_{tot}, BOD_5, NKj, ammonia, phosphorous, sulfate and solids concentrations, that were found to be higher than average values of sewage in other developing countries. The high concentrations in the sewage is explained by low water consumption, people's habit, since the neighborhood is merely residential (Mahmoud, 2008).

Table 4.1. Characteristics of Influent raw sewage Al-Tireh WWTP/ Ramallah/Palestine

		Raw		Sieved	
Parameter	**No. samples**	**Range**	**Average (STD)**	**Range**	**Average (STD)**
COD_{tot}	25	903-1293	1058(110)	494-866	717(93)
COD_{sus}	25	433-722	571(83)	171-414	319(71)
COD_{co}	25	136-331	193(47)	103-199	138(28)
COD_{dis}	25	198-377	295(45)	168-349	259(43)
BOD_5	10	409-593	494(55)	299-431	356(43)
COD/BOD_5	10	1.9-2.5	2.1(0.2)	1.9-2.0	2.0(0.1)
pH	25	6.43-7.64	7.28(0.36)	6.42-7.44	7.05(0.34)
NH_4^+ as N	5	49-71	60(8)		
Total P	5	10-15	13(2)		

NKj as N	4	67-94	82(11)		
PO_4^{3-} as P	4	13-19	15.5(3)		
SO_4^{2-} as SO_4^{-2}	5	81-107	94(10)		
TSS	12	496-888	658(113)	348-632	500(90)
VSS	12	328-792	524.7(130)	299-532	401(82)
T_{ww}	25	20-30	25(3)		
T_{amb}	25	25-36	30(3.3)		

The influent sewage COD fractions in Al-Tireh WWTP is depicted in Table 4.1. The COD_{sus} part of the influent wastewater represent a substantial percentage of the COD_{tot} of 54% (570 mg/L) (Figure 4.1), which is in the typical range f 43-54% (Al-Shayah and Mahmoud, 2008; Al-Jamal and Mahmoud, 2009), but less than the percentage in Al Bireh sewage of 59% (Mahmoud, 2008).

COD_{col} composes 18.2 % of the raw sewage COD_{tot}, which is lower close to the range of 20-30% in the sewage of Bennekom-The Netherlands (Elmitwalli, 2000), however, it is greater than the 10% indicated by Halalsheh (2010) for Amman City's sewage in Jordan.

Likewise, data presented in Table 4.1 reveals that in raw sewage the COD_{dis}/COD_{tot} ratio is 27.9%. Portion of the raw COD_{tot} and fractions might be converted from a form to another while travelling in the sewerage network heading the treatment plant. The COD_{tot} and fractions (COD_{sus}, COD_{col} and COD_{dis}) concentration values in the Al-Tireh WWTP influent wastewater along the research period are presented in Figure 4.1.

The average concentration values of TSS and VSS, as well as the VSS/TSS ratio of the raw sewage were respectively 658 and, 525 mg/L, and 79.8%. The attained concentrations values were greater than those typically reported for municipal sewage in Palestine and Jordan (Halalsheh, 2002; Al-Shayah and Mahmoud, 2008; Al-Jamal and Mahmoud, 2009). This might be because Al-Tireh is a merely residential neighborhood in Ramallah City with almost no commercial or industrial activities. In contrast to this result, the sewage strength of Al-Tireh neighborhood/ Ramallah city, is pit less than previous results presented by Mahmoud *et al*. (2003) as presented in Table 1.3.

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1.18 Performance of Sieved Influent UASB reactor

The performance of sieved influent fed UASB reactors (R1 and R2) achieved removal efficiencies during the entire operation period is depicted in Table 4.2. Moreover, the difference in COD_{dis}, COD_{sus}, COD_{col}, COD_{dis}, BOD_5, TSS and VSS concentrations between R1 and R2 is statistically significant ($\rho<0.05$).

Table 4.2. Characteristics of Influent raw and sieved sewage and the removal efficiencies at Al-Tireh WWTP-Palestine

Parameter	**Samples**	**Raw Sewage**	**Sieved Sewage**	**Efficiency (%)**
COD_{tot}	25	1058	717	22.2
COD_{sus}	25	571	319	44.2
COD_{col}	25	193	138	28.5
COD_{dis}	25	295	259	12.2
BOD_5	10	494	356	28
TSS	12	658	501	23.9
VSS	12	525	402	23.4

1.19 Process performance the both UASB reactors

The both UASB reactors, process performance, R1 and R2 which had been studied during the research period are summaries in Tables 4.4 which explains the specification in form of numbers, and percentage.

1.19.1 Efficiency of COD removal

The COD removal efficiency results for both UASB reactors are given in Table 4.3 and illustrated by the figures (4.1- 4.6) for respectively COD_{tot} and fractions. Over the research period, R1 with achieved efficiencies for COD_{tot}, COD_{sus}, COD_{col}, COD_{dis} removal of 68%, 80%, 60%, 50%, respectively. Also, R2 achieved mean efficiencies of removal for COD_{tot}, COD_{sus}, COD_{col}, COD_{dis} of respectively 76%, 84 %, 72%, 61%. Therefore, R2 achieved better removal efficiencies of all COD fractions, and as such this UASB reactor more effective than other reactors previously researched by Al-Jamal and Mahmoud (2009) during winter period and Al-Shayah and Mahmoud (2008) during summer period.

1.19.2 CODtot

The mean removal efficiencies and COD_{tot} effluent concentrations are shown in Table 4.3.for both reactors. The mean COD_{tot} concentrations in the effluents of UASB 1 and UASB 2 were 336 mg/l and 259 mg/l, respectively. The mean removal efficiencies were respectively 68% and 76% for R1 and R2. The course, concentration of COD_{tot} in the effluent of R1 and R2 and the removal efficiencies are presented in Figure 4.1. Therefore, R2 achieved better COD_{tot} removal efficacies as compared to R1. Moreover, the difference in COD_{tot} concentrations between R1 and R2 is statistically significant ($\rho<0.05$).

The variation in hydraulic condition can explain a lot of the difference in efficiency between two reactors. The sieved that decrease suspended solids effluent into reactors and the temperature (25-36 ºC). Compared with the results that had been reported by Wafa Al-Jamal (2009), Mohammad Al-Shayah, (2008) and Mahmoud (2008).

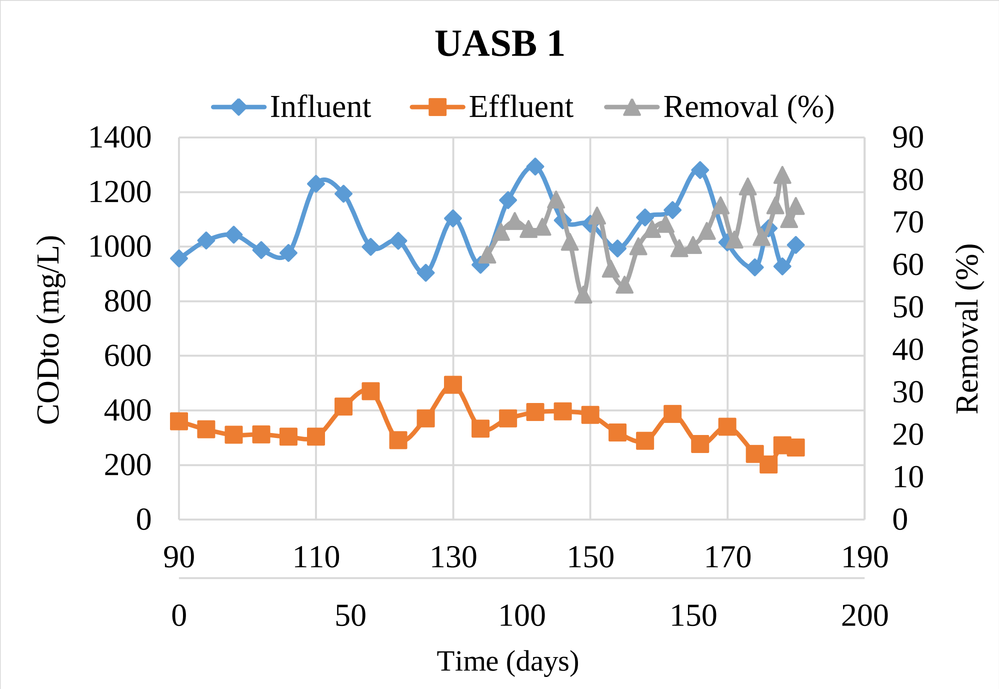

Figure 4.1: COD_{tot} concentrations and removal efficiency - UASB 1

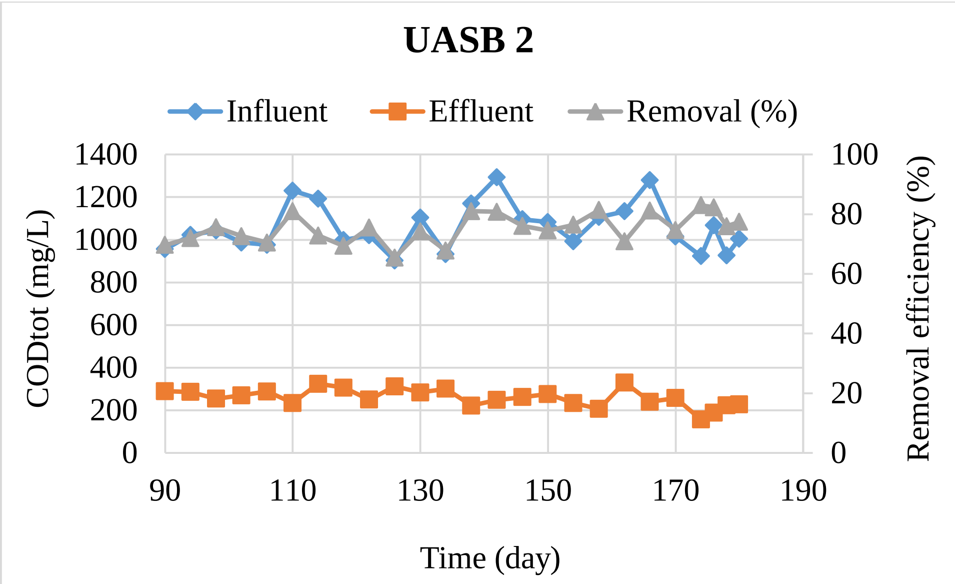

Figure 4.2: COD_{tot} concentrations and removal efficiency - UASB 2

1.19.3 CODsus

The results in this research as shown in Table 4.3 recorded a medium average removal efficiency for COD_{sus} in both of the reactors 80% and 84% for R1 and R2, and mean concentration of effluent COD_{sus} 113 mg/l and 91 mg/l for R1 and R2, respectively.

Table 4.3 and Figure 4.2 show that the effluent concentration of COD_{sus} was very stable in comparison with the influent COD_{sus} shown in Figure 4.3. Also, this could be proved by the standard deviations, which was seen in both of the two reactors R1 and R2. Moreover, the difference in COD_{sus} concentrations between R1 and R2 is statistically significant ($\rho<0.05$)

If the results obtained in this research are compared to the results that had been recorded by Al- Shayah and Mahmoud (2008), one can see that the COD_{sus} average removal efficiency decreased with the value 80% and 84% for R1 and R2, respectively. Likewise, as compared to Al-Jamal and Mahmoud (2009), average removal efficiencies of 83% and 85% were achieved in R1 and R2.

The reduction in the efficiency at the same rate could be caused by the change in temperature. According to Mahmoud (2002), increasing Vup reduces solids removal efficiency by increasing the hydraulic shearing force and solids particles, causing solids particles to flow out of the reactor.

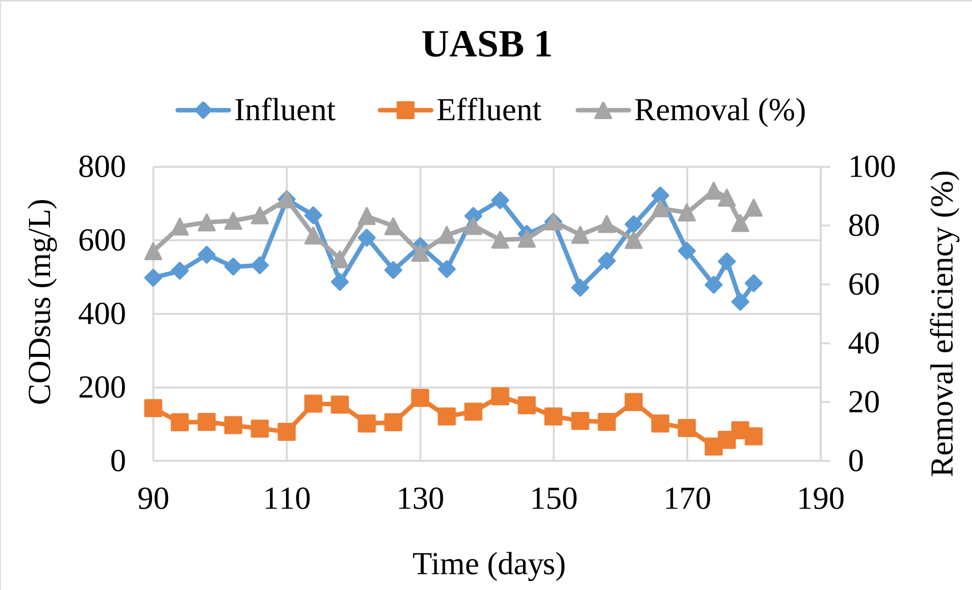

Figure 4.3: COD_{sus} concentrations and removal efficiency - UASB 1

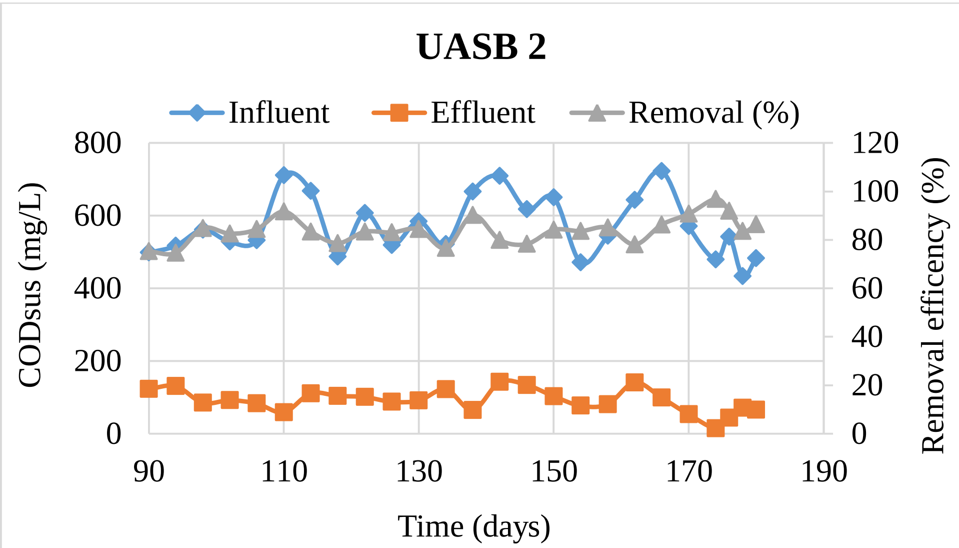

Figure 4.4: COD_{sus} concentrations and removal efficiency - UASB 2

1.19.4 CODcol

In this research and as shown in Table 4.3 and Figure 4.3and 4.4 one can see that both of the reactors R1 and R2 are not sufficient for removing COD_{col} from the influent during the research durations. The average removal efficiency was 60% and 72% of R1 and R2, respectively, but the removal efficiencies varied widely. The big variation of COD_{col} removal efficiency with some negative removal values was in some cases observed in both R1 and R2. This phenomenon might be explained by two points. First, there is a change in the influent COD_{col}, as well as improved COD_{sus} removal as a result of improved conditions of digestion. This supports the enhancement of COD_{col} removal, as colloidal particles might be produced as explained by Elmitwalli (2000) from COD_{sus}.

The difference in the concentration of COD_{col} between both reactors was statistically significant ($\rho<0.05$). The results had also increase compare to Al-Shayah and Mahmoud (2005) and Elmitwalli (2002). Where Elmitwalli (2002) justify the results as the increase in the COD_{col} was generated from the COD_{sus} that had been degraded in the reactor. The temperature variations may affect the removal efficiency of the COD_{col} where from Figure 4.3 and 4.4 at the

The decrease in the removal rate efficiency may be regarding to the hydraulic rate where the COD_{sus} takes more time to degradable and so produce more and more COD_{col} in the reactors. However, this is proved from the high removal rate of COD_{sus} in R2 compared to R1. In R1 the solids leave the reactor faster than R2 without complete degradation relatively to R2 so there will be no more COD_{col} from the degradation of COD_{sus}.

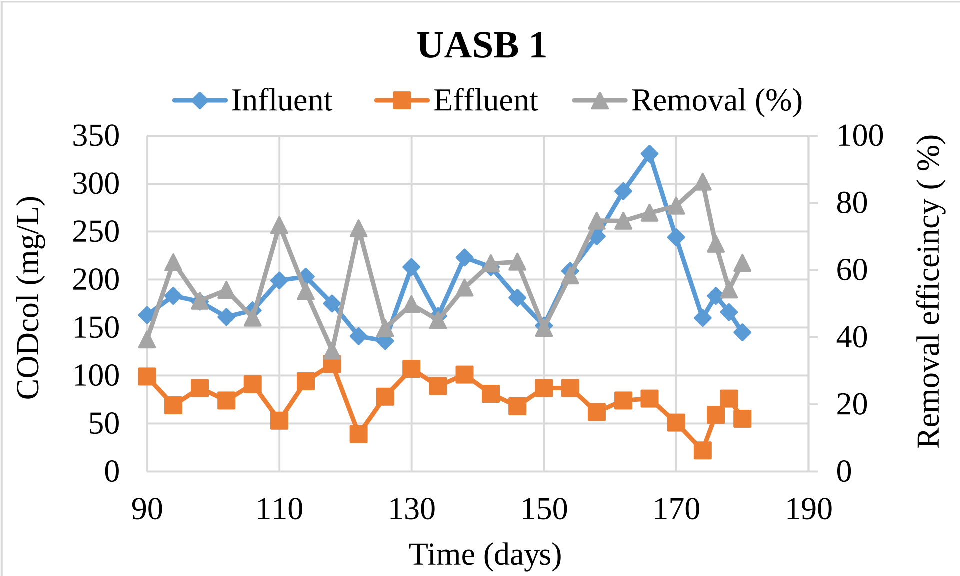

Figure 4.5: COD_{col} concentrations in and removal efficiency - UASB1

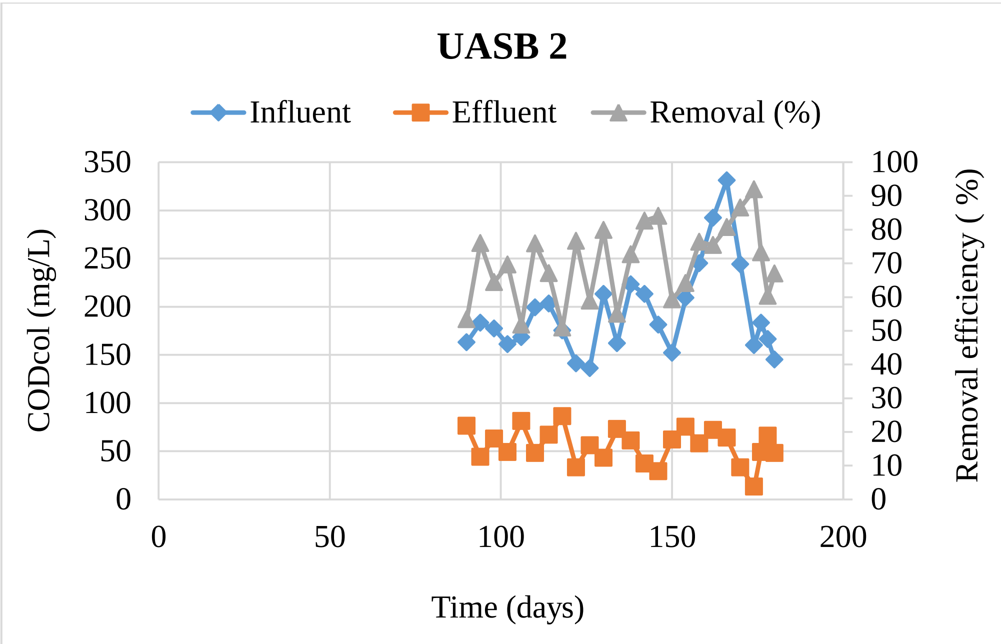

Figure 4.6: COD_{col} concentrations and removal efficiency - UASB 2

1.19.5 CODdis

Referring to the results obtained in research in removing COD_{dis} that are shown in Table 4.3 one can see that the average removal rate was 50% and 61% for respectively R1 and R2. Also, the pattern at which the removal took place in both of the reactors was the same as shown in Figure 4.5. This may indicate that the biological conditions are better in R2 than R1. Moreover, the difference in COD_{dis} concentrations between R1 and R2 is statistically significant ($\rho<0.05$)

The overall removal efficiency obtained in this research in this research is relatively higher than previously reported results of UAB reactors tested in Palestine treating raw sewage (Al-Shayah and Mahmoud, 2008; Al-Jamal and Mahmoud, 2009).

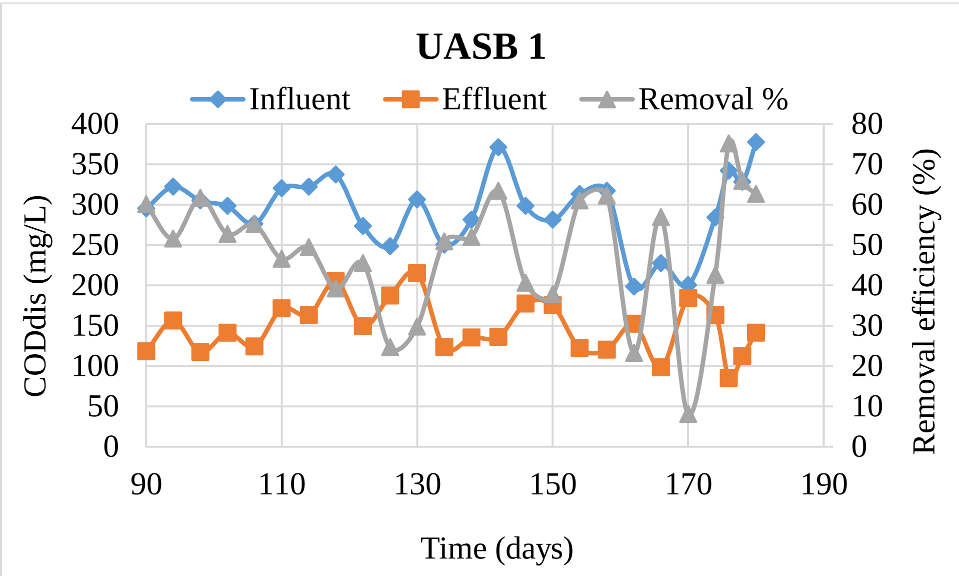

Figure 4.7: COD_{dis} concentrations in and removal efficiency - UASB1

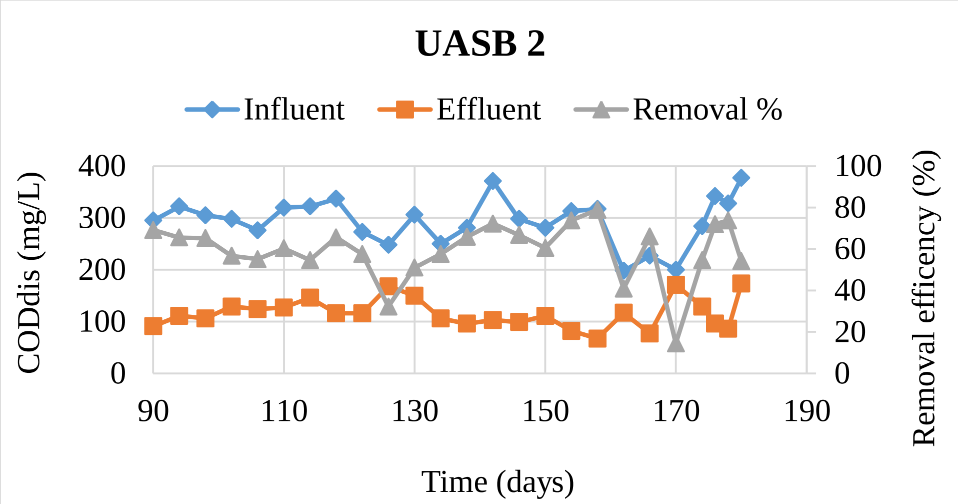

Figure 4.8: COD_{dis} concentrations and removal efficiency - UASB 2

Table 4.3**.** Influent and effluent concentrations (mg/l), as well as removal efficiencies (%), were measured in the two UASB-reactors at Al-Tireh WWTP.

Parameter	Sample #	Influent concentration	**UASB-(R1) HRT =12 hours** Effluent concentration Range	Average	Removal efficiency (%) Range	Average	**UASB-(R2) HRT =24 hours** Effluent concentration Range	Average	Removal efficiency (%) Range	Average
COD_{tot}	25	1058	201-493	336	31-72	68	157-330	259	54-78	76
COD_{sus}	25	571	39-176	113	45-88	80	15-142	91	56-95	84
COD_{col}	25	193	22-112	76	19-84	60	13-86	55	38-90	72
COD_{dis}	25	295	85-215	147	17-67	50	67-173	116	33-74	61
BOD_5	10	494	110-201	153	44-71	69	90-172	153	52-75	69
pH	40	7.28	6.42 -7.51	7.07	-	-	6.46-7.40	7.07	-	-
NH_4^+ as N	5	60	47-61	55	3.5-22	8	51-58	57	3.5-15	5
NKj as N	4	82	56-71	63	13-32	23	48-70	59	15-42	28
Total phosphate as P	5	13	10-15	12	0-23	8	11-13	12	0-15	8
PO_4^{3-} as P	4	15.4	16.8-19.5	17.9	- efficiency	- efficiency	22.1-25.8	24.3	- efficiency	- efficiency
SO_4^{2-} as SO_4^{2-}	5	94	34-45	41	52-64	56	17-29	22	69-92	77
TSS	12	658	128-219	194	67-81	71	88-177	137	73-87	79
VSS	12	525	86-103	94	80-84	82	41-89	73	83-92	86

1.20 Biogas production

The average CH_4 gas measured at Al-Tireh wastewater treatment plant for R1 and R2 respectively was 42 l/d and 43 l/d. Figure 4.9 shows the rate of gas generation in UASB1 and UASB2 and the ambient air temperature variation during the research period.

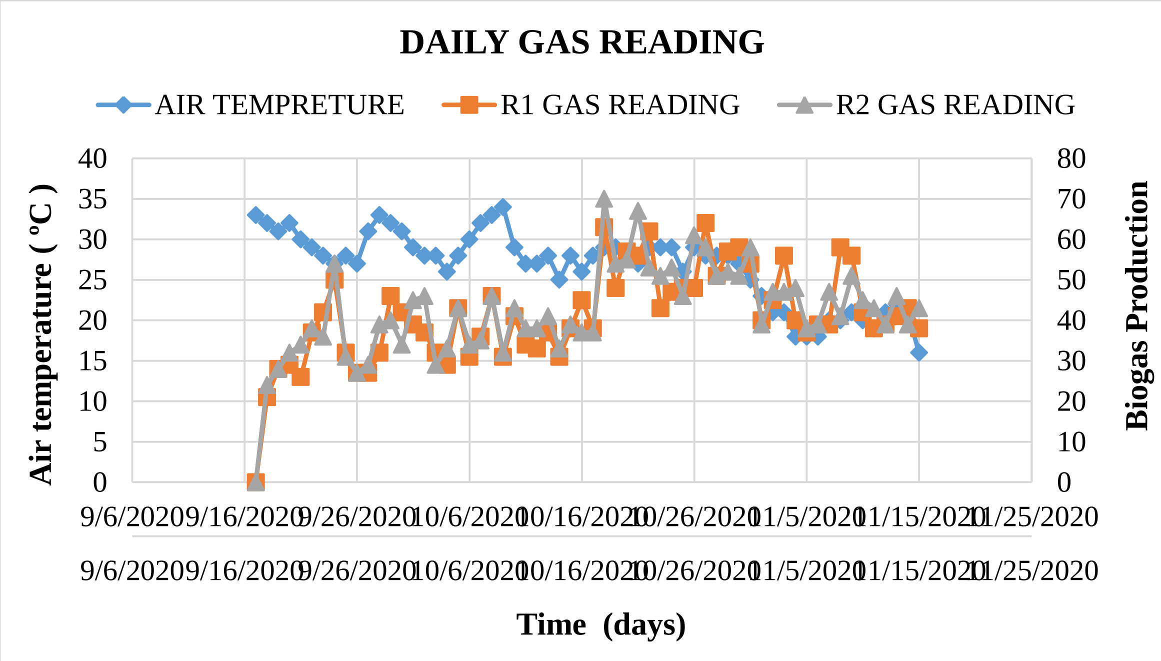

Figure 4.9: Biogas production (m^3/day) of reactors 1 and 2 vs. with temperature variations (ºC) during time (day)

1.21 Characteristics of the UASB reactors accumulated sludge

In this research, both reactors used R1 and R2 are characterized for the retained sludge (see Table 4.5). The sludge samples during of the study period were collected from port no.1 of both reactors which is about 15 cm from the bottom of the reactor. The sludge samples were analyzed for total solids (TS), volatile solids (VS) and COD.

Table 4.4. Retained sludge characteristics of the two UASB- reactors/ sludge collected from port 1 (0.15 m from reactors bottom)

Parameter	Reactor 1(R1)	Reactor 2 (R2)
COD_{tot}	23	18.5
TS	33	29
VS	27	23
VS/TS	82	79
COD/VS	0.85	0.80

In general, the height of the sludge at the end of the research (after 6monthes) reach to 60 cm at R1 and 50 cm at R2 see Table 4.7. The characteristics of the sludge from (port 2) which was analyzed only one time at the end of the research period and the following results obtained and written in Table 4.6.

Table 4.5. Characteristics of the retained sludge in the UASB reactors/ sludge collected from port 2 (0.4 m from reactors bottom)

Parameter	UASB 1	UASB 2
COD_{tot}	14.1	10.3
Total Solids (TS)	12.6	8.4
Volatile Solids (VS)	9.3	6.2
(VS/TS)	74	73

The mean concentration of total solids (TS) of the R1 and R2 sludge were about 33 g/l and 29 g/l, respectively, with a comparison to 46.8 g/l and 48.6 g/l as reported by Al-Shayah and Mahmoud (2008) and 66.65g/l, 52.9 g/l for R1 and R2 respectively reported by Al-Jamal and Mahmoud (2009). The increase in the sludge concentration in R1 rather than R2 could be regarding to the increase in the HRT which directly increased the OLR.

The (VS/TS) ratio at both reactors where the average ratio was 82 and 79 for R1 and R2 respectively which was approximately the same but, higher than the values obtained by Al-Shayah and Mahmoud (2008) about 73% and 71% and Al-Jamal and Mahmoud (2009) 68%, 67% for R1 and R2 respectively. Regarding to Wang (1994) a (VS/TS) ratio of 63% can be considered a well-stabilized sludge. The decline trends in (VS/TS) ratio during the research period indicate a more stable sludge is achieved as reported by Al-Shayah (2005).

These results were reasonable regarding to the variation in the HRT of the two reactors that lead to expect high stability for the returned sludge in the reactor that had lowest HRT.

1.22 Removal efficiency of BOD5

BOD_5 considered as a measure for the biodegradable organic matter in the wastewater. In this research the BOD_5 mean value of the influent and the effluent for the two reactors and removal efficiency for each of them are tabulated in Table 4.3. From the table one can see that the average BOD5 for the Influent is about 356 mg/l. The average BOD_5 effluent from the two reactors R1 and R2 are respectively 153 mg/l and 153 mg/l, and mean efficiency in terms of removal during the period of the experiment for R1 and R2 69 %. Figure 4.13 shows the influent and the effluent of the BOD_5 level, and so the relation between, and the removal efficiency for both of the reactors.

From Figure 4.13 the BOD_5 effluent quality for R1 and R2 relatively stable if compared with the BOD_5 of the influent and the value of the standard deviation can also confirm this result. But the difference of the DOD_5 concentration was statistically no insignificant (*p* >0.05).

In this research the removal efficiency in R1 and R2 the same value in comparison with the removal efficiency for both reactors at summer period where the removal efficiency were respectively 56% and 59% for UASB 1 (R1) and UASB 2 (R2), as reported by Al-Shayah and Mahmoud (2008) and increase than Al-Jamal and Mahmoud (2009) where the removal efficiency were 43% and 49% for R1 and R2, respectively.

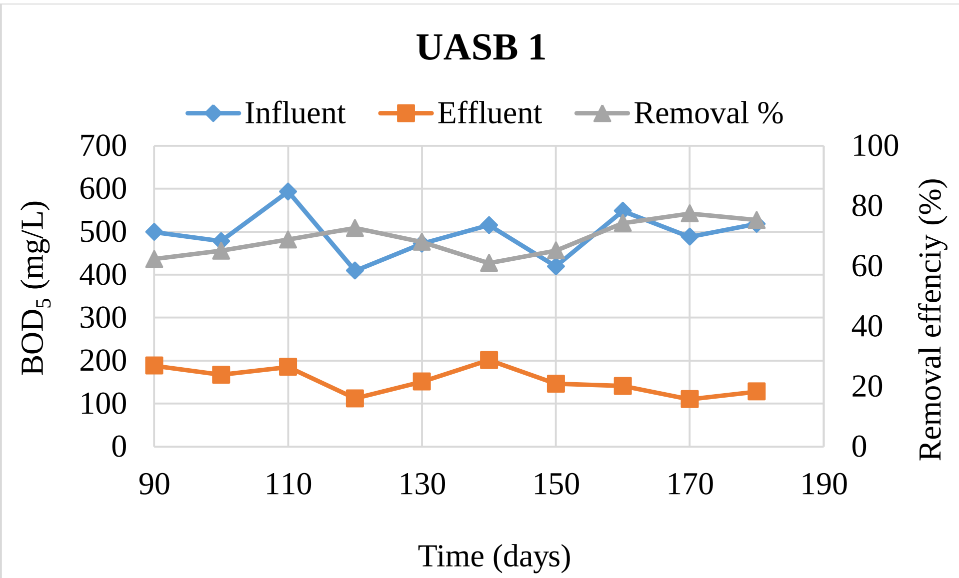

Figure 4.10. BOD_5 concentrations and removal efficiency - UASB 1

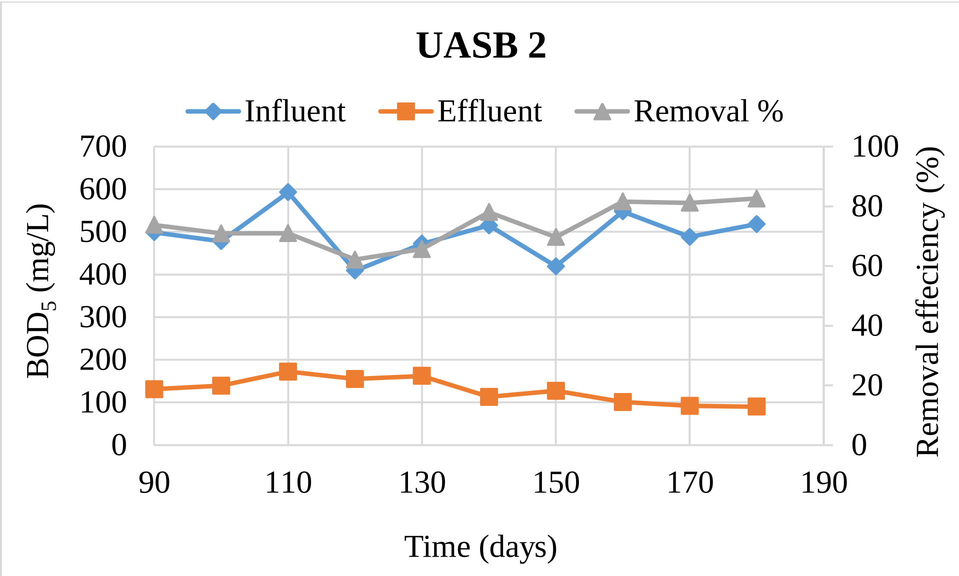

Figure 4.11. BOD_5 concentrations and removal efficiency - UASB2

1.23 Removal efficiency of TSS and VSS

The removal efficiency of the suspended solids is one of the main focal points of sewage treatment. UASB reactors are very effective with retaining suspended solids from sewage, particularly in tropical regions (Haandel and Lettinga, 1994, Cavalcanti, 2003). In this research and during its period the average TSS and VSS of the influent and effluent of the two reactors R1 and R2 are tabulated in Table 4.3.

In this research some results were encouraging as the TSS removal efficiency that is 71 % and 79% removal efficiency for respectively R1 and R2, but with statistically insignificant difference ($\rho > 0.05$) between the two reactors. These results and if are compared with the reactor efficiency during the summer period which is 79% and 80% for R1 and R2, respectively as reported by (Al-Shayah, 2008) one indicates that the removal efficiency for both of the reactors decrease.

Figure 4.14 presents the TSS concentrations and efficiency in terms of TSS removal for R1 and R2. From this figure one can see how much the two reactors are stable regarding to the TSS concentrations measured at the effluent throughout the period of the research. The here attained results of TSS removal are better than what was reported in the literature for conventional UASB reactors at household wastewater.

For this study, the average removal efficiencies for VSS were 82 % and 86 % for respectively R1 and R2. R2 achieved superior performance of VSS removal as compared to R1 with significant difference from R1 ($\rho < 0.05$). If those results are compared to the results that had been obtained by Al-Shayah, and Mahmoud (2008) 79% and 80% VSS removal efficiency for R1 and R2, respectively one can conclude that the VSS removal efficiency increase.

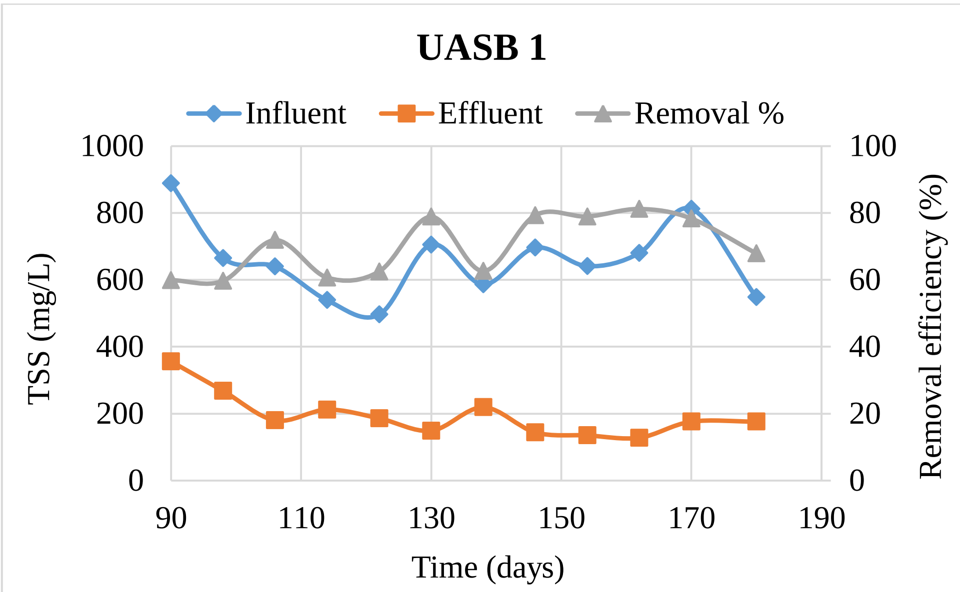

Figure 4.12. TSS concentrations and removal efficiency - UASB 1

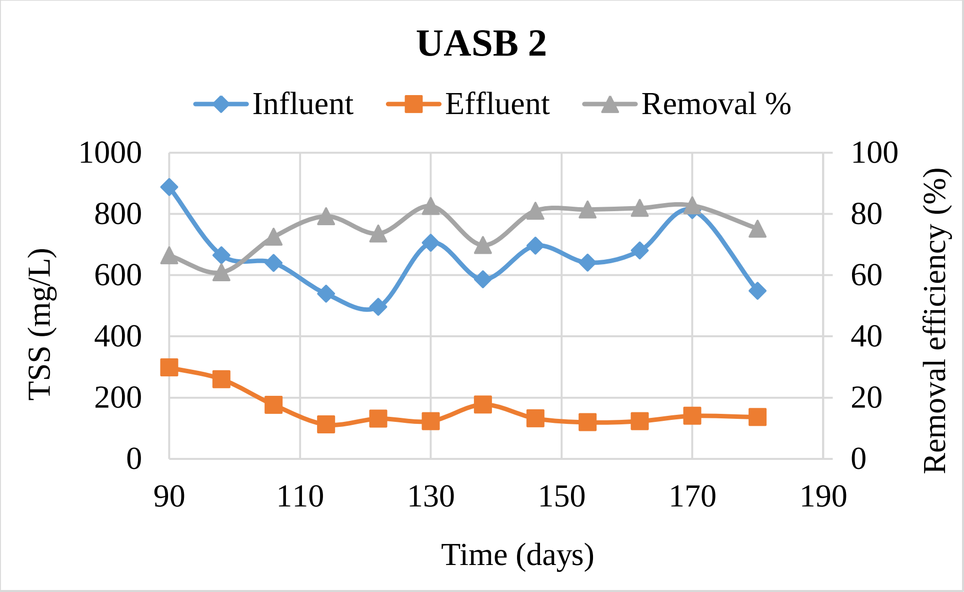

Figure 4.13 TSS concentrations and removal efficiency - UASB 2

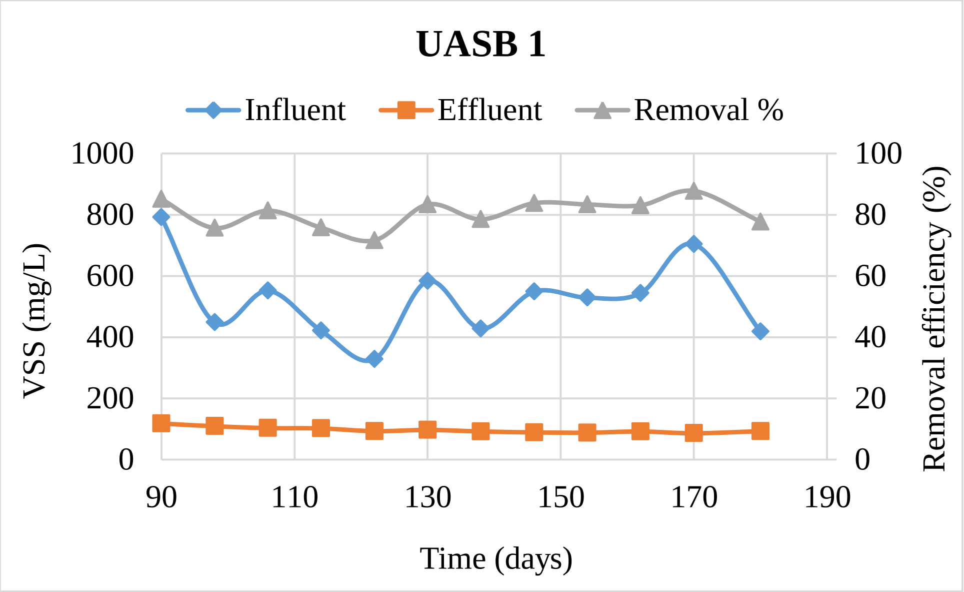

Figure 4.14. VSS concentrations and removal efficiency - UASB 1

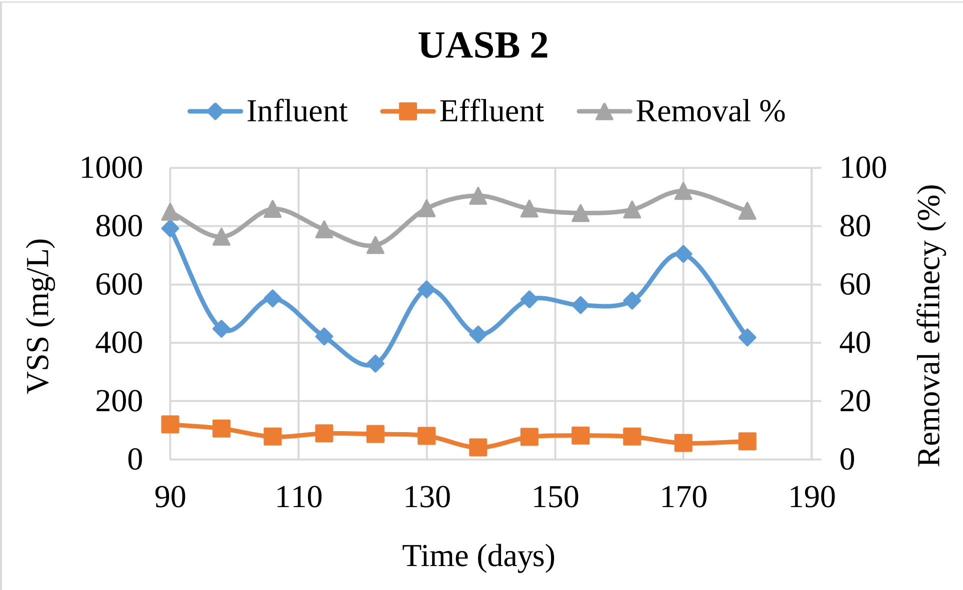

Figure 4.15. VSS concentrations and removal efficiency - UASB 2

1.24 Removal efficiency of nutrients

1.24.1 Nitrogen removal

NH_4^+ removal

The NH_4^+ removal efficiency was very limited in both reactors over the entire research period, with the average (NH_4^+-N) concentration for the UASB reactors R1 being 55 mg/l and a mean removal of 8%; also, R2 being 57 mg/l and a mean removal of 5%. (22.6). The difference in (NH_4^+-N) concentration was not statistically significant (p>0.05).

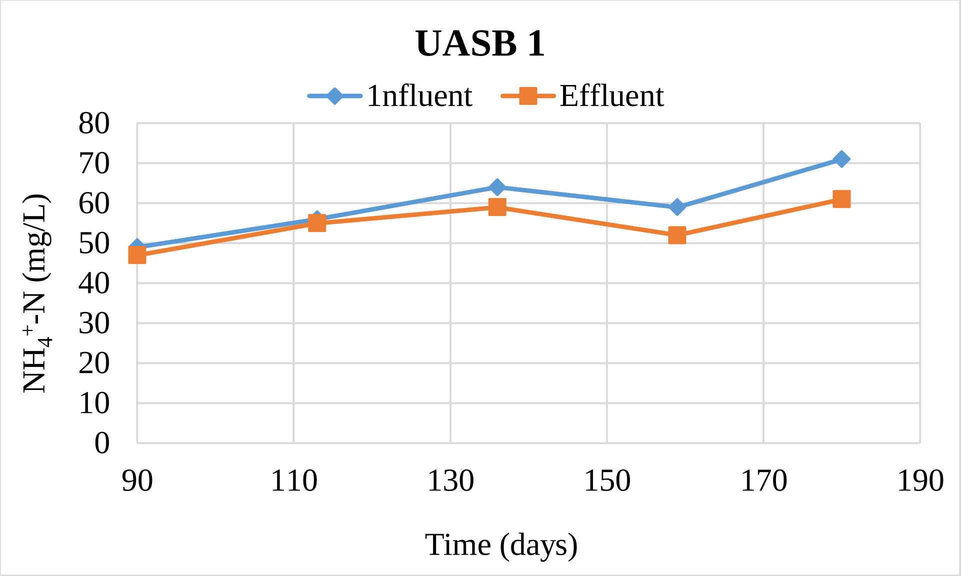

Figure 4.16. NH_4^+-N concentrations - UASB 1

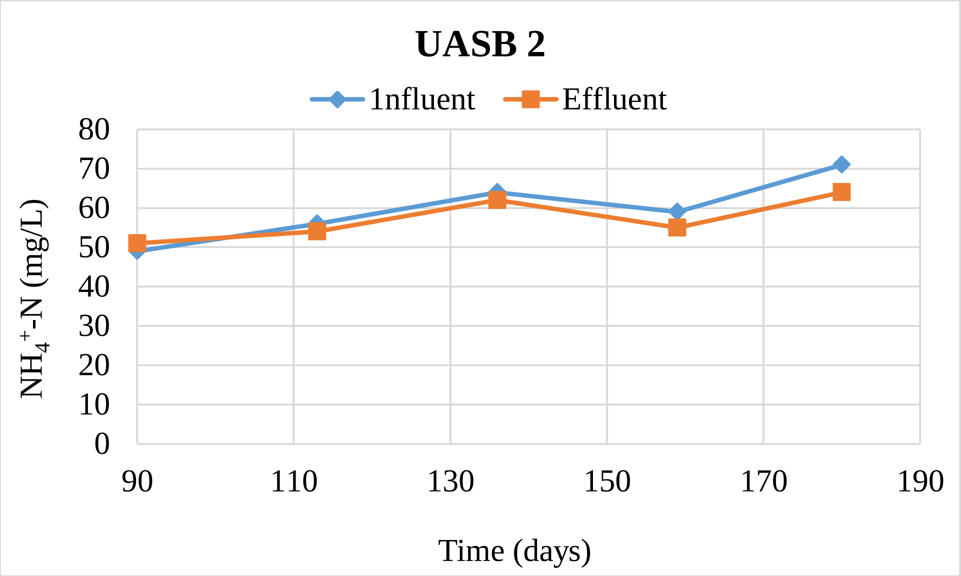

Figure 4.17. NH_4^+-N concentrations - UASB 2

1.24.2 (Nk_j-N)

Nkj was partially removed in the both UASB reactors as consequence of particulate N removal (Table 4.3 and Figure 4.17). The average removal efficiencies of Nkj-N were 23 % and 29 % for R1 and R2, respectively. Moreover, the difference in concentration of (Nkj-N) were not statistically significant (p>0.05).

If those results are compared again to the results during the summer period that had been obtained by (Al-Shayah, 2005) one can see that the efficiency of removing Nkj-N was also increased but in a form of small change 16 % and 12 % for R1and R2, respectively. Similar findings were also found for Nkj-N when domestic wastewater was treated in UASB reactors (Bogte *et al.*, 1993; Mahmoud, 2002).

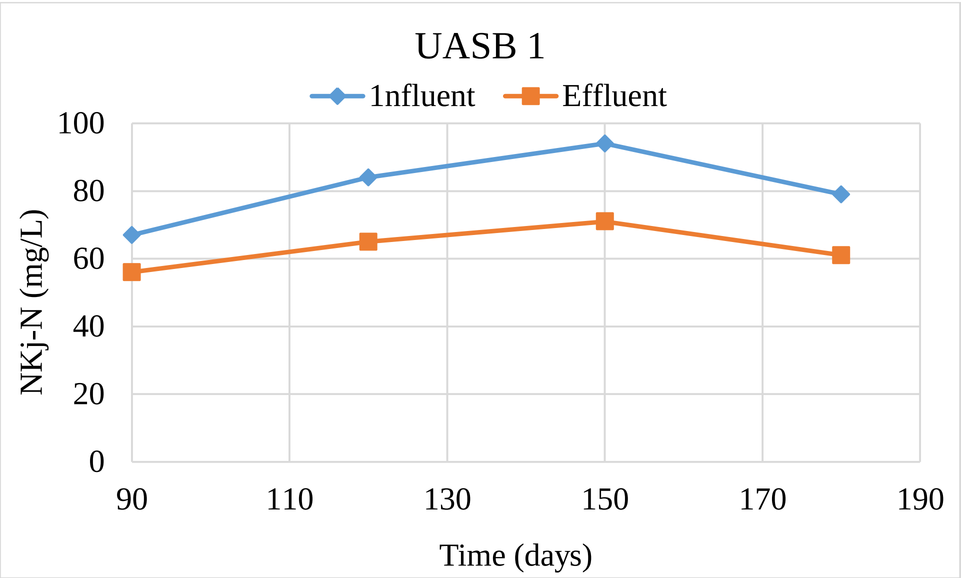

Figure 4.18. Nkj-N concentrations - UASB 1

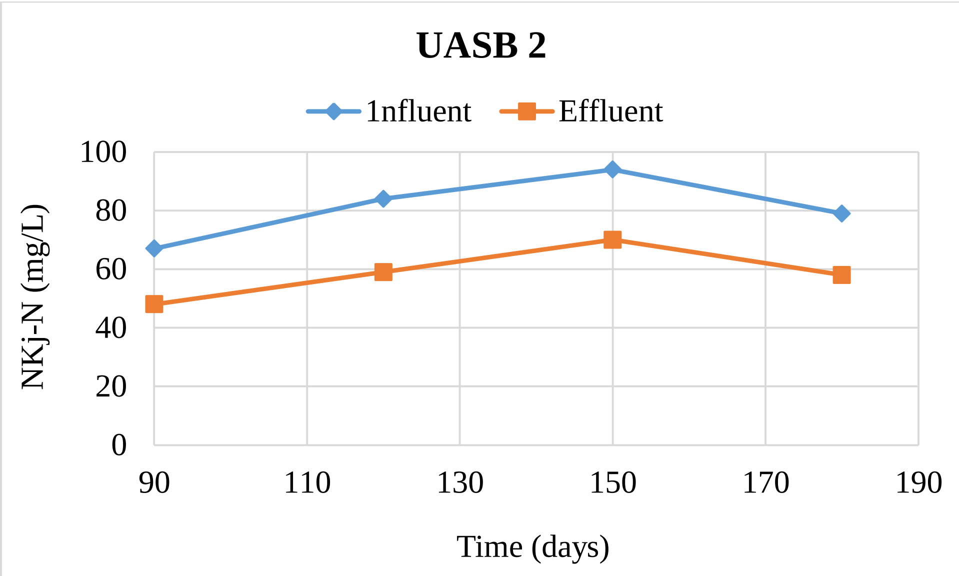

Figure 4.19. Nkj-N concentrations - UASB 2

1.24.3 Removal of phosphorus compounds

(Total – P)

The results showed variation in the total P concentration between the flow and drainage in the two reactors was very low and. The average removal efficiencies of the UASB reactors were similar of about 8%. Regarding the result obtained by Al-Shayah and Mahmoud (2008) and Al-Jamal and Mahmoud (2009) removal efficiency increase. The difference in (Total – P) concentrations between R1 and R2 were not statistically significant (p>0.05).

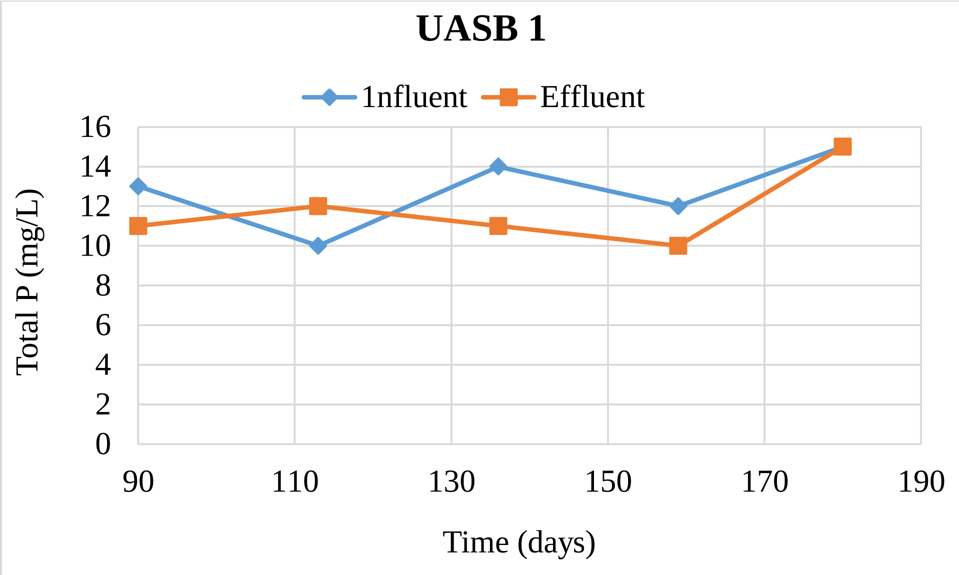

Figure 4.20. Total phosphorous concentrations - UASB 1

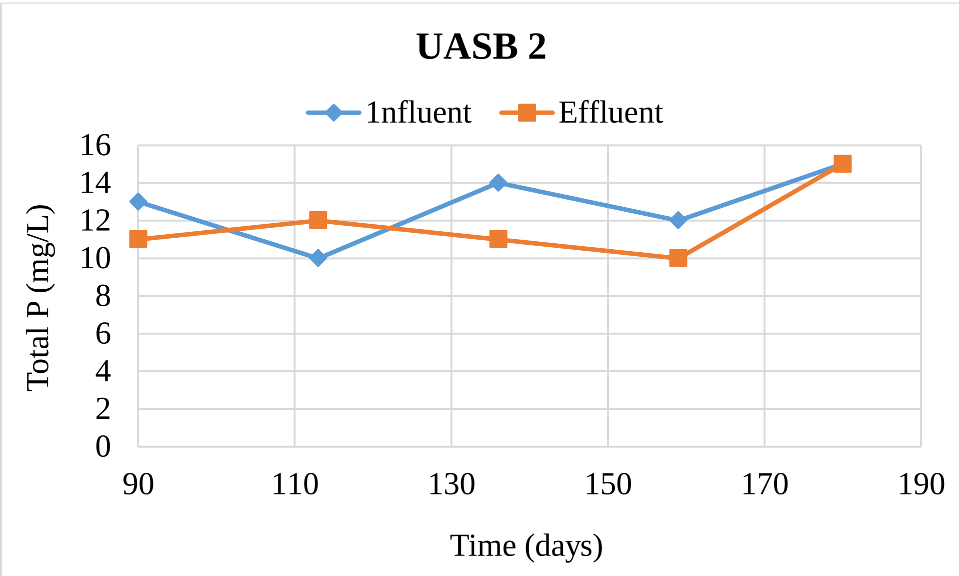

Figure 4.21. Total phosphorous concentrations - UASB 2

***Ortho*- phosphorous**

The research shows that there is no removal take place for *ortho*-phosphorous, on the opposite the effluent concentration an increase in both of the reactors from average concentration at the influent 15.4mg / l to 17.9 and 24.3mg / l for R1 and R2, respectively.The same results also had been obtained by Al-Shayah (2008) during the experiment period.

The difference in *Ortho*- phosphorous concentrations between R1 and R2 were not statistically significant (p>0.05).

As a conclusion of the results that obtained through nutrient removal, the UASB reactors are not efficient for removing nutrient from wastewater and only a change in the chemical forms of nitrogen and phosphorus take place as reported by Bogte *et al.*, 1993. Therefore, a nutrient removal can only be achieved in separate post-treatment step after the UASB septic tank Haandel and Lettinga (1994).

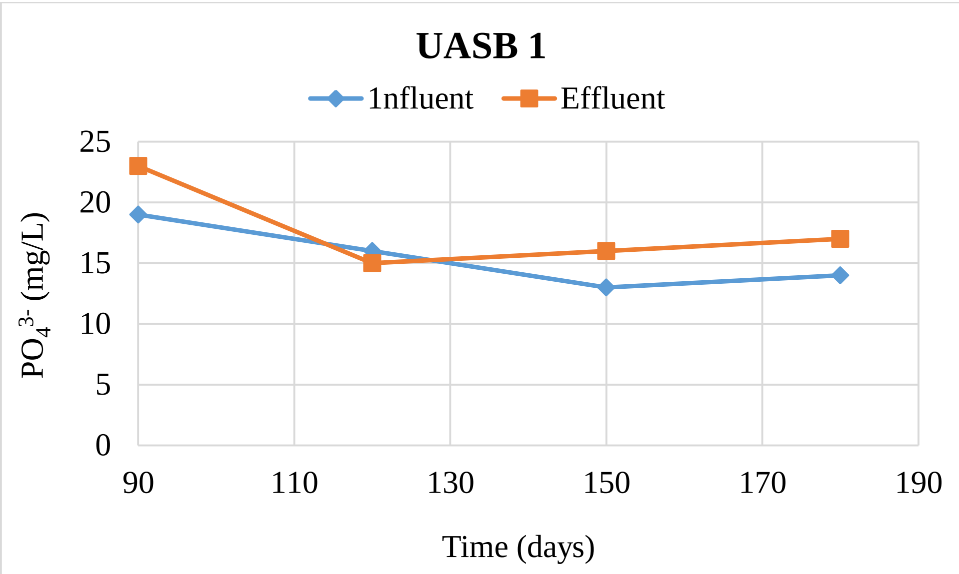

Figure 4.22. *Ortho*-phosphorous (PO_4^{3-}) concentrations - UASB 1

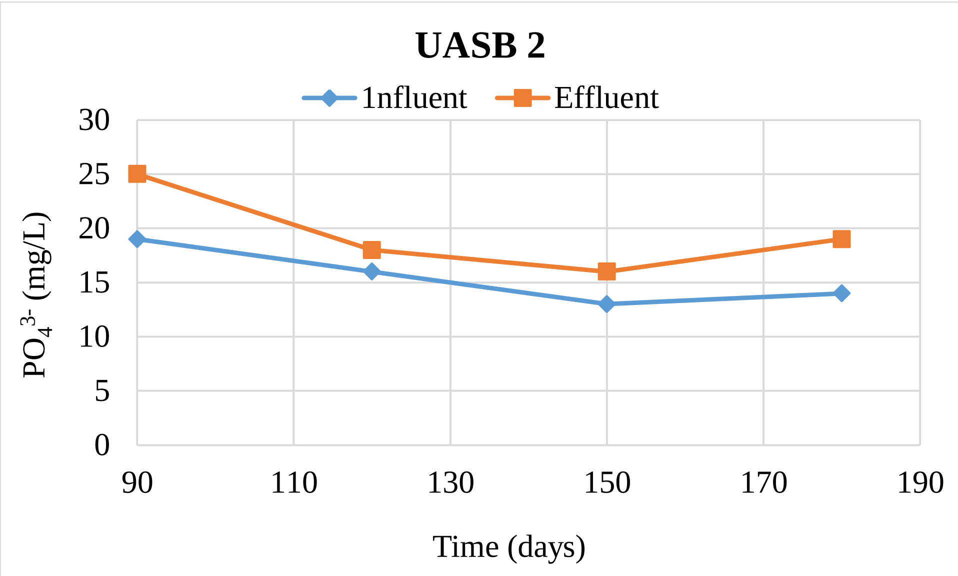

Figure 4.23. *Ortho*-phosphorous (PO_4^{3-}) concentrations - UASB 2

1.24.4 Removal efficiency of sulfate

The main issue with anaerobic treatment of sulfate-rich wastewater is the production of sulfide. Since sulfide may lead to serious complications such as toxicity, bad smell, corrosion, deteriorated quality and quantity of the biogas and reduction of COD removal efficiency (Mahmoud et al.,2003).

In this research the average concentration for sulfate SO_4^{-2} in the effluent of R1 and R2 were respectively 40.8 mg/l and 22.2 mg/l. The difference in SO_4^{2-} concentration was significant difference in both reactors ($p>0.05$). The influent concentration as shown at Table 4.3 was about 94.1 mg/l and so the removal efficiency for removing SO_4^{-2} for reactors R1 and R2 are 56% and 77 %, respectively.

If those results are compared again to the results during the summer period that had been obtained by (Al-Shayah, 2008) one can see that the efficiency of removing Sulfate was decrease in R1 71 % and increase for R2 72%.

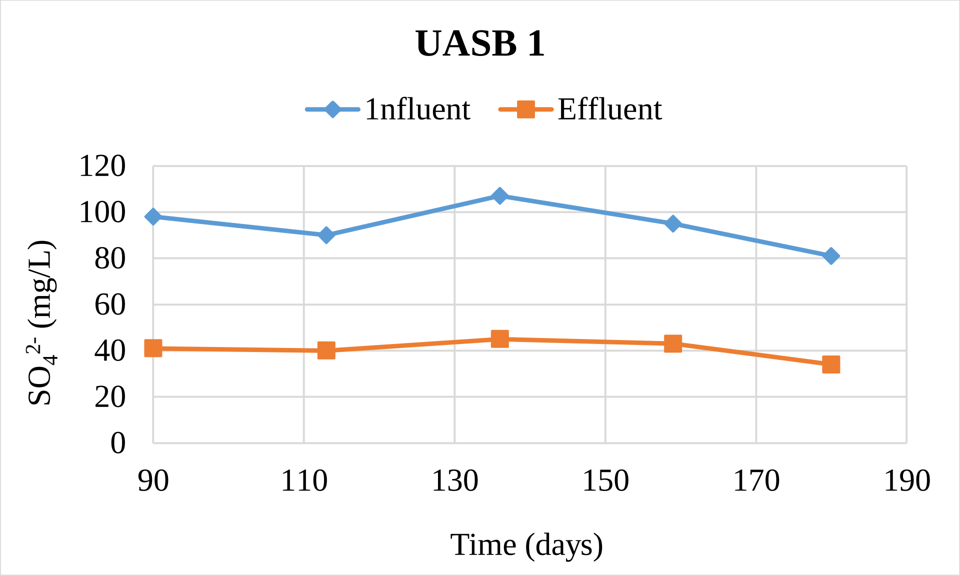

Figure 4.24. Sulfate (SO_4^{2-}) concentrations - UASB 1

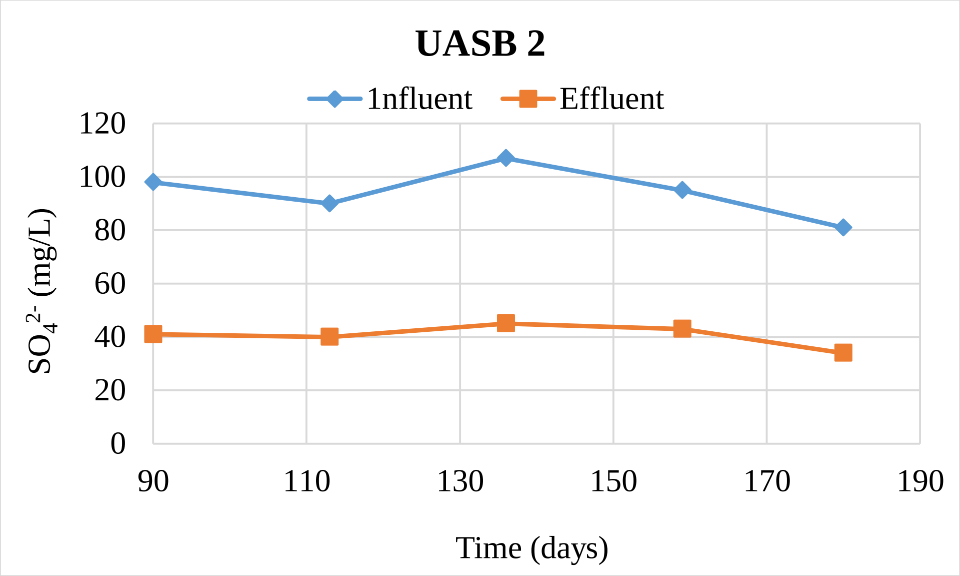

Figure 4.25. Sulfate (SO_4^{2-}) concentrations - UASB 2

Table.4.6. Pervious research on the UASB treatment domestic wastewater in Palestine and Jordan

		Removal (%)											
Treatment Type	Wastewater	COD	BOD	TSS	VSS	NH_4^+ as N	NKj as N	Total phosphorous as P	PO_4^{3-} as P	SO_4^{2-} as SO_4^{2-}	HRT (d)	Temperature	References
UASB-Reactor	Domestic	68 76	69 69			8 5	23 28	8 8	- -	56 77	0.5 1	25	This study
UASB-digester system	Domestic	72		93		-5		8			10	35	Mahmoud (2008)
UASB-Septic tank	Domestic	51 54	43 49	74 78	74 78	11.5 13.1	17 15	0.43 -4.34	-37.8 -57.3	57.65 61.45	2 4	17.34	Al-Jamal and Mahmoud (2009)
UASB-Septic tank	Domestic	56 58	59 60	81 81	81 82	5.5 2	15 12	4.42 0.52	-24.9 -29.7	72 71	2 4	24	Al-Shayah and Mahmoud (2008)
UASB-AF	Domestic	32 35									0.66 0.16	23	Halahsha et al. (2010)

1.25 pH in the UASB - reactors

The pH value and its stability in anaerobic reactor is extremely important, since methanogenisis only proceeds optimally when pH is maintained in the neutral range of 6.3 to 7.8 (Haandele, Lettinga, 1994). During the treatment of complicated wastewater, for example municipal sewage, pH is typically with the optimal span with no need to add external chemicals for pH adjustment. In anaerobic digester, the acid-base system such as carbonate system provide adequate buffering capacity (Haandle and Lettinga, 1994).

In this research the pH mean value for the raw sewage influent was 7.28 and 7.07 for the effluent of R1 and R2, respectively. The slightly low pH values which was observed in the effluent of UASB reactor is due to the domestic wastewater buffering that is adequate to neutralize the produced volatile fatty acids as well as the dissolved carbon dioxide (Drost, 1997).

During the whole of the experiment was no observation for pH value out of the normal and optimum range where for R1 the pH ranged from pH (6.42 -7.51) and for R2 pH ranged from (6.46-7.40) and this could be clear from Figure 4.21.

If the results obtained in this research compared to the results reached at the summer period by Al-Shayah, and Mahmoud (2008) one can see that the pH mean value for R1 and R2 was around 7.4 with range of (7.12-7.7) during the summer period in both reactors.

Chapter 5

Conclusions and recommendation

The performance efficiency of sieved influent sewage was for COD_{tot}, COD_{sus}, COD_{col} and COD_{dis} 22.2%, 44.2%, 28.5% and 12.2% respectively and BOD_5, TSS and VSS 28%, 23.9% and 23.4, respectively.

The UASB reactor were effective in treatment domestic wastewater in Palestine condition, it provide removal efficiency for COD_{tot}, COD_{sus}, COD_{col}, COD_{dis}, TSS and VSS of 68%, 80%, 60%, 50%, 69%, 71% and 80% respectively for R1 and 76,84,72,61,69,79 and 86 for the same parameter in R2.

The efficiency R2 (HRT= 1d) were better than R1 (HRT=0.5 d) which reinforces the importance of HRT in UASB reactor, then the icrease of anaerobic time icrease the efficiency of UASB treatment.

The average CH_4 gas measured at Al-Tireh wastewater treatment plant for R1 and R2 respectively was 42 l/d and 43 l/d.

The UASB- reactors are ineffective at removing nutrients from wastewater. As a result, nutrient elimination can only be achieved in a subsequent step of treatment after the UASB reactor.

Recommendations

- On the basis of the results presented in this research and concerning the reactors performance, the design HRT = 24 Hours UASB reactors is recommended for the anaerobic treatment of domestic sewage under Palestine conditions.

- A post-treatment step is recommended in most cases after UASB reactor to remove nutrient.

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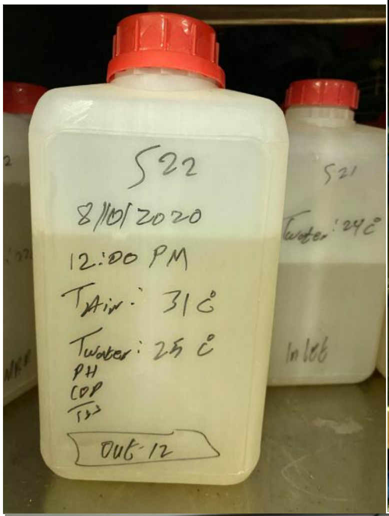
Appendix 1


Figure1. UASB reactor at al Tireh WWTP

Figure 2. Gas meter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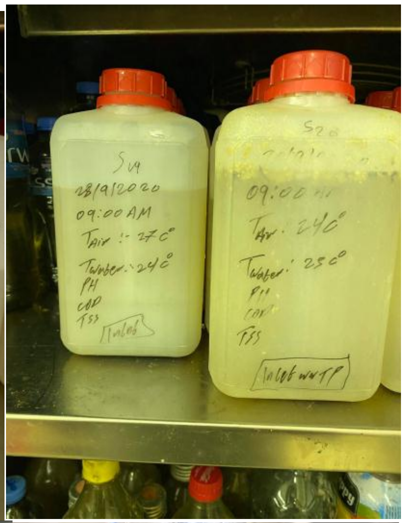
PH
COD
TSS
Out-12


28/9/2020
09:00 AM
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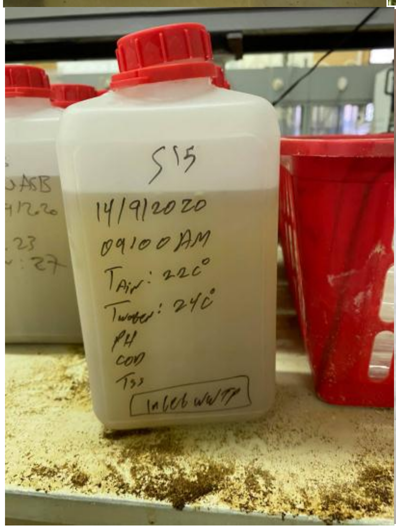
COD
TSS
Inlet
Inlet WWTP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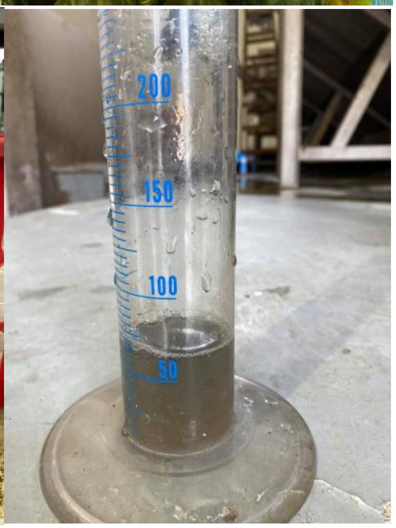
200
150
100
50

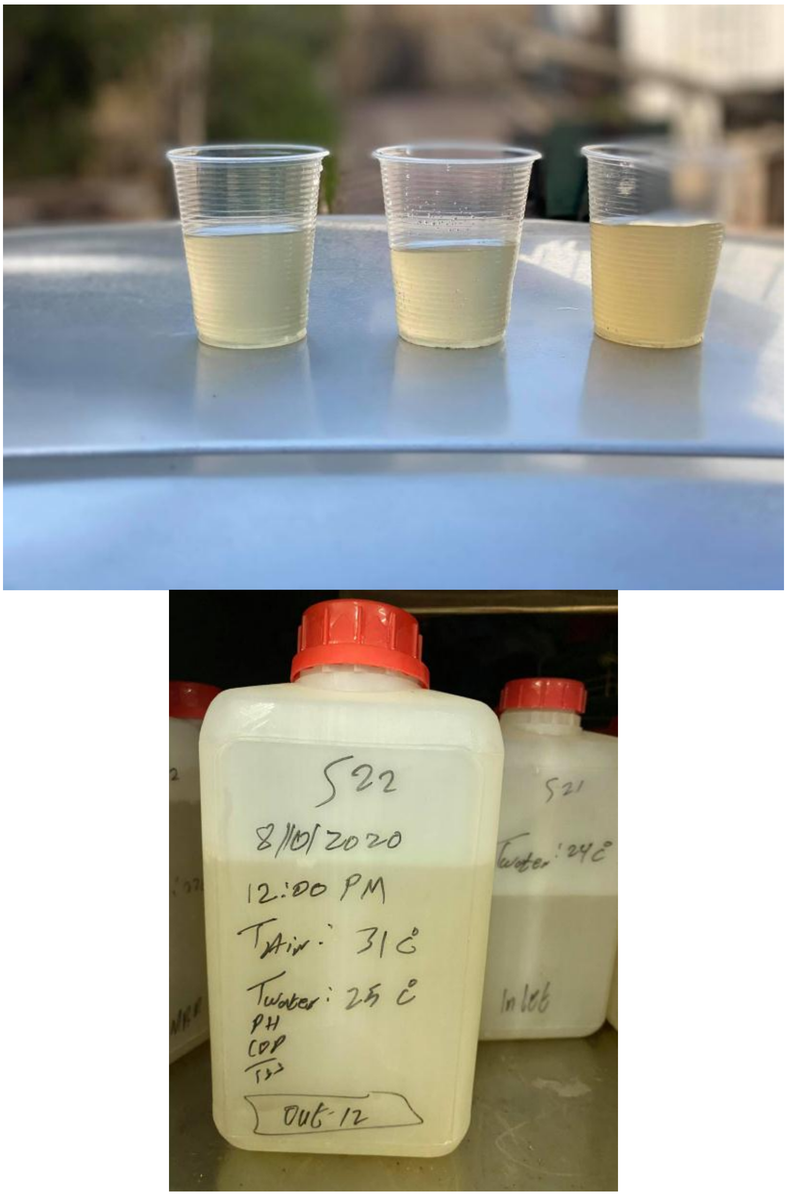

Figure 3. Sampling step

Figure 4. Measurements in the lab

Figure 5. UASB reactor effluent