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Efficacy of UASB System for the Pretreatment of Mixed Industrial Wastewaters from Poultry Slaughterhouse and Olive Mill

فعالية نظام حمأة لاهوائي صاعد (UASB) في معالجة أولية لمياه صرف صناعية مختلطة من مسلخ دواجن ومعصرة زيتون

A Master Thesis

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The finding, interpretations, and conclusions expressed in this study do not necessary express the views of Birzeit University, the views of individual members of the M.Sc. committee or the views of their respective employers

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ABSTRACT

The dire situation and various challenges in the current management of industrial wastewater in Palestinian communities are the drivers behind this research study. Rapid urban expansion contributes to increased municipal wastewater generation (MWW) and inadequate wastewater treatment (WWT) which leads to deterioration of the receiving environment, poses health risks and leads to deterioration of sewage infrastructures. This study investigates the effectiveness of a pilot system, installed at Birzeit University campus, which includes UASB system pretreating industrial wastewater mixture from a chicken slaughterhouse and an olive press (Zibar). This system follows a post-treatment in parallel treatment systems; waste stabilization ponds (WSPs) and vertical flow constructed wetlands (VFCWs). The effect of mixing ratios of industrial wastewater on the efficacy of UASB system and the effect of hazardous pollutants (phenol and some elements of heavy metals) on biogas production measured. Laboratory analyzes of physical and chemical parameters performed on the effluent in the UASB system and in the outlet. Two UASB experimental reactors were installed on the campus of Birzeit University to treat mixed industrial wastewater from olive mill water (Zibar) and chicken slaughterhouses. The two reactors were operated in parallel for a period of four months at ambient temperatures ranging between 25-35 ºC. The operation was carried out in two different stages. The first stage works at two different speeds, the feeding rate of the first system (UASB 1) was 166 l/day, the second system (UASB 2) was 230 l/day, and the Zibar ratio was 5%. While in the second phase the pump was installed at a feeding rate of 155 l/day, and the rate of Zibar increased to 10%.

Samples were taken from the two systems inlet and outlet and analyzed inside the university's laboratories. The table below lists the design parameters including the results obtained including the removal efficiency rates for the key parameters during the first and second operational phases.

The wastewater treatment of mixed industrial water was studied using the UASB anaerobic reactor over a period of 4 months. As this system was operated under different operating conditions (different feed flow rates of the two systems, organic loading rate, and different hydraulic retention time), to remove organic matter and solids from mixed industrial wastewater. The organic pollutants were removed in the UASB anaerobic reactor, and the removal efficiency rate of first stage was for the COD, VSS, TSS, TKN, and Total Phenol were 36.1%, 68%, 51%, 16.8%, 100%, respectively, for the UASB 1, 61%, 69%, 74%, 24% and 100% respectively for the UASB 2. As for the heavy elements, the rate of removal efficiency ratio for Zn, Cr, and Cu were 38.8%, 54.8%, and 83.8%, respectively for the UASB 1, and 9.45%, 57%, and 83.8% respectively for the UASB 2, and the components Cd and Pb were not present for both. The removal efficiency rate for the second stage was for the COD, VSS, TSS, TKN, and Total Phenol were 64.6%, 71%, 80%, 39.5%, 100%, respectively for UASB 1, 59.6%, 73%, 77%, 28.5% and 100% respectively for the UASB 2, as for the production of biogas, the average production was for the UASB 1 were 0.544 m^3/kg.COD and 1.568 m^3/kg.COD for the UASB 2. The results showed that UASB 2 is better than UASB 1. The overall removal efficiency of the two systems during the applied phases was good, and most of the time it met the sewage network drainage standards. The results of the research lead to future directions in the framework of research and development in anaerobic treatment to achieve optimal utilization of biogas as an alternative energy source and reduce the load of organic pollution in the receiving environment as well as avoid the deterioration of sanitation facilities.

الملخص

إن الوضع المريع والتحديات المتنوعة في الإدارة الحالية لمياه الصرف الصحي الصناعي في المجتمعات الفلسطينية هي الدوافع وراء هذه الدراسة البحثية. يسهم التوسع الحضري السريع في زيادة توليد مياه الصرف الصحي البلدية (MWW) وعدم كفاية معالجة مياه الصرف الصحي (WWT) مما يؤدي إلى تدهور البيئة المستقبلة، ويشكل مخاطر صحية ويؤدي إلى تدهور البنى التحتية لمعالجة مياه الصرف الصحي. تبحث هذه الدراسة تقصي فعالية نظام تجريبي، في حرم جامعة بيرزيت، يشمل مفاعل الحمأة اللاهوائي الصاعد (UASB) كمرحلة أولية لمعالجة مزيج مياه صرف صناعي من مسلخ دجاج ومعصرة زيتون (زيبار). يتبع هذا النظام معالجة لاحقة في أنظمة معالجة طبيعية تعمل بالتوازي؛ أحواض تثبيت النفايات السائلة (WSP) واراضي الرطبة ذات تدفق عمودي(VFCW) . تم قياس أثر نسب الخلط للمياه الصناعية على فعالية نظام ال UASB وتأثير الملوثات الخطرة (مادة الفينول وبعض عناصر المعادن الثقيلة) على نتاج الغاز الحيوي. وإجراء تحاليل مخبرية لمعايير فيزيائية وكيميائية وبيولوجية على المخلفات السائلة افي محل ومخرج نظام ال UASB. تمت إضافة مفاعلان تجريبيين UASB تم تركيبهم في حرم جامعة بيرزيت لمعالجة مياه الصرف الصناعية المختلطة من مياه مطحنة الزيتون (زيبار) ومسالخ دجاج وتم تشغيل المفاعلين بالتوازي لمدة أربعة شهور في درجات حرارة محيطة تتراوح ما بين 25-35 درجة مئوية وتم التشغيل على مرحلتين مختلفين فكانت المرحلة الأول تعمل على سرعتين مختلفتين، فسرعة معدل التغذية للنظام الأول 166 لتر لكل يوم والنظام الثاني 230 لتر لكل يوم ونسبة الزيبار 5% ، أما في المرحلة الثانية تم تثبيت المضخة على معدل تغذية 155 لتر كل يوم، وزيادة نسبة الزيبار إلى 10%. وتمت تشغيل هذا النظام في ظل ظروف تشغيل مختلفة (معدلات تدفق تغذية مختلفة للنظامين، ومعدل تحميل عضوي، ووقت احتجاز هيدروليكي مختلف)، لإزالة المواد العضوية والمواد الصلبة من مياه الصرف الصناعي المختلطة. أخذت عينات من النظامين للداخل والخارج منهما وتحليلها داخل مختبرات الجامعة وتم إزالة الملوثات العضوية في المفاعل اللاهوائي UASB، وكان معدل كفاءة الإزالة للنظام الأول لــــ COD وVSS وTSS وTKN وإجمالي الفينول 36.1٪، 68٪، 51٪، 16.8٪، 100٪ على التوالي.، بالنسبة لنظام UASB 1 61٪، 69٪، 74٪، 24٪، 100٪ على التوالي بالنسبة لنظام UASB 2. أما بالنسبة للعناصر الثقيلة، فإن نسبة كفاءة الإزالة للزنك والكروم والنحاس كانت 38.8٪،

54.8 ٪ و83.8٪ على التوالي لـــ UASB 1 و9.45٪ ،57٪ ،83.8٪ على التوالي لـــ UASB 2، ولم يكن عنصر الكادميوم والرصاص متواجدين في العينات للنظامين. وكان معدل كفاءة الإزالة للنظام الثاني لـــ COD وVSS وTSS وTKN وإجمالي الفينول 64.6٪، 71٪، 80٪، 39.5٪ و100٪ على التوالي، بالنسبة لـUASB 1 ، 59.6٪، 73٪، 77٪، 28.5٪ و100٪ على التوالي بالنسبة لـــ UASB 2. أما بالنسبة لإنتاج الغاز الحيوي فكان معدل الإنتاج $0.544\ m^3$/kg.COD لـــ UASB 1 و $1.568m^3$/kg.COD لـــ UASB 2، وقد بينت النتائج أن النظام الثاني (UASB 2) أفضل من النظام الأول (UASB 1)، حيث كانت كفاءة الإزالة الإجمالية للنظامين خلال المراحل المطبقة جيدة، واستوفت معايير تصريف شبكة الصرف الصحي في معظم الأحيان. نتائج البحث تفضـــي إلى توجهات مســـتقبلية في إطار البحث والتطوير في أنظمة المعالجة اللاهوائية لتحقيق اسـتغلال أمثل للغاز الحيوي كمصـدر بديل للطاقة وخفض حمل التلويث العضـوي في البيئة المسـتقبلة وكذلك تجنب تدهور عمل مرافق الصرف الصحي.

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LIST OF ABBREVIATIONS

UASB	Up Flow Anaerobic Sludge Reactor
OMW	Olive Mill Wastewater
BOD	Biochemical Oxygen Demand
COD	Chemical Oxidant Demand
PADUCO	Palestinian-Dutch Academic Cooperation Program
MWW	Municipal Wastewater
MOA	Ministry of Agriculture
TSS	Total Suspended Solid
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
MEnA	Ministry of Environmental Affair
FAO	Ministry of Environmental Affair
PH	Negative log of the activity of the hydrogen ion
HRT	Hydraulic Retention Time
OLR	Organic Loading Rate
SRT	Sludge Retention Time
Zn	Zinc
Cd	Cadmium
Pb	Lead
Cr	Chromium
Cu	Copper
ND	Non-detected
IEMS	Integrated Environmental Management Strategy
VSS	Volatile Suspended Solids
WSRC	Water Sector Regulatory Council
WWT	Wastewater Treatment

1. CHAPTER ONE – INTRODUCTION

1.1 Background and Problem Definition

Since the establishment of the Palestinian Authority in 1994, it has paid great attention to the water sector, and in 2014 a new water law was issued, hence the great focus on the water sector. Capital expenditures invest by the Palestinian Authority to protect public health, raise the level of wastewater treatment, develop and protect water sources, and plan their use (Palestine Economic Policy Research, 2013; PWA, 2014).

According to the Water Sector Regulatory Council (WSRC, 2013), the Law No. 16 pertinent to the "internal regulations of the House of Representatives and the system for communicating facilities with the public sewage network" limits industrial discharge and wastewater from homes and municipalities to the public sewage network. Article (2) focuses on the specifications of industrial wastewater in relation to heavy metals and other materials.

Manage industrial wastewater and set regulations and standards for liquid water discharge and treatment to improve environmental protection and calls for pre-treatment of industrial wastewater before connected to sewage networks (Ministry of Local Government, 2013). One of the factors is the increased overload of organic and inorganic materials, which promotes eutrophication and damages sewage networks (Yang et al., 2008).

Over the past few decades because of high population growth and increased demand for food products there has been an increase in the quantities of wastewater and related problems that cause wastewater-related diseases and are dangerous to humans and the environment. In Palestine and due to the shortage of treatment plants, which leads to drainage most of the wastewater is in the environment. The Palestinian Authority has made efforts to prepare policies and strategies, supervision, control and development of systems to improve the resources and sustainability of water and the surrounding environment to protect public health and the environment and raise levels of wastewater treatment. Laws and regulations for water and the environment impose restrictions on treated industrial discharges, as this wastewater contains high concentrations of salts, minerals, organic materials and other pollutants that can damage the sewage networks. Regulations and standards dictate the treatment of industrial waste before contacting public sewer networks. Today, the Palestinian society and industrial companies suffer from a critical crisis in the sustainable management of wastewater, as they work and strive to repair, improve and modernize wastewater treatment facilities to meet the increasing wastewater discharge regulations. This study examines the treatment of agricultural and industrial liquid water in chemical, physical and biological ways. The intended results must base on enabling decision makers to choose environmentally sound and sound strategies that are technically feasible for industrial wastewater management. Because of the increase in population and the increase in industrial activities, there was a need to manage waste using a sustainable technology, which has a high potential for biological transformation using a high-flow anaerobic sludge reactor (UASB) (Mainardis and Goi. 2019).

In this research, we focus on the most important industrial and agricultural wastewater, which comes from the sewage of olive factories and chicken slaughterhouses. From the extraction of olive oil and chicken slaughterhouses, large quantities of liquid and solid waste produced from them, which are considered one of the most important environmental problems, and causes problems in the operation of wastewater treatment plants.

Extracting olive oil from it produces large quantities of liquid and solid waste. Disposal of wastewater from the olive presses, one of the most important environmental problems related to the olive oil industry. More than 800 million olive trees planted all over the world and the Mediterranean Sea, up to 10 and 2000 million tons produced respectively. Wastewater production in the olive presses reached 30 million tons annually in the Mediterranean basin, because of the high organic loads of olive oil, eliminating and treating this liquid waste is a major problem for the olive oil industry (Khadir et al., 2019).

Animal production is an integral part of the agricultural sector in Palestine, it is the main source of income and food security in Palestine, the meat processing industry consumes approximately 29% of fresh water worldwide (Bustillo-Lecompte., Mehrvar, 2015). Slaughterhouses produce large quantities of water with a high concentration of organic matter, suspended solids, fats, nitrogen and phosphorous, it is disposed of without pre-treatment, and this is one of the most important environmental problems for slaughterhouses, it leads to contamination of water bodies and valleys if they are drained directly (Al-Najar, 2019).

Due to their high loads of organic matter and the olive mill water containing toxic and antibacterial phenol materials, which resist biological degradation, due to these properties, urban wastewater is not disposed of (Aktas et al., 2001). The chemical composition of the olive mill is very different in quantity and type; this depends on the type of diversity, climatic conditions, fruit ripening and methods of oil extraction (Paredes et al., 1986). Slaughtering and cleaning operations consume water, which generates large amounts of wastewater (Al-Najar, 2019).

In general, the olive mill wastewater (OMW) usually contains high levels of Biological oxidant demand (BOD), and high levels of chemical oxygen demand. In addition, the water of the olive mill contains very high concentrations of fats, oils and greases, the majority of the organic materials for the OMW are polyphenols, polyolefin alcohol, and lipoproteins (Al-Khatib et al., 2015). This study focuses on two mixed industrial wastewaters, sewage from the slaughterhouse, and the wastewater from the olive mill presses, anaerobic treatment applied as a pretreatment method.

Anaerobic treatment is a widely used technology, characterized by low energy consumption and cost of operation and maintenance, it has good efficiency and ability to recover energy and it is a process capable of treating wastewater with a high content of organic matter (Cheng et al, 2019). The process of using UASB in this study to reduce industrial organic pollutants, for wastewater to discharged safely within acceptable specifications, before entering the sewage network. Based on

Based on the literature and assumptions it contains, the olive mill considered one of the main industrial facilities for industrial pollutants.

This research is part of the second Palestinian-Dutch Academic Cooperation Program (PADUCOII) and aims to develop and stimulate practices and integrated application techniques for sustainable industrial wastewater management in Palestine.

The results envisaged shall provide science based data to enable decision makers and agro-food industries select feasible technologies for industrial wastewater management towards biogas recovery and water recycling.

1.2 Research Aim and Objectives

The specific objectives are as follows:

- Monitor and evaluate the efficacy of two UASB systems, run in parallel, treating a mixture of poultry slaughterhouse and olive mill wastewater.
- Determine the adequate mixture ratio of OMW considering hydraulic and organic pollution loads of the two UASB systems.
- Investigate the potential effects of hazardous pollutants (phenols and heavy metals) on the biogas production.

1.3 Research Questions

- What is the overall efficiency of the pilot USAB system as a pretreatment stage of mixed Industrial and agricultural wastewaters?
- Which ratio is more technically feasible? A 5 or 10% of OMW as best operational practice for the UASB system?
- What are the impacts of total phenols and heavy metals on the performance of the UASB system?

1.4 Thesis Outline

This research consists of five chapters. Chapter one is the introduction, aim and objectives and research questions. Chapter two presents literature review form previous studies and study area. Chapter three presents the approach and methodology used in research. Chapter four discusses the system start up and operation and results. And finally chapter five included the conclusion and recommendations.

2. CHAPTER TWO - LITERATURE REVIEWS

2.1 Olive Mill Wastewater

2.1.1 Background

The production of olive oil is an important source of income for the agricultural sector in Palestine. According to the Ministry of Agriculture (MOA), olives and olive oil contribute greatly to the Palestinian economy, and it is the main component in vegetable production. It is an important economic resource because of its high quality specifications in terms of taste, color and aroma. The area planted with olives is about a million acres, or 50% of the cultivated area in Palestine. Where plant production contributes to more than 59% of the amount of agricultural production, the MOA gives a great attention to the development of olive tree cultivation, improving the quality of its production, and treatment of olive mill waste (MOA, 2014).

It was estimated that 750 million olive trees are planted all over the world, and 95% are located near the Mediterranean Sea. Among the most olive producing areas are southern Europe, then Morocco and then the Levant. (Wiesman, 2009).

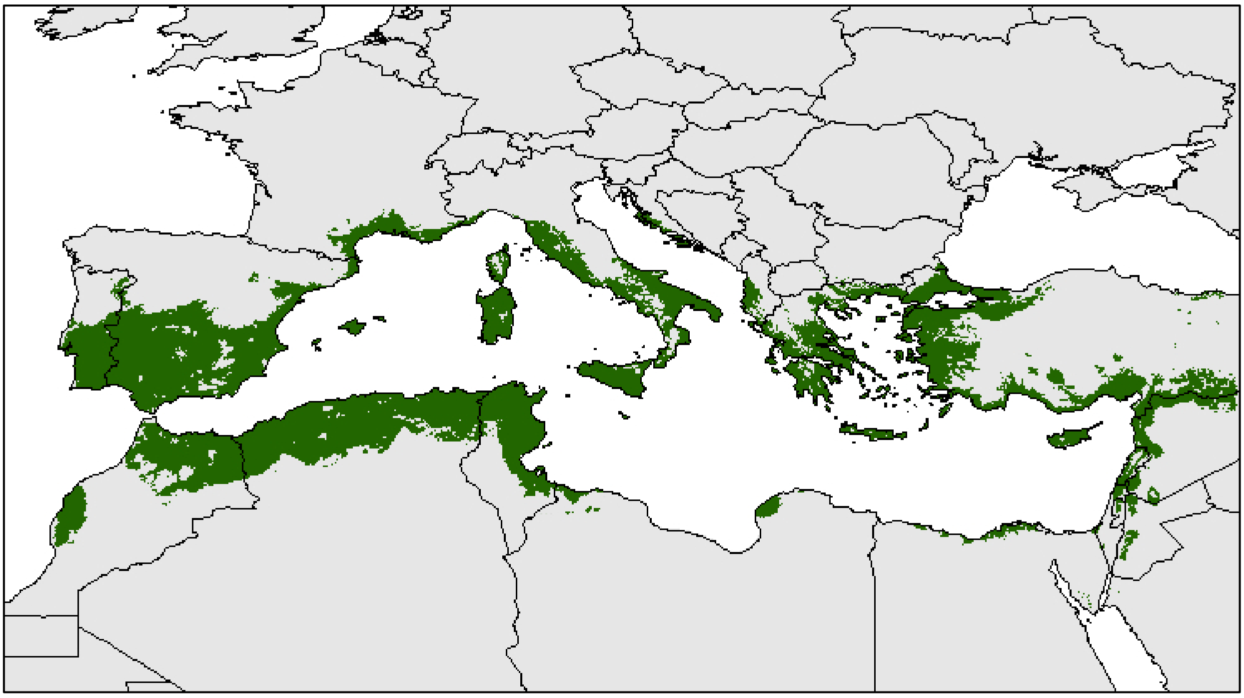

Figure 2. 1. Distribution of olive trees in the Mediterranean basin (Oteros, 2014).

Figure 2. 2 show the size of olive production worldwide in 2012-2019 is almost 3.12 million metric tons.

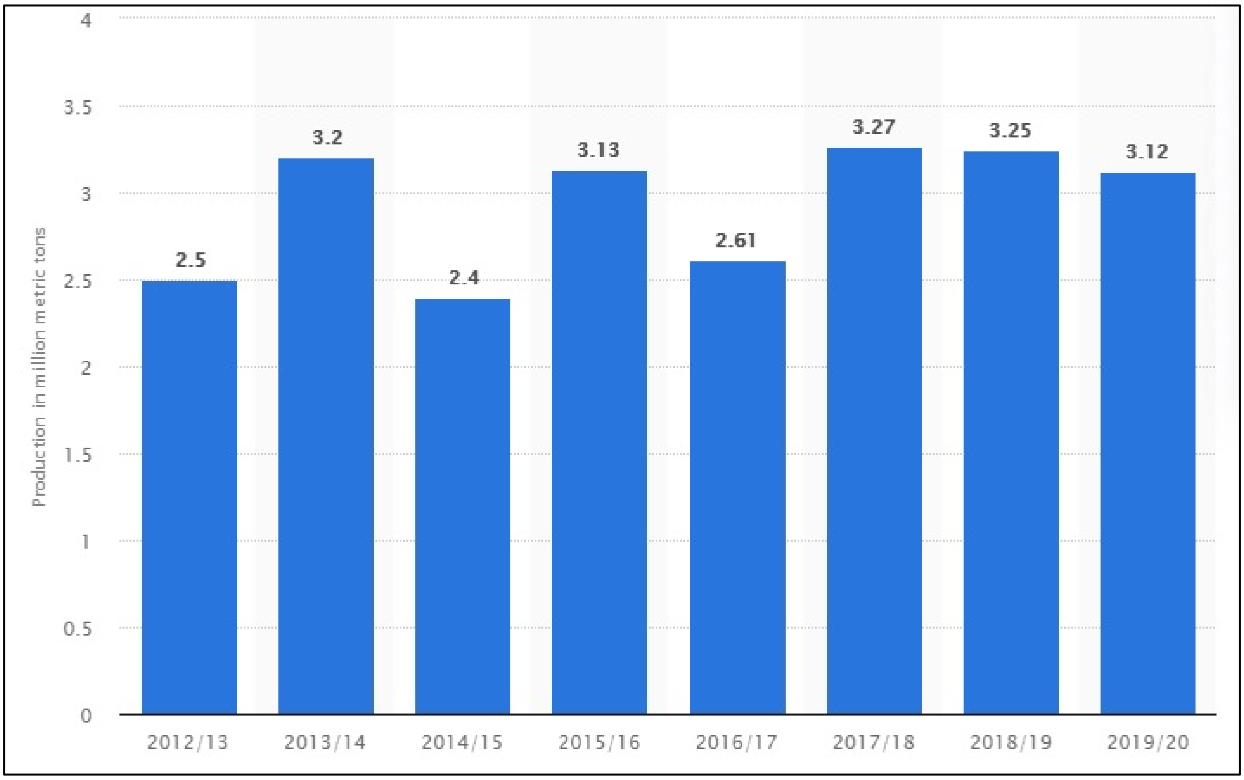

Figure 2. 2. Production volume of olive oil worldwide from 2012/13 to 2019/20 (Statista, 2020)

Previous studies (Khoufi et al., 2006; Sayadi et al., 2000; Bustillo-Lecompte., Mehrvar, 2015) reported that olive oil mills produce large amounts of wastewater due to production processes and cleaning of unit operations. The wastewater characteristics of industries vary according to the type of olive mills presses, and the water requirements of the various production processes. However, the olive mill wastewater usually contains high levels of organics. Several olive mill wastewater in Palestine discharge their wastewater directly into the municipal sewer system without even any primary pretreatment at the olive plant. Therefore, due to the high-strength characteristics of the industrial effluents, an extensive treatment for a safe discharge into the environment is required. The awful situation and diverse challenges in the current industrial wastewater management in Palestinian communities are the motivations behind the present research study. Rapid urbanization contributes to increased municipal wastewater (MWW) generation and inadequate handling of MWW degrades the receiving environment, poses health hazards and deteriorates the wastewater treatment infrastructures (Al-Sa`ed, 2017).

In general, the wastewater from the olive mill contains organic and inorganic materials and a high content of phenol, proteins and mineral materials (Smeti et al, 2019). Olive oil obtained through the process of continuous pressing and discontinuous pressure or by centrifuging the crush mixture with hot water. The result of these processes is olive oil, solid residue, and aqueous liquid, which constitutes 83-94%, and 4-16% of the olive mill, which are organic compounds, 0.4-2.5% of mineral salts, 2-15% of polyphenols, and many phenolic, alcohols and aldehydes found (Rahmanian et al., 2013).

Olive presses produce large quantities of wastewater annually, which is a serious environmental concern because it contains complex compounds and high demand for chemical oxygen and demand for biochemical oxygen, and the concentration of suspended solids, that cannot be disposed of easily, and needs treatment which can be reduced using treatment processes Physical, chemical and biological. The study showed that the two-stage system in oil production contains a high percentage of moisture, while the three-stage system requires the use of more water, which generates huge quantities of olive water, the application of the anaerobic treatment system is effective if the pre-existing physical, chemical and biological treatments are achieved (Bernardi et al, 2017).

Agricultural food industries produce huge amounts of waste that contains large organic materials. It is rich in nutrients that can converted into energy. The presence of toxic substances and complex compounds such as phenol in olive presses that harm plants. However, the use of several methods of treatment including anaerobic treatment followed by aerobic treatment has yielded acceptable results (El Hajjouji et al, 2014).

Livestock production is an important part of the industry in the world, according to the study, the slaughterhouse industry consumes 29% of the total fresh water, it is used for slaughtering and cleaning production, the quantities of waste water and pollutants depend on the numbers and types of slaughtered animals (Hernández-Fydrych et al, 2019). The water consumption varies in the field of meat processing, slaughterhouses produce huge amounts of water because fresh water not used efficiently during production and clean, it is necessary to classify and reduce the production of wastewater at the source (Bustillo-Lecompte and Mehrvar, 2017).

The reason for the increase in slaughterhouses is the high demand for food products in recent years and this leads to the production of large quantities of wastewater, in addition to that, slaughterhouse water characterized by high levels of organic materials, pathogens, bacteria and detergents used in cleaning activities. Moreover, the composition of wastewater for slaughterhouses varies depending on the number and type of slaughtered animals and the water requirement for this process. There are many slaughterhouses in Palestine that drain the slaughterhouse water directly into the wastewater network without any initial treatment-taking place on the site, given that the characteristics of the high slaughterhouse wastes are necessary to make an initial treatment before entering the municipal sewage network.

Sewer ingredients from slaughterhouses include blood, fats, oils, greases, carcasses, feces, urine, detergents and production residues (Rizvi et al, 2016), and wastewater of the olive mill contains an enormous amount of organic matter rich in phenolic compounds, in addition to a low amount of heavy metal. Large quantities of water are used in the treatment processes (slaughtering and cleaning) as a result, the composition of slaughtered wastewater varies as it contains large amounts of organic concentration and nutrients, and is usually measured by Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and Total Kjeldahl Nitrogen (TKN) (Kundu et al. 2013). Slaughterhouses produce tons of solid and liquid waste resulting from the slaughter of animals. They are a source of environmental pollution and public health risks such as epidemics and diseases that may cause by poor hygiene and lack of infrastructure in many areas (Aziz et al. 2019). Therefore, achieving a high level of environmental protection, whether by preventing or mitigating the source, and finding ways to prevent and control pollution (Bugallo et al, 2014).

Dairy water is an industry that produces large quantities of liquid waste and is a concern, it contains proteins, carbohydrates, high organic, inorganic loads and fats, it characterized by high demand for chemical oxygen demand (COD) (Akansha et al, 2020). As a result of wastewater disposal without prior treatment adequate treatment had to be provided before disposal including anaerobic treatment has become a prominent process of treatment, which obtained practical and acceptable results within a short period of time (Charalambous et al, 2020).

2.1.2 Current Status of Olive Mill Water and Industrial Wastewaters in Palestine and World

The current and future situation of wastewater treatment plants in Palestine, designed for intolerance, sudden overload, and drainage issues and problems, there must be an effective and sustainable treatment of the olive mill water.

The water of the olive mill is discharged in various areas within the sewage networks and valleys. This leads to mixing it with untreated municipal water or rainwater, which affects high organic wastewater on the soil and causes problems in the system. It negatively affects groundwater, which is the main water resource in Palestine and causing environmental degradation significantly, as in the Zomar Valley, municipal wastewater is discharged to the Alexander River towards the Mediterranean (Abdel-Karim and Shaheen, 2007).

Olive mill water produced in the West Bank during the olive season within a few months, from October to December. Nearly 100,000 annual productions and approximately 300 olive production factories are concentrated in the northern region (Al-Sa`ed, 2013).

At Nablus station, there is an anaerobic treatment unit that was started in 2013 and the olive mill water is transported for treatment. In 2018, approximately 390 cubic meters of olive mill water transported and gradually pumped into the anaerobic digester, the gradual pumping aims to reduce the load on the digested biomass. During a month of the experiment, the results showed that the anaerobic digester was able to treat the water of the olive mill and worked on its anaerobic digestion, and led to an increase in the production of biogas by about 12,000 Nm / month, this led to an increase in electricity production. The disposal of the olive mill water in the anaerobic digester was effective and no inhibition or negative effects on performance were seen (Nablus Municipality, 2018).

Industrial wastewater in the West Bank includes olive mill, leather, textiles, quarries, dairy, and slaughterhouses, some of them produce hazardous waste and others are not, they are usually disposed of in the environment without adequate primary treatment, which poses a serious risk, because it contains very dangerous substance. Recently, it became a great interest in industries and the use of primary treatment methods before disposal (Hudhud, 2003).

In a study titled Two-Stage Anaerobic Digestion of Meat Processing Solid Wastes: Methane Potential Improvement with Wastewater Addition and Solid Substrate Fermentation, this study aims to evaluate the performance and stability of anaerobic digestion of solid waste and wastewater slaughterhouse. By taking three mixtures of substrates diluted in different proportions and then adding them in a series of reactors for anaerobic digester, it found that the dilution improved the hydrolysis of the organic compounds. Some samples in the experiment produced a small amount of gas due to the high content of fats and proteins, which may prevent the activity of methanogens. In addition, it proved in the experiment that the percentage of methane production during anaerobic digestion of fat-rich waste increases with the increase of the dilution factor. There is a decrease in methane production in substrates with a high solid content as it found in the first diluted sample with the lowest percentage of substrates and the best methane production potential and volatile solid matter output obtained 0.38-m3 kg VS added −1 and 86%, respectively. Moreover, for the sample with a high organic content level, biological treatment carried out by fermentation bacteria, by fermenting the solid substrate this significantly improved the activity of methanogens, the production of methane and volatile solids removal yield increased by 52 and 22.7%, respectively. The biological pretreatment integrated with anaerobic digestion (Younes, 2019). In a study entitled Anaerobic treatment, basic concepts, applications and new perspectives. The average gas production was 500 L /kg $COD_{removed}$ (Pohland, 1992).

The results of this study in Netherlands explained, which titled performance of UASB reactor at different flow rate treating sewage wastewater, were explained that at low flow rate of 2 mL / min. The COD removal efficiency was 74.2%, is better than high flow rate 64 ml/min, the COD removal efficiency was 38.5%, this is due to the low residence rate inside the bioreactor (Yadav and Pal, 2013). High rate anaerobic treatment systems have become good for treating low, medium strength and high solubility wastewater; these systems provided only a partial treatment of complex wastewater that contains a high percentage of suspended solids such as slaughterhouse wastewater (Sayed, 1987). In a study of a slaughterhouse in Ethiopia on characterization and evaluation of biogas production for wastewater, the results of the study showed that the removal efficiency rate of TKN was 77.4% (Dawana, 2020).

In a study entitled Monitoring and evaluation of a UASB upstream reactor for primary treatment of wastewater from a Palestinian chicken slaughterhouse (Diab, 2020), the researcher discussed the problem of disposal of slaughterhouse water in sewage networks, explain how to solve this problem by designing and building a pilot system for wastewater treatment in the slaughterhouses. In addition, verify the feasibility of using Up flow anaerobic sludge blanket, as an option for wastewater treatment to reduce wastewater pollution, the results showed after analyzing samples of the chicken slaughterhouse from two different sources using the anaerobic reactor, it was the average removal efficiency for COD, TSS, VSS was 77%, 55% and 58%, respectively. The removal rate of the COD was 20-96%. Moreover, the SSI removal rate is 11-90%. The result is that industrial water meets sometimes sanitation network standards.

2.1.3 Olive Mill Wastewater Characteristics

Olive mill water produced from olive residues, its production is very high in a short period of time, which leads to pollution of wastewater due to its complex, and harmful environment, the olive mill water depends on the composition of the olive variety, maturity. In addition, process of extraction, extractions way used to extract oil in Palestine is traditional way by using pressure with stones, semi-automatic oil extraction process and full-automatic oil extraction process using a hydraulic piston. (Tsagaraki, 2007).

The water of the olive mill contains high levels of organic matter, mineral salts and phenolic compounds are toxic in the form of monocyclic or polymeric, aromatic molecules and high concentration polyphenols (Abdel-Karim, 2007). To assess the quality of the olive mill water, the properties must be expressed in terms of parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solid (TSS), total Kjeldahl nitrogen (TKN). As in the table 2.1 shows the parameters that are commonly used when measuring, it is noted that each concentration component of wastewater is widespread, this is due to the diversity in the quality of olives and the method of oil extraction.

Table 2. 1. General characteristics of olive mill wastewater

Parameter	Value
pH	3.0-5.9
BOD	23,000 – 100,000
COD	40,000 – 220,000
Total Suspended Solids	1400-36000
Organic Nitrogen	154-1106
Kjeldahl nitrogen	395–915
Total phenols	2950-6110

Adapted from: Fragoso and Duarte (2012); Aladham (2012), values are in mg/l unless indicated.

2.1.4 OMWW and Wastewater Discharge Standards in Different Worldwide

The fate of the olive mill water depends on the extent of pre-treatment; the OMWW is able to change the microbial composition of the soil due to its high toxicity. Which leads to environmental degradation, so the industrial olive mill water is subject to the standards of industrial wastewater discharge before entering the network, as stipulated by national legislation (Bevilacqua, et al, 2013). The table (2-2) shows for different countries the criteria for treatment before discharge.

Table 2. 2. OMWW standards for wastewater discharge for different authorities worldwide

Parameter (mg/ltr)	Palestinian standards (Ground water recharged)	Palestinian standards (discharge to sewer system)	Jordan	Italy	Greece	Spain	Portugal
pH	6-9	6-9	5.5-9.5	5.5-9.5	6-9.5	5.5-9.5	6-9
BOD_5 (mg/l)	40.0	500.0	800.0	250	250-500	40-300	40
COD (mg/l)	150.0	2000.0	2100.0	500	1000	160-500	150
TSS	60.0	500.0	1100	200	500-3000	30-300	60
Total phenol	0.002	3.0	10.0	1	5-10	0.5-1	0.5

Adapted from: (MEnA, 2000), (MEnA, 2001), (AL-KHATIB et al, 2009), (Aladham, 2012).

2.2 Slaughterhouse Wastewater

2.2.1 Introduction

The meat processing industry consumes large quantities from fresh water, and with the increased demand for meat, production has doubled. This leads to an increase in the number of slaughterhouse facilities, which leads to an increase in the volume of wastewater because slaughterhouse water contains high organic matter. Residues and detergents used for cleaning purposes, which requires major treatment to be safe and sustainable disposal in the environment, where the disposal of slaughterhouse water is necessary in terms of public health (Bustillo-Lecompte, 2017).

The characteristics of the slaughterhouse wastewater vary depending on the industrial process and the consumption of the slaughtered chicken with technological improvements, their quantities and production increased. Slaughterhouse wastewater characterized by high concentrations of organic and solid materials, Grease, fat, tissue, blood, stool, leather, urine, and cleaning and sterilization compounds. Anaerobic systems are suitable for wastewater treatment of slaughterhouses with high organic loads

2.2.2 Slaughterhouse Wastewater Characteristics

The characteristics of sewage from slaughterhouses depend on various factors, including the type of slaughtered animals, the type of slaughter, the size of the slaughter facility, the amount of water that consumed for each animal, and the washing of slaughter equipment. Slaughterhouse wastewater installations are complex, as they contain a large amount of organic substances, toxins, pathogens, and medicines for veterinary purposes and detergents.

It also contains large amounts of demand for biological oxygen, demand for chemical oxygen, total organic carbon, total phosphorous, total nitrogen, and total suspended solids. In the table below, the characteristics of slaughterhouse wastewater (Bustillo-Lecompte, 2015).

Table 2. 3. Common characteristics of slaughterhouse wastewater.

Parameter	Value Range (mg/Ltr)
COD	500-15,900
BOD_5	150-4635
TSS	270-6400
TN	50-841
pH	4.90-8.10
TOC	70-1200

Adapted from: Bustillo-Lecompte and Mehrvar, 2017.

2.2.3 Regulations for management slaughterhouse wastewater

Regulations are important in mitigating the harmful environmental impacts of slaughterhouses on the environment and society. There must be a preliminary treatment and the use of treatment methods before discharged, environmental legislation and the latest methods provide recovery of resources from biogas generation using the anaerobic treatment method (Bustillo-Lecompte, 2015).

The various laws and regulations of SWW shown in the table 2-4 below.

Table 2. 4. Standard limits for drainage of slaughterhouses for different authorities around the world.

Parameter (mg/ltr)	World Bank	European Union	Canada	Australia	Palestinian standards (Ground water recharged)	Palestinian standards (discharge to sewer system)
BOD_5	30	25	5 - 30	6 - 10	60	500
COD	125	125	---	3*BOD	200	2000

TSS	50	35	5 - 30	10 - 15	50	500
TN	10	10	1	0.1 - 15	50	60

Adapted from: Palestinian Standards Institution (PS, 2010), Environment Canada (2012), US EPA (2004), World Bank (2007), ANZECC (2000).

2.3 Olive mill and Slaughter House Wastewater Treatment

As a result of the modernization of the olive factories, the olive oil industry sector has grown and the increasing demand for olive oil around the world, the increased in the quantity of olive presses and slaughterhouse production, this increases its impact on the environment and its degradation because of the high content of organic matter and pollutants. A prior treatment requires to get rid of it, currently, the focus is on recovering by-products such as fertilizers and natural gas, there are several treatment processes used to reduce the negative impact on the olive mill water (Ochando-Pulido et al, 2016).

The treatment stages of the olive mill and slaughterhouse water consist of pre-treatment, primary, secondary and tertiary treatment in some cases and this study focuses on secondary treatment, which contains biological treatment.

Biological treatment is considered environmentally friendly and effective, it is effective in removing organic and inorganic substances, the most convenient and least expensive. Biological treatment includes aerobic and anaerobic treatment, usually anaerobic digester basis in the biological treatment process compared to aerobic treatment, anaerobic process less energy consumption and power generation on a vital form of gas, it produces less waste, and the process adapts to seasonal production and easy to run after several months of shutdown (Mantzavinos and Kalogerakis, 2005).

The treatment technology for wastewater divided into three general methods: Physical, chemical, and biological methods

2.3.1 Physical treatment

It is considered a primary treatment and the includes evaporation, dilution, sedimentation, filtration, and centrifugation, it is used for dilution before starting biological treatment and reducing sediment and get rid of oils, greases, fats, sand, rocks, etc. The process alone is not able to reduce organic pregnancy and requires high-energy costs and emissions of air pollutants (Paraskeva and Diamadopoulos 2006).

2.3.2 Chemical treatment

Among the chemical processes used in wastewater treatment are chemical coagulation, chemical precipitation, chemical oxidation and advanced oxidation, ion exchange, disinfection, chemical neutralization and stabilization, which in turn stimulates chemical reactions, to achieve different water standards (Otles and Selek, 2012).

2.3.3 Biological treatment

Introduction

Biological treatment is the most suitable and the most affordable wastewater treatment, and it divided into two parts: aerobic and anaerobic processes. Aerobic treatment indicates the presence of oxygen while anaerobic treatment does not contain oxygen; biological treatment is often a secondary treatment process, microorganisms such as bacteria, algae and fungi, which in turn analyzes organic and toxic substances (Otles and Selek, 2012), use organic materials.

Biological treatment characterized by the use of natural substances that help break down organic matter. In addition, the process involves the production of bioenergy, which are biochemical reactions, this type of reaction requires an external energy source while biodegradable organic matter, living organisms use this material as food and energy for it (Diab, 2020).

The figure 2-3 shows the processes used in wastewater treatment, including the olive mill wastewater, which summarized in three operations.

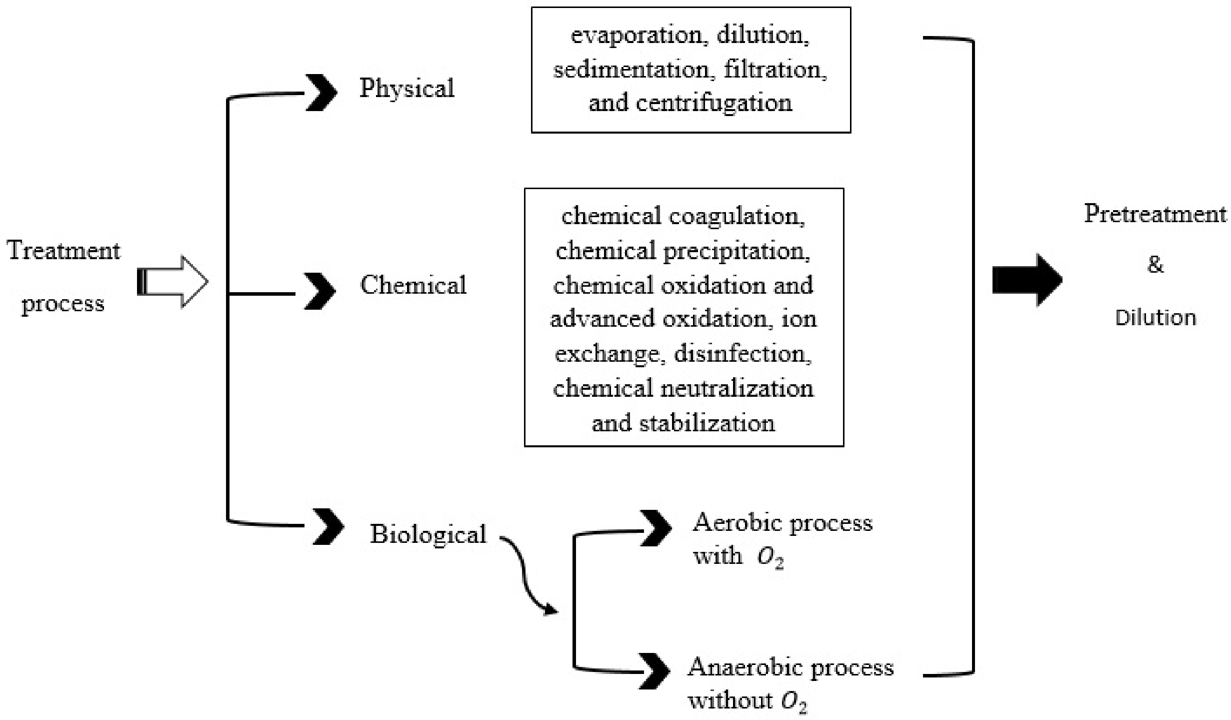

Figure 2. 3. Treatment processes used in wastewater treatment.

2.3.3.1 Aerobic Processes

1. Process Description

In this process, the aerobic organisms analyze the pollutants and remove them by oxidation using oxygen as electron acceptor or an oxidizing agent, then convert the organic compounds into energy, new cells and residual materials. The process depends on adding continuous air to mix with waste, during the oxidation and synthesis process, organic materials consumed, carbon dioxide, heat released, and water and new cells made, as shown by the following equation (Gavrilescu and Macoveanu, 1999).

$$\text{organic matter} + O_2 + \text{ nutrients} \rightarrow CO_2 + H_2O + C_5H_7NO_{2\,(\text{new cells})} + \text{others product} + \text{heat} \quad (2.1)$$

Where $C_5H_7NO_2$ are the newly synthesized cells.

- Endogenous respiration

In endogenous respiration, biodegradable organic materials consumed; organisms consume all nutrients to maintain metabolic reaction as shown in the equation (2.2). Due to the microbial activity, the amount of oxygen depleted and the oxygen is slightly soluble in water, in order for the process to remain aerobic, it is necessary to continue stirring so that it does not become anaerobic.

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3 + \text{energy} \quad (2.2)$$

- Nitrification process

A two-step process in which ammonia (NH_4^+) converted to nitrate (NO_2^-) by bacteria, it is fast and takes place within days or weeks. Ammonia converted to nitrate (NO_3^-) if conditions are favorable. First step, ammonia converted to Nitrite by Nitrosomonas bacteria that take energy from the conversion process while using carbon dioxide as a carbon source, as shown in the equation 2.3 below.

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- - + 2H_2O + 4H^+ + \text{energy} \quad (2.3)$$

The second step, in which the nitrite is converted into nitrate by genus Nitrobacter bacteria, that get their energy from the oxidation process, as shown in the equation 2.4 below.

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + \text{energy} \quad (2.4)$$

2. Aerobic Composting

It is a biochemical oxidation process includes oxidation of biodegradable materials by aerobic microorganisms, this leads to a decrease in the sludge mass. The final electron receptor can be dissolved oxygen or nitrate and the cell tissue oxidized to carbon dioxide, water and biomass as shown in the equation 2.5.

$$\text{Cellular material} + O_2 \rightarrow \text{Digested sludge} + Co_2 + H_2O \quad (2.5)$$

Among the factors affecting the performance of the air digester are temperature, pH, mixing, type of solids. It features low cost, stable sludge without odor and easy operation reduces pathogens and pathogens (Shammas and Wang).

3. Aerobic Wastewater Treatment

Providing clean water is a prerequisite for human activities, liquid and solid waste pollutes most water sources and must treated to provide valuable food. Aerobic treatment is a biological process through which oxygen used by naturally occurring microorganisms to analyze organic waste and treat wastewater.

It consists of bacteria, fungi, other microbes, to enhance the biochemical reaction, the rate of oxygen supply must be sufficient due to the limitations of oxygen feeding, and providing the ideal conditions for it, oxygen can add mechanically. This helps to speed up the oxidation of organic matter.

Initially, wastewater enters the ventilation unit with the addition of dissolved oxygen or added oxide mechanically, aerobic microorganisms convert organic matter into new energy and cells, nitrogen and ammonia converted into nitrates. The efficiency of the treatment depends on the system area; the higher the area of contact with the surface, the more oxygen transferred according to the figure 2-4 shown below, the presence of an abundant amount of dissolved oxygen and soluble organic matter. Makes the microbes in the initial stage of growth by consuming organic pollutants increasing exponentially the bacterial growth rate exponentially (lag phase and growth phase), then microbes consume organic pollutants, exponentially increasing bacterial growth rate, until it reaches the maximum growth (stationary phase). It stabilized here without any further increase until the concentrations of organic matter decrease then the bacteria enter a self-feeding stage that eats itself (endogenous phase) (Seabloom and Buchanan, 2005).

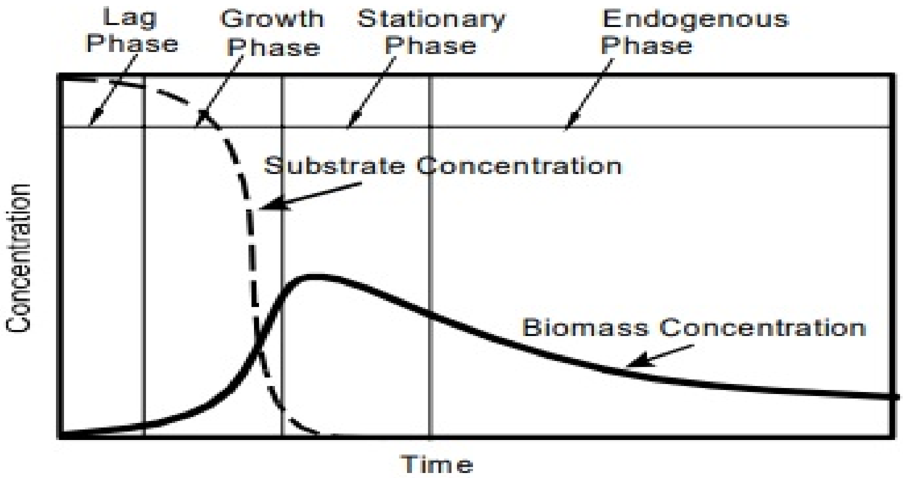

Figure 2. 4 The relationship between substrate and biomass in terms of concentration and time.

Source: Adapted from: (Seabloom and Buchanan, 2005).

2.3.3.2 Anoxic Processes

The oxidation process is usually used to remove nitrogen from wastewater, this process is known as the denitrification process, and the presence of nitrogen in large quantities causes toxic conditions for wildlife and leads to oxygen depletion and algae growth and this affects the environment and humans, anoxic (low or zero DO) zone to provide denitrification. In this equation 2.6, the biological nitrogen removed.

$$NH_3 \rightarrow \rightarrow NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow NO_2 \text{ (gas)} \quad (2.6)$$

De-nitrogen bacteria require an electronic donor to dispose of nitrates (NO_3^-), it is an electron receiver such as nitrate and nitrite and reduced to nitrogen gas and the rest of the components are oxidized to carbon dioxide and water. The organic carbon is the carbon source for the cell, the addition of carbon is an important source of nitrogen production. In the example, acetate as a carbon source, in which nitrogen is removed, as in the following equation 2.7(Wong et al., 2003).

$$1.77CH_2O + 0.62HNO_3 + 0.2NH_3 \rightarrow CH_{1.4}O_{0.4}N_{0.2} + 0.77CO_2 + 1.68H_2O + 0.305N_2 \quad (2.7)$$

2.3.3.3 Anaerobic Processes

The successful application of anaerobic treatment technology in waste treatment, make it competitive with aerobic technology, especially in recent years. The processes differ in the way that the microorganisms are preserved and in limiting the limitations of anaerobic digestion.

Anaerobic digestion is a relatively inexpensive energy production process that consumes less energy and space and produces excess sludge, which is the most appropriate and sustainable as it treats approximately 1.3 billion tons of waste worldwide every year (FAO, 2013).

1. Process Description

A process that microbes analyze organic matter under conditions where there is no oxygen. These biodegradable organic materials, by a group of prokaryotic microorganisms, bacteria participate methanogens in anaerobic digestion, which transforms organic matter into carbon dioxide, water and methane, as shown in the equation 2.8.

$$\text{Organic matter} + H_2O \rightarrow CH_2 + CO_2 + H_2O \tag{2.8}$$

In this process, biogas produced at a rate of 90-95% and a rate of 1-5% to a new bacterial mass (Samer, 2015).

The process of anaerobic include several steps for metabolic in the wastewater treatment, which is as follows (Shah, 2014):

1. Hydrolysis:

Insoluble polymerase organic compounds such as carbohydrates and proteins, fat decomposes into soluble monomers and inhibitors, which is amino acids, fatty acids and monosaccharides.

At this stage, methane formed through extracellular enzymes produced by suitable strains of aqueous bacteria; the rate of the hydrolysis process depends on particle size, enzyme production, pH, diffusion and that by bacteria from the group of anaerobes.

2. Acidogenesis

At this point, the acidic bacteria convert the biodegradable chemicals with water to organic acids, alcohols, aldehydes, carbon dioxide, and hydrogen. Amino acids and peptides arise from the breakdown of proteins, which are an energy source for anaerobic microorganisms. This process can divide into two parts: hydrogenation and dehydrogenation. The main pathway for oxidation of the compounds produced by acid formation is through acetate.

3. Acetogenesis

In this process, acetate bacteria convert acid phase products into acetate and hydrogen, which can have used by methane bacteria. Because of the release of acetate, hydrogen released. Acetogenesis is a conceptual stage for efficient biogas production, because about 70% of methane gas produced during the process of reducing acetate. Therefore, acetate is an important intermediate product for methane digestion and during the decomposition process; about 25% of acetate and 11% of hydrogen formed.

4. Methanogenesis

Methane bacteria form methane at this stage, methane is a product of the previous stages. The vast majority of methane production comes from acetic conversions, by heterogeneous methane bacteria, 30% of methane comes from reducing carbon dioxide and it made by self-feeding methane bacteria. During this process, H_2 used to create good conditions and develop acidic bacteria. In the Figure 2-5, it shows the steps for metabolism in anaerobic digestion.

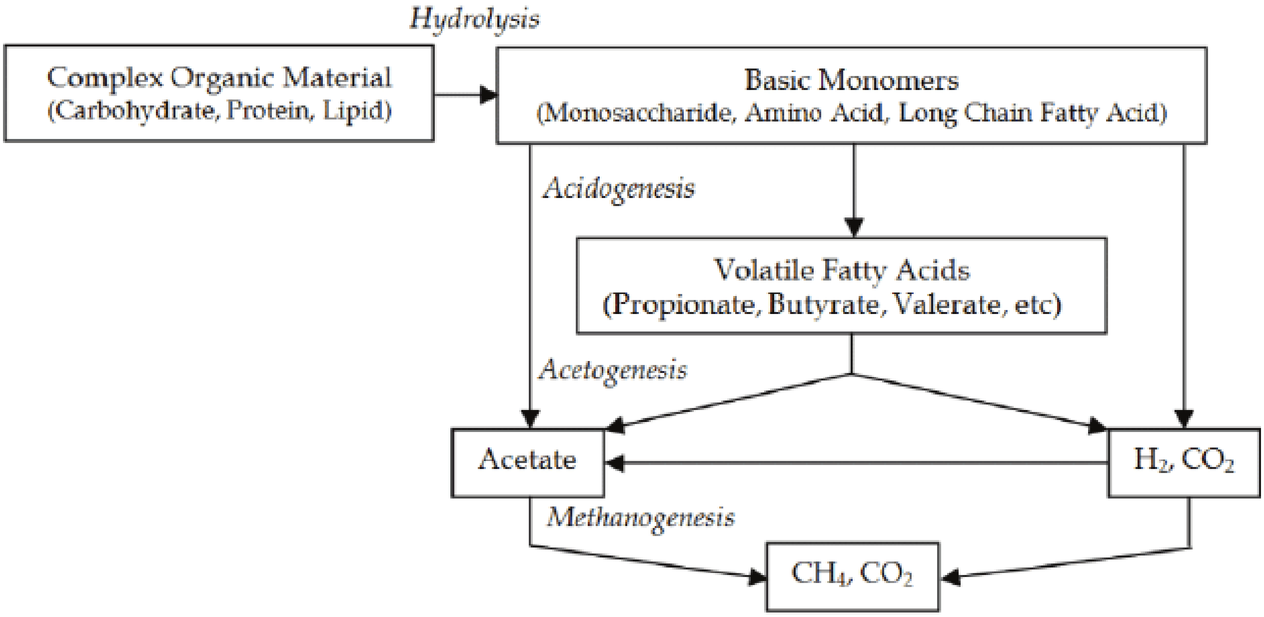

Figure 2. 5 Schematic diagram of metabolic steps in anaerobic digestion.

2. Types of Anaerobic systems

Usually many anaerobic reactors used to treat industrial polluted water, and each system has advantages and disadvantages, here are some examples of the most common anaerobic reactors:

- Fluidized and expanded bed reactors

It includes layers of gravel, sand and activated carbon granules which bacteria are attached to it, cells are attached to solids such as granules and due to the pulling force of the sewage flow upward they can be kept suspended which causes higher rates of decomposition of organic waste.

Fluid bed reactors are good for exothermic reactors; it used in many industries, including fuel, waste treatment and its complications. The reactors offer many advantages such as fast mixing of stages and good heat rates, some of its disadvantages are high catalytic depletion, internal reactor wear and back mixing.

- Upflow Anaerobic Sludge Blanket Bioreactor

One of the most prominent developments in anaerobic treatment technology and the bioreactor that used to treat wastewater. Is effective in converting organic matter to hydrogen, Waste water passes into the bioreactor depending on temperature and retention time up through the anaerobic sludge layer, the microorganisms come in the sludge and come into contact with the wastewater substrates,

Living organisms can form naturally and have high precipitation speed. Thus, it resists washing from the system even at a hydraulic load. The resulting biogas produced in the anaerobic process (Evren, 2011).

In a study to treat high-fat wastewater, the hydraulic retention time was (7.2 ± 2.8 h), the results showed USAB's experiments achieve (78 ± 8%) total COD removal (61 ± 17%) convert COD to methane. When running at organic loading rates 15.1 g.l^{-1}. d^{-1} Moreover, hydraulic retention time was 6.1 h and the result is 80% of the fat can be removed (Palenzuela-Rollon, 2002).

- Anaerobic Sequencing Batch Reactor

It a high-speed anaerobic process that performs the following steps: feeding, reacting, sedimentation and decantation. In the first step, it involves adding the substrate to the reactor, where the ingredients are constantly mixed, the size of the substrate depends on several factors including hydraulic retention time, organic loading, and stability characteristics, and the conversion of biodegradable organic matter into biogas carried out through the reaction step. Then reaction content is mixed to allow close contact between organic matter and bacteria, the time required for the reaction step depends on flow quality, biomass concentration, type of mass, and substrate characteristics, at the end of the reaction period, the mass is stopped to block and settle. The time required for precipitation depends on the concentration of the biomass, the type of biomass and its temperature. At the end of stability, decantation occurs (Evren, 2011).

- Anaerobic filters

A fixed-bed biological reactor with one or more filter chambers in series, wastewater flows through the filter, and particles trapped the organic matter and then degraded by the active biomass attached to the surface of the filter material with this technology, the BOD removal rate can reach 90%. Where the nitrogen removal in this method ranges to 10%. Initially the large solids that block the filters in the sedimentation chamber removed, the sewage then inserted into a biofilm layer containing bacteria, consisting of materials such as ceramics, engineering plastics and wood, in the filter room for treatment and reducing the organic loading rate. The hydraulic retention time is important in filter performance and is usually 12 to 36 hours (Tilley et al., 2016).

- Membrane Bioreactor

It is a biological treatment technology and is a mixture of filtering membranes and activated sludge. In this process, the biological analysis of the organic pollutants carried out by the presence of microorganisms in the bioreactor followed by the filtering of the membrane to separate the microorganisms, membranes used to remove solids from wastewater. One of the advantages of this process is that it allows high biomass concentrations and higher removal efficiency than conventional treatment plants, high removal for COD (> 90%) and a higher separation for solid suspensions, it is more efficient at removing total BOD (Singh, 2015).

- Continuous Stirred Tank Reactor

Bioreactor that used to produce hydrogen; it is simplicity in configuration and ease of operation. Stirred uniformity, maintaining temperature and pH, because of the continuous mixing, the microorganisms are evenly mixed inside the reactor fluid. There is an appropriate connection between the substrate and the microbe and the best reaction to the vaccine substrate and mass transfer can obtained (Gopalakrishnan, 2019).

The figure shows the reactor of UASB, it is the most highly modified anaerobic system in the world Wastewater enters the reactor from the bottom and exits from the top.

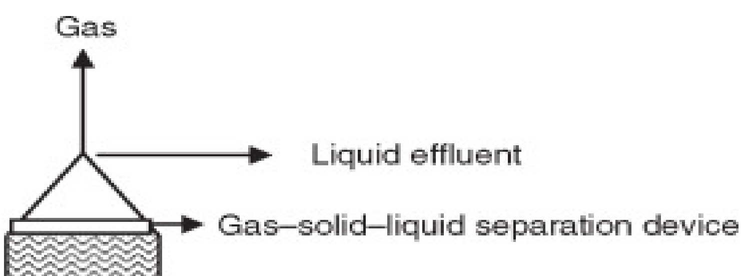

Figure 2. 6 UASB reactor diagram

2.4 Advantages and disadvantages of the UASB bioreactor

In the table 2.5, it shows the advantages and disadvantages of the UASB bioreactor

Table 2. 5. Advantages and disadvantages of the UASB bioreactor.

Advantage	Disadvantage
Significant reduction of BOD	It is difficult to maintain proper hydraulic conditions
Low production of sludge	It takes a long time to start
Biogas can be used to produce energy	A steady source of electricity is required
Significant decrease in organic matter	Granulation depends on the characteristics of the wastewater
It can withstand high membership load rates	Float granules
High COD removal efficiency	Inadequate removal of pathogens without appropriate prior treatment
Low odor emissions	Methane and odor emissions
Low energy demand	Sensitive to toxic substances

Adapted from: (Tilley et al., 2016).

2.5 Effect of various parameters on the UASB reactor performance

A number of large factors regulates the USB reactor; deterioration of unwanted pollutants also depends on these criteria. These parameters related to the operating conditions of the reactor. They are as follows (Abdelgadir, 2014):

1. Temperature

Temperature is important and affects water acceptability and treatment, anaerobic bacteria classified according to temperature and wastewater treatment processes affect by temperatures. The removal of the particles affected by temperature where the viscosity is associated with temperature, also changes in temperature affect the activity of microorganisms, increasing the temperature improves the mixing and reduces the viscosity and promote sedimentation, improve fusion and adsorption between sludge and solids. This leads to more biogas production; it also affects the operating system design of the treatment system.

2. pH

It is a measure of the acidity of the solution, it expresses the intensity of the basic or acidic state of the liquid, at neutral pH (7) methanogens in wastewater treatment are more active. The suitable concentration for most organisms from 6.0 to 9.0 after this range it continues to digest but with less efficiency, acid conditions are very toxic to methane bacteria. The optimum pH for anaerobic treatment is 6.6 to 7.6, if this range not maintained; it will cause a negative impact on the performance of the reactor.

3. Hydraulic Retention Time (HRT)

Hydraulic retention time, which is a measure of the average length of time that the soluble compound stays in the bioreactor, expressed by the volume of the aeration tank divided by the flow rate.

$$\text{HRT [d]} = \frac{\text{Volume of aeration tank [m3]}}{\text{Influent flow rate [m3/d]}} = \frac{\mathrm{V}}{\mathrm{Q}} \tag{2.9}$$

Where HRT is hydraulic retention time (d) and also expressed in hours, the V is the volume of aeration tank or reactor volume (m^3), and Q is the influent flow rate (m^3/d).

Operational parameter that is easy to control; long hydraulic retention time has a negative impact on the sludge granulation process.

4. Organic Loading Rate (OLR)

Organic load represents the amount of biodegradable organic matter, expressed in BOD and COD; it is an important factor in removing COD. The additional increase in the organic loading rate leads to operational problems such as excessive foam, the organic loading rate can changed by changing the affecting concentration and changing the flow rate, organic loading can be expressed as follows:

$$\text{OLR} = \frac{(\text{Q} \times \text{COD})}{V} \tag{2.10}$$

Where OLR is organic loading rate (kg COD/m^3·d), Q is flow rate (m^3/d), COD is chemical oxygen demand (kg COD/m^3), and V is reactor volume (m^3).

5. Sludge Retention Time (SRT)

Main parameter that affects the physical and chemical properties of sludge, the success of the UASB anaerobic reactor depends on the time of sludge retention, the factor that determines the final amount of hydrolysis and methane generation at a given temperature, and SRT determined by the loading rate. SRT and temperature affect the hydrolysis of fats, proteins and carbohydrates. According to the study, the sludge retention time is between 5 and 15 days at a temperature of 25 ° C, and methane production was 51%.

6. Upflow Velocity

It is one of the factors that influence the efficiency of the reactor; the flow velocity is closely related to the hieratic retention time, at a high flow velocity, the efficiency of the removal of the COD decreases. Height increases sludge and wastewater contact time, the velocity of the flow helps to provide an adequate mixture of biomass and substrate which maintains hydraulic retention time. The appropriate and permissible flow velocity is 0.5 - 1.5 m/h (Daud, 2018).

7. Particle Size Distribution

The size of the particles plays their role in the efficiency of the filtering process; studies show that the small size of the particles gives removal that is more efficient.

8. Treatment Efficiency

The percentage of removal efficiency for the pollutant removed calculated using the following formula and the equation used to measure the BOD, VSS, TSS removal efficiency (Zhu, 2016).

$$\%COD\ removal = \frac{S_0 - S_e}{S_0} \times 100 \tag{2.11}$$

Where

S_O = influent COD concentration, (mg/l).

S_e = effluent COD concentration, (mg/l).

9. Specific Biogas Yield

Biogas can evaluate and measured from the estimated COD loaded to the reactor, which converted to methane, which measured by biogas production from a certain amount of the organic compound, which can be determined as follows (Chernicharo, 2007):

$$Y_{biogas} = \frac{Q_{biogas}}{Q(S_0 - S_e)} \tag{2.12}$$

Where,

Y_{biogas} = specific biogas yield, COD load converted into methane, m^3 biogas / kg $COD_{removed}$

Q_{biogas} = production rate of biogas, m^3 / day

Q = average influent flow m^3 / day

S_0 = influent COD in wastewater, kgCOD / m^3

S_e = effluent COD concentration in wastewater, kgCOD/ m^3

10. Toxic heavy metals

Heavy metals affect biochemical reactions during anaerobic digestion; it is play an important role in these reactions. In the study of the effect of heavy metals on the up flow anaerobic sludge blanket process, zinc, cadmium, chromium and lead appeared to be inhibitory and under toxic conditions during biochemical reactions, depending on its concentration.

The toxic effect of heavy metals such as cadmium disrupts the enzyme's function and structure in this thesis، heavy metals such as mercury, zinc, copper, lead, and cadmium will be studied in the anaerobic experiment to study the effect of heavy metals on biogas production.

2.6 Advantages and Disadvantages of Anaerobic Wastewater Treatment Vs Aerobic.

The main advantages and disadvantages of anaerobic wastewater treatment listed compared to the aerobic process, as shown in the table 2.6 below.

Table 2. 6. Advantages and Disadvantages of Anaerobic Wastewater Treatment Vs Aerobic.

Advantages	Disadvantages
Less energy required	Longer start time
Decreased demand for nutrients	Risks arise because of the possibility of methane explosion.
Produce less biological sludge	May need heated
Methane production	May require alkalinity
Effectively remove diseases	The temperature must be maintained throughout the operating period
No oxygen requirement	pH must be controlled
Tolerance of high organic load	
Under space requirements	

Source: Adapted from: Show (2017).

2.7 Anaerobic and Aerobic System Performance.

Through the discussion at the top, the table 2.7 below summarizes the advantages and disadvantages of both the Anaerobic and aerobic system.

Table 2. 7. Anaerobic and Aerobic System Performance.

Parameter	Anaerobic	Aerobic
Startup time	2 to 4 months	2 to 4 weeks
Nutrients requirements	Low	High
Energy requirements	Low	High
Odor	Possible odor problems	Less odors
Sludge production	Low	High
Biogas production	Yes	No
Alkalinity requirements	High	Low

Source: Adapted from: Eckenfelder (1988).

3. MATERIALS AND METHODS

3.1 Background

The study focuses on two mixed industrial wastewaters, sewage from slaughterhouses that was brought from the Birzeit slaughterhouse and wastewater from the olive press taken from the olive factory in Ramallah. Anaerobic treatment was applied as a pretreatment method, the effects of pre-treatment will be to reduce pollution from the agro-food industries and the treated wastewater connected to the appropriate reclaimed water for reuse or safe disposal.

3.2 Materials

In the Figure 3-2, a schematic diagram of the reservoir shows the anaerobic sludge blanket, the cylindrical shape reactor is 200 cm high and 45 cm in diameter and the total volume of the reactor is 300 liters, the reactor is made of epoxy coated galvanized steel with a thickness of 0.2 mm. Which is connected to the reactor inlet tube they are located in the lower bowl and are made of galvanized steel with holes of 16 mm in diameter, a 6 cubic meter tank is provided to feed the two UASB, it contains a mechanical mixer to avoid material deposition and keep the mixed wastewater homogeneous and balanced. On the side of each of the reactors, there are six taps installed on the wall visually verify from any accumulation of sludge inside the reactors. And also there is a spout at the end of the reactor from below for use in the transportation of excess sludge and there is an outlet for the reactor sampling point for sampling, it also contains a gas flow meter that calculates the current and cumulative amount of gas total production and measure the ambient temperature. Figure 3.1 and 3.2 shows the two systems in the reality.

3.3 Methodology

1) Type of research:

Applied research using locally installed two UASB, it is located on the campus of Birzeit University.

2) Target samples:

Slaughterhouse owners, owners of olive factories, municipalities, water and environmental institutions.

3) Research Tools:

Experimental processing units, Integrated two UASB system.

4) Research methodology in analysis: Through collect data, operation system, process control, test and analysis, and laboratory analysis.

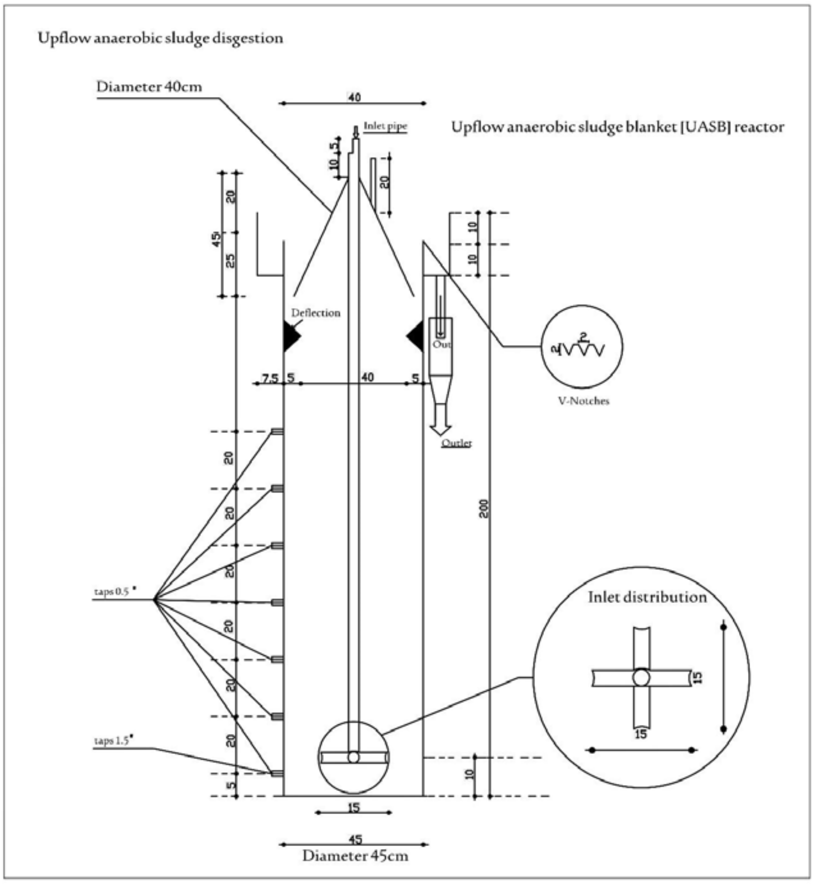

Figure 3. 1. Schematic diagram of a UASB reactor.

Figure 3. 2. Constructed Pilot Scale of two UASB-septic tank installed at BZU Campus.

3.4 System Operation

An earlier system was available running on one UASB and another reactor added, the system became 2 UASB. Slaughterhouse and olive mill wastewater added to the equalization tank and mixed; two adjustable variable pumps feed the UASB two system, in the first system it is low rate fed (166 l / day) and the second-high rate fed (400 l / day) and this is in the first stage of the system. In addition, in the second stage of the system, the pump flow became constant at (115 l / day), and the variable is the olive mill (Zibar). The creation of granular sludge enhanced in the UASB system and added 40 liters of anaerobic sludge from the West Nablus plant, which treats local sewage from the western city of Nablus. The system's storage tanks fed monthly in batches; each batch is about nine m3.

3.5 Sample testing and analysis

- A 2500-liter sample of wastewater collected from a slaughterhouse in Birzeit by a perfusion vehicle and collecting a capacity of 35 liters of wastewater for the olive mill from the mill plant in Birzeit, during the month of May and mixed them together.

- **First stage:**

The percentage of olive mill (zibar) and slaughterhouses is fixed and the variable is the fed rate for two UASB system, at flow rate 166 L/d is low fed rate for (UASB 1) and at flow rate, 230 L/d is high fed rate for (UASB 2).

- In the month of July, 5,000 liters of wastewater for slaughterhouses and 16 liters of olive mill wastewater added and mixed them together.

- At the beginning of the month of August, 5,016 liters of olive mill wastewater added to equalization tank and mixed with old content and at the end of the month; 5,000 liters of wastewater for slaughterhouses and 16 liters of olive mill wastewater added and mixed them together.

- Added 20 liters of anaerobic biomass to the old first reactor and 40-liter biomass to the new second reactor from West Nablus station.

Figure 3. 3. Influent of anaerobic biomass for two UASB

- **Second stage:**

In September, the system was changed and the pump flow became constant at 115 L/d, and the variable is the olive mill (Zibar), 10% added (32 L).

- At the month of September 32, liters of Zibar and 4,500 liters of slaughterhouse water added, and at the end of the month, 16 liters of Zibar and 3,000 liters of slaughterhouse water added.

- Samples with a capacity of 250 ml are taken for each sample, approximately once a week, to analyze the chemical, physical and biological properties on the basis of standard methods (APHA, 2005), for analyzing water and wastewater.

- Samples taken from the inside and outside of the system for the analysis of COD, TSS, TKN, heavy metals and phenols, according to the standard methods.

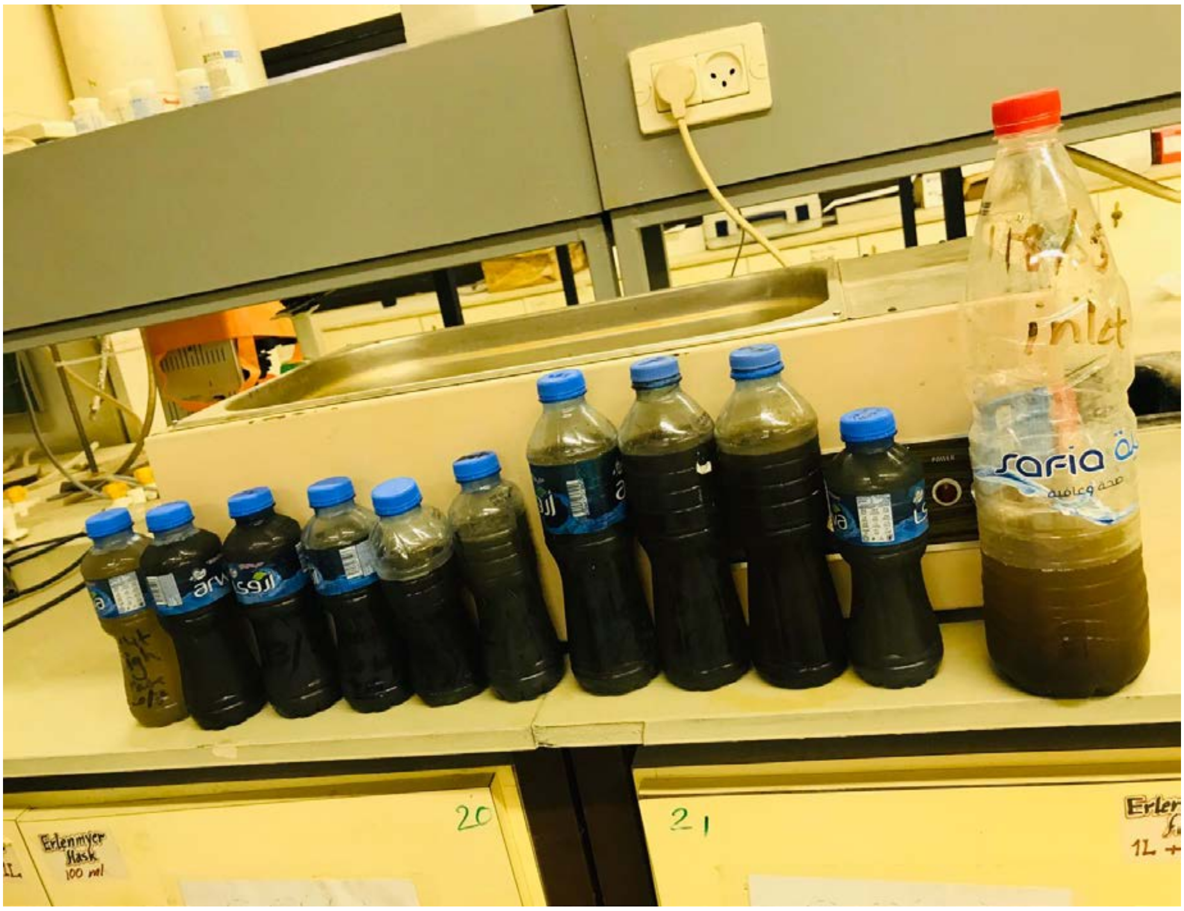

Figure 3. 4. Samples of slaughterhouses and olive mill wastewater taken from the start of the project

3.6 UASB Design

Below, it shows the size and capacity of the system equipment that used to measure the pilot scale of UASB:

1. Volume of UASB reactor: 300 liters
2. Equalization tank: 6 m^3
3. Mechanical mixer: 200 rpm
4. Adjustable feeding pump for first UASB 166 ltr/day, for second UASB: 400 ltr/day for first stage and for second stage is 115 ltr/day for UASB 1 and 2.
5. Gas flow meter: 0-200 SLPM

3.7 Calculations

The following is the design calculation for the two stages based on analysis of the samples obtained for the following parameters.

3.7.1 Calculations of first stage for UASB 1 (Low rate)

3.7.1.1 Up flow velocity

By using the following equation, the up flow velocity calculated

$$\text{Velocity} = \frac{\text{feed flow rate}}{\text{reactor surface area}}$$

Velocity = 0.042 m/h

3.7.1.2 Hydraulic retention time (HRT)

Equation (2.9) used to calculate the HRT and achieved the following results:

$$\text{HRT [d]} = \frac{\text{Volume of aeration tank [m3]}}{\text{Influent flow rate [m3/d]}}$$

HRT = 1.81 d = 43.5 hours

3.7.1.3 Organic loading rate (OLR)

Equation (2.10) used to calculate the OLR and achieved the following results:

$$\text{OLR} = \frac{(\text{Q} \times \text{COD})}{V}$$

$$\text{OLR} = 1.826 \ \frac{\text{kg COD}}{m^3 \cdot \text{d}}$$

3.7.1.4 VSS removal efficiency %VSS

Equation (2.11) used to calculate the VSS removal and achieved the following results:

- maximum removal efficiency achieved: 91%
- minimum removal efficiency achieved: 49%
- average removal efficiency achieved: 68%

3.7.1.5 COD removal efficiency %COD

Equation (2.11) used to calculate the COD removal and achieved the following results:

- maximum removal efficiency achieved: 84%
- minimum removal efficiency achieved: 24.5%
- average removal efficiency achieved: 36.1%

3.7.1.6 TSS removal efficiency %TSS

Equation (2.11) used to calculate the TSS removal and achieved the following results:

- maximum removal efficiency achieved: 91%
- minimum removal efficiency achieved: 30%
- average removal efficiency achieved: 51%

3.7.2 Calculations of first stage for UASB 2 (high rate)

As was calculated for the first reactor, the same methods were calculated but with different flow

3.7.2.1 Up flow velocity

By using the following equation, the up flow velocity calculated

$$\text{Velocity} = \frac{\text{feed flow rate}}{\text{reactor surface area}}$$

Velocity = 1.05 m/h

3.7.2.2 Hydraulic retention time (HRT)

Equation (2.9) used to calculate the HRT and achieved the following results:

$$\text{HRT [d]} = \frac{\text{Volume of aeration tank [m3]}}{\text{Influent flow rate [m3/d]}}$$

HRT = 0.75 d = 18 hours

3.7.2.3 Organic loading rate (OLR)

Equation (2.10) used to calculate the OLR and achieved the following results:

$$\text{OLR} = \frac{(\text{Q} \times \text{COD})}{V}$$

$$\text{OLR} = 4.4\ \frac{\text{kg COD}}{m^3 \cdot \text{d}}$$

3.7.2.4 VSS removal efficiency %VSS

Equation (2.11) used to calculate the VSS removal and achieved the following results:

- maximum removal efficiency achieved: 97%
- minimum removal efficiency achieved: 42%
- average removal efficiency achieved: 69%

3.7.2.5 COD removal efficiency %COD

Equation (2.11) used to calculate the COD removal and achieved the following results:

- maximum removal efficiency achieved: 67%
- minimum removal efficiency achieved: 25%
- average removal efficiency achieved: 61%

3.7.2.6 TSS removal efficiency %TSS

Equation (2.11) used to c2alculate the TSS removal and achieved the following results:

- maximum removal efficiency achieved: 95%
- minimum removal efficiency achieved: 59%
- average removal efficiency achieved: 74%

3.7.3 Calculation of second stage for UASB 1 and UASB 2 (High rate)

3.7.3.1 Up flow velocity

By using the following equation, the up flow velocity calculated:

$$\text{Velocity} = \frac{\text{feed flow rate}}{\text{reactor surface area}}$$

Velocity = 0.03 m/h

3.7.3.2 Hydraulic retention time HRT

Equation (2.9) used to calculate the HRT and achieved the following results:

$$\text{HRT [d]} = \frac{\text{Volume of aeration tank [m3]}}{\text{Influent flow rate [m3/d]}}$$

HRT = 2.6 d = 62.5 hours

3.7.3.3 Organic loading rate (OLR)

Equation (2.10) used to calculate the OLR and achieved the following results:

$$\text{OLR} = \frac{(\text{Q} \times \text{COD})}{V}$$

OLR = 0.39 $\frac{\text{kg COD}}{m^3 \cdot \text{d}}$ for UASB 1 and 0.46 $\frac{\text{kg COD}}{m^3 \cdot \text{d}}$ for UASB 2.

3.7.3.4 TSS removal efficiency %TSS

Equation (2.11) used to calculate the TSS removal and achieved the following results:

- **For UASB 1**

- maximum removal efficiency achieved: 93%
- minimum removal efficiency achieved:68%
- average removal efficiency achieved: 80%

- **For UASB 2**

- maximum removal efficiency achieved:87 %
- minimum removal efficiency achieved: 66%
- average removal efficiency achieved: 77%

3.7.3.5 COD removal efficiency %COD

Equation (2.11) used to calculate the COD removal and achieved the following results:

- **For UASB 1**

- maximum removal efficiency achieved: 89%
- minimum removal efficiency achieved: 27%
- average removal efficiency achieved: 64.6%

- **For UASB 2**

- maximum removal efficiency achieved: 87%
- minimum removal efficiency achieved: 41%
- average removal efficiency achieved: 59.6%

3.7.3.6 VSS removal efficiency %VSS

Equation (2.11) used to calculate the VSS removal and achieved the following results:

- **For UASB 1**

- maximum removal efficiency achieved: 94%
- minimum removal efficiency achieved:48%
- average removal efficiency achieved: 71%

- **For UASB 2**

- maximum removal efficiency achieved: 88 %
- minimum removal efficiency achieved: 57%
- average removal efficiency achieved: 73%

3.7.3.7 Specific biogas yield $\boldsymbol{\Upsilon_{biogas}}$

Equation (2.12) used to calculate the biogas yield and achieved the following results.

- **For UASB 1**

- daily average of biogas production quantity: 0.599 m^3/day
- daily average amount of solid wastewater fed inside reactor: 0.1152 m^3/day
- COD influent average: 4.103 kg/m^3
- COD effluent average: 1.331 kg/m^3
- biogas specific yield Υ_{biogas} =0.544 m^3 biogas/ kg.$COD_{removed}$ (is not accumulated reading)

- **For UASB 2**

- daily average of biogas production quantity: 1.477 m^3/day
- daily average amount of solid wastewater fed inside reactor: 0.1152 m^3/day
- COD influent average: 4.103 kg/m^3
- COD effluent average: 1.548 kg/m^3
- biogas specific yield Υ_{biogas} =1.568 m^3 biogas/ kg.$COD_{removed}$ (is not accumulated reading)

4. CHAPTER 4 RESULTS AND DISCUSSION

4.1 General

Anaerobic wastewater treatment systems become a good alternative to traditional anaerobic processes. Currently, the UASB system is the most widely used anaerobic system for the complete treatment of this complex waste.

The research focus on whether the operating conditions and environmental conditions of the two bioreactors in series are suitable for the complete treatment of slaughterhouse water and agricultural wastewater in practical terms and under any operational and environmental conditions.

4.2 Reactor start-up and operation

Diab previously operated the first reactor (UASB 1), then the second system UASB 2, was added and it was activated by adding slaughterhouse water to the pond and adding olive mill water (Zibar) to it and mixing them and then the mixed water in the basin is lifted onto the reactor by the pump. Then the anaerobic sludge brought from the sewage treatment plant in West Nablus, which treats domestic sewage from Nablus, the western side and through the first period of start-up, there were no satisfactory results due to several problems, including the burst explosion, which supplies the two UASB bioreactors with wastewater through the pump. This is because of the accumulation of sediments in the equalization tank, which closes the tower and leads to a system failure of about five hours; it solved by placing a filter at the bottom of the tower to prevent sediments from entering through the tower. Consequently, the two UASB reactor systems did not show results in this period with respect to COD, TSS, VSS, gas production and heavy metals.

4.3 Performance of the two UASB-septic tank reactors

The system consists of two stages, where in the first stage it consists of high and low rate anaerobic wastewater treatment system as a good alternative to the traditional anaerobic processes and the second stage, the pump flow is fixed and the variable flow is the olive mill (Zibar). Currently, the UASB system is the most widely used anaerobic system for the complete treatment of this complex waste.

This thesis focuses on whether the operating conditions and environmental conditions of the two bioreactors are respectively; they are suitable for the complete treatment of slaughterhouse water and agricultural wastewater in practical terms and under any operational and environmental conditions.

4.4 Vacuum problem

The system problem during execution, the tube connecting the basin and the pump for the two reactors, which is the connecting line to feed the two reactors, was dispersed due to the entry of some sediments from the basin due to the narrow entrance of the tube and This leads to the closure of the tube, and thus to explode. In addition, the tube withdrawn from its place and pumping water to the two systems stopped, and thus the system would stop working and the tube also worn out, it solved by placing a filter at the bottom of the tower to prevent sediments from entering through the tube into the two systems. During the experience of the project, this error used to happen a lot, and this makes the system unstable in the beginning, especially with Corona (Covid-19) and the closures that occurred between cities by the government during the period from May to July.

4.5 Data analyses

4.5.1 pH in the UASB reactors

The pH is an important parameter for the anaerobic reactor because methane formation processes continue when high pH levels maintained in the range of (6.3-7.8) (Daud, 2018). The optimum pH for anaerobic treatment ranges from 6.6 to 7.6 (Abdelgadir, 2014).
Some samples taken to confirm the pH range during the experiment, the result obtained for the pH range from 6.93 to 7.66 was among the range according to this study, so there is no need to add any chemical. This indicates that the pH value falls within the optimum range of methanogens activity providing an ideal working environment for anaerobic digestion and industrial wastewater treatment efficiency.

4.5.2 Temperature in the UASB reactors

The efficiency of the anaerobic process is highly dependent on the temperature of the reactor, the two reactors operated for 4 months at an ambient temperature of (25-35) C°, the efficiency of the reactor affected at lower temperatures and this causes a decrease in biological activity.
Improvement of decomposition of organic matter takes place at elevated temperatures (mesophilic conditions), the temperature for mesophilic ranges between (20 ± 40) degrees Celsius (Rajeshwari, 2000).

4.5.3 First stage for UASB 1 and UASB 2 (Low and High rate fed)

4.5.3.1 COD removal efficiency

COD usually measured for organic matter in wastewater, indirectly by measuring the mass of oxygen required for its total oxidation to carbon dioxide. The table below shows the data obtained from the COD analysis of wastewater influent and effluent the system and removal efficiency.

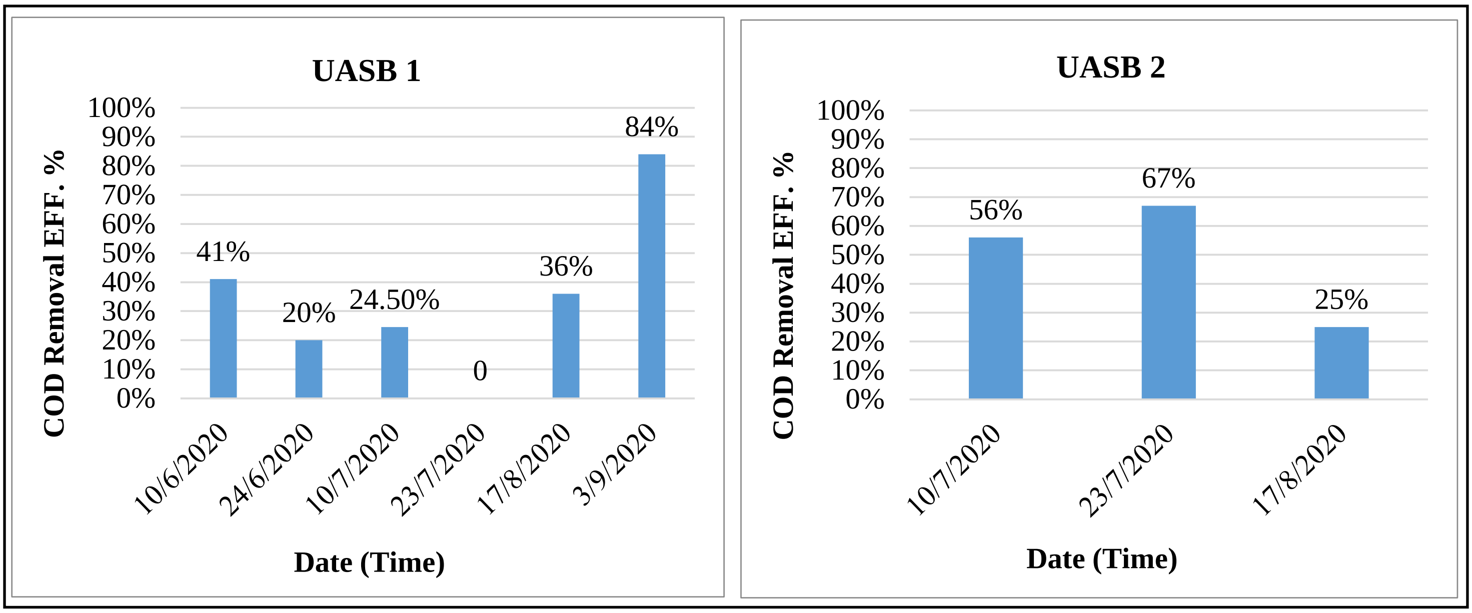

Figure 4. 1. COD Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

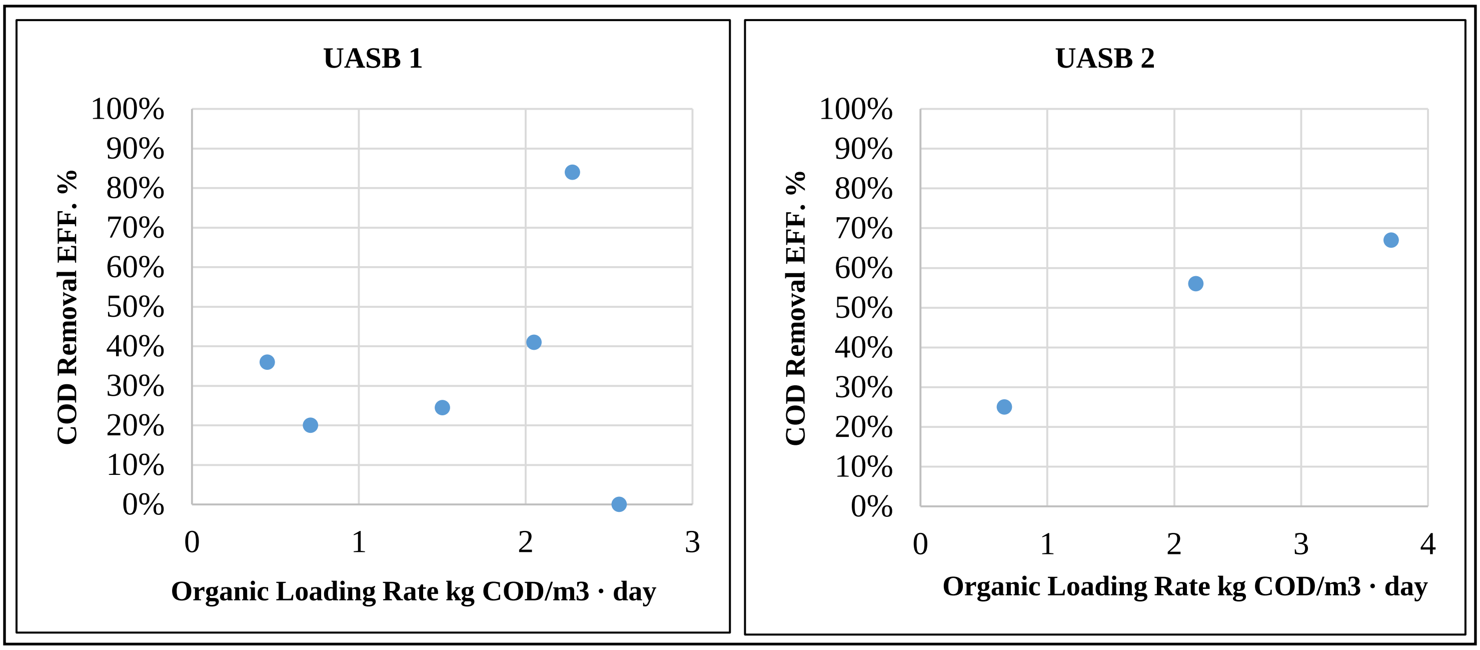

Figure 4. 2. COD Removal Efficiency Vs Organic Loading Rate for UASB 1 and UASB 2

All results for the removal efficiency of COD and OLR for the UASB 1 and UASB 2 reactors represented by Figures 4.2 and 4.3, respectively, we can find the following:

- COD influent range (4373-14901 mg/l), average value (2,883 mg/l)
- COD effluent SWW for (UASB 1) range (530-2178 mg/l), average value (1,288 mg/l)
- COD effluent SWW for (UASB 2) range (620-1540 mg/l), average value (1,117 mg/l)
- OLR for (UASB 1) range (0.45-2.56 Kg.COD/m^3.day), average value (1.59 Kg.COD/m^3.day)
- OLR for (UASB 2) range (0.66-3.71 Kg.COD/m^3.day), average value (1.71 Kg.COD/m^3.day)
- COD removal efficiency range for (UASB 1) (20-84%), average value (41.1 %)
- COD removal efficiency range for (UASB 2) (25-56%), average value (49. 3 %)

In the system the UASB 1 and UASB 2, there was no variation in the COD inlet the system, which is suitable for the stability of the system. There is a decrease in COD concentrations over time, which is a good indication of the presence of activity of anaerobic digestion of mixed wastewater industrial and successful degradation within the system.

There has been a decrease in the removal efficiency rate due to the system failure, the pipe connecting the basin to the pump was bleed and sometimes did not drain mixed industrial wastewater for reactors, this takes time to restore the activity of the anaerobic microorganisms and adapt inside the two reactors

The pilot UASB system was able to provide good performance for high organic loading and good removal efficiency; it reached 84% and 67% for the UASB 1 and UASB 2 reactors, respectively. The efficiency of UASB 1 and UASB 2 anaerobic reactors increased with an increasing in the OLR (Ren, 2009), this observed during the experiment. Under optimum operating conditions and during the summer period with an ambient temperature of about 34 ° C.

The rate of removal increases with the decrease of the hydraulic retention time and that the flow velocity is directly related to the hydraulic retention time (Rizvi, 2015), the UASB 2 gave better results than the UASB 1.

4.5.3.2 VSS and TSS removal

The figures below show the information obtained from the VSS and TSS for solid wastewater influent/effluent and the removal efficiency.

4.5.3.2.1 VSS removal efficiency

The values of the volatile suspended solids and the calculated removal efficiency, shown in the table below, the information obtained shown from VSS analysis for inlet and outlet solid wastewater and calculating removal efficiency for UASB 1 and UASB 2.

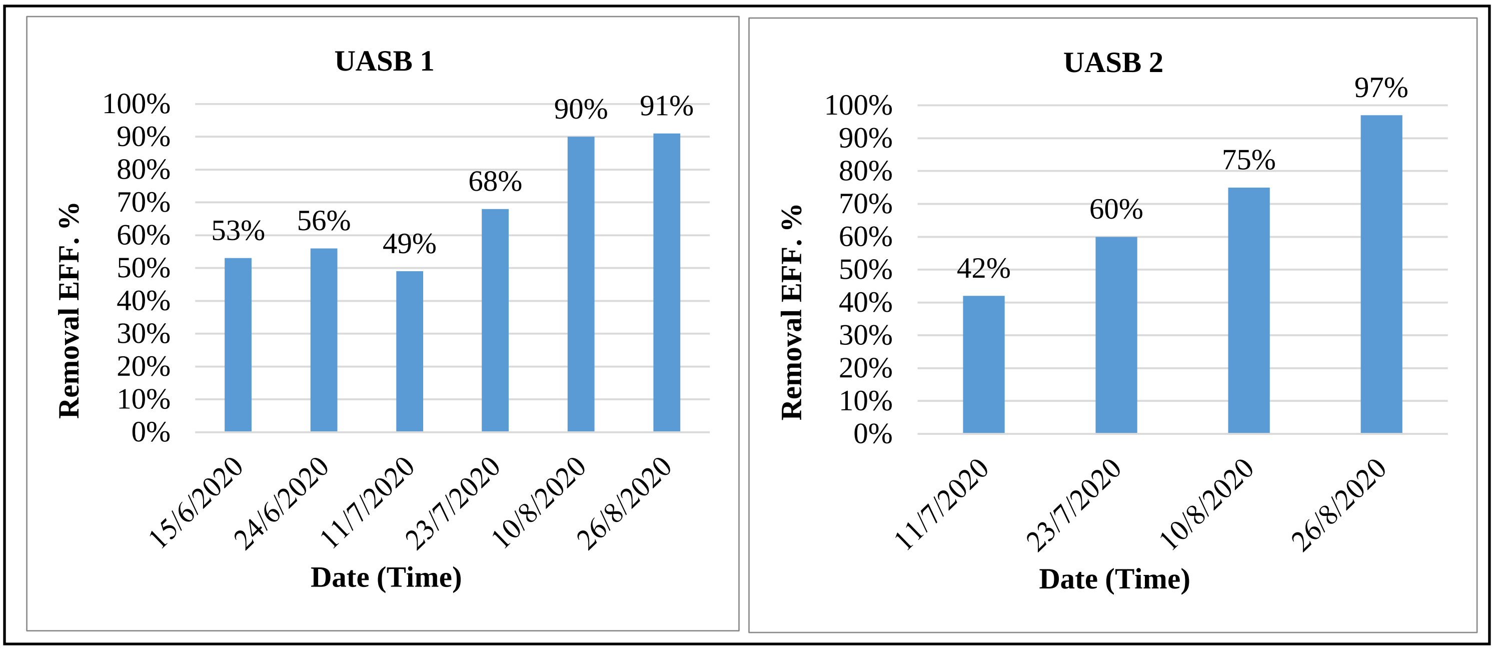

Figure 4. 3. VSS Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

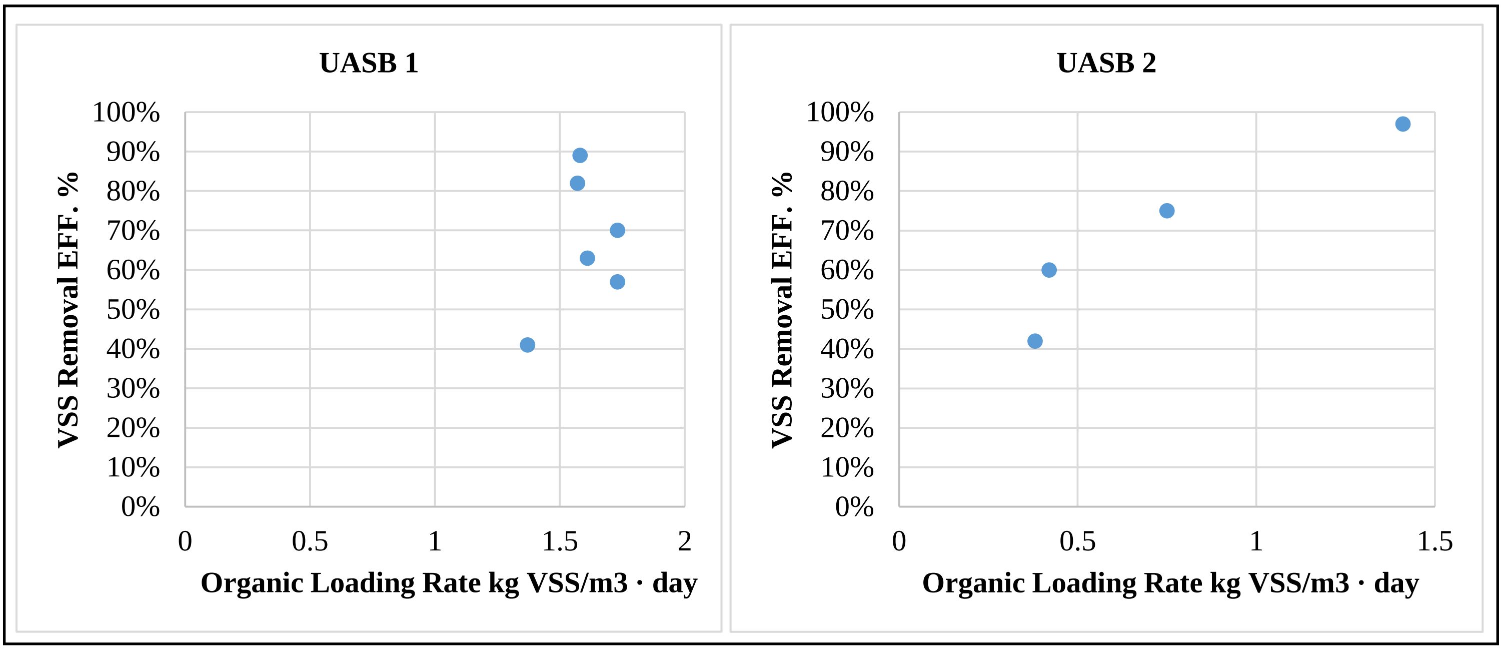

Figure 4. 4. VSS Removal Efficiency Vs Organic Loading Rate for UASB 1 and UASB 2

4.5.3.2.2 TSS removal efficiency

In the Figure 4.5 and 4.6 below, the information obtained shown from TSS analysis for inlet and outlet solid wastewater and removal efficiency.

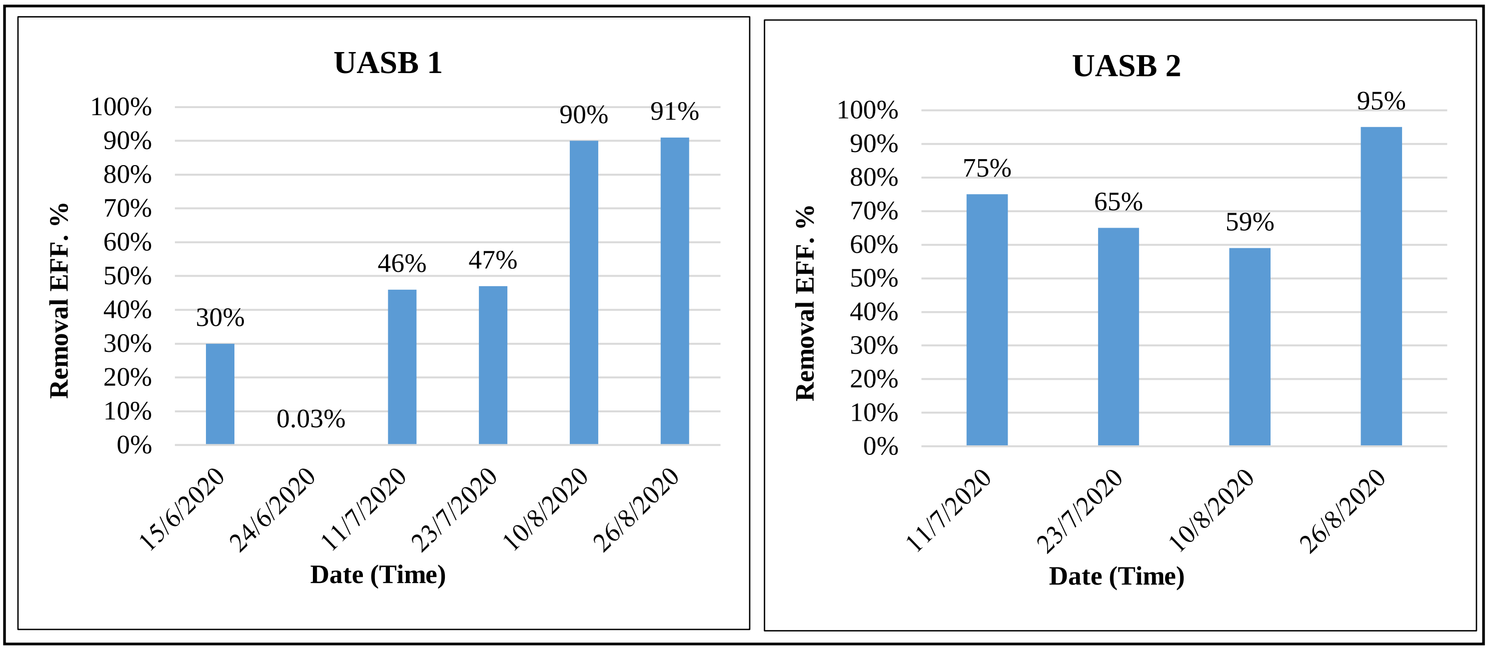

Figure 4. 5. TSS Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

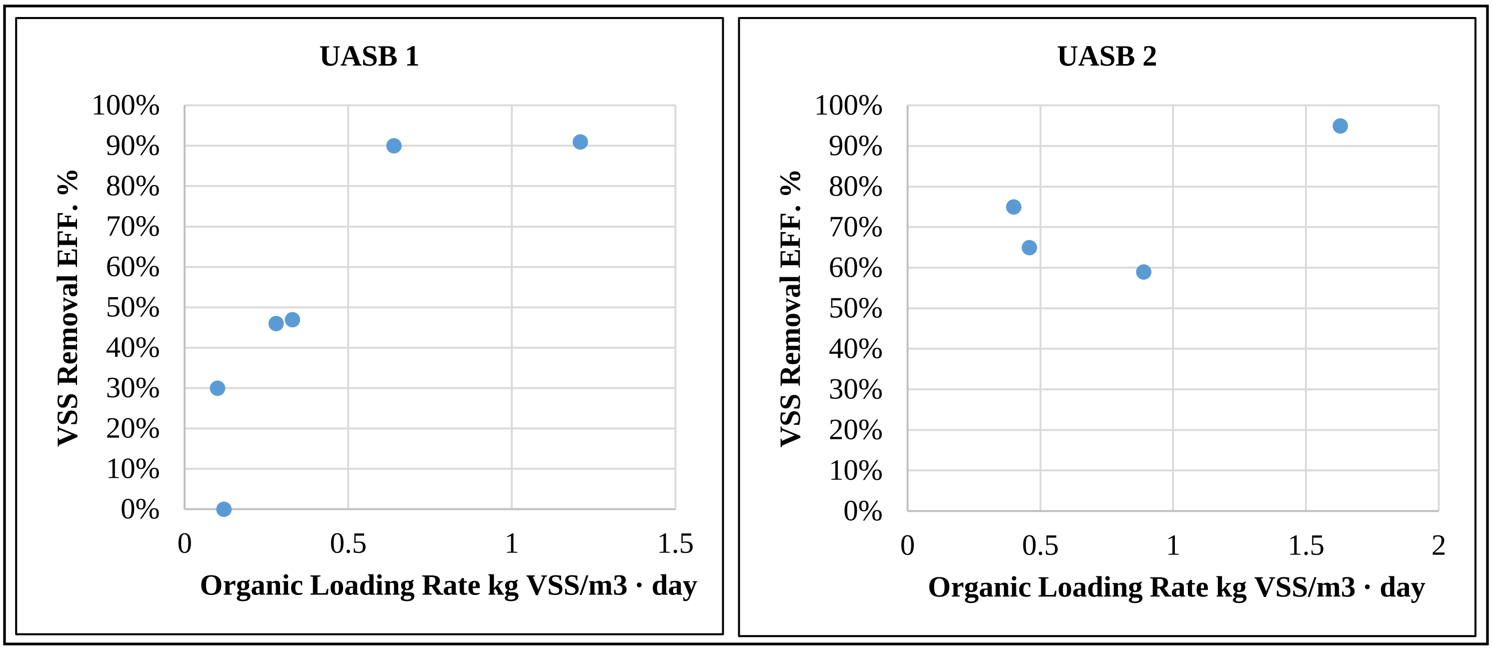

Figure 4. 6. TSS Removal Efficiency Vs Organic Loading Rate for UASB 1 and UASB 2

The results obtained from the figures above, we find the following

- VSS influent range (216-1840 mg/l), (495-1840 mg/l) for UASB 1 and UASB 2, respectively.
- TSS influent range (176-2192 mg/l), (520-2192 mg/l) for UASB 1 and UASB 2, respectively.
- VSS and TSS effluent range (94-252 mg/l), (108-320 mg/l) for UASB 1 and (44-289 mg/l), (108-472 mg/l) for UASB 2, respectively.

- OLR for VSS range between (0.12-1.026 Kg COD/m^3.day) for UASB 1 and (0.38-1.41 Kg COD/m^3.day) for UASB 2, respectively. Average value for UASB 1 were (0.4 Kg COD/m^3.day) and (0.74 Kg COD/m^3.day) for UASB 2.
- OLR for TSS range between (0.1-1.21 Kg COD/m^3.day) for UASB 1 and (0.4-1.63 Kg COD/m^3.day) for UASB 2, respectively. Average value for UASB 1 were (0.45 Kg COD/m^3.day) and (0.85 Kg COD/m^3.day) for UASB 2.
- VSS and TSS removal efficiency range (49-91%), (30-91%) for UASB 1 and (42-97%), (59-95%) for UASB 2, respectively.
- VSS and TSS average removal efficiency (68%), (51%) for UASB 1 and (69%), (74%) for UASB 2, respectively.

The graphs and data show the removal efficiency of both the UASB 1 and the UASB 2 reactors, in this research, the removal of solids in the two reactors w satisfactory and encouraging. As the solids removal efficiency rate for VSS and TSS were 68% and 51% for UASB 1, 69% and 74% for UASB 2, respectively, and the OLR rate for VSS and TSS were (0.4 Kg COD/m^3.day) and (0.74 Kg COD/m^3.day) for UASB 1, (0.45 Kg COD/m^3.day) and (0.85 Kg COD/m^3.day) for UASB 2, respectively. The UASB 2 is better than the UASB 1 with regard to removing suspended solids.

Figure 4.5 and 4.6 shows the suspended solids concentrations, OLR and removal efficiencies for UASB 1 and UASB 2, it can see that the removal efficiency of the system improves over time. If these results are compared with the results obtained by Diab (Diab, 2020), the removal efficiency of VSS and TSS (55% and 58.2%) of UASB 1, respectively. It can be concluded that the removal efficiency of suspended. The low-value results that appeared because of the tube explosion that occurred during the experiment and was a period of closures due to the Corona virus (Covid-19).

4.5.3.3 Heavy metals removal efficiency

Figures below shows the research results for the effluent average concentration and removal efficiency (%) during the trial period of the experiment for UASB 1 (Low fed rate) and UASB 2 (High fed rate), Under the imposed operating conditions.

4.5.3.3.1 Zinc removal efficiency

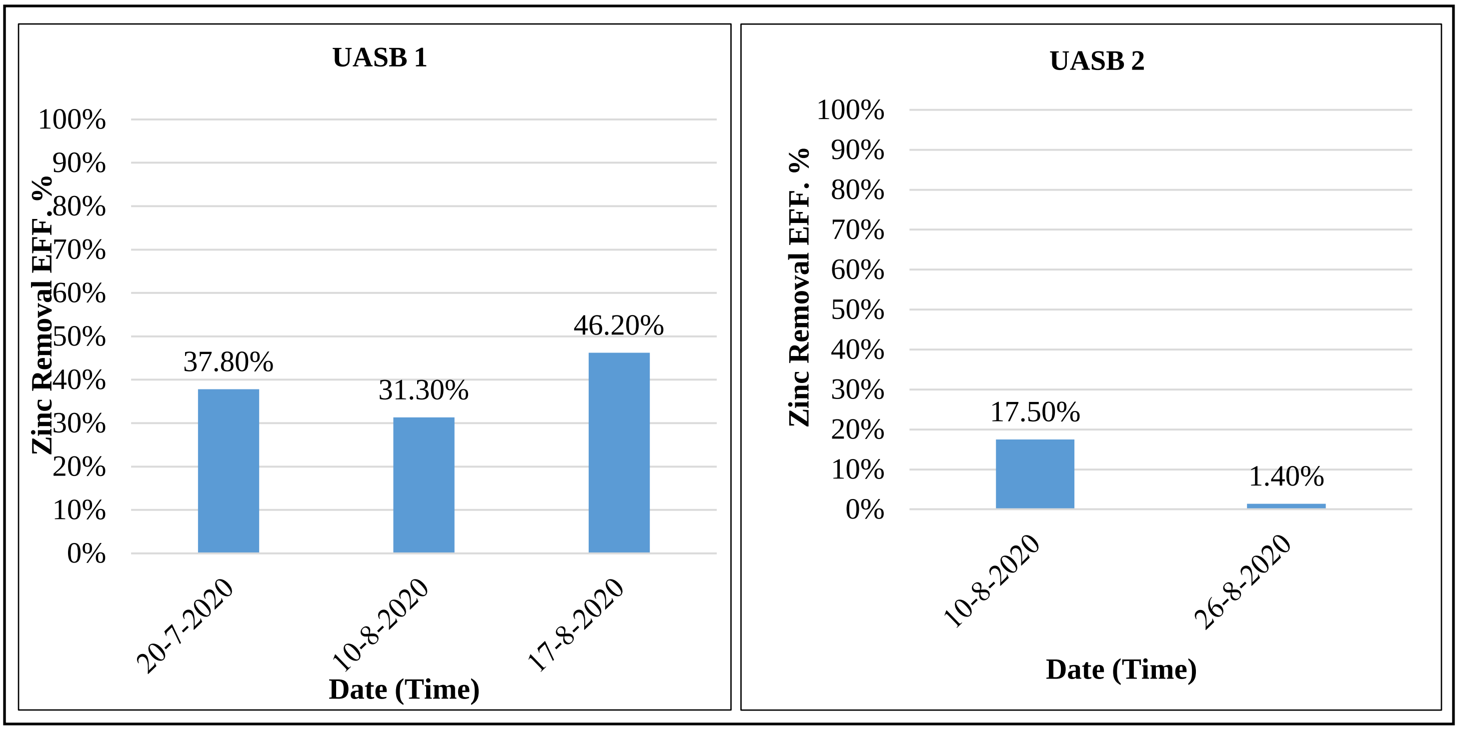

Figure 4. 7. Zinc Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

4.5.3.3.2 Cadmium removal efficiency

Non-detected within the test sample.

4.5.3.3.3 Lead removal efficiency

Non-detected within the test sample.

4.5.3.3.4 Chromium removal efficiency

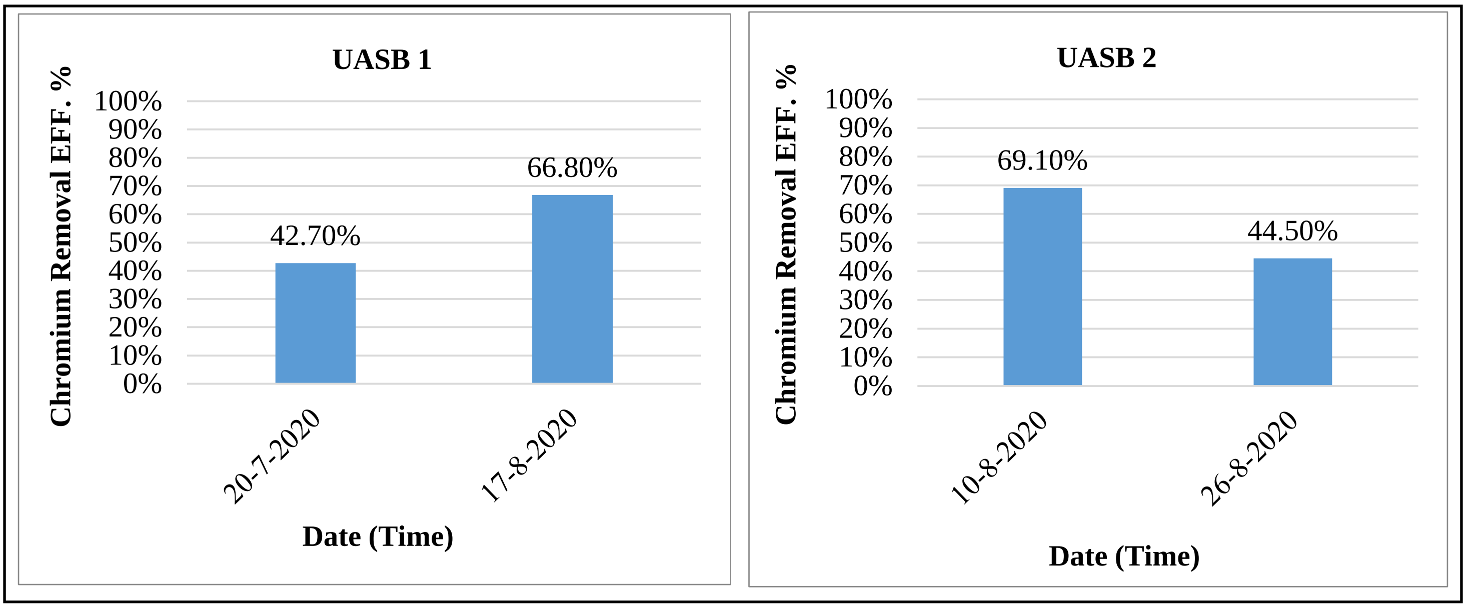

Figure 4. 8. Chromium Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

4.5.3.3.5 Copper removal efficiency

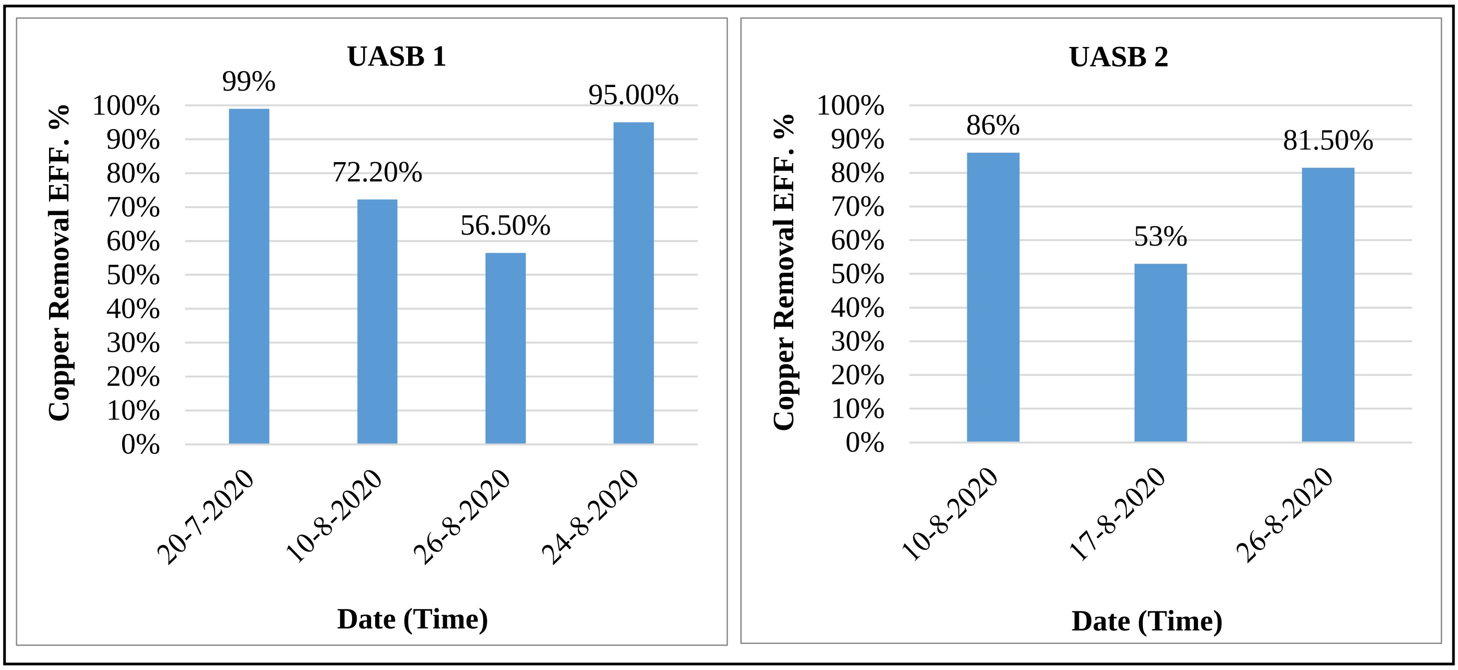

Figure 4. 9. Copper Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

All results for removal efficiency tabulated and represented in Figures above; in a study the removal efficiency examined for Zinc, cadmium, lead, copper, and chromium. In the first reactor (UASB 1), the removal efficiency rate for zinc, copper, and chromium was 38.8%, 54.8%, and 76%, respectively and for second reactor (UASB 2) had the removal efficiency rate of zinc, copper and chromium 9.45%, 57%, and 83.8%, respectively and for cadmium and lead, they were not present.

These results show the good efficacy of the high-speed anaerobic sludge blanket reactor and its results were slightly higher than the low speed anaerobic sludge blanket reactor, this indicates a good removal rate, and the system is operating well. The two reactors found to be able to work effectively for high degradation.

4.5.3.4 TKN

In the Figures below, the information obtained shown from TKN analysis for inlet and outlet solid wastewater and removal efficiency.

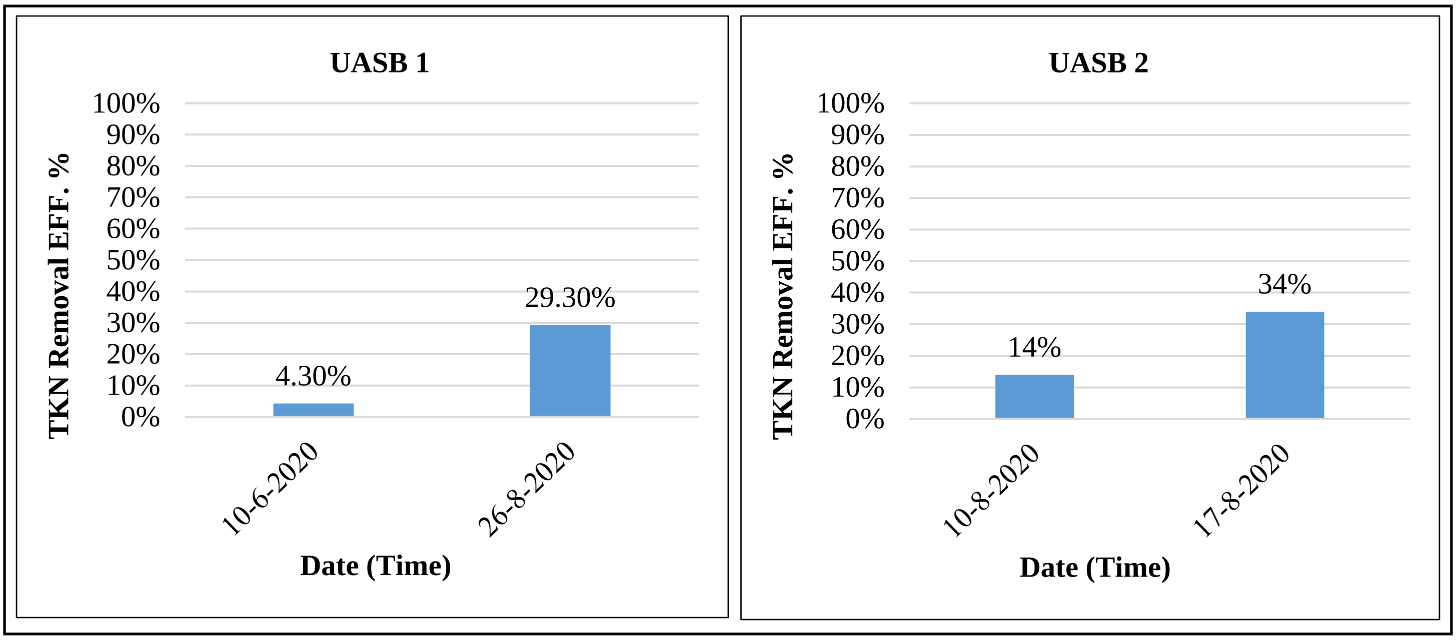

Figure 4. 10. TKN Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2.

In the figure 4.10 above displays the results obtained, which are as follows:

TKN partially removed in the UASB reactors, and the average removal efficiency was 16.8% and 24% for the UASB 1 system and the UASB 2 system, respectively. The difference between the two systems in removal efficiency was not statistically significant.

It found that the removal efficiency of the UASB 2 at the fed rate of 230 l/ day and at low HRT is better than the removal efficiency of the UASB 1 at fed rate of 166 l/day.

4.5.3.5 Phenol

The results in figures show the data collected from the phenol analysis of the effects of wastewater and effluents during the research periods, and the removal efficiency.

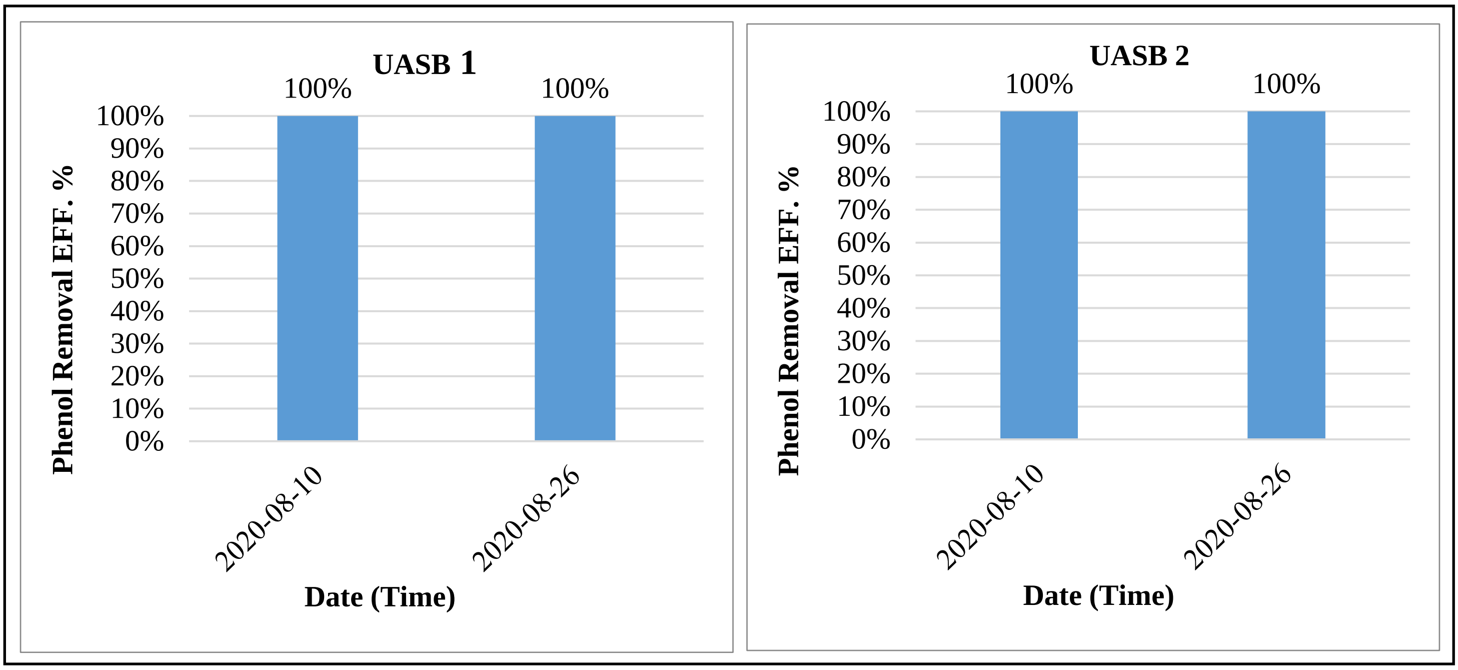

Figure 4. 11. Phenol Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

In the figure 4.11, the average inlet rate of phenol for the low and high rate system was 0.0414 mg/l and the values of phenol were very small, the results in the first reactor (low rate) and the second reactor (high rate) were zero. There was good phenol treatment and removal efficiency reaching 100% for the two reactors, the figure 4.11 shows the removal efficiency of phenol over time.

In some of the results, it found that there is no phenol in the samples. The reason is that the olive presses were not working at this time during my research and we used phenol in the refrigerator from last year.

4.5.4 Second stage for UASB 1 and UASB 2

4.5.4.1 COD removal efficiency

The figures below show the data obtained from the COD analysis of wastewater influent and effluent for UASB 1 and UASB 2 system and the removal efficiency.

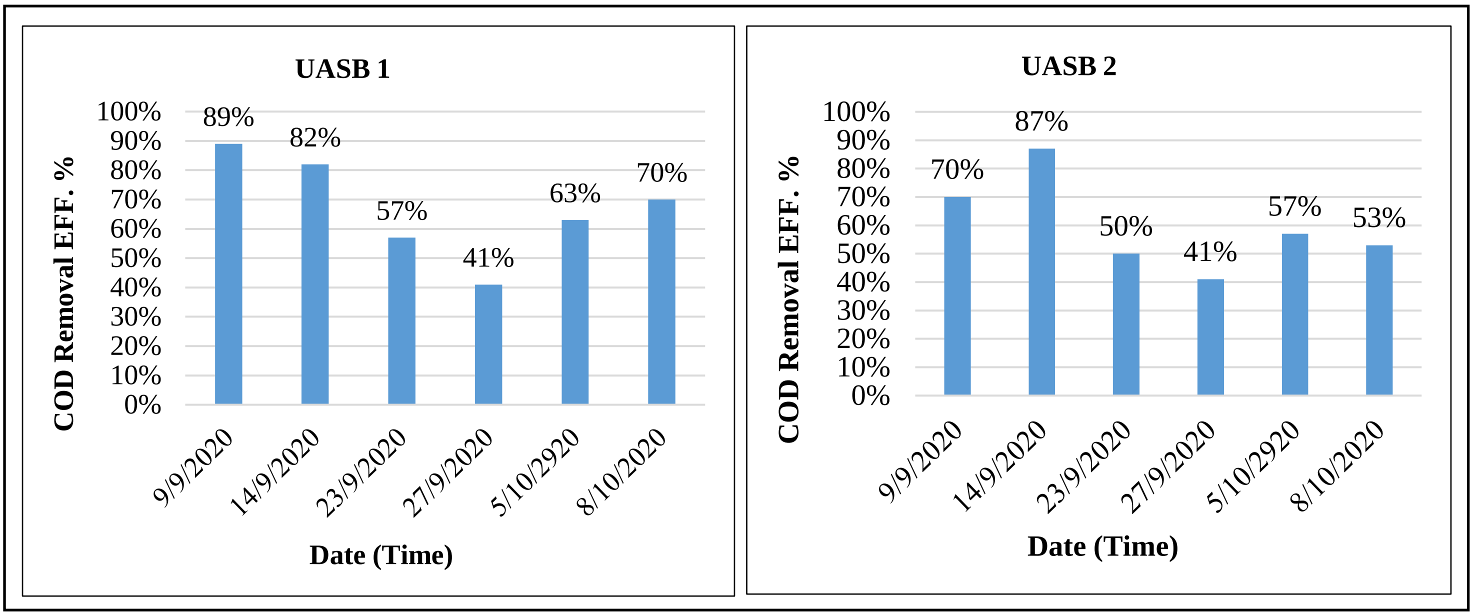

Figure 4. 12. COD Removal Efficiency Vs Time for low and high rate for UASB 1 and UASB 2

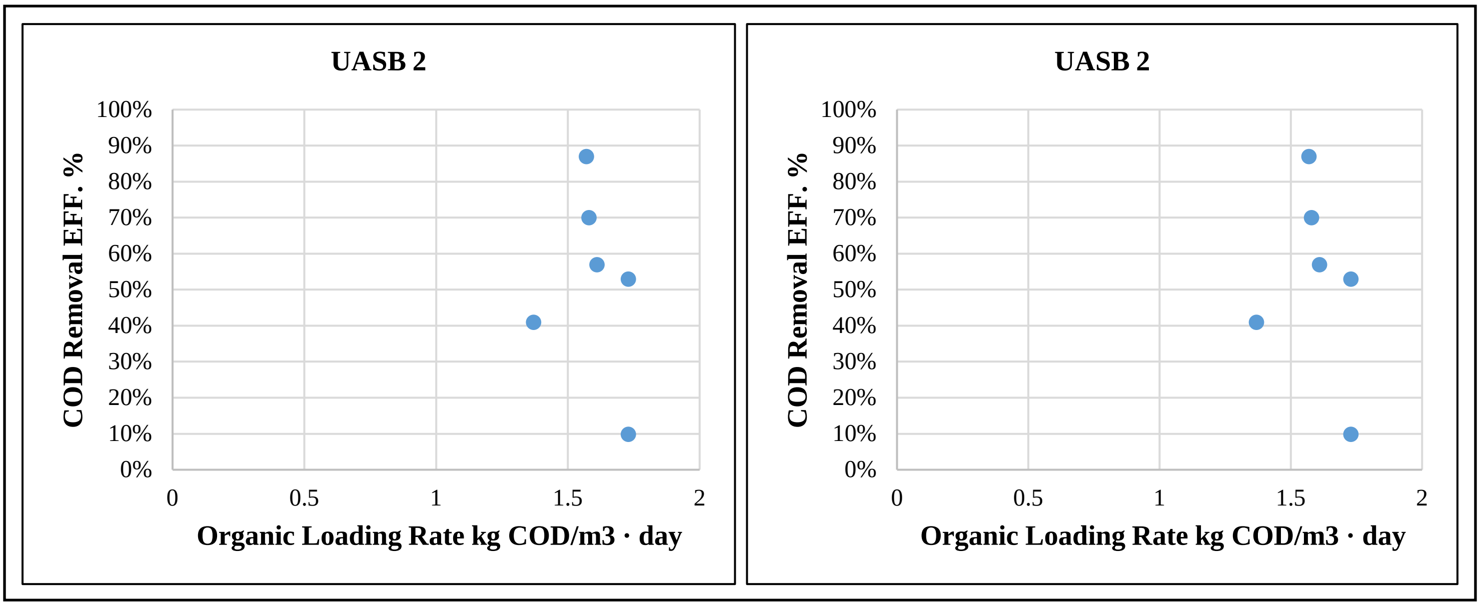

Figure 4. 13. COD Removal Efficiency Vs Organic Loading Rate for UASB 1 and UASB 2

All results for the removal efficiency of COD and OLR for the UASB 1 and UASB 2 reactors represented by figures 4.12 and 4.13, respectively, we can find the following:

- COD influent range (3566-4514 mg/l), Average value (4172 mg/l)
- COD effluent SWW for (UASB 1) range (732-1935 mg/l), average value (1,43 mg/l)
- COD effluent SWW for (UASB 2) range (527-2234 mg/l), average value (1,66 mg/l)
- OLR for (UASB 1 and 2) range (1.37-1.73 Kg COD/m^3.day), average value (1.6 Kg COD/m^3.day)
- COD removal efficiency range for (UASB 1) (41-89%), average value (67 %)
- COD removal efficiency range for (UASB 2) (41-87%), average value (59.6 %)

In the system the UASB 1 and UASB 2, there was no variation in the COD inlet the system, which is suitable for the stability of the system. There is a decrease in COD concentrations over time, which is a good indication of the presence of activity of anaerobic digestion of mixed wastewater industrial and successful degradation within the system.

There has been a decrease in the removal efficiency rate due to the system failure, the pipe connecting the basin to the pump was bleed and sometimes did not drain mixed industrial wastewater for reactors, this takes time to restore the activity of the anaerobic microorganisms and adapt inside the two reactors

The pilot UASB system was able to provide good performance for high organic loading and good removal efficiency; it reached 89% and 87% for the UASB 1 and UASB 2 reactors, respectively. The efficiency of UASB 1 and UASB 2 anaerobic reactors increased with an increasing in the OLR (Ren, 2009), this observed during the experiment. Under optimum operating conditions and during the summer period with an ambient temperature of about 34 ° C.

The rate of removal increases with the decrease of the hydraulic retention time and that the flow velocity is directly related to the hydraulic retention time (Rizvi, 2015), the UASB 1 gave better results than the UASB 2.

4.5.4.2 VSS and TSS removal

The figures below show the information obtained from the VSS and TSS for solid wastewater influent/effluent and the removal efficiency.

4.5.4.2.1 VSS removal efficiency

The values of the volatile suspended solids and the calculated removal efficiency, shown in the table below, the information obtained shown from VSS analysis for inlet and outlet solid wastewater and the removal efficiency.

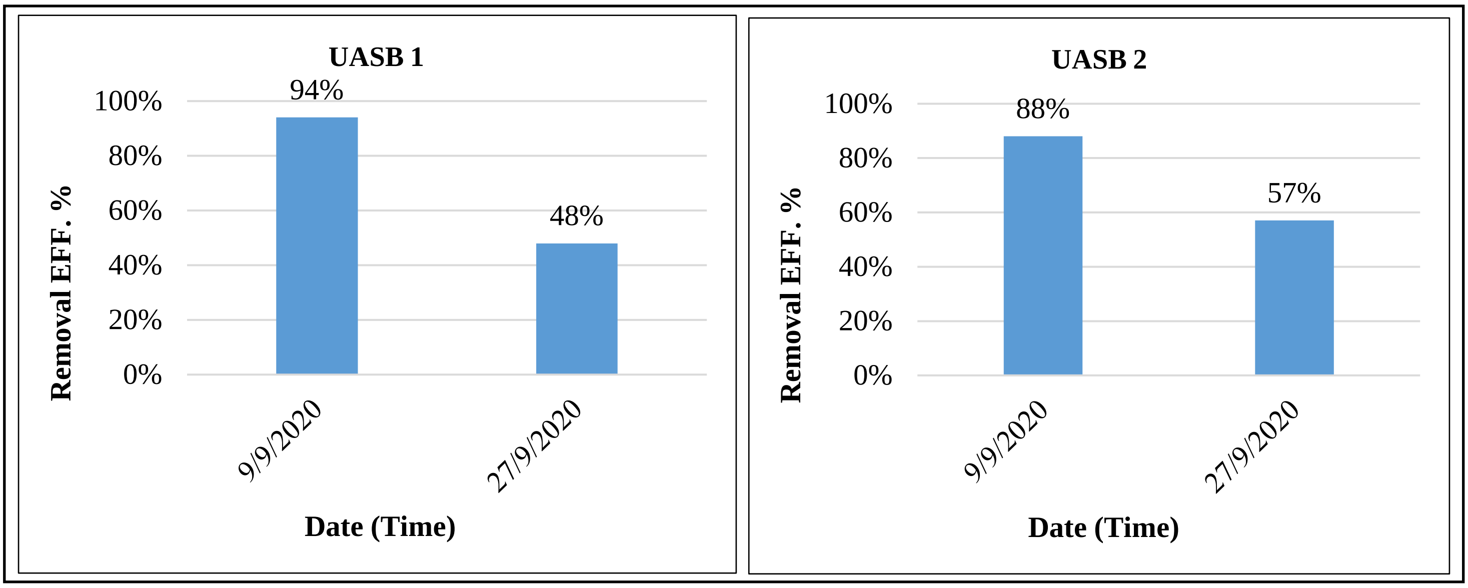

Figure 4. 14. VSS Removal Efficiency Vs Time for UASB 1 and UASB 2

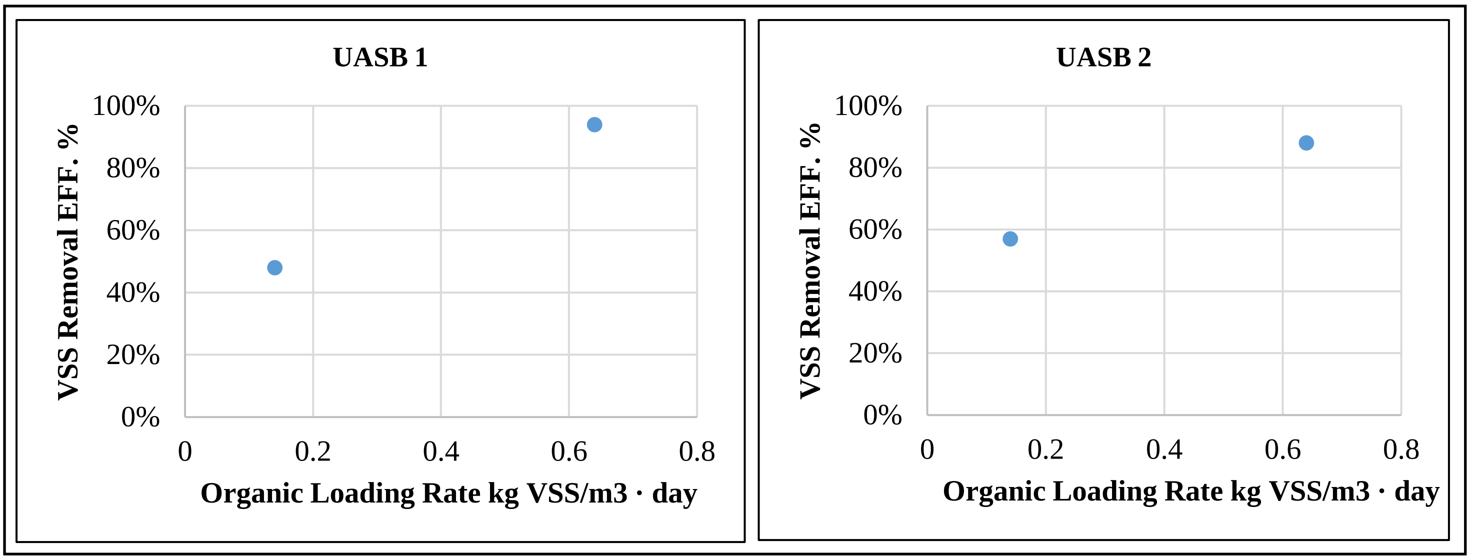

Figure 4. 15. VSS Removal Efficiency Vs Organic Loading Rate for UASB 1 and UASB 2

4.5.4.2.2 TSS removal efficiency

In the figures below, the information obtained shown from TSS analysis for inlet and outlet solid wastewater and the removal efficiency.

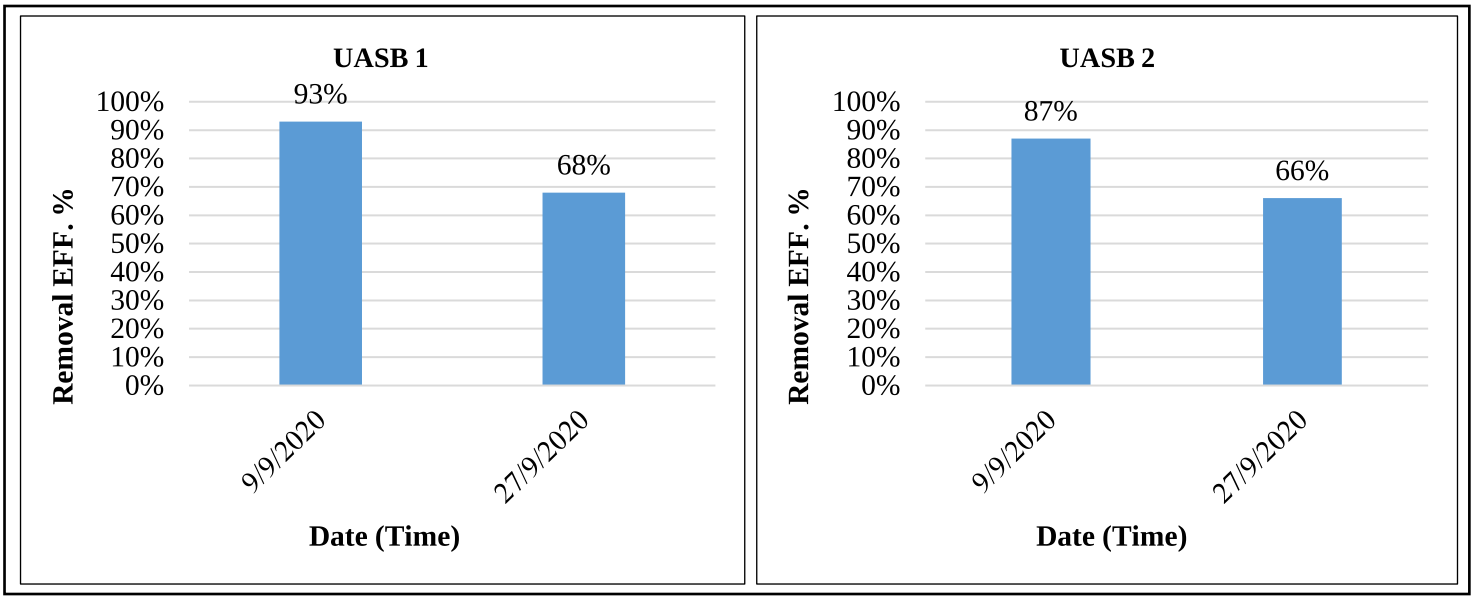

Figure 4. 16. TSS Removal Efficiency Vs Time for UASB 1 and UASB 2

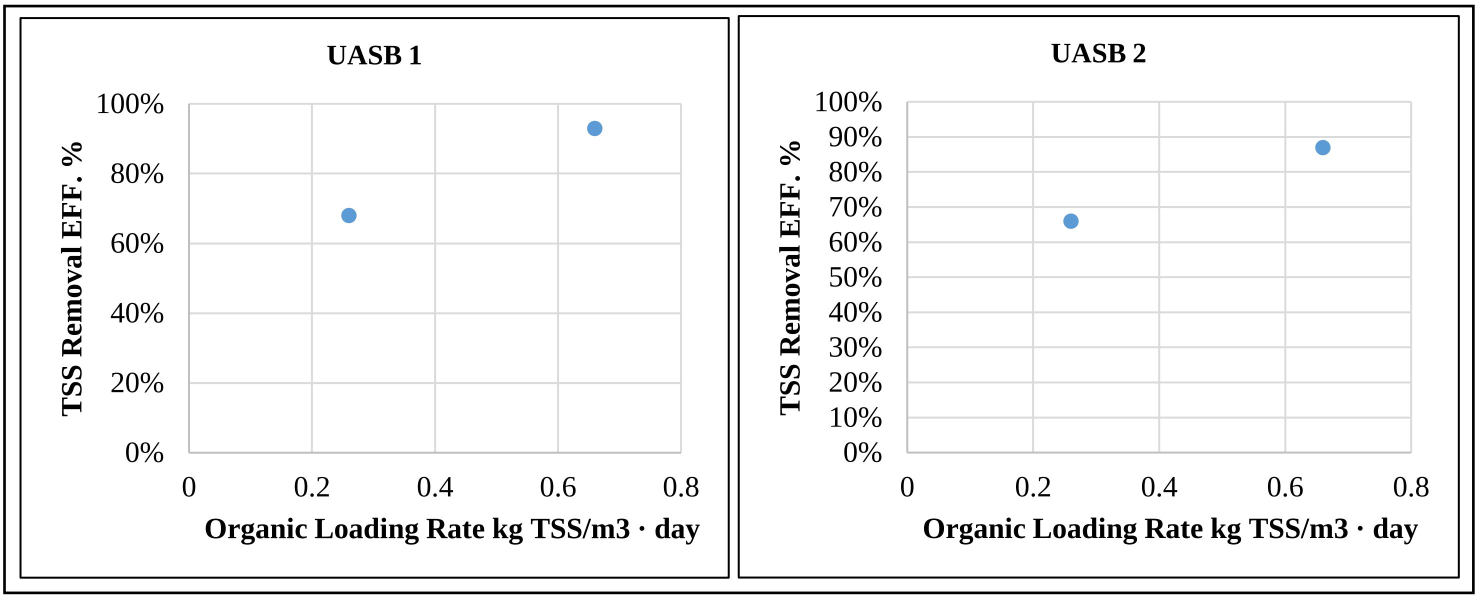

Figure 4. 17. TSS Removal Efficiency Vs Organic Loading Rate for UASB 1 and UASB 2

The results obtained from the figures, we find the following:

- VSS and TSS influent range (352-1664 mg/l), (680-1708 mg/l), respectively.
- VSS and TSS effluent range (102-184 mg/l), (164-192 mg/l) for UASB 1 and (120-216 mg/l), (220-232 mg/l) for UASB 2, respectively.
- OLR for VSS range between (0.14 – 0.64 Kg COD/m^3.day) and average value were (0.39 Kg COD/m^3.day) for UASB 1 and UASB 2.

- OLR for TSS range between (0.26 – 0.66 Kg COD/m^3.day) and average value were (0.46 Kg COD/m^3.day) for UASB 1 and UASB 2.
- VSS and TSS removal efficiency range (48-94%), (57-88%) for UASB 1 and (68-93%), (66-87%) for UASB 2, respectively.
- VSS and TSS average removal efficiency (71%), (80%) for UASB 1 and (73%), (77%) for UASB 2, respectively.

The graphs and data show the removal efficiency of both the UASB 1 and the UASB 2 reactors, in this research, the removal of solids in the two reactors was satisfactory and encouraging. As the solids removal efficiency rate for VSS and TSS were 71% and 73% for UASB 1, 80% and 77% for UASB 2, respectively, and the OLR rate for VSS and TSS were (0.39 Kg COD/m3.day) for UASB 1 and (0.46 Kg COD/m3.day) for UASB 2, respectively. The UASB 1 is better than the UASB 2 with regard to removing suspended solids. Figures above show the suspended solids concentrations, OLR and removal efficiencies for UASB 1 and UASB 2.

4.5.4.3 TKN

In the figures below, the information obtained shown from TKN analysis for inlet and outlet solid wastewater and the removal efficiency.

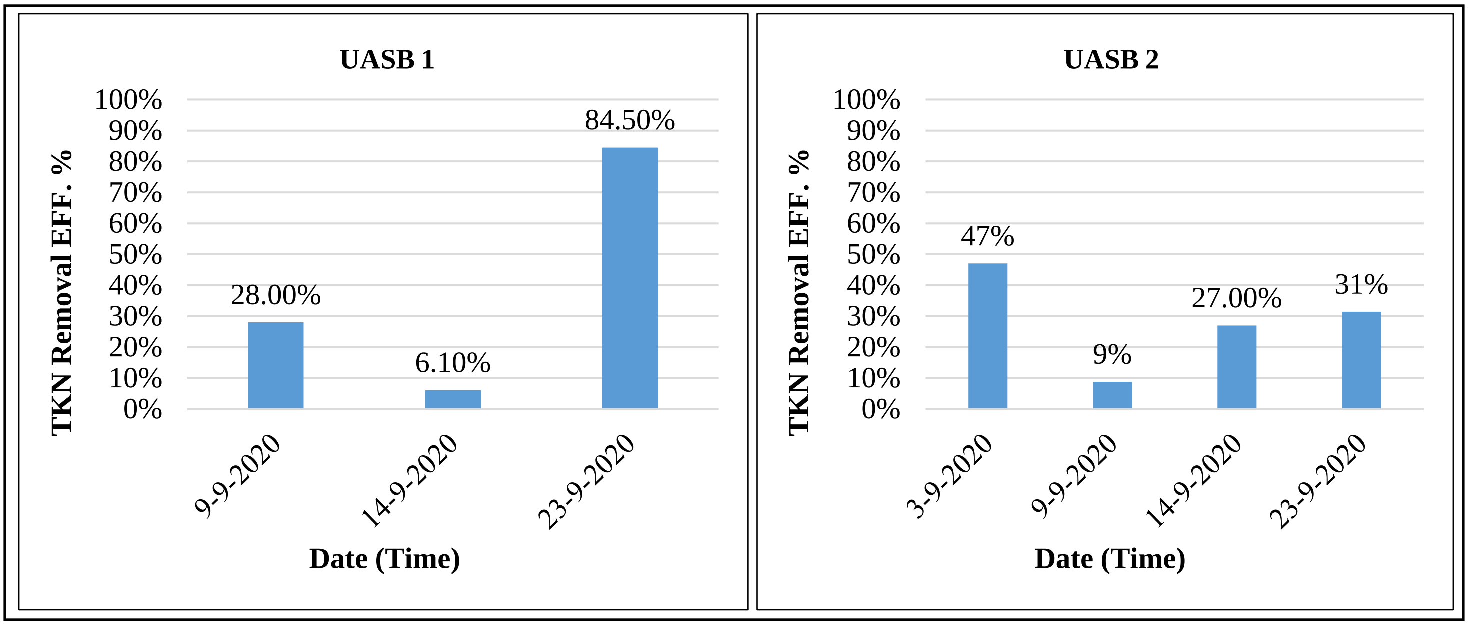

Figure 4. 18. TKN Removal Efficiency Vs Time for UASB 1 and UASB 2

In the figures above displays the results obtained, which are as follows:

TKN removed well in the two UASB reactors, and the average removal efficiency was 39.5% and 28.5% for the UASB 1 system and the UASB 2 system, respectively. It found that the removal efficiency of the UASB 1 at the fed rate of 166 l/ day and at high HRT is better than the removal efficiency of the UASB 2 at fed rate of 230 l/day.

4.5.4.4 phenol

The results in figures show the data collected from the phenol analysis the effects of wastewater and effluents during the research period, and the removal efficiency.

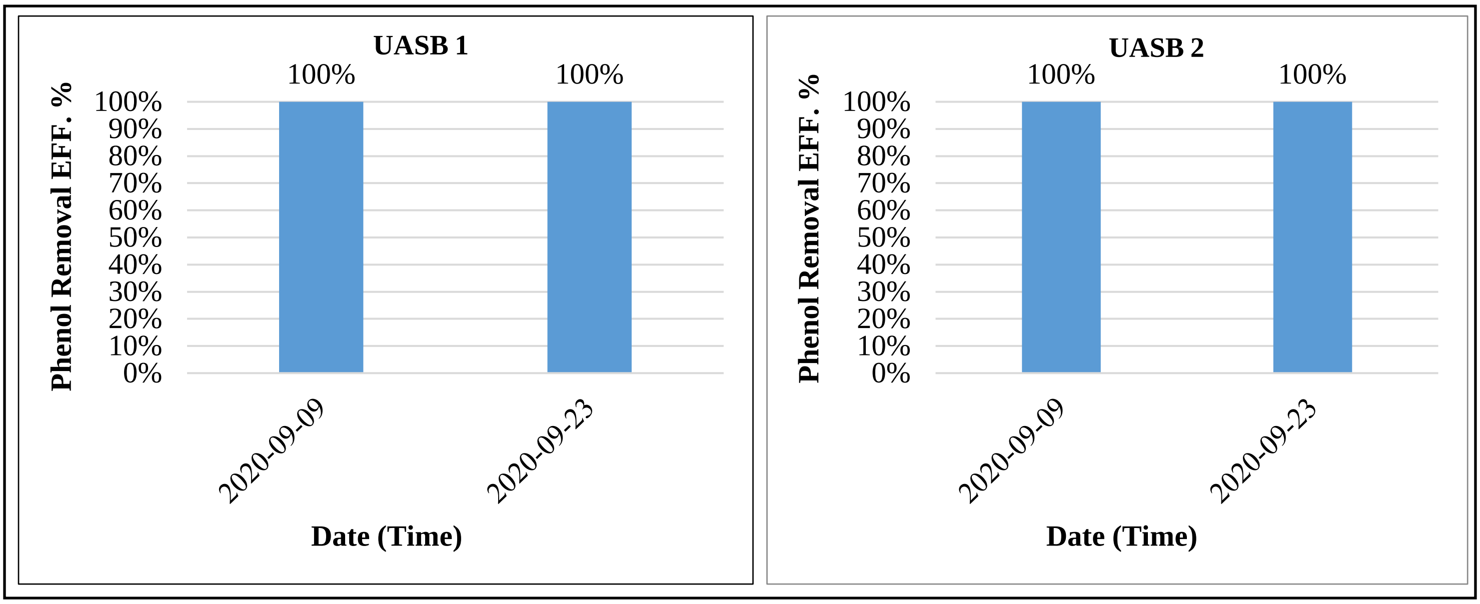

Figure 4. 19. Phenol Removal Efficiency Vs Time for UASB 1 and UASB

The results were similar to the first system and the table illustrates the average inlet rate of phenol for the UASB 1 and UASB 2 system was 0.0545 mg/l and the values of phenol were very small, the results in the first reactor and the second reactor were zero. There was good phenol treatment and removal efficiency reaching 100% for the two reactors, the figure 4.19 show the removal efficiency of phenol over time.

In some of the results, it found that there is no phenol in the samples. The reason is that the olive presses were not working at this time during research and used phenol in the refrigerator from last year.

4.5.4.5 Biogas production

The figures below show the data obtained from the biogas flowmeter for the two reactors, the table includes daily gas production and specific biogas yield for each reactor.

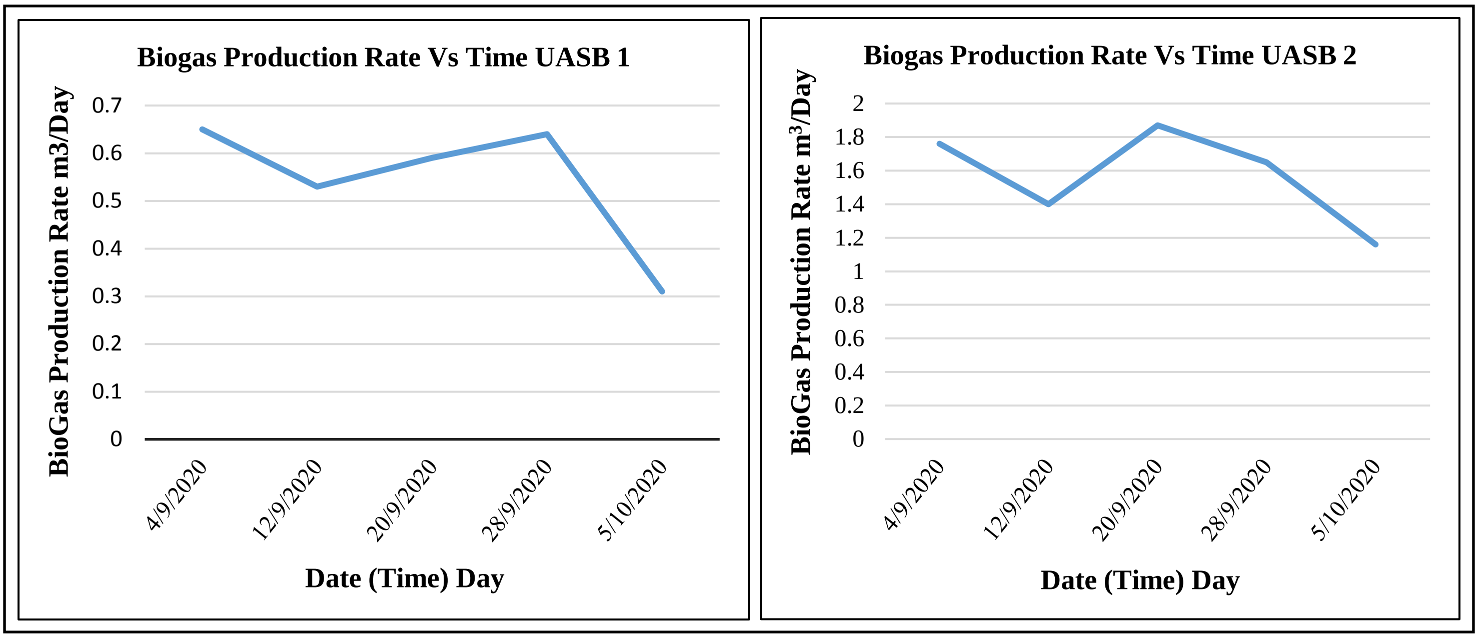

Figure 4. 20. Biogas daily gas production Vs specific biogas yield for UASB 1 and UASB 2

Through the figure 4.20, it shows the results obtained during the thesis, it is as follows:

The average daily gas pro3duction from the anaerobic treatment of the UASB 1 and UASB 2 system respectively was 0.599 m^3/day and 1.477 m^3/day.

The average yield gas production of the UASB 1 and UASB 2 system respectively was 0.532 m^3/ kg.COD removed and 1.568 m^3/ kg.COD removed and it reached the highest value of yield gas production of the system UASB 1 and UASB 2 respectively was 0.65 m^3/ kg.COD removed and 1.87 m^3/ kg.COD removed, this value is high over a short period of time.

Temperature is expected to have a significant impact on biogas production due to the higher value within a short period of time (within a month), compared to a study conducted by Diab it's average specific gas production was 0.059 m^3/ kg.COD removed, which was expected to be higher throughout the research period (Diab, 2020).

The gas meter not put in place since the beginning of the study due to Corona (COVID-19), which led to a delay in the arrival of the device. For this reason, no gas analyzes have been carried out to determine the percentage of each component, and to know the exact amount of methane production.

5. CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- The results for anaerobic treatment using Upflow anaerobic sludge blanket system shown satisfactory results for COD, Heavy Metals, Phenol, TKN, TSS and VSS in removal efficiency for the two stages and Potential for biogas (methane) recovery.

- There were heat waves during summer reason and its effect on the system good, and temperatures was between (25-35) degrees Celsius.

- The overall removal efficiency of the two systems during the applied stages was good, and most of the time they met the sewage network drainage standards.

- For first stage the average COD effluent form the UASB 1 and UASB 2 systems relatively represented about 1.84 kg/m3 and 1.09 kg/m3 for R1 and R2 respectively, with average removal efficiency rate of 36.1% and 61% for R1 and R2 respectively.

- For second stage the average COD effluent form the UASB 1 and UASB 2 systems relatively represented about 1.43 kg/m3 and 1.62 kg/m3 for R1 and R2 respectively, with average removal efficiency rate of 67% and 59.6% for R1 and R2 respectively.

- The results for the first stage showed that the removal efficiency rate for VSS and TSS was 68%, 51% for UASB 1, 69% and 74% for UASB 2, respectively, and the organic loading rate was (0.4 Kg COD/m3.day) and (0.74 Kg COD/m3.day) for UASB 1, (0.45 Kg COD/m3.day) and (0.85 Kg COD/m3.day) for UASB 2, respectively.

- The results for the second stage showed that the removal efficiency rate for VSS and TSS was 71%, 80% for UASB 1, 73% and 77% for UASB 2, respectively. The organic loading rates were (0.39 Kg COD/m3.day) for UASB 1 and (0.46 Kg COD/m3.day) for UASB 2, respectively.

- The results indicate that the first stage of anaerobic treatment of mixed industrial wastewater effectively removes heavy metals. The removal efficiency rate of the elements Zn, Cr, and Cu was 38.8%, 54.8% and 76%, respectively, for the first system UASB 1 (low rate) and 9.45%, 57%, 83.8%, for the second system UASB 2 (high rate), Moreover, the results also show that the two components, CD and B, are not present in the samples that were tested.

- The results showed moderate removal efficiency for TKN where the removal efficiency averaged 16.8% and 24% for UASB 1 and UASB 2, respectively for the first system and the average removal efficiency for the second system was 39.5% and 28.5% for UASB 1 and UASB 2, respectively for the removal of TKN.

- Good results showed in the removal efficiency of phenol in the first and second stage, and the removal efficiency rate was 100% in both stage.

- The overall effect of phenol and heavy metals was good on system performance and there was good overall removal efficiency of phenol and heavy metals.

- The most feasible ratio was 10% of OMW as an operating best practice for the UASB anaerobic system.

- The anaerobic system features low operating cost, low maintenance and energy consumption, low sludge production and electricity production.

- The anaerobic treatment system can be easily control from the bad smell and insect problem because the reactor is completely sealed.

5.2 Recommendations

- It is recommend that the pilot system be continued for at least another six months, including winter to keep monitoring the UASB system, in order to demonstrate the stability of system performance.

- Temperature is an important factor for the anaerobic process. System monitoring in future study investigations during the winter period warrants further exploration.

- The pH is an important factor that must monitored and controlled during the study period. Noting that the anaerobic treatment process stabilizes and creates a favorable environment for bacteria to develop and perform their functions in digestion, which depends heavily on it, so it recommended to monitor it through a pH meter throughout the study period and in order to demonstrate the stability of performance the system.

- It is recommended that this small pilot scale of the UASB anaerobic system be done in this research to the level of a larger pilot scale to be applied by industry owners or nationwide.

- Avoiding feed system shutdowns, a strainer/coarse screen must be installed before the raw industrial wastewater is introduced into the balancing tank.

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ANNEX (A): RESULTS

- **Results for stage 1 for UASB 1 and UASB 2**

- COD inlet/outlet, OLR and removal efficiency for low and high rate UASB 1 and 2.

UASB 1				
Date	COD influent (Kg/L)	COD effluent (Kg/L)	OLR, Kg COD /m3 day	COD removal efficiency (%)
10/6/2020	3.711	2.178	2.05	41%
24/6/2020	1.28	1.02	0.71	20%
10/7/2020	2.72	2.053	1.5	24.50%
23/7/2020	4.638	off	2.56	off
17/8/2020	0.827	0.53	0.45	36%
3/9/2020	4.123	0.66	2.28	84%
UASB 2				
10/7/2020	2.72	1.193	2.17	56%
23/7/2020	4.638	1.54	3.71	67%
17/8/2020	0.827	0.62	0.66	25%
3/9/2020	4.123	Was turned off	3.3	Was turned off

- VSS inlet/outlet, OLR and removal efficiency for low and high rate UASB 1 and 2.

UASB 1				
Date	VSS influent (Kg/L)	VSS effluent (Kg/L)	OLR, Kg COD /m3 day	VSS removal efficiency (%)
15/6/2020	0.216	0.102	0.12	53%
24/6/2020	0.272	0.120	0.15	56%
11/7/2020	0.495	0.252	0.27	49%
23/7/2020	0.552	0.174	0.3	68%
10/8/2020	0.979	0.094	0.54	90%
26/8/2020	1.840	0.166	1.02	91%
UASB 2				
11/7/2020	0.495	0.289	0.38	42%
23/7/2020	0.552	0.220	0.42	60%
10/8/2020	0.979	0.240	0.75	75%
26/8/2020	1.840	0.044	1.41	97%

- TSS inlet/outlet, OLR and removal efficiency for low and high rate UASB 1 and 2.

UASB 1				
Date	TSS influent (Kg/L)	TSS effluent (Kg/L)	OLR, Kg COD /m3 day	TSS removal efficiency (%)
15/6/2020	0.176	0.124	0.1	30%
24/6/2020	0.227	0.220	0.12	0.03%
11/7/2020	0.520	0.280	0.28	46%
23/7/2020	0.6	0.320	0.33	47%
10/8/2020	1.164	0.108	0.64	90%
26/8/2020	2.192	0.196	1.21	91%
UASB 2				
11/7/2020	0.520	0.130	0.4	75%
23/7/2020	0.6	0.208	0.46	65%
10/8/2020	1.164	0.472	0.89	59%
26/8/2020	2.192	0.108	1.63	95%

- Research results for the effluent concentration and removal efficiency (%) for UASB 1 (Low rate) and UASB 2 (High rate)

Parameter	Influent concentration	UASB 1 (Low fed rate)				UASB 2 (High fed rate)			
		Effluent concentration		Removal efficiency (%)		Effluent concentration		Removal efficiency (%)	
		Range	Average	Range	Average	Range	Average	Range	Average
Zn	1941	918 - 3097.5	897.5	31.3 – 46.2	38.8	1865-1886	1697	1.4 – 17.5	9.45
Cd	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr	195.6	8.8 – 60.8	29.1	42.7 – 66.8	54.8	18.8 – 79.3	30.25	44.5 – 69.1	57
Cu	2496	30.8 – 153.3	107	56.5 - 99	76	13.8 – 114.3	64	81.5 - 86	83.8

All parameters are in μg /l

- TKN inlet/outlet and removal efficiency for low and high rate UASB 1 and UASB 2.

UASB 1			
Date	Inlet UASB (mg/l)	TKN effluent (mg/L)	TKN removal efficiency (%)
10/6/2020	405.37	387.94	4.3%
26/8/2020	275.49	194.55	29.3%
UASB 2			
10/8/2020	382.52	327.22	14%
15/8/2020	562	151.81	34%

- Phenol influent effluent and removal efficiency for low and high rate UASB 1 and 2

Date	Inlet UASB (mg/l)	Effluent UASB 1	Effluent UASB2	Removal efficiency UASB 1	Removal efficiency UASB 2
2020-08-10	0.01	0	0	100%	100%
2020-08-17	0	0	0	0	0
2020-08-26	0.0728	0	0	100%	100%

- **Results for second stage for UASB 1 and UASB 2**

  - COD inlet/outlet, OLR and removal efficiency for UASB 1 and UASB 2

UASB 1				
Date	COD influent (Kg/L)	COD effluent (Kg/L)	OLR, Kg COD /m3 day	COD removal efficiency (%)
9/9/2020	4.135	0.453	1.58	89%
14/9/2020	4.105	0.732	1.57	82%
23/9/2020	4.514	1.935	1.73	57%
27/9/2020	3.566	2.6	1.37	41%
5/10/2920	4.2	1.55	1.61	63%
8/10/2020	4.513	1.32	1.73	70%
UASB 2				
9/9/2020	4.135	1.222	1.58	70%
14/9/2020	4.105	0.527	1.57	87%
23/9/2020	4.514	2.234	1.73	50%
27/9/2020	3.566	2.09	1.37	41%
5/10/2920	4.2	1.805	1.61	57%
8/10/2020	4.513	2.1	1.73	53%

  - VSS inlet/outlet, OLR and removal efficiency for UASB 1 and UASB 2.

UASB 1				
Date	VSS influent (Kg/L)	VSS effluent (Kg/L)	OLR, Kg COD /m3 day	VSS removal efficiency (%)
9/9/2020	1.664	0.102	0.64	94%
27/9/2020	0.352	0.184	0.14	48%
UASB 2				
9/9/2020	1.664	0.192	0.64	88%
27/9/2020	0.352	0.164	0.14	57%

  - TSS inlet/outlet, OLR and removal efficiency for UASB 1 and UASB 2

UASB 1				
Date	TSS influent (Kg/L)	TSS effluent (Kg/L)	OLR, Kg COD /m3 day	TSS removal efficiency (%)
9/9/2020	1.708	0.12	0.66	93%
27/9/2020	0.68	0.216	0.26	68%
UASB 2				
9/9/2020	1.708	0.22	0.66	87%
27/9/2020	0.68	0.232	0.26	66%

- TKN inlet/outlet and removal efficiency for UASB 1 and UASB 2.

UASB 1			
Date	Inlet UASB (mg/l)	TKN effluent (mg/L)	TKN removal efficiency (%)
9/9/2020	331.72	238.39	28%
14/9/2020	331	310.92	6.1%
23/9/2020	291.24	44.97	84.5%
UASB 2			
3/9/2020	444.17	236.14	47%
9/9/2020	331.72	302.48	9%
14/9/2020	331	241.2	27%
23/9/2020	291.24	199.59	31%

- Phenol influent/effluent and removal efficiency for UASB 1 and UASB 2

Date	Inlet UASB (mg/l)	outlet UASB 1	outlet UASB 2	Removal efficiency UASB 1	Removal efficiency UASB 2
2020-09-03	0	0	0	0	0
2020-09-09	0.0706	0	0	100%	100%
2020-09-14	0	0	0	0	0
2020-09-23	0.0348	0	0	100%	100%

- Biogas daily gas production and specific biogas yield for UASB 1 and UASB 2

UASB 1		
Date	**Daily gas production (m^3/day)**	**Specific biogas yield (m^3/ kg.COD) removed**
4/9/2020	0.277	0.65
12/9/2020	0.459	0.53
20/9/2020	0.527	0.59
28/9/2020	0.735	0.64
5/10/2020	1.001	0.31
UASB 2		
4/9/2020	0.593	1.76
12/9/2020	1.305	1.4
20/9/2020	1.465	1.87
28/9/2020	1.843	1.65
5/10/2020	2.18	1.16

- Final results for thesis

	First Stage		**Second Stage**	
Parameter/Unit	UASB 1	UASB 2	UASB 1	UASB 2
Upflow velocity [m/h]	0.024	1.05	1.05	1.05
HRT [h]	43.5	18	62.5	62.5
OLR [kg COD/m^3.day]	1.826	4.4	0.39	0.46
Removal Efficiency [%]				
COD	36.1	61	64.6	59.6
VSS	68	69	71	73
TSS	51	74	80	77
Zn	38.8	9.45		
Cd and Pb	ND	ND		
Cr	54.8	57		
Cu	76	83.8		
TKN	16.8	24	39.5	28.5
Total phenol	100	100	100	100
Biogas yield (m^3/kg.COD)			0.544	1.568

- Final results for thesis in Arabic language

	المرحلة الأولى		**المرحلة الثانية**	
Parameter/Unit	UASB 1	UASB 2	UASB 1	UASB 2
Upflow velocity [m/h]	0.024	1.05	0.03	0.03
HRT [h]	43.5	18	62.5	62.5
OLR [kg COD/m^3.day]	1.826	4.4	0.39	0.46
Removal Efficiency [%]				
COD	36.1	61	64.6	59.6
VSS	68	69	71	73
TSS	51	74	80	77
Zn	38.8	9.45		
Cd and Pb	ND	ND	-	-
Cr	54.8	57	-	
Cu	76	83.8	-	-
TKN	16.8	24	39.5	28.5
Total phenol	100	100	100	100
Biogas yield (m^3/kg.COD)	-	-	0.544	1.568