Birzeit University

Process Performance Assessment of Anaerobic Baffled Reactor (ABR) Followed by Activated Sludge Process for Wastewater Treatment

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Birzeit University

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

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The findings, interpretations and the conclusions expressed in this study don't necessarily express the views of Birzeit University, the views of the individual members of the MSC committee or the views of their respective employers.

DITICATION

To My Parents, My Brothers,

My Wife and My Friends

With love and respect

Mohammed N. Adas

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لكم جميعا جزيل الشكر

Abstract

The sewerage system in Palestine is a critical issue to be discussed. Since; the existing wastewater treatment plants (WWTPs) were overloaded which means not functioning and operating within the required standards. Around 54.7% of the Palestinian communities have no sewerage systems and depend on cesspits (PCBS, 2006) .These may cause several environmental and healthy problems. Even rural areas which have sewerage system have poor trained staff. So much attention must be paid to the rural areas and execute a decentralized wastewater management to achieve integrated and sustainable wastewater management in Palestine.

Water is a scarce and precious resource in Palestine, the deficit in water supply reached up to 50 million cubic meters. The consumption for agriculture purposes reaches 40% of total consumption, so to cope with water scarcity to face the raising demand, looking for alternative resources is a must, one option might be to use the treated water for agriculture. A lot of research was done in the Palestinian area to solve problems mentioned above. A suggested method of treatment will be optimism and control under semi arid region, the application of this method was by the pilot wastewater treatment built in Ein Sinya, with the aim of collecting and treating part of the wastewater, passing through Jifna and Ein Sinya.

This thesis aimed to study the low-cost and appropriateness of treating wastewater in comparison to other wastewater treatment technologies for small and large communities. Also it aimed to utilize the results in solving un-controlled sewerage disposal in West Bank. Hypothetically it was assumed that the cost of treatment using Anaerobic Baffled Reactor (ABR) method followed by Activated Sludge system (AS) will be cost efficient in comparison to other WWT technologies, and will minimize the problem of un-controlled sewerage disposal in Ramallah District, the results then can be optimized to cover the West Bank

Results showed 54.63% removal efficiency of Biochemical Oxygen Demand (BOD_5) in ABR with effluent of 117 mg/l and 89.52% System overall removal efficiency of BOD with effluent of 27 mg/l.

Removal Efficiency of Chemical Oxygen Demand COD in ABR was 54.64% with effluent of 199 mg/l and 89.57% System overall removal efficiency of COD with effluent of 46 mg/l.

ABR showed 21.03% average Removal Efficiency of Total Kjeldahl (TKN) with effluent of 73.6 mg/l, while System showed 61.44% overall removal efficiency of TKN with effluent of 35.94 mg/l.

NH_4^+ concentration increased in ABR, while system removal efficiency of NH_4^+ was 53.52% with effluent of 13.4 mg/l. In general no removal of phosphorous compounds in ABR or overall system occurred.

Total Suspended Solids (TSS) effluent from ABR was 96 mg/l, effluent from AS system was 42.13 mg/l and effluent from the system was 6 mg/l.

Average removal efficiency of total nitrogen was 46.45%. 2.36 log removals of pathogen indicators occurred in ABR, while 4.72 log removals occurred in the system.

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List of Abbreviations

ABR:	Anaerobic Baffled Reactor
AF:	Anaerobic Filter
ARIJ:	Applied Research Institute-Jerusalem
AS:	Activated Sludge
AT:	Aeration Tank
BOD_5:	Biochemical Oxygen Demand
BZU:	Bir Zeit University
COD:	Chemical Oxygen Demand
EC:	European Commission
FC:	Fecal Coliform
F/M ratio:	Food/Microorganisms ratio
HRT:	Hydraulic Retention Time
IEWS:	Institute of Environmental and Water Studies
ILS:	Israeli Shekel
L:	Liter
M:	Meter
Mg:	Milligram
Ml:	Milliliter
MLSS:	Mixed Liquor Suspended Solids
O & M:	Operation & Maintenance
OLR:	Organic Load Rate
PCBS:	Palestinian Center Bureau of Statistics
p.e.:	Population Equivalent
PSI:	Palestine Standards Institute
PWA:	Palestinian Water Authority
R.A.S.:	Return Activated Sludge
SA:	Sludge Age
S.A.S.:	Surplus Activated Sludge
SBR:	Sequence Batch Reactor
SRB:	Sulphate Reducing Bacteria

SV:	Sludge Volume
S.V.I:	Sludge Volume Index
T:	Temperature
TDS:	Total Dissolved Solids
TKN:	Total Kjeldhal
TSS:	Total Suspended Solids
UASB:	Upflow Anaerobic Sludge Blanket
UV:	Ultraviolet
VSS:	Volatile Suspended Solids
W.A.S.:	Waste Activated Sludge
WWTP:	Wastewater Treatment Plant

CHAPTER ONE
Introduction

1.1 Background

Water is a scarce and precious resource in Palestine, the deficit in water supply reached up to 50 million cubic meters (PWA, 2007). The consumption for agricultural purposes reaches 40% of total consumption (PWA, 2008), so to cope with water scarcity to face the rising demand, alternative resources such as treated wastewater to use for agriculture have to be created, especially if we know that estimated wastewater at Palestinian Territories is 78 million cubic meter (PCBS 2008), which is a large quantity that we can invest in if treated and used in agriculture.

The wastewater sector in Palestine is characterized by poor sanitation, lower wastewater quality, insufficient treatment, unsafe disposal of untreated or partially treated wastewater and the use of untreated wastewater in some areas to irrigate edible crops. Applied Institute Research – Jerusalem (ARIJ, 2007), based on survey showed that only 56 communities in West Bank are connected to sewage networks, whereas 513 communities use cesspits to dispose their sewage to the nearest Wadis (ARIJ, 2007).

Few treatment plants are found in Palestine and most of the treatment plants were built in 1970s and 1980s under the Israeli occupation. The majority of the treatment plants are overloaded, badly maintained, and poorly equipped which form a major threat to the plant workers, the farmers, and the consumers. The reuse of treated wastewater is practiced on a small scale and this option has been generally absent from wastewater treatment plans.

The most recent wastewater treatment plant was built in 2000 in Al-Bireh by a German fund. Al-Bireh WWTP was designed to serve 50,000 people at the first phase, with the possibility to serve 100,000 people at the second phase with an extended aeration treatment technology. Al-Bireh WWTP serves now 44,000 capita with average daily flow of 4500 m^3/day (Tomaleh, 2007).

Most of the rural areas have no sewerage systems, and neglected by donors (IEWS, BZU, "Prospects of Efficient Wastewater Management & Reuse in Palestine" Country Report, 2004). They depend on cesspits that may cause environmental and healthy problems. Even rural areas which have sewerage system have poor skilled staff. Therefore attention should be paid to the rural areas and a decentralized wastewater management plan needs to be implemented to achieve integrated and sustainable wastewater management in Palestine.

Beside the different researches done in Palestine to solve the above problems, other types of treatment will be implemented in the semi arid region. The pilot treatment plant in Ein Sinya was constructed within the framework of the EMWater project which was funded by the European Commission (EC). The objective of the plant was to investigate the appropriateness of the Anaerobic Baffled Reactor (ABR) system as low cost treatment system for managing wastewater sector in Palestine.

The treatment plant has two biological processes namely anaerobic and aerobic processes, respectively. The first process consists of Anaerobic Baffled Reactor (ABR) which comprises three steps: hydrolysis, digestion and anoxic denitrification of returned effluent of the second aerobic stage. The second biological process is an Activated Sludge System. Tertiary treatment unit follows these two biological processes, consists of Sand Filter and UV Disinfection.

1.2 Objectives

The objectives of this study are the following:

- Evaluating of Ein Sinya WWTP during the initial period and the steady state in treating domestic wastewater.
- Assessing and finding the operational parameters of the treatment plant.
- Preliminary assessment of the operational and maintenance costs (O& M) of the System.

1.3 Thesis structure

This thesis consists of five chapters. Chapter 1 is the introduction which contains background and research objectives. Chapter 2 is a literature review on wastewater situation in Palestine, anaerobic baffled reactor (ABR), and aeration tank system. Chapter 3 focuses on materials and methods used in this research. Chapter 4 presents and discusses the results of the research. Finally, conclusions and recommendations are summarized in Chapter 5.

CHAPTER TWO

Literature Review

2.1 Existing treatment plants in West Bank

In Ramallah and Al Bireh District, Al-Bireh Municipality had built a wastewater treatment plant; it was located at a distance of 1.5 km down stream the Wade Al–Ein to the east of Al-Bireh city, which was based on extended aeration treatment technology. The plant's capacity is 4,500m^3/day (Tomaleh 2007). The fees for sewage disposal are collected within the water bill, in agreement with Jerusalem Water Undertaking.

The most common wastewater treatment system used in rural areas is the septic tank. The septic tank removes settleable and floatable solids from the wastewater, and the soil absorption field filters and treats the clarified septic tank effluent. Removing solids from the wastewater in the septic tank protects the soil absorption system from clogging and premature failure. In addition to removing solids, the septic tank also permits digestion of a portion of the solids and stores the undigested portion, the system was designed to provide treatment and disposal for normal domestic sewage. No non-biodegradable material should be introduced into the wastewater treatment and disposal system. Plastic and paper (except toilet paper) were examples of non-biodegradable materials that should not be placed down the drain. Normal amounts of dirt and small non biodegradable debris (buttons, dental floss, etc,) from washing will inevitably get into the system. These solids would be retained in the septic tank until it would be pumped during its normal maintenance. Oils and grease should not be placed down the drain in excess quantities. Because septic tanks are buried and are out of sight, many homeowners forget that septic systems require periodic maintenance. Failure to pump-out the septic tank is possibly the greatest single cause of septic system failure. After several years of use, a build-up of bottom sludge and floating scum would reduce the effective capacity of the system).

At present, some of the water and wastewater service providers or utilities recover the operation and maintenance costs. However, none of these utilities recovered the full costs (capital and operational). This situation was not solely due to existing socio-economic factors or to public affordability, as there were other internal and external factors within the utilities and their surrounding environment (Issa, 2004).

In recent years some projects promoting small-scale, decentralized wastewater treatment in rural areas have been implemented. Table 2-1 below shows the implemented technologies of Onsite wastewater systems in West Bank:

Table 2-1: Implemented Technologies of Onsite Wastewater Systems in the West Bank (PWA, 2003)

Treatment Type	Village	District
Anaerobic Pond-Facultative Pond-Polishing Pond	Tarqumia	Hebron
Up flow Anaerobic Sludge Blanket Reactor	Artas	Bethlehem
Sequencing Batch Reactor	Jerich Casino	Jericho
Septic Tank – Anaerobic Filter	Aqba School	Jenin
Low Rate Trickling Filter	Al Samu' School	Hebron
Contact Stabilization Pond	BZU	Ramallah
UASB – Septic Tank	BZU	Ramallah
Collective Gray Wastewater – Anaerobic Filter	Beit Diko	Jerusalem
Duckweed and Algae Based Ponds	BZU	Ramallah

2.2 Reuse in agriculture

Reuse of treated wastewater often disproportionately benefits the poor. It must be combined with strategies to prevent or mitigate health risks from pathogens, heavy metals, pesticides, and endocrine disrupters and environmental damage from heavy metals and salinity. Long-term institutional coordination among water, agricultural, environmental, service providers and end users is a requirement for water reuse investments to pay off. Investments in urban water supply and sewerage coverage are rising, however, adequate treatment for agricultural reuse with acceptable risk mitigation for human health and the environment will require further investments. While this investment addresses reuse after treatment, it is critical to ensure that investments in treatment appropriate for reuse schemes will be made. Urban wastewater is well suited to agricultural reuse and landscaping because of the reliability of supply, proximity to urban markets, and its nutrient content. To have an impact on scarcity, reuse of wastewater must substitute for, not add to, existing uses of fresh water (PWA, 2003).

2.3 Wastewater management, visions, policies and strategies in Palestine:

Wastewater management in Palestine has been a neglected issue over the past years (Al-Sa’ed and Mubarak, 2006). Despite the setting of the national policies for wastewater management, it has yet to be implemented in Palestine.

The Palestinian Water Authority, the regulator of the water sector, prepared a reuse strategy in 2003 that encouraged and enforced reuse of treated wastewater, the main principles of this strategy were:

- The reuse of treated wastewater must be established in all treatment projects.
- Co-operation and coordination must be established with all relevant stakeholders.
- Flexible reuse plans should be developed to enable the reuse and storage in winter season and when the effluent quality drops below the standards.

- Establishment of the planning tools (Regulations, Standards, Guidelines, etc.) for reuse and recharge.
- Discharges of water to the surface may be considered as an interim action, or if reuse is not feasible.
- Irrigation of crops consumed raw is prohibited, enforcement means should be applied.
- For better water quality and reuse efficiency, consider (i) mixing of treated effluent with urban and surface runoff, (ii) artificial recharge of groundwater with treated effluent wherever possible, and (iii) establish surface storage of treated effluent with or without harvested runoff.
- Allow the private sector and/or public to manage or share the management of wastewater reuse projects.
- Develop a program for modifying use habits to include reuse of treated effluent in urban centres (greening, fountains, urban parks and landscape irrigation, forestation, and other areas).

2.4 Guidelines used for wastewater treatment and reuse:

Palestinian Standards for treated wastewater quality parameters for reuse will be used to determine the field that treated wastewater from Ein Sinya could be used for. Table 2-2 shows the Palestinian classification of treated wastewater

Table 2-2: Palestinian Classification of Treated Wastewater (PSI)

Class		**Water Quality Parameters**		
		BOD_5	**TSS**	**Faecal Coliforms**
Class A	High Quality	20 mg/l,	30 mg/l,	200 CFU/100 ml
Class B	Good Quality	20 mg/l,	30 mg/l,	1000 CFU/100 ml
Class C	Medium Quality	40 mg/l,	50 mg/l,	1000 CFU/100 ml
Class D	Low Quality	60 mg/l,	90 mg/l,	1000 CFU/100 ml

Table 2-3 shows treated wastewater quality by basic indicators

Table 2-3: Treated Wastewater Quality by basic indicators / maximum values (PSI)

Indicator	**Discharge to the Sea, 500m far**	**Groundwater recharge by infiltration**	**Dry Fodders**	**Green Fodders**	**Gardens, Play grounds, Parks**	**Industrial and cereal crops**	**Forests**	**Fruiting Trees**
COD (mg/l)	**200**	**150**	**200**	**150**	**150**	**200**	**200**	**150**
DO (ppm)	**>1**	**>1**	**>0.5**	**>0.5**	**>0.5**	**>0.5**	**>0.5**	**>0.5**
TDS (mg/l)	**-**	**1500**	**1500**	**1500**	**1200**	**1500**	**1500**	**1500**
pH	**6-9**	**6-9**	**6-9**	**6-9**	**6-9**	**6-9**	**6-9**	**6-9**
Fat Oil & Grease	**10**	**0**	**5**	**5**	**5**	**5**	**5**	**5**
Phenol	**1**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**
MBAS*[*]**	**25**	**5**	**15**	**15**	**15**	**15**	**15**	**15**
NO_3 (mg/l)	**25**	**15**	**50**	**50**	**50**	**50**	**50**	**50**
NH_4 (mg/l)	**5**	**10**	**-**	**-**	**50**	**-**	**-**	**-**
TKN (mg/l) (Org - N)	**10**	**10**	**50**	**50**	**50**	**50**	**50**	**50**
Cl (mg/l)	**-**	**600**	**500**	**500**	**350**	**500**	**500**	**400**
SO_4 (mg/l)	**1000**	**1000**	**500**	**500**	**500**	**500**	**500**	**500**
Na (mg/l)	**-**	**230**	**200**	**200**	**200**	**200**	**200**	**200**
Mg (mg/l)	**-**	**150**	**60**	**60**	**60**	**60**	**60**	**60**
Ca (mg/l)	**-**	**400**	**400**	**400**	**400**	**400**	**400**	**400**

2.5 Anaerobic Baffled Reactor (ABR):

2.5.1 Introduction:

The anaerobic baffled reactor (ABR) can be considered as an upgraded septic tank. The ABR consists of an initial settler compartment and a second section of a series of baffled reactors. The baffles are used to direct the wastewater flow in an upflow mode through a series of sludge blanket reactors. This configuration provides a more close contact between anaerobic biomass and wastewater, which improves treatment performance.

In the wastewater treatment field, systems based on anaerobic biological processes have traditionally been adopted to stabilize both primary and secondary waste sludge, as this application is well-suited to the main requirements of anaerobic systems. These include:

- Good removal ability of the biodegradable substrates;
- Efficiency levels that is not excessively high;
- High production of biogas;
- And low running costs, mainly due to the lack of a forced aeration system.

Innovative anaerobic biological systems guarantee a fairly good removal of carbonaceous matter (which may even reach high efficiency levels in the case of rapidly biodegradable substrates), but are markedly inadequate to remove nitrogen and phosphorus compounds. Consequently, use of the anaerobic system alone cannot guarantee compliance with legal standards, a goal that could be reached by using the so-called integrated systems in which anaerobic biological systems constitute only one of the stages in the treatment flow-sheet (Lettinga and Hulshoff Pol, 1991). The integrated systems developed over the last few years differ according to the various treatment systems that they consist of and the substrates that they eliminate, with specific reference to wastewater treatment in small communities.

2.5.2 ABR performance:

In 2004, Water Research Commission of South Africa and National Research Foundation implemented a project that has studied the appropriateness of the ABR for on-site primary sanitation in low-income communities in South Africa (Pillay et al., 2004). A 3000 Liters ABR pilot plant was Constructed using domestic wastewater to assess the performance of ABR in terms of COD, TSS, VSS, Ammonia, Phosphate and pathogens removal efficiencies and measure the gas and sludge production. Tests were performed and results were obtained at 22 hours Hydraulic Retention Time (HRT) (average flow rate of 3.3 m^3 / day) during five months, and pilot plant operated at relatively controlled conditions.

Figure 2-1 shows schematic layout of this pilot ABR system.

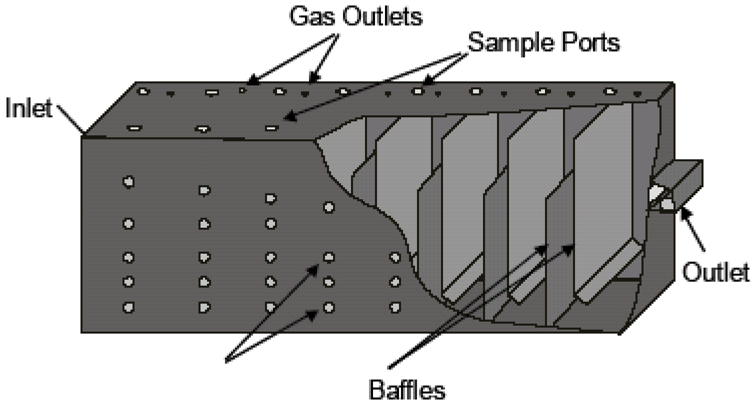

Figure 2-1: Schematic Layout of the Pilot ABR Implemented in South Africa 2004 (Pillay et al., 2004).

Influent wastewater concentrations were 716 mg/l for COD, 25 mg/l for ammonia, 5 mg/l for phosphorous, 480 mg/l for TSS and 1.3 x 10^8 cfu/100 ml for FC.

Results showed that COD removal efficiencies varies from 58% to 72% with effluent below 200 mg/l. Effluent TSS values were between 50 and 400 mg TSS/l (average = 225 mg TSS/l). Effluent VSS values were between 50 and 200 mg VSS/l (average = 127 mgVSS/l). Ammonia concentration increased and no Phosphorous removal. 1 log removal of pathogen indicators occurred. The rate of gas production for each compartment was measured on two occasions in the 5 months operating period using a manual constant pressure liquid displacement system. Overall sludge production is characteristically low.

This ABR pilot plant has the following advantages:

- No energy input, relatively little maintenance;
- Nutrients become a resource;
- Low sludge production;
- Biogas could be used as energy source;
- ABR is more resistant to shock loads than most conventional anaerobic treatment processes;
- ABR basic mechanical design is very simple.

Although ABR had good removal efficiency of organic matter (50 – 75%) at the specified retention time, effluent quality didn't meet the required extent of pathogen removal. Also, Nutrients effluents had never complied with the General Standards for the discharge to water resource. So ABR had potential as a part of wastewater treatment system and post treatment is a must (Pillay et al., 2004).

2.5.3 UASB-septic tank system

In 2005, community on-site two pilot scale UASB- septic tank reactors treating domestic sewage under two different HRTs (2 days for Reactor1 and 4 days for Reactor2) were operated in parallel at the sewage treatment plant of Al-Bireh City, Palestine by Al-Shayah and Mahmoud. The main objective of those two pilot plants was to investigate the performance and feasibility of using the UASB-septic tank reactor for the pre-treatment of domestic wastewater under the conditions that arise at community level in Palestine. Moreover, possibilities to evaluate the influence of HRT on the performance of the UASB-septic tank reactor (Al-Shayah and Mahmoud, 2008). The two reactors were operated for six months at ambient temperatures ranges between 15 and 34 ^{0}C with an average value of 24.4 ^{0}C;

samples were taken and analyzed for chemical, physical and microbiological parameters.

Influent wastewater concentrations were 1185 mg/l for COD, 616 mg/l for BOD_5, 614 mg/l for TSS, 78 mg/l for TKN as nitrogen, 58.9 mg/l for NH_4^+ as nitrogen, 14 mg/l for PO_4^{-2} as phosphorous and 2.1 x 10^7 cfu/100 for FC. Mean organic loading rates (OLR) applied during the whole period of operation were 0.6 kg COD/m^3 (range 0.44 – 0.86) and 0.3 kg COD/m^3 (range 0.22 – 0.43) in R1 and R2, respectively.

Results for Reactor1 (HRT = 2 days) showed average Total COD average removal efficiency of 54% with average effluent concentration of 537 mg/l, BOD_5 average removal efficiency of 56% with average effluent concentration of 264 mg/l, TSS average removal efficiency of 79% with average effluent concentration of 123 mg/l, TKN as nitrogen average removal efficiency of 16% with average effluent concentration of 65 mg/l, NH_4^+ as nitrogen average removal efficiency of 5% with average effluent concentration of 56 mg/l, PO_4^{-2} as phosphorous average removal efficiency of 2% with average effluent concentration of 13.7 mg/l and average effluent concentration of FC was 1.55 x 10^6 CFU.

While, results for Reactor2 (HRT = 4 days), showed average Total COD removal efficiency of 58% with average effluent concentration of 493 mg/l, BOD_5 average removal efficiency of 59% with average effluent concentration of 248 mg/l, TSS average removal efficiency of 80% with average effluent concentration of 117 mg/l, TKN as nitrogen average removal efficiency of 12% with average effluent concentration of 68 mg/l, NH_4^+ as nitrogen average removal efficiency of -0.4% with average effluent concentration of 59 mg/l, PO_4^{-2} as phosphorous average removal efficiency of -2% with average effluent concentration of 14.2 mg/l and average effluent concentration of FC was 1.26 x 10^6 CFU.

The results obtained in that study showed that the longer HRT, such the case in Reactor2, seems to contribute slightly to better reactor performance. This suggests that the design HRT = 4 days in UASB-septic tank reactors seem more adequate for the anaerobic treatment of domestic sewage under Palestine conditions (Al-Shayah and Mahmoud, 2008)

As general conclusion, it could be said that the one-step UASB-septic tank reactors configuration is a potential compact and effective community onsite pre-treatment unit for domestic wastewater. This system is more economical and affordable for local, relatively poor communities. A post-treatment step is recommended in most cases after UASB-septic tank systems to remove organic matter, nutrients and fecal coliforms to meet requirements needed for reuse in irrigational purposes (Al-Shayah and Mahmoud, 2008).

2.5.4 Combined ABR system:

In 1995, a bench-scale experimental study was carried out in Durham City, UK to investigate the overall performance of combined anaerobic reactor for treating municipal wastewater at ambient temperatures 12-28 C. A modified Anaerobic Baffled Reactor (ABR) was tested (Yu and Anderson, 1995). The reactor consisted of three chambers (0.1 m x 0.1 m x 0.36 m). The first chamber was a UASB without a gas-solid-liquid separator, the second one was a down flow fixed film reactor filled with plastic media, while the third one was a hybrid UASB-AF with plastic Paul ring media located in the top 3/5 of it. It is postulated that such a combined reactor may have advantages over UASB, hybrid UASB-AF and ABR.

Raw municipal wastewater from Durham City, UK, was used for this lab-scale experiment. The raw wastewater was collected from a municipal wastewater treatment plant and brought to the laboratory. The raw wastewater was pre-settled and then pumped into the reactor.

Figure 2-2 below shows schematic diagram of this combined ABR system.

Influent COD concentration for pre-settled wastewater ranged from 386 – 516 mg/l.

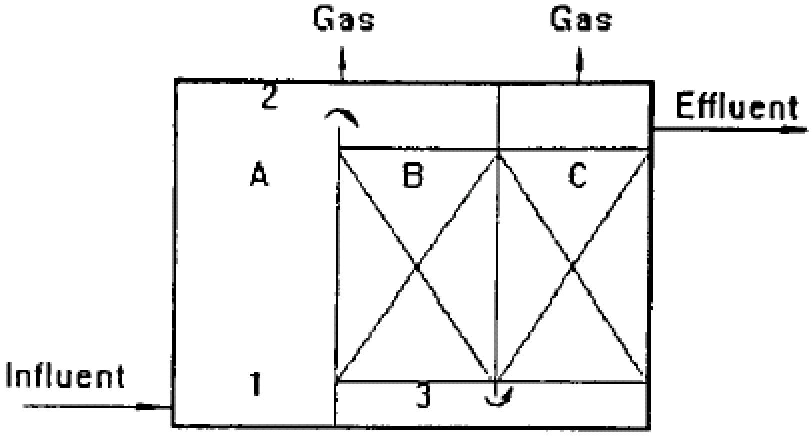

Figure 2-2: Schematic Diagram of the Modified Reactor implemented in UK, 1995 (Yu and Anderson, 1995).

Operation process included two phases; start up phase and steady state phase. In start up phase, the reactor was started with presettled wastewater at an HRT of 16 h and an organic loading rate (OLR) of 0.6 kg COD/m^3.day. Within a period of 2 months, the HRT was stepwise decreased to 11 h with a concomitant increase in OLR up to 0.9 kg COD/m3.day. This phase lasted for four months until the reactor achieved 75% COD removal efficiency, and the reactor could be operated at steady state.

In steady state phase, the pre-settled wastewater was pumped into the reactor with the increase in influent flow rate and decrease in HRT. During this phase, the effect of HRT on the performance of the reactor was evaluated using COD removal efficiency, SS removal, and biogas production in each chamber.

In order to thoroughly test the reactor’s ability to withstand the flow variation, in this phase an abrupt decrease of inflow rate was imposed on the reactor and the reactor’s performance was evaluated in terms of substrate removal and methane production. HRT had decreased abruptly from 4 h to 2 h.

Results showed that COD Removal efficiencies in the steady state operation course varied from 83.5% at HRT of 10 h to 67.8% at HRT of 4 h.

The effluent SS concentration increased with the decrease in HRT. When the HRT was more than 5 h, the effluent SS concentration was less than 40 mg/l. Results also showed increasing in NH_4^+ concentration.

The granular sludge at the bottom of the first chamber played a major role in removing influent substrate, but as the HRT fell, more and more bacteria in the biofilm of the second and third ones were involved in removing substrate. Acetate and butyrate were produced and degraded mainly in the first chamber, while propionate was only converted in the last chamber.

After the HRT decreased from 4 h to 2 h, the reactor's performance deteriorated. The total COD removal efficiency decreased to 52.3% and a high effluent SS concentration over 75 mg/l was discharged. The soluble COD removal efficiency and methane yield were 48.7% and 0.07 m3/kg COD removed. This indicates that, after the HRT fell, the decrease in contact time between the biogas and the substrate in the wastewater is an important reason behind the reactor's poor performance. The hydraulic loading became the dominant factor for the reactor's performance. As a consequence, in order to keep the reactor operating under stable conditions, extremely short HRTs should be avoided, although the anaerobic baffled reactor has an excellent capability of coping with flow fluctuation.

Above results were similar to, or compared favorably with, other anaerobic reactor systems for municipal wastewater treatment at ambient temperature and proved the technical feasibility of this compartmentalized reactor. Considering its simple structure and operation, it could be considered a potential reactor system for treating municipal and domestic wastewaters in tropical and sub-tropical areas of developing countries (Yu and Anderson, 1995). Because of the increasing concern over eutrophication of surface waters and strict regulations on nitrogen discharges, direct anaerobic treatment of municipal wastewater would necessitate aerobic or physical-chemical post-treatment.

2.6 Activated Sludge system.

2.6.1 Introduction:

Activated sludge is a process dealing with the treatment of sewage and industrial wastewaters. Basically atmospheric air or pure oxygen is forced into raw sewage (or industrial wastewater) combined with organisms to develop a biological floc which reduces the organic content of the sewage. The combination of raw sewage (or industrial wastewater) and biological mass is commonly known as Mixed Liquor. In all activated sludge plants, once the sewage (or industrial wastewater) has received sufficient treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new sewage (or industrial wastewater) entering the tank. This fraction of the floc is called Return Activated Sludge (R.A.S.). Excess sludge which eventually accumilates beyond what is returned is called Waste Activated Sludge (W.A.S.). W.A.S is removed from the treatment process to keep the ratio of biomass to food supplied (sewage or wastewater) in balance. This is called the F/M ratio. W.A.S is stored away from the main treatment process in storage tanks and is further treated by digestion, either under anaerobic or aerobic conditions prior to disposal. Sometimes another term for W.A.S is S.A.S (Surplus Activated Sludge), both terms have the same meaning.

Activated sludge is also the name given to the active biological material produced by activated sludge plants and which affects all the purification processes. This material, which is healthy sludge is a brown floc, is largely composed of saprophytic bacteria but also has an important protozoan flora mainly composed of amoebae, Spirotrichs, Peritrichs including Vorticellids and a range of other filter feeding species. Other important constituents include motile and sedentary Rotifers. In poorly managed activated sludge, a range of mucilaginous filamentous bacteria can develop including Sphaerotilus natans which produces a sludge that is difficult to settle and can result in the sludge blanket decanting over the weirs in the settlement tank to severely contaminate the final effluent quality. This material is often described as sewage fungus but true fungal communities are relatively uncommon. In a sewage (or industrial wastewater) treatment plant, the activated sludge process can be used for one or several of the following purpose:

- Oxidizing carbonaceous matter: biological matter.
- Oxidizing nitrogeneous matter: mainly ammonium and nitrogen in biological materials.
- Removing phosphate.
- Driving off entrained such as gases carbon dioxide, ammonia, nitrogen, etc.
- Generating a biological floc that is easy to settle.
- Generating a liquor low in dissolved or suspended material.

The activated sludge process was discovered by accident in Britain in 1913. Experiments on treating sewage in a draw-and-fill reactor (the precursor to today's sequencing batch reactor) produced a highly treated effluent. Believing that the sludge had been activated (in a similar manner to activated carbon) the process was named activated sludge. Not until much later was it realized that what had actually had occurred was a means to concentrate biological organisms, decoupling the liquid retention time (ideally, low, for a compact treatment system) from the solids retention time (ideally, fairly high, for an effluent low in BOD_5 and ammonia.)

The general arrangement of an activated sludge process for removing carbonaceous pollution includes the following items: Aeration tank where air (or oxygen) is injected in the mixed liquor. Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs to settle, thus separating the biological sludge from the clear treated water. Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (meaning that there is no residual dissolved oxygen.)

Where land is in short supply sewage may be treated by injection of oxygen into a pressured return sludge stream which is injected into the base of a deep columnar tank buried in the ground. Such shafts may be up to 100 metres deep and are filled with sewage liquor. As the sewage rises the oxygen forced into solution by the pressure at the base of the shaft breaks out as molecular oxygen providing a highly efficient source of oxygen for the activated sludge biota. The rising oxygen and injected return sludge provide the physical mechanism for mixing of the sewage and sludge. Mixed sludge and sewage is decanted at the surface and separated into supernatant and sludge components. The efficiency of deep shaft treatment can be high. Surface aerators are commonly quoted as having an aeration efficiency of 0.5 - 1.5 kg O2/kWh, diffused aeration as 1.5 - 2.5 kg O2/KWh. Deep Shaft claims 5 - 8 kg O2/kWh. However, the costs of construction are high. Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80% to 90% removal of BOD_5 with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and utilize motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O2/kWh. However, they do not provide as good mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units (Beychok, 1971).

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C (Beychok, 1971).

2.6.2 AS System in Palestine:

Activated Sludge System is the commonly most used technology in Palestine. The most successful wastewater treatment plant in Palestine is Al-Bireh Wastewater Treatment Plant, where the treated effluent is being discharged into Wadi Al-Ein towards the Jordan Valley without any reuse. Schematic diagram of Al-Bireh WWTP is shown in Fig. 2-3 below:

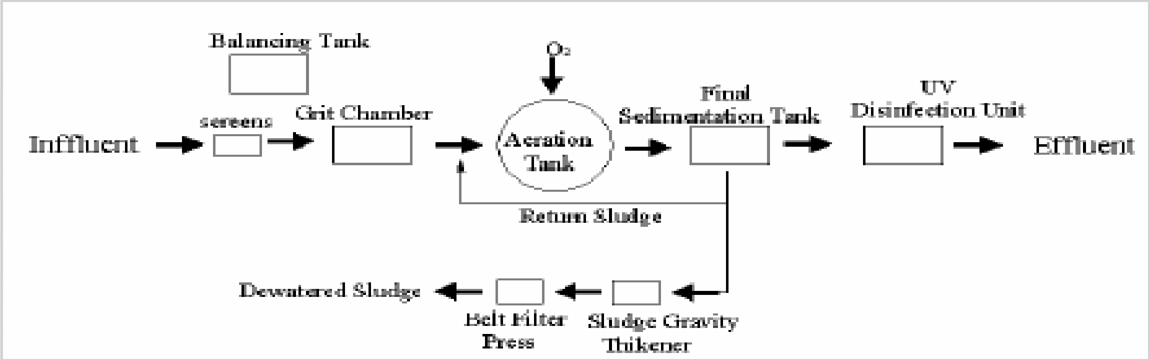

Figure 2-3: Schematic Diagram of Al-Bireh WWTP (Tomaleh, 2007)

Al-Bireh WWTP uses nitrification and denitrification process for total nitrogen removal, and aerobic process for sludge stabilization. Preferable operational parameters for this treatment plant were as follows (Zimmo, 2008):

- The Food to Microorganisms ratio (F/M) ranges between 0.05 -0.20 day^{-1}

- Sludge Volume Index (S.V.I) ranges between 0.12 – 0.15 ml/mg.
- Mixed Liquor Suspended Solids (MLSS) in the Aeration Tank ranges between 3000 – 6000 mg/l.
- Sludge Age (SA) ranges between 20 – 30 days.
- Hydraulic Retention Time (HRT) ranges between 18-36 hours.
- Organic Loading Rate (OLR) ranges between 0.05 – 0.14 kg BOD_5/ m^3 /day.

Periodic monitoring and evaluation of Al-Bireh WWTP is conducted by The Civil Engineering Department at Birzeit University, in order to determine the efficiency of the treatment plant and advise the operators about modifying the operational parameters in order to obtain better performance.

Last monitoring report investigated the efficiency of the treatment plant by conducting tests from April 2007 to February 2008. Tests carried out were COD, BOD_5, TSS, NH_4^+, PO_4^{-2}, TKN, and Fecal Coliform.

The average overall efficiencies were 86% for BOD_5 (effluent characteristics varied from 19 -110 mg/l), 89% for COD (effluent characteristics varied from 53 – 112 mg/l), 58% for TSS (37 – 369 mg/l), 43% for NH_4^+ (4-36 mg/l), 30% for TKN (17- 51 mg/l) and 28% for PO_4^{-2}. Average FC log removal was 4 (knowing that UV disinfection unit is out of order). The quality for the effluent met the requirements for reuse in restricted irrigation. If UV unit is put in place, more pathogen removal will be achieved and effluent quality will be suitable for unrestricted irrigation.

In order to keep the operational parameters with the desired range, and to assure the excellent removal efficiency of the treatment plant, the second aeration tank put in operation to increase SVI and improve settling characteristics of the sludge in the settling tank. Operating second aeration tank decreased volumetric loading rate and increased HRT which result in better performance of the plant and better effluent quality which meets the local and international quality standards for reuse in irrigation.

Although Al –Bireh WWTP has good performance and good removal efficiencies, it has many drawbacks:

- This technology needs skilled labor and frequent operational and maintenance costs, such technology may not achieve cost recovery.
- Operational problems.
- Relatively high sludge production.
- Activated Sludge system is sensitive to shock loads.
- High land requirements.

In conclusion, different treatment alternatives should be investigated when planning and designing new treatment plant to serve the Palestinian urban communities (Zimmo, 2008).

2.6.3 ANANOX system:

In 1988, the research staff at Italy's ENEA Institute (Ente per le Nuovetecnologie, l'Energia e l'Ambiente) proposed the two-stage biological integrated system known as ANANOX (ANaerobic- ANoxic-OXic - Garuti et al., 1992). The schematic diagram of the ANANOX system is represented in the figure 2-4 below.

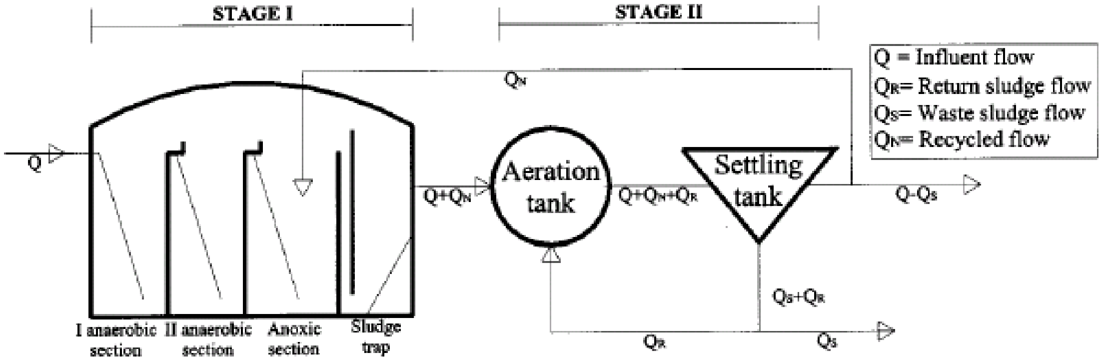

Figure 2-4: Schematic diagram of the ANANOX System (Garuti et al., 1992).

The first stage uses an ABR comprising two floc sludge blanket sections; one anoxic sludge blanket section, and a sludge trap. The second stage is fed to an aeration and settling tanks, with the effluent from the first stage is made up of an activated sludge aeration tank and a settling tank. In the ABR, the following processes primarily take place: ammonification of organic nitrogen; separation and hydrolysis of suspended organic solids; degradation of a part of the dissolved carbonaceous substance through the combined action of acid forming and methane-forming micro-organisms; reduction of sulphates to sulphides through the action of sulphate reducing bacteria (SRB.) The lower the COD content and the ratio between COD and sulphate concentration in the incoming wastewater, the greater the efficiency of the Sulphate reduction process (Choi and Rim, 1991). The sludge trap has the only function of preventing any first-stage sludge that might have escaped from the blanket from being fed into the subsequent aerobic phase (Garuti et al., 1992). The second stage consists of a classic activated sludge process, where oxidation of the residual carbonaceous fraction, ammonia nitrogen and sulphides occurs. Denitrification takes place in the anoxic section of the first stage, where a portion of the effluent clarified in the second stage (and not the mixed liquor, as is often the case) is recycled. Although this solution overloads the settling tank, it makes it possible to reduce the amount of dissolved oxygen recycled to the anoxic section.

The configuration of the ANANOX system with its anaerobic, anoxic and aerobic sections prevents biomass transfer; and the system can thus be classified as a "separated biomass" system. The presence of anaerobic sections upstream of the anoxic section is a characteristic feature of ANANOX operation, as it guarantees the availability of electron donors for the denitrification process even when there is little or no residual carbonaceous substrate in the ABR effluent. Under these conditions, the development of denitrifying heterotrophic biomass that uses short chain fatty acids as electron donors is accompanied by the development of denitrifying autotrophic biomass that uses the sulphides produced by the SRBs in the anaerobic sections. In the presence of both these denitrifying micro-organisms, the denitrification rate is affected by physical and environmental parameters (detention time, temperature, pH, nitrate recycled, etc.) and is not influenced by possible imbalances in the C/N ratio in the incoming wastewater, a feature typical of traditional systems. With municipal wastewater the imbalance in the above ratio may even be manifested for only a few hours each day because of the oscillations in the hydraulic and organic load, which may assume important proportions for systems serving medium-sized and small Communities and/or a rapidly variable population (Heduit et al., 1990). In these cases the adoption of traditional biological solutions has sometimes led to the inhibition of the denitrification process (Vismara, 1998), a problem which can be solved only by introducing an accumulation and homogenisation (balancing) tank or by adding an external source of carbon (methanol), which has obvious economic implications (Van Haandel and Marais, 1981).

The ANANOX system has so far been thoroughly tested on laboratory-scale pilot prototypes. In particular, during an extended investigation in 1990 and 1991 on a pilot-scale system installed at the waste treatment plant in the municipality of San Giovanni in Persiceto (Bologna Province - Italy). High values were obtained for the elimination of COD (89.6 %), Total Suspended Solids (TSS, 89.2 %) and total nitrogen (81.2 %). In addition, there was extremely small production of sludge (only 0.2 kg of TSS per kg of COD removed) and methane production equal to 0.103 m3 per kg of COD removed. Moreover, the sludge from the anoxic section was found to contain *Thiobacillus denitrificans*, which under anoxic conditions can achieve denitrification by oxidising sulphides into sulphates (Garuti et al., 1992).

Once the successful operation of the ANANOX system had been ascertained, it was decided to assess its performance using a full-scale system operating under uncontrolled load conditions. The primary objectives of the experiments were to analyze ABR operation in relation to biomass concentration in the sludge blanket and wastewater upflow velocity, and to examine the role played by sulphides in the denitrification process. To this end, in the municipality of San Giovanni in Persiceto, an ANANOX system was built for the treatment of wastewater from the village of Biancolina, which has 350 population equivalents (p.e.). The system became operational and an initial series of experimental investigations was carried out between July and October 1998 in order to:

- Systematically determine the concentrations and removal efficiencies in the various phases of the plant for COD, TSS, volatile suspended solids (VSS), and nitrogen and phosphorus compounds;
- Establish the influence exerted by biomass concentration in the sludge blanket on the overall efficiency of the anaerobic phase;
- Define the function of sulphides in the denitrification process.

Influent wastewater concentrations were 598 mg/l for COD, 302 mg/l for TSS, 51.1 mg/l for ammonia nitrogen. Flow rate was equal to10 m^3/day.

ABR sections dimensions were as follow: (2.8 x 1.42 x 2.05) m for section 1, (2.8 x 1.42 x 1.9) m for section 2, (2.8 x 1.7 x 1.75) m for section 3 and the sludge trap

(2.8 x 1.37 x 1.65) m. Aerobic phase was carried out in rectangular basin measuring 1.4 m x 3.6 m x 3 m high.

Results of Full-Scale ANNANOX treatment plant showed 74% maximum COD removal efficiency in ABR with 152.3 mg/l COD effluent. Larger reduction occurred in the anoxic zone (compartment III). Overall system maximum COD removal efficiency was 95% with 30.7 mg/l COD effluent. TSS effluent from the ABR was 72.4 mg/l, and TSS effluent from the system was 11 mg/l with 96.1% maximum removal efficiency. NH_4^+ concentration increased in the ABR and 80% removal efficiency occurred in the Activated Sludge System. NO_3^- reduction in the denitrification process in the anoxic zone of ABR was 58.1%, which is satisfactory.

In conclusion, the results obtained show the system's ability to ensure efficiency levels that comply with stringent effluent regulations while also allowing considerable savings in running costs (Garuti et al., 1998).

The overall conclusions from the above mentioned studies and research:

- Although Anaerobic Baffled Reactor (ABR) is good in organic and solids removal, simple in operation and maintenance, more resistant to shock loads and has low sludge production, it could not be used as secondary treatment unit because its poor removal efficiency of nutrients and pathogen; i.e. effluent quality doesn't meet the international standards for reuse in irrigation even the modified ABR.
- Hydraulic Retention Time (HRT) above 5 h is recommended for ABR.
- Activated Sludge system has excellent removal efficiencies, but it is relatively an expensive technology for developing countries, it requires high operational and maintenance costs, and high land requirement.
- Combined system using ABR followed by Activated Sludge system (ANANOX) may achieve the advantages of the both technologies and

get over their drawbacks, i.e. good effluent quality with low running cost. ANANOX system could be a low-cost onsite sanitation approach.

2.7 Combination of ABR and AS system

As mentioned before, wastewater situation in Palestine is so critical, most of rural areas have no sewerage systems; even existing WWTPs in urban areas are overloaded. This research is trying to find innovative solutions for wastewater treatment in Palestine, and apply decentralized wastewater management and low-cost onsite sanitation approach.

In Palestine, aerobic processes are widely used for municipal wastewater treatment. However, aerobic processes have serious drawbacks including considerable investment, operation and maintenance costs and high sludge production. So hardly there will be a cost recovery and because there is no sludge management in Palestine, sludge production causes many problems.

In this research, previous problems related to aerobic treatment are designed to be solved by pretreatment anaerobic treatment stage to assure the advantages of good removal efficiency of organic and inorganic matter, and low running cost due to lack of forced aeration system.

CHAPTER THREE

Methodology

3.1 Experimental set up of the pilot plant

The pilot plant is located in Ein Sinya area, 11 Km north of Ramallah at an altitude of 640 meters above the sea level. The coordinates of Ein Sinya are as Follows: 153 900 and 172 250. The area is connected to Ramallah/Birzeit with asphalt-paved road passing through Jifna city.

The average daily air temperature in summer is 28 degree and the average daily temperature in winter is 8 degree. The average relative humidity in the area varies from 51% in May to 76% in January. The hours of sunshine reach about 3300 hours per year out of possible total of 4400 hours. The average rainfall is 600mm/year comes as moderate in non-continuous quantities during the winter season.

The pilot plant was built with reinforced concrete walls and steel walls to ensure water tightness. It consists of two biological processes; Anaerobic Baffled Reactor (ABR) consisted of three compartments and Activated Sludge (AS) as shown in Figure 3-1.

3.2 System operation and monitoring

ABR Dimensions are (2.08 x 5.51 x 2.20) m, with HRT of 2.5 days. Activated Sludge system dimensions are (2.29 x 3.88 x 2.52) consisting of aeration tank (2.29 x 2.19 x 2.52) m and Settling Tank, with HRT of 30 hours. The goals of this combination are:

1- Applying innovative solutions for decentralized wastewater management.

2- Have a good effluent quality appropriate for agricultural use, and save part of the 60% of water consumption, i.e. achieve reuse policy in the Palestinian Territories.

3- Saving power energy consumption, i.e. applying low-cost treatment technology (cost/m3 is relatively low) and achieve cost recovery (low running cost).

4- Low sludge production.

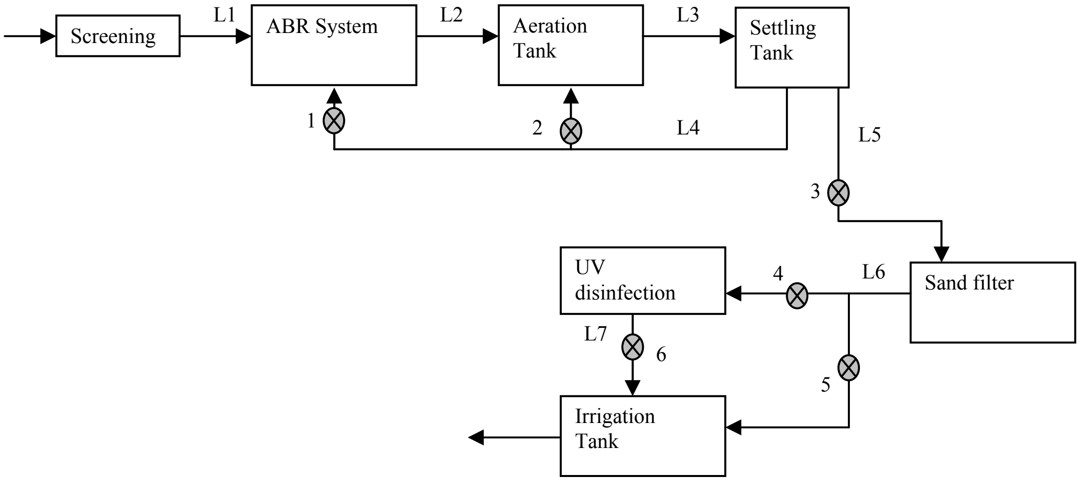

Figure 3-1: Schematic diagram of the pilot plant operation.

The pilot plant is designed to receive an average flow of 10 m^3/d. Wastewater diverted from the existing closed channels sewer system flows through a bar screen so that large solid particles are trapped and kept from flowing into inlet station pit. The inlet station pit collects the wastewater, and acts as a buffer zone in order to balance inlet flow during peak periods and interruptions. Two grinder submersible pumps (one duty/one stand by) are used to transfer wastewater from the inlet station pit (Photo 2).

Photo 1: Bar Screen

Photo 2: Pit Station and Lifting Pumps

Wastewater from inlet pit first passes through a rotary screen for preliminary treatment. The influent flows through a cylindrical surface where solid particles are retained on the outside screen surface. The outlet flow from the rotary screen (Photo 3) is then stored in the header tanks (Photo 4). Header tanks act as a buffer zone to balance outlet flow from the rotary screen.

Photo 3: Rotary Screen

Photo 4: Header Tanks

The anaerobic baffled reactor (ABR) (Photo 5) is the first stage in secondary treatment of wastewater. Wastewater from header tank flows and distributed uniformly over the bottom of the first part of the ABR. The effluent then flows to the second part of the ABR via another distribution system. Piping systems are constructed and installed in the ABR to ensure uniform distribution of wastewater.

Photo 5: Anaerobic Baffled Reactor (ABR) Compartments

Denitrification takes place in the third part (Anoxic Zone) of the ABR, by circulating a portion of the clarified effluent containing nitrates from the setting tank. Two dedicated pumps (one duty/one stand by) are used for circulation.

The fourth and last part of the ABR is a sludge trap.

The second stage of secondary treatment is an activated sludge process (Photo 6), where aeration tank is the main chamber where biological aerobic treatment takes place. Fine bubbles of air are diffused into liquor by means of two air blowers (photo 7) (one duty/one stand by.) Oxygen transferred to sewage water to provide the bacteria with suitable environment for reproduction. To save operational costs, air blowers operated for six hours / day; i.e. activated sludge system was operated as intermittent aeration.

The settling tank (Photo 8), which is a part of the aeration tank, serves as clarifier and sludge circulation source. The aerated sewage flows to the inclined part of the settling tank, where the effluent faces a sudden drop in kinetic energy allowing enough time for the suspended particles to settle down to the bottom of the tank. Clear effluent continues and flows to storage tank.

Part of the settled matter is circulated back to aeration tank for continuous feed of activated sludge to maintain the volatile microorganism's concentration. Excess sludge in settling tank is transferred to sludge holding tank (Photo 9) for storage and truck disposal.

Photo 6: Activated Sludge System (AS)

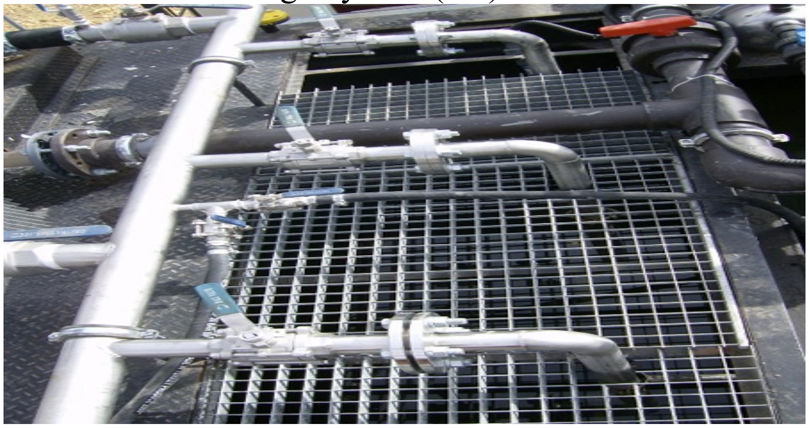

Photo 7: Aeration Tank and Air Blowers


Photo 8: Settling Tank


Photo 9: Sludge Holding Tank

The tertiary stage of treatment consists of filtration via a multi-media granule filter (Photo 10) and disinfection through ultraviolet (UV) unit (Photo 11) (UV unit is out of order). Clarified effluent from storage tank is pumped by two filter feed pumps (one duty/one stand by) through the filter. Filtered effluent is then directed to the UV system for disinfection.


Photo 10: Multi-Media Granule Filter


Photo 11: UV Disinfection Unit

The filter will be backwashed everyday by two backwash pumps (one duty/one stand by).

Disinfected water is then transferred to irrigation tank (photo 12), where treated water is stored. Water distribution for restricted irrigational purposes is achieved by two submersible irrigation pumps (one duty/one stand by).

Photo 12: Irrigation Tank

Design criteria for the plant are shown in table 3-1 below

Table 3-1: Design Criteria

Flow Rate	**10m3/day (0.42m3/hr)**
Peak Flow	**12m3/day (0.5m3/hr)**
BOD_5	**600mg/l**
COD	**1100mg/l**
TSS	**200mg/l**
TKN	**71mg/l**
Temperature Range	**12-28°C**

Aerobic sludge was seeded in the Aeration Tank, and anaerobic sludge was seeded in the ABR to enhance the biological process.

This research was divided into two experimental periods:

Experimental Period 1

Where dedicated pumps were not functioning; no recirculation of clarified effluent to the anoxic zone of ABR. This stage aimed to achieve nitrification. 10 samples, one sample every one or two weeks were taken from April 2008 to July 2008. The main goal of this experimental period is to monitor and evaluate the performance of the pilot plant under operation conditions where average flow = 10 m^3/d until the treatment plant reaches its steady state and achieves nitrification process. Monitoring of different locations and sampling analysis will represent the major task of the work.

Experimental Period 2

Where recirculating pumps were functioning. This stage aimed to achieve denitrification process and improve total Nitrogen removal. Five samples, one sample every one or two weeks were taken from November 2008 to January 2009. This experimental period represents the achieving of the denitrification process.

15 samples were taken weekly from different locations:

- Inlet pumping station (raw wastewater).
- ABR system (effluent from each section of ABR system (three sets)).
- Aeration tank.
- Settling tank.
- Irrigation tank (effluent).

Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Nitrogen compounds, Phosphorous compounds, Total Suspended Solids (TSS), Sludge Volume (SV), Sludge Volume Index (SVI) and Fecal Coliform (FC) were analyzed for each sample taken to asses the performance of the pilot plant. One sample from effluent was taken and analyzed to measure heavy and dissolved metals concentrations.

The data were analyzed statistically using Microsoft Excel program.

In this pilot plant, operational parameters for Al-Bireh WWTP will be the same as those used for Ein Sinya WWTP for the Activated Sludge System, which are:

- The Food to Microorganisms ratio (F/M) ranges between 0.05 -0.20 day^{-1}.
- Sludge Volume Index (S.V.I) ranges between 0.12 – 0.15 ml/mg.
- Mixed Liquor Suspended Solids (MLSS) in the Aeration Tank ranges between 3000 – 6000 mg/l.
- Sludge Age (SA) ranges between 20 – 30 days.
- Hydraulic Retention Time (HRT) ranges between 18-36 hours.
- Organic Loading Rate (OLR) ranges between 0.05 – 0.14 kg BOD_5/ m^3 .day.

3.3 Influent wastewater characteristics

One day samples from the influent were taken every two hours and mixed (composite sample). The main characteristics of the influent wastewater to the system are shown in Table 3-2 below:

Table 3-2: Influent Wastewater Characteristics

Parameter	**Influent Concentration**
pH	6,9
TS	2002
TSS	620
TDS	1364
VS	996
VSS	42
Faecal Coliform	$5 * 10^6$
SO_4^-	60,8
NH_4^+	59,8
PO_4^{-3}	17,1
CODtot	912,3
CODf	673,7
CODmem	434,8
CODss	238,6
CODcol	238,9
CODdis	434,8
BOD5	465
TKN	72,2

All parameters are in mg/l, except pH (no unit) and FC (cfu/100 ml)

3.4 Analytical methods

3.4.1 Chemical analysis

- Biochemical Oxygen Demand (BOD_5) was measured according to standard method (5 – day BOD_5 Test method).
- Chemical Oxygen Demand (COD) was measured according to standard methods (Closed Reflux, Titrimetric method).
- Total Kjeldal (TKN) was measured according to standard method (marco – Kjeldahl method).
- Ammonium Nitrogen (NH_4^+-N) was measured according to standard method (Nesslerization Method).
- Nitrate Nitrogen (NO_3^--N) was measured according to standard method (Electrode Method).
- Phosphorous Phosphour (PO_4^{-3}-P) was measured according to standard method 4500-PE ascorbic acid method.
- Heavy and dissolved metals were measured according to standard method 3500-C inductively coupled plasma method.

3.4.2 Physical analysis

- Total Suspended Solids (TSS) was measured according to standard method 2540 D.
- Total Dissolved Solids (TDS) was measured according to standard method 2540 C Total Dissolved Solids dried at 180 ^{0}C.
- Sludge Volume (SV) was measured according to standard method 2710 C.
- Sludge Volume Index (SVI.) was measured according to standard method 2710 D.
- pH was measured according to standard method 4500-HB electrometric method.
- Temperature was measured according to standard method 2550 B laboratory and field method.

3.4.3 Microbiological parameters

- Fecal Coliform (FC) was measured according to standard method (membrane filter procedure).

3.5 Calculations

- Organic Loading Rate (OLR) (kg BOD_5/m^3.day) = ($BOD_{5\ Inf.}$ x Q) / (AT Volume)
- Vol. COD Loading Rate (kg COD/m^3.day) = ($COD_{Inf.}$ x Q)/ (AT Volume)
- Sludge Volume Index (S.V.I) = Sludge Volume / $MLSS_{AT}$
- F/M Ratio = ($BOD_{5\ inf.}$ x Q) / (AT Volume x $MLSS_{AT}$)
- Total Nitrogen = TKN + NO_3 + NO_2
- TKN = NH_4^+ + Organic Nitrogen

Where, Q = 10 m^3/day

AT Volume = 12.64 m^3

CHAPTER FOUR

Results and Discussion

4.1 Results

Ein Sinya WWTP has been put in operation since December 2007. Start up period started with average flow rate of 10 m^3/day. 15 Samples from April 2008 to January 2009 were taken periodically and analyzed for five chemical parameters, five physical parameters and one microbiological parameter.

Last results showed kind of stability and steadiness in effluent concentrations and removal efficiencies for organic matter, nutrients and fecal coliform in treatment process. Also, results for operational parameters for the pilot plant showed stability and steadiness, which is an indication that pilot plant has reached its steady state.

Table 4-1 summarizes effluent concentrations and removal efficiencies in ABR and in the System for the parameters that had been measured.

The removal efficiencies (%) of ABR were: 54.63 for $BOD_{5,}$ 54.64 for COD, 92.95 for TSS, 21.03 for TKN, -6.54 for NH^+_4 and 2.36 logs for FC. The removal efficiencies (%) of AS were: 89.52 for $BOD_{5,}$ 89.57 for COD, 96.91 for TSS, 61.44 for TKN, 53.52 for NH^+_4, 46.5 for Total N and 2.87 logs for FC. The removal efficiencies (%) of the overall system were: 90.31 for $BOD_{5,}$ 90.42 for COD, 99.56 for TSS, 62.23 for TKN, 55.1 for NH^+_4, 48.62 for Total N and 4.72 logs for FC.

Results showed that there is no significant effect of sand filter tertiary unit on the removal efficiency of BOD_5, COD, Total N, TKN and NH^+_4 after AS system. So, tertiary unit effect could be neglected on those parameters, and it could be considered that effluent quality of AS and overall system is the same.

Results also showed that there is no significant effect of temperatures variation during the period of study on the pilot plant efficiency.

Table 4-1: Research results for the effluent concentrations and removal efficiencies (%) during the whole period of experiment in ABR, AS and in the system. All parameters are in (mg/l), except pH (no unit) and FC (log). Standards deviations are presented between brackets:

Parameter	Samples #	Influent Concentration		ABR Effluent Concentration		AS Effluent Concentration		System Effluent Concentration		ABR Removal Efficiency (%)		AS Removal Efficiency (%)		System Removal Efficiency (%)	
		Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
pH	15	6.9		-	-	6.9-7.6	7.26(0.18)	-	-	-	-	-	-	-	-
BOD (mg/l)	15	98-630	258 (123.72)	41-236	117(69.17)	8-54	27(16.95)	7-51	25(16.23)	9.27-93.5	54.63(22.22)	72.54-96.31	89.52(8.82)	73.1-96.94	90.31(8.83)
COD (mg/l)	15	165-1067	438(209.76)	69-400	199(117.19)	13-91	46(28.75)	11.7-86	44(28.46)	9.21-93.50	54.64(22.19)	72.55-96.31	89.57(8.82)	73.16-97.04	90.42(8.81)
TSS (mg/l)	15	200-3500	1363(1113)	14-200	96(49.54)	12-76	42.13(19.23)	4-8	6(1.85)	68.35-99.05	92.95(7.91)	81.90-99.25	96.91(5.05)	98.00-99.88	99.56(0.58)
TKN (mg/l)	15	42-118	93.20(18.42)	53-112	73.6(16.41)	7-84	35.94(19.81)	6.8-82	35.1(19.87)	-33.33-38.71	21.03(18.01)	14.29-91.94	61.44(22.29)	15-92	62.23(21.9)
NH4 (mg/l)	15	12.66-53.39	28.83(15.01)	15.25-59.73	30.71(13.96)	1.71-34.60	13.40(10.59)	1.57-32.48	11(10.72)	-70.62-17.92	-6.54(20.16)	-34.25-90.23	53.52(33.91)	-33.19-91.90	55.1(31.13)
Total N (mg/l)	5	98-117.6	105(8.04)	98-117.6	105(8.04)	39.7-62.5	56(9.83)	39.4-62.1	55.3(9.8)	0	0	36.22-62.69	46.45(10.01)	34.53-61.05	48.62(9.21)
PO4 (mg/l)	14	5.1 - 20.3	9.39(4.59)	5.21 - 21.78	10.27(5.05)	3.55 - 25.46	9.23(5.79)	3.32 - 24.7	8.98(5.6)	-28.33-9.54	-9.34(9.7)	-25.42-49.65	1.73(19.42)	-24.19-50.12	1.82(19.13)
FC (Log)	14	7.25-8.7	7.85(0.41)	4.00-6.41	5.5(0.62)	3.90-5.96	4.99(0.56)	2.00-3.89	3.14(0.62)	1.58-4.00	2.36(0.55)	2.13-3.57	2.87(0.44)	4.37-5.58	4.72(0.32)

4.1.1 Operational parameters

4.1.1.1 Volumetric COD loading rate & Organic Loading Rate (OLR):

Table 4-2 and Figure 4-1 below show the Volumetric COD Loading Rate and Organic Loading Rate of the AS system

Table 4-2: Volumetric COD Loading Rate and Organic Loading Rate of the AS system

Sample No.	**Vol. COD Load. Rate (kg COD/m^3.day)**	**OLR (kg BOD$_5$/m^3.day)**
1	0,29	0,17
2	0,31	0,18
3	0,19	0,11
4	0,17	0,10
5	0,08	0,05
6	0,25	0,15
7	0,31	0,18
8	0,13	0,08
9	0,083	0,05
10	0,077	0,05
11	0,073	0,04
12	0,132	0,08
13	0,055	0,03
14	0,091	0,05
15	0,098	0,06
Average	0,16	0,09

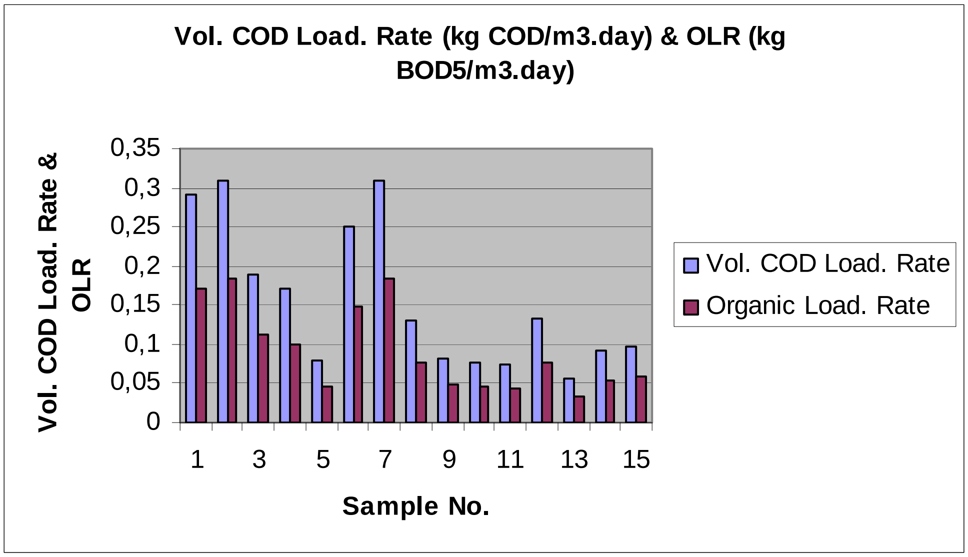

Figure 4-1: Volumetric COD Loading Rate and Organic Loading Rate of the AS system

4.1.1.2 Sludge Volume (SV), Sludge volume Index (SVI), Mixed Liquor Suspended Solids (MLSS) and F/M ratio

Table 4-3 below shows S.V., S.V.I, MLSS and F/M ratio:

Table 4-3: SV, SVI, MLSS and F/M Ratio

Sample No.	MLSS (mg/l)	S.V (ml/l)	S.V.I (ml/mg)	F/M (day^{-1})
1	1766	250	0,14	0,096
2	1356	300	0,22	0,135
3	2796	350	0,125	0,04
4	2620	300	0,114	0,037
5	2900	320	0,11	0,017
6	3916	500	0,12	0,037
7	3500	450	0,13	0,053
8	3844	520	0,135	0,02
9	3736	450	0,12	0,013
10	3500	450	0,128	0,013
11	2860	430	0,15	0,015
12	2920	420	0,14	0,026
13	3040	440	0,144	0,011
14	2850	420	0,147	0,012
15	2920	420	0,14	0,026

While Figures 4-2, 4-3, 4-4 and 4-5 show MLSS in AS, S.V. in AT, S.V.I in AT and F/M ratio in AT, respectively:

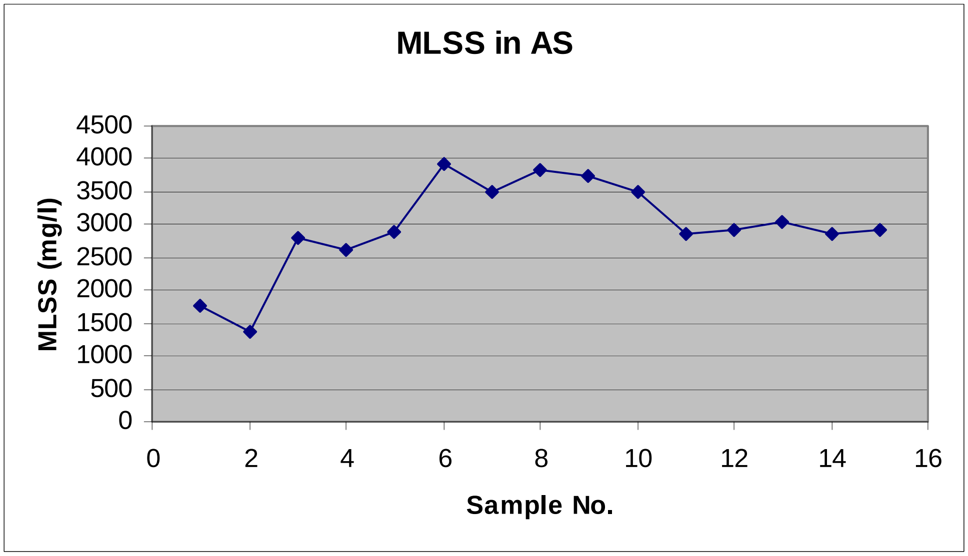

Figure 4-2: Mixed Liquor suspended Solids (MLSS) in the Aeration Tank (AT)

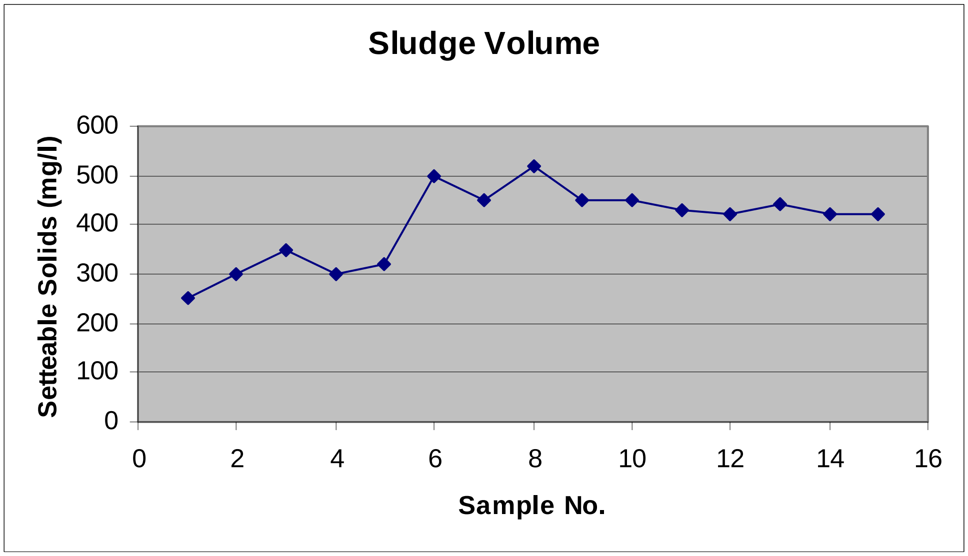

Figure 4-3: Sludge Volume (SV) in the Aeration Tank (AT)

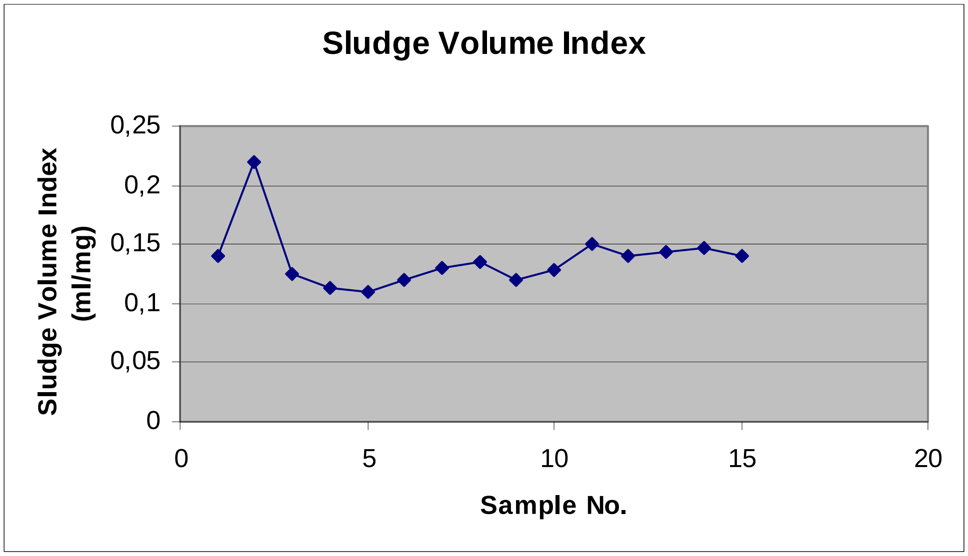

Figure 4- 4: Sludge Volume Index (SVI) in the Aeration Tank (AT)

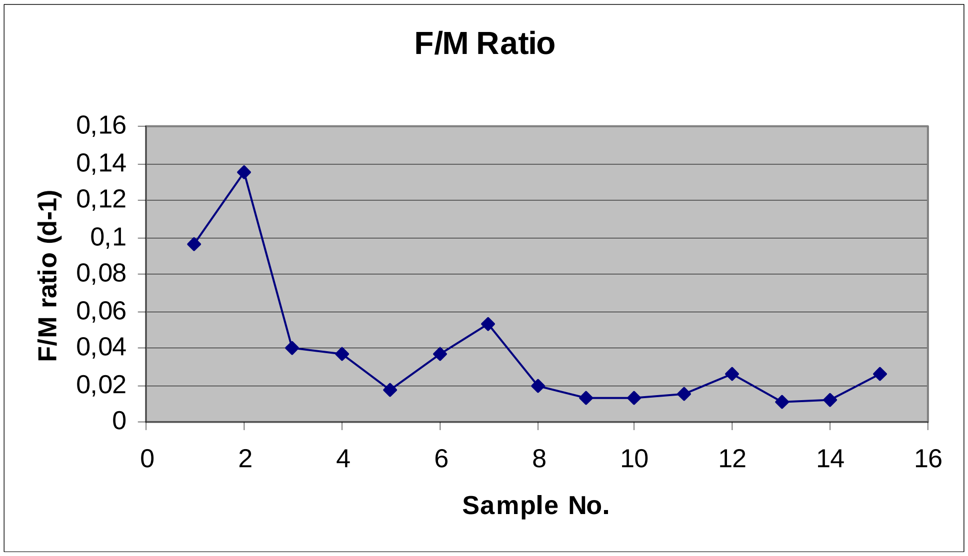

Figure 4-5: F/M Ratio in the Aeration Tank (AT)

4.1.2 Environmental conditions

4.1.2.1 pH

Values of pH for effluent were measured during the experiment period. pH values were consistent and ranged from 6.9 – 7.6, with average pH values of (7.26 ± 0.18).

Results for pH are shown below in figure 4-6.

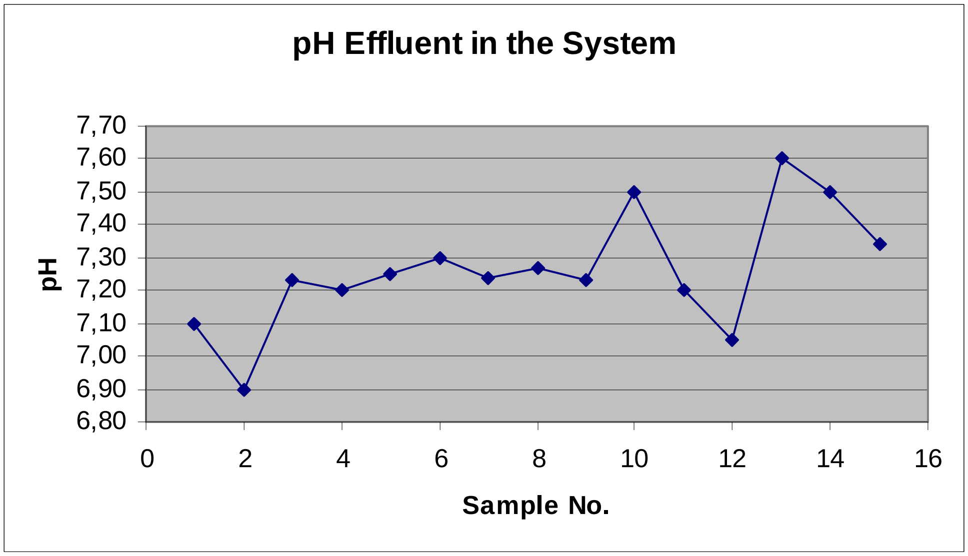

Figure 4-6: system effluent pH

4.1.2.2 Temperature (^{0}C):

Temperatures of influent raw wastewater were measured. Temperature values ranged from 12 – 27 ^{0}C with average temperature values of (20.13 ± 5.5) ^{0}C. Variation of temperature was due to the fact that 10 samples were taken during summer (dry weather), and 5 samples were taken during winter (wet weather). Values of temperatures measured during summer and winter are shown in figures 4-7 and 4-8.

For samples taken during summer (from 1st April to 30th July, 2008), mean temperature was (23.29 ± 3.51) ^{0}C. Extreme values observed were 18 ^{0}C and 27 ^{0}C.

For samples taken during winter (from 29th November, 2008 to 3rd January, 2009), mean temperature was (13.8 ± 1.75) ^{0}C. Extreme values observed were 12 ^{0}C and 16 ^{0}C.

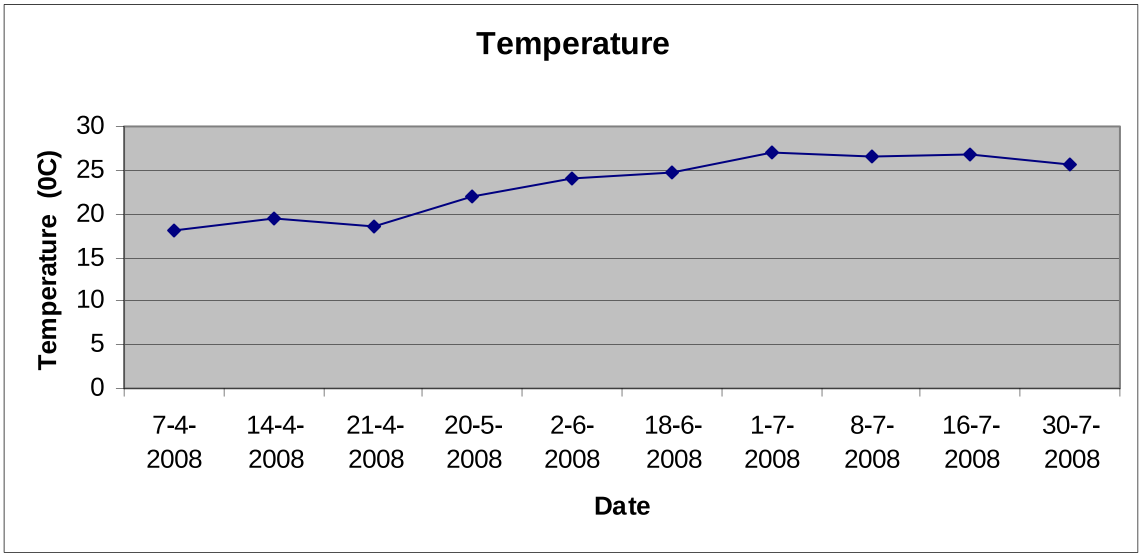

Figure 4-7: Temperatures of influent raw wastewater during summer (^{0}C)

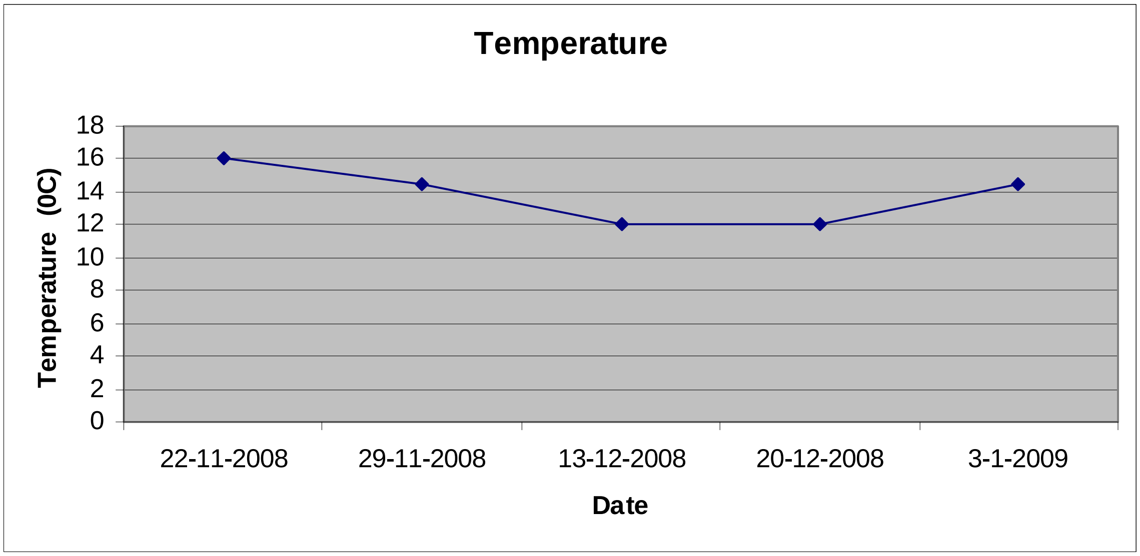

Figure 4-8: Temperatures of influent raw wastewater during winter (^{0}C)

4.1.3 Organic removal

4.1.3.1 BOD_5 removal efficiency

BOD_5 influent and effluent concentrations in ABR and in AS are shown in Figure 4-9. Average influent concentration was (258 ± 123.72) mg/l. Average effluents concentrations were (117 ± 69) and (27±17) mg/l in ABR and AS, respectively.

Minimum and maximum influent concentrations were (98, 630) mg/l. Minimum and maximum effluent concentrations were (41, 8) and (236, 54) mg/l for ABR and AS respectively.

Figure 4-10 shows BOD_5 removal efficiencies in ABR and in AS. Average removal efficiencies were (55±22) and (90 ± 9) % for ABR and AS, respectively. Minimum and maximum removal efficiencies were (9, 72.5) and (93.5, 96.3) % for ABR and AS, respectively.

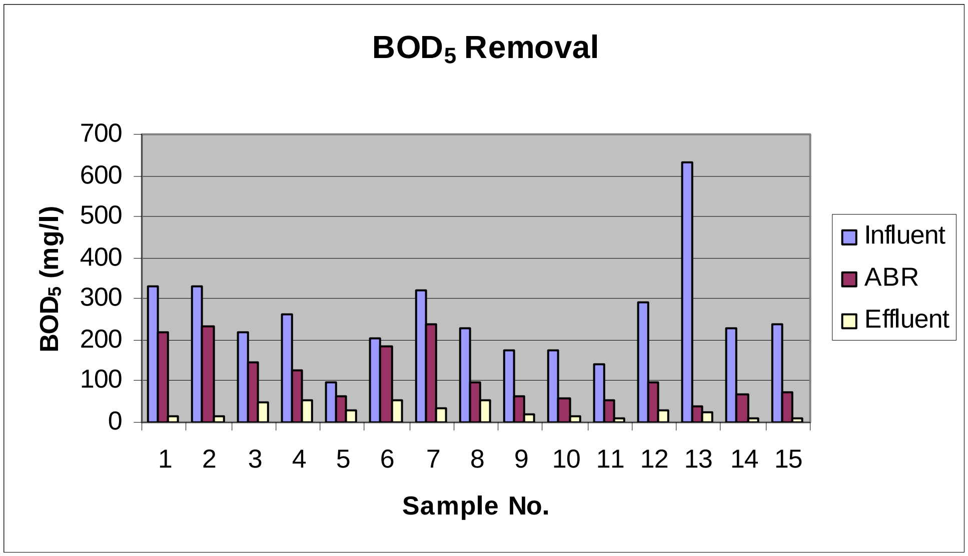

Figure 4-9: BOD_5 influent, ABR effluent and AS effluent (mg/l)

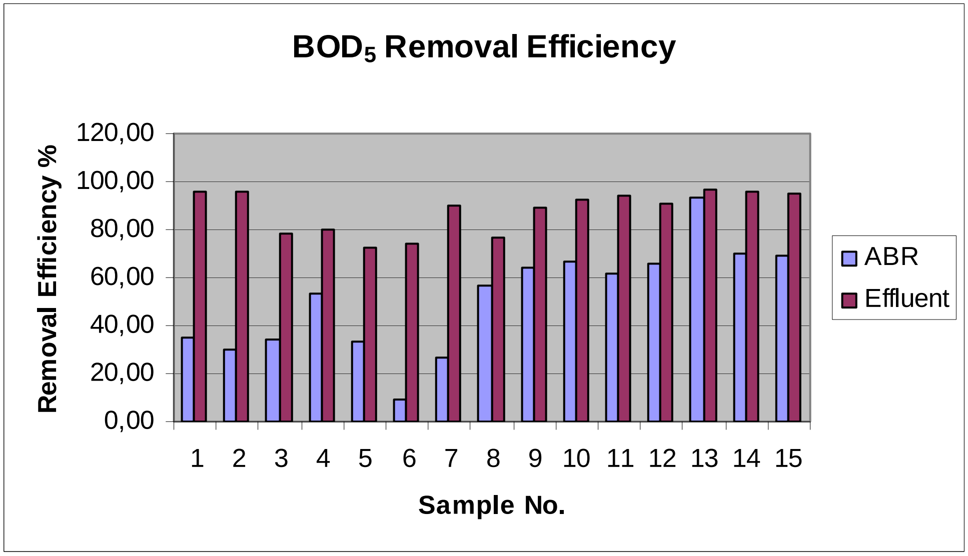

Figure 4-10: BOD_5 removal efficiency (%) in ABR and in AS

4.1.3.2 COD removal efficiency

Figure 4-11 shows COD influent and effluent concentrations in ABR and AS. An average influent concentration was (438 ± 209.76) mg/l. Average effluent concentrations were (199 ± 117) and (46 ± 29) mg/l for ABR and AS, respectively.

Minimum and maximum influent concentrations were (165, 1067) mg/l. Minimum and maximum effluent concentrations were (69, 13) and (400, 91) mg/l for ABR and AS respectively.

COD removal efficiencies in ABR and AS are shown in Figure 4-12. Results showed average removal efficiencies (54.64 ± 22.19) and (89.57 ± 8.82) % for ABR and AS, respectively. Minimum and maximum removal efficiencies were (9.21, 72.55) and (93.5, 96.3) % for ABR and AS, respectively.

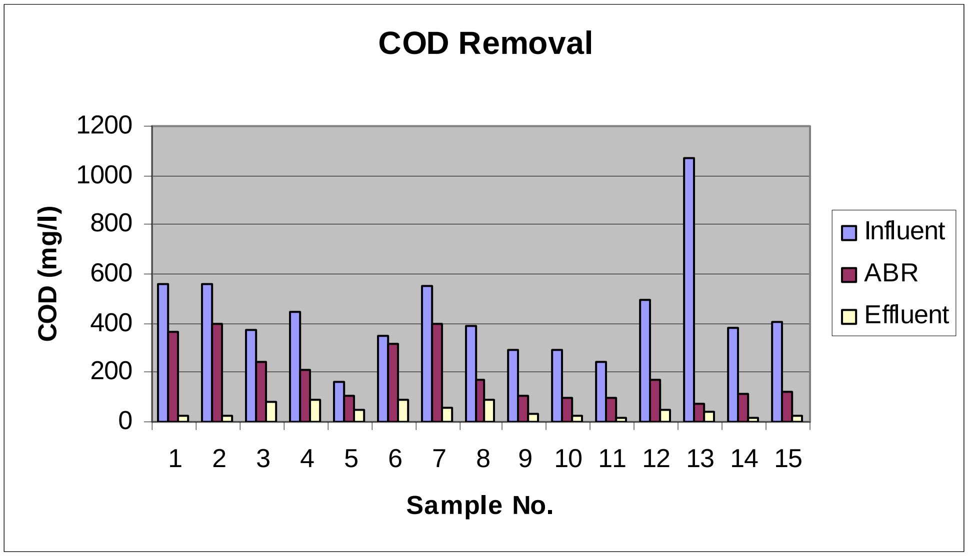

Figure 4-11: COD Influent, ABR Effluent and AS Effluent (mg/l)

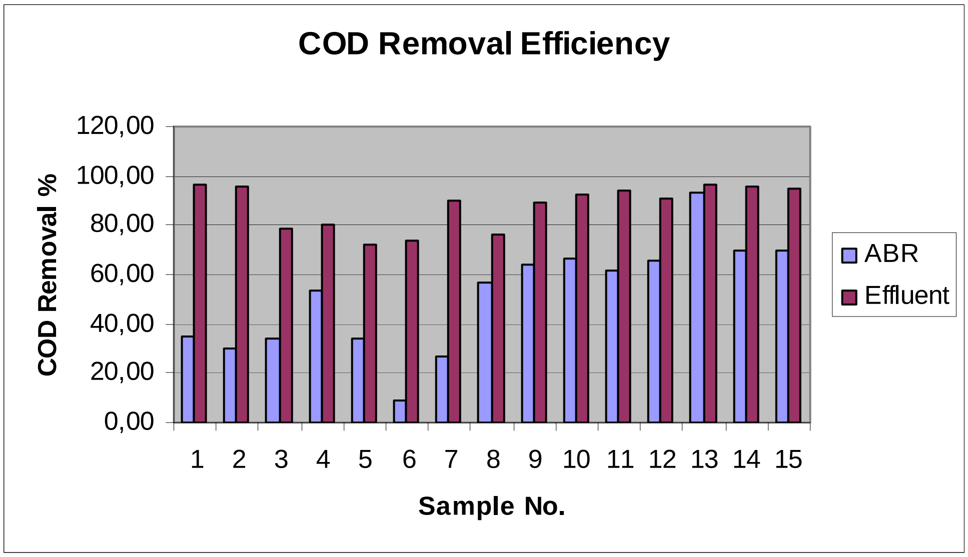

Figure 4-12: COD removal efficiency (%) in ABR and in AS

4.1.3.3 TSS removal efficiency

TSS influent and effluent concentrations in ABR, AS and the overall system are shown in Figure 4-13. An average influent concentration was (1363 ± 1113.91) mg/l. Average effluents concentrations were (96 ± 49.54), (42.13 ± 19.23) and (6 ± 1.85) mg/l in ABR, AS and overall system, respectively.

Minimum and maximum influent concentrations were (200, 3500) mg/l. Minimum and maximum effluent concentrations were (14, 200), (12, 76) and (4, 8) mg/l for ABR, AS and overall system, respectively.

Figure 4-14 shows TSS removal efficiencies in ABR, AS and overall system.

Average removal efficiencies were (92.95 ±7.91), (96.91 ± 5.05) and (99.56 ± 0.58) % for ABR, AS and overall system, respectively. Minimum and maximum removal efficiencies were (68.35, 99), (81.90, 99.25) and (98, 99.88) % for ABR, AS and overall system, respectively.

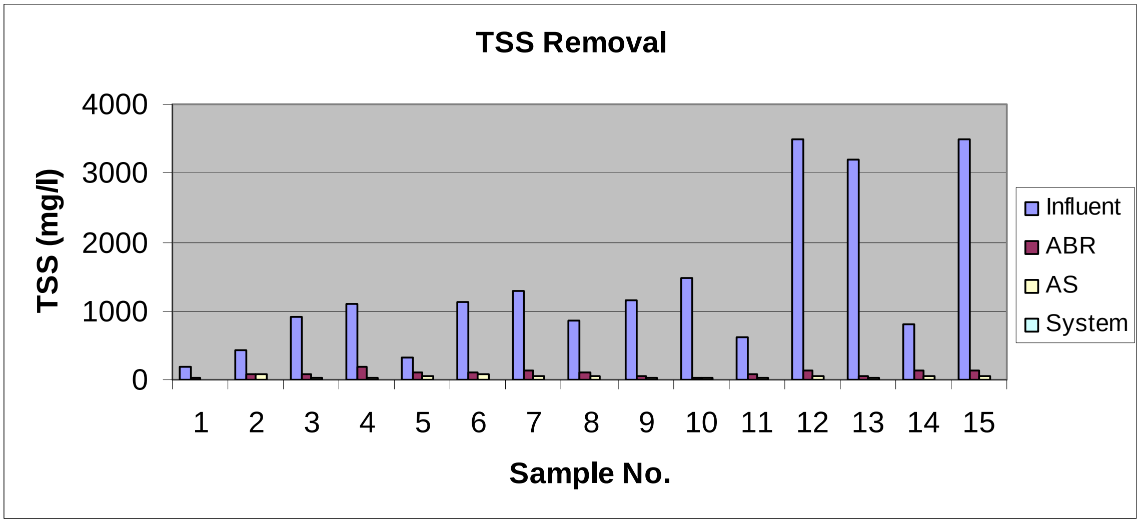

Figure 4-13: TSS influent, ABR, AS and overall system effluent (mg/l)

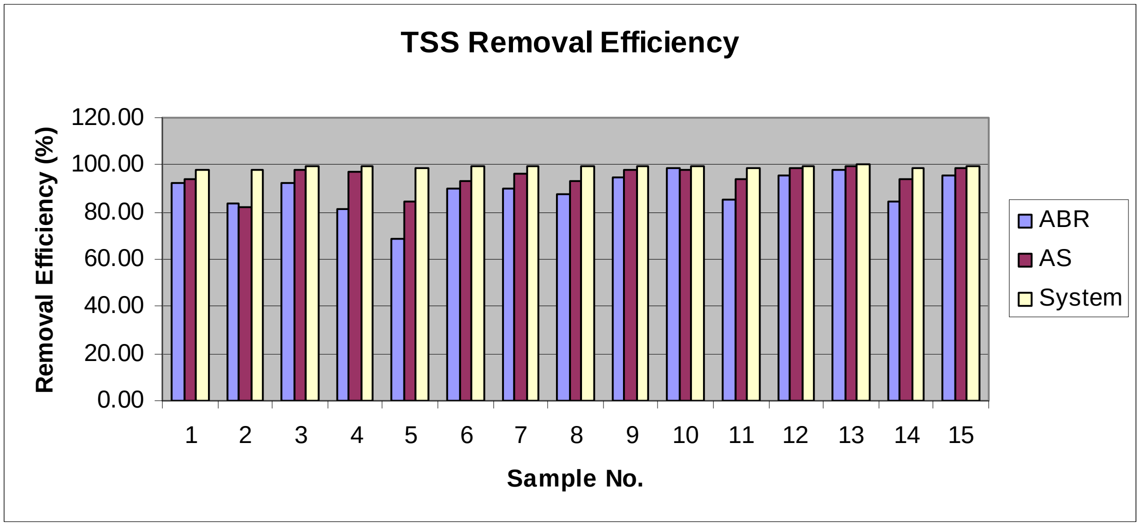

Figure 4-14: TSS removal efficiency (%) in ABR, AS and overall system

4.1.3.4 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) concentrations of the overall system effluent were measured using electrodes, to test if effluent quality could be used for irrigational purposes or not. Measurements showed TDS concentrations of less than 1200 mg/l for all samples taken and analyzed during experimental period. Extreme values were 1110 mg/l and 1190 mg/l.

4.1.4 Nitrogen removal

4.1.4.1 NH_4^+ removal efficiency

Figure 4-15 shows NH_4^+ influent and effluent concentrations in ABR and AS. An average influent concentration was (28.83 ± 15.01) mg/l. Average effluent concentrations were (30.71 ± 13.96) and (13.4 ± 10.59) mg/l for ABR and AS, respectively. Minimum and maximum influent concentrations were (12.66, 56.39) mg/l.

Minimum and maximum effluent concentrations were (15.25, 1.71) and (59.73, 34.6) mg/l for ABR and AS respectively.

NH_4^+ concentration had increased in ABR. Figure 4-16 shows that NH_4^+ average effluent concentration in ABR had increased by 6.54 %. While, NH_4^+ average removal efficiency in AS was (53.52 ± 33.91) % with maximum removal efficiency of 90.23 %.

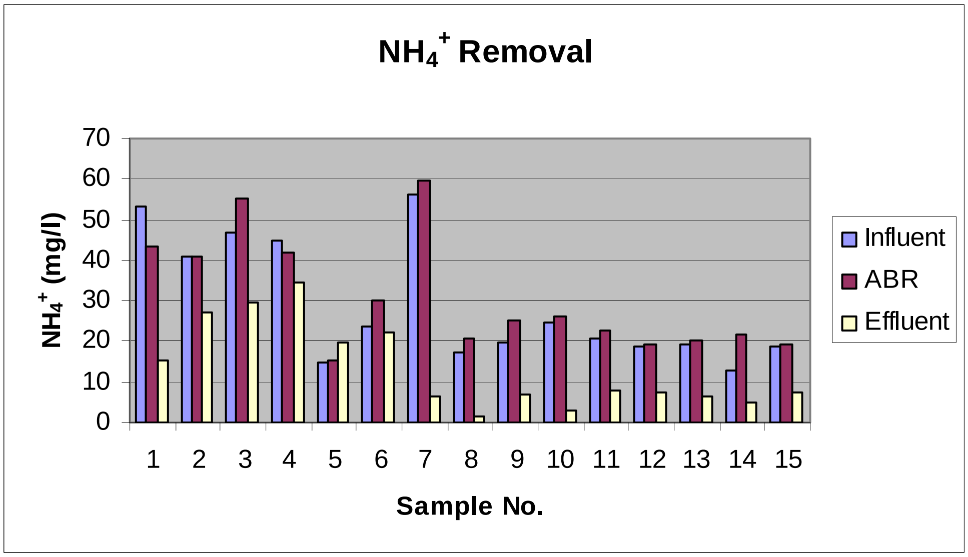

Figure 4-15: NH_4^+ influent, ABR effluent and AS effluent (mg/l)

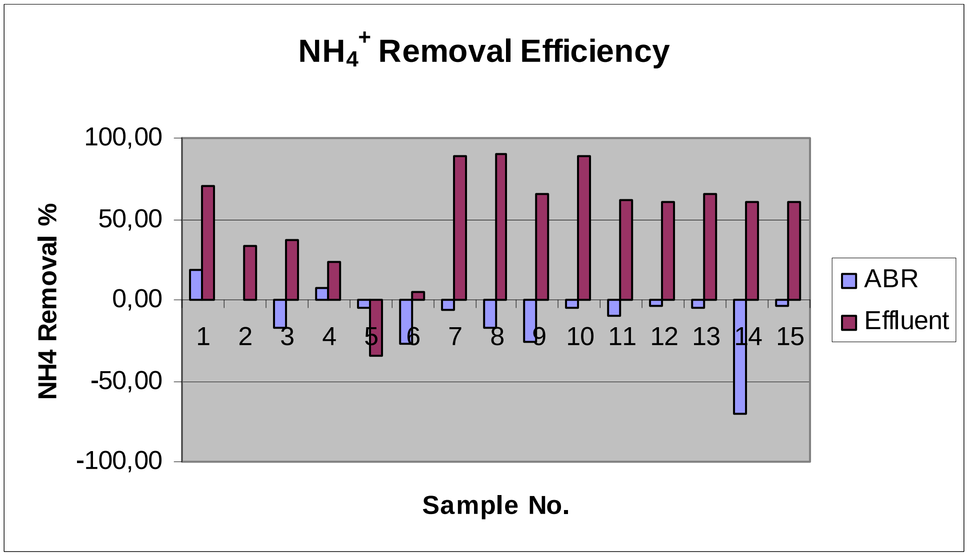

Figure 4-16: NH_4^+ Removal efficiency (%) in the ABR and in AS

4.1.4.2 TKN removal efficiency

Figures 4-17 and 4-18 show TKN influent concentration, effluent concentrations and removal efficiencies in ABR and AS. An average influent concentration was

(93.2 ± 14.42) mg/l. Average effluent concentrations were (73.6 ± 16.41) and (35.94 ± 19.81) mg/l for ABR and AS, respectively.

Minimum and maximum influent concentrations were (42, 118) mg/l. Minimum and maximum effluent concentrations were (53, 7) and (112, 84) mg/l for ABR and AS, respectively.

ABR had relatively low TKN removal efficiency; (21.03 ± 18.01) % with minimum and maximum removal efficiency of -33.33% and 38.71%. The average removal efficiency for AS was (61.44 ± 22.29) %, with minimum removal efficiency of 14.29 %, while maximum removal efficiency reached 91.94%.

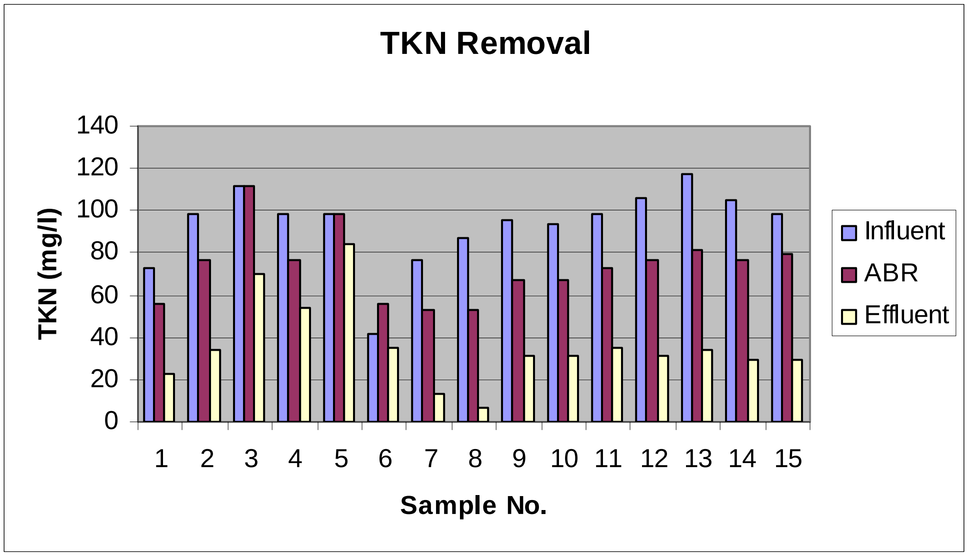

Figure 4-17: TKN influent, ABR effluent and AS effluent (mg/l)

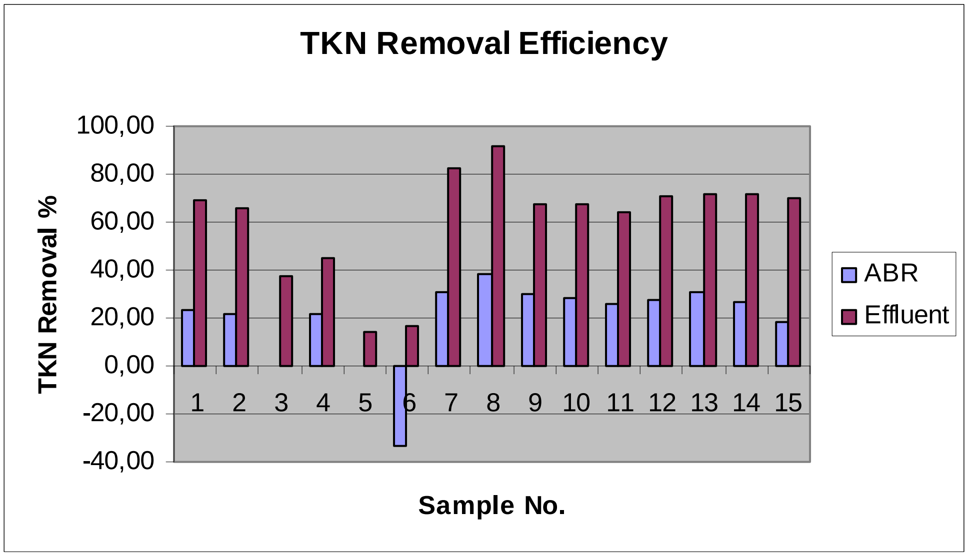

Figure 4-18: TKN removal efficiency (%) in the ABR and in AS

4.1.4.3 Total nitrogen removal

Due to technical issues related to the installation of recirculation pumps aimed at recirculation of nitrified flow to the anoxic zone in the ABR in order to achieve denitrification, total nitrogen removal tests were divided into two experimental periods:

1- First experimental period, where dedicated pumps were not functioning; no recirculation of clarified effluent to the anoxic zone of ABR. This stage aimed to achieve nitrification. 10 samples, one sample every one or two weeks were taken and analyzed for NO_3^- concentrations.
   Figure 4-19 shows the Nitrate concentrations, and therefore the development of the nitrification process.
2- Second experimental period, where recirculation pumps were functioning. This stage aimed to achieve denitrification process and improve total Nitrogen removal. 5 samples, one sample every one or two weeks were taken and analyzed for NO_3^- concentrations.

Figure 4-20 shows the NO_3^- effluent concentrations. Values range from (8.9 – 32.6) mg/l with average value of (24.36 ± 9.14) mg/l.

Figure 4-21 shows the total nitrogen removal efficiency. The System achieved nitrogen removal of (46.5 ± 10) %. Minimum and maximum total nitrogen removal efficiencies were 36.22 % and 62.69%, respectively.

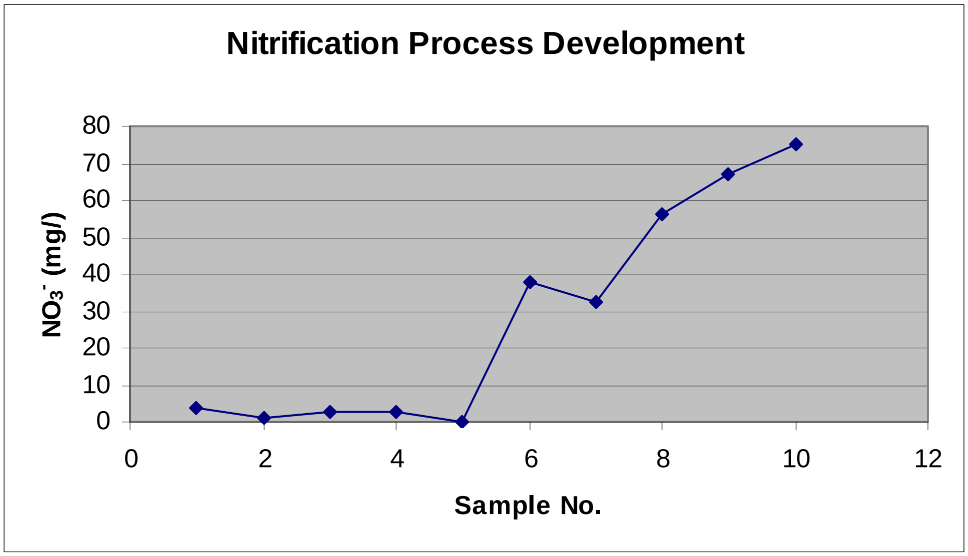

Figure 4-19: Nitrification process development (experimental period 1)

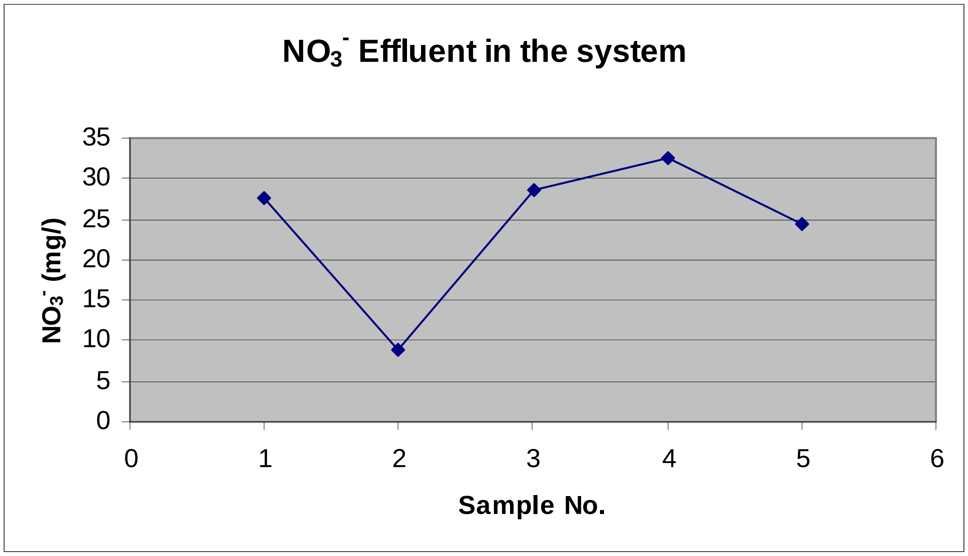

Figure 4-20: No_3^- effluent concentration (mg/l) (experimental period 2)

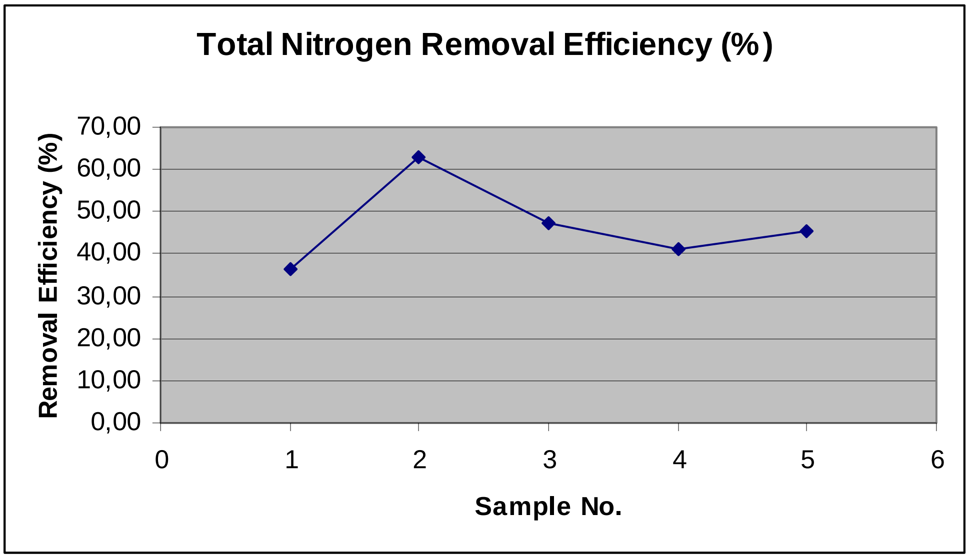

Figure 4-21: Overall system nitrogen removal efficiencies (%)

4.1.5 PO_4^{-3} removal efficiency

Concentrations of PO_4^{-3} influent and effluents in ABR and AS are shown in figure 4-22. Average PO_4^{-3} influent concentration was (9.39 ± 4.59) mg/l. Average PO_4^{-3} effluent concentrations were (10.27 ± 5.05) and (9.23 ± 5.79) mg/l for ABR and AS, respectively.

No PO_4^{-3} removal had been occurring in ABR and AS. Figure 4-23 shows that PO_4^{-3} effluent concentration had increased in ABR by 9.34 % on average. For AS, PO_4^{-3} effluent concentration had slightly decreased by 1.73 % on average.

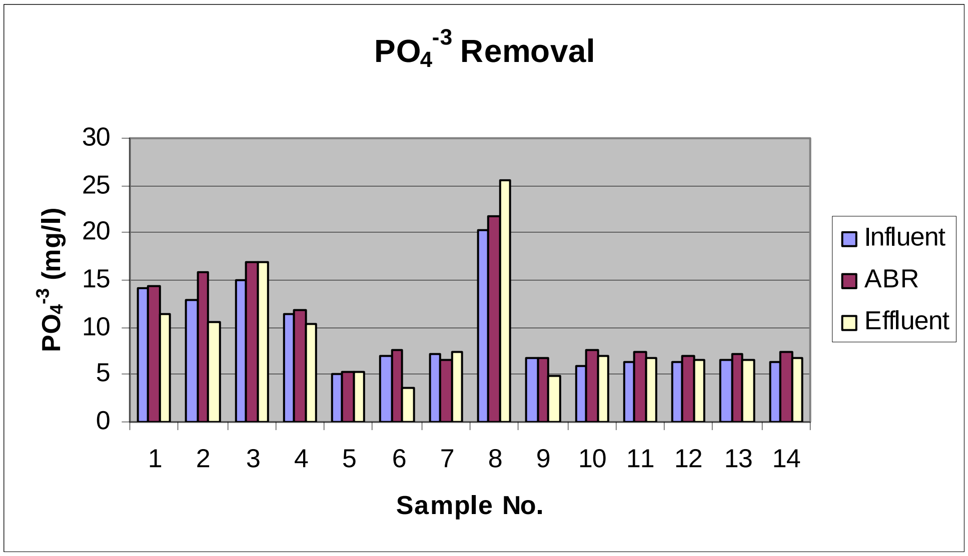

Figure 4-22: PO_4^{-3} influent, ABR effluent and AS effluent (mg/l)

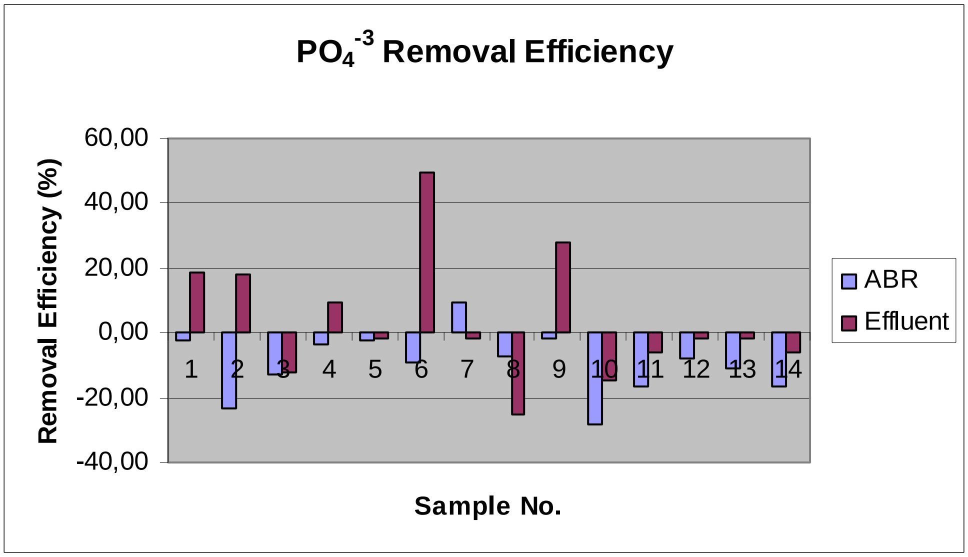

Figure 4-23: PO_4^{-3} removal efficiency (%) in the ABR and AS

4.1.6 Fecal Coliform removal

Average log removals of pathogen indicators were (2.36 ± 0.55), (2.87 ± 0.44) and (4.72 ± 0.32) log in ABR, AS and the whole system, respectively, taking into consideration that UV disinfection unit is out of order.

Minimum and maximum log removals were 1.58 and 4 in ABR, 2.13 and 3.57 in AS and 4.37 and 5.58 in system.

Results for ABR, AS and the whole system FC removal are shown in figure 4-24 below

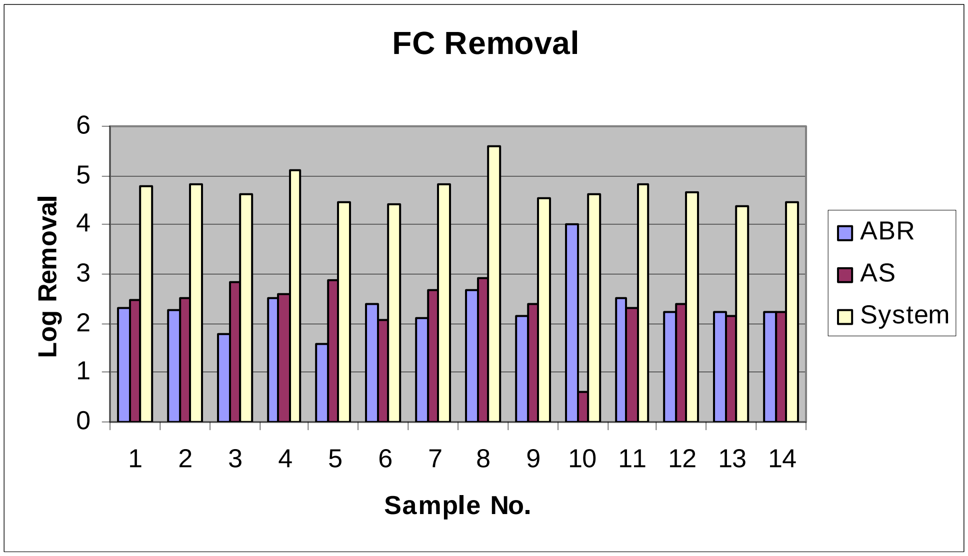

Figure 4-24: FC removal efficiency (Log removal) in the ABR, AS and the overall removal of the System

4.1.7 Dissolved and heavy metals

Concentrations of dissolved metals in the plant effluent were measured. Tables 4-4 and 4-5 show the concentrations of major dissolved metals namely: calcium (Ca^{+2}), potassium (K^{+}), magnesium (Mg^{+2}) and sodium (Na^{+}) and heavy metals namely: zinc (Zn^{+2}), chromium (Cr^{+}), cadmium (Cd^{+2}) and lead (Pb^{+4}). Tables also show the threshold values in effluents to be discharged in Wadis according to Palestine Standards Institute (PSI).

Table 4-4: Concentrations of major dissolved metals in the plant effluent and threshold values according to PSI standards

Element	Effluent Sample (mg/l)	Limits (mg/l)
Ca^{+2}	77	200
K^{+}	41	10
Mg^{+2}	37.31	60
Na^{+}	148	200

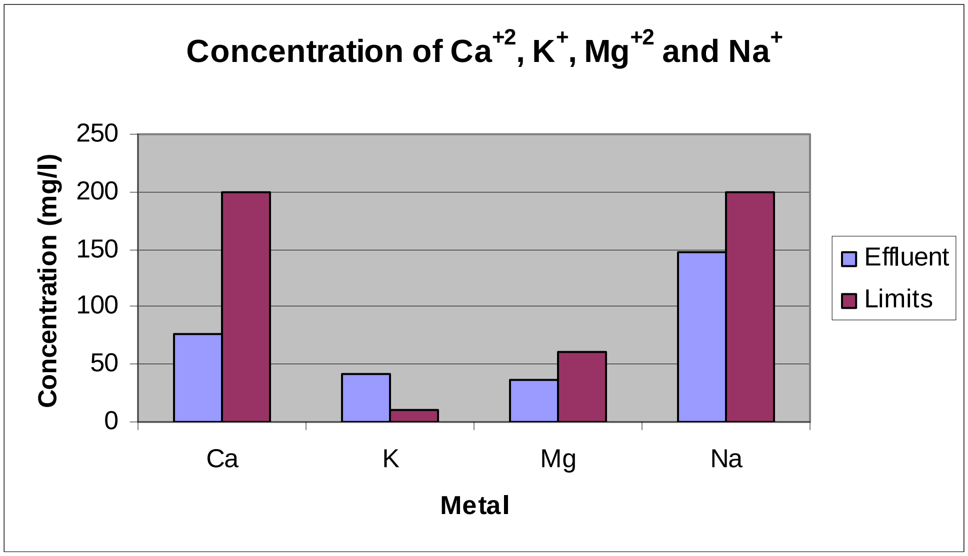

Figure 4-25: Concentrations of major dissolved metals in the plant effluent

Table 4-5: Concentrations of heavy metals in the plant effluent and threshold values according to PSI standards

Element	Effluent Sample (mg/l)	Limits (mg/l)
Zn^{+2}	0.13	2
Cr^{+}	0.00738	0.1
Cd^{+2}	0.00293	0.01
Pb^{+4}	0.023	0.1

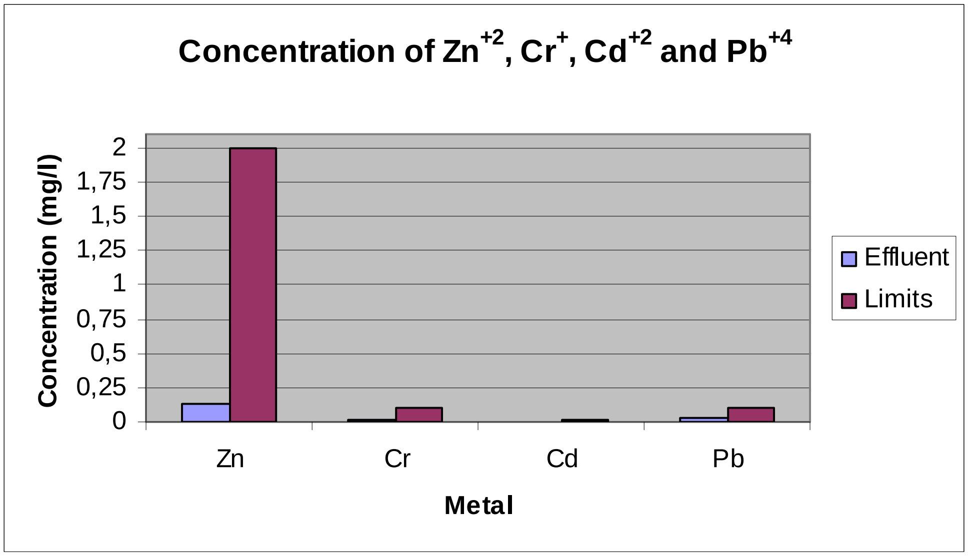

Figure 4-26: Concentrations of heavy metals in the plant effluent

4.1.8 Summary of overall removal efficiencies

Figure 4-27 illustrates average removal efficiencies (%) for the whole measured parameters.

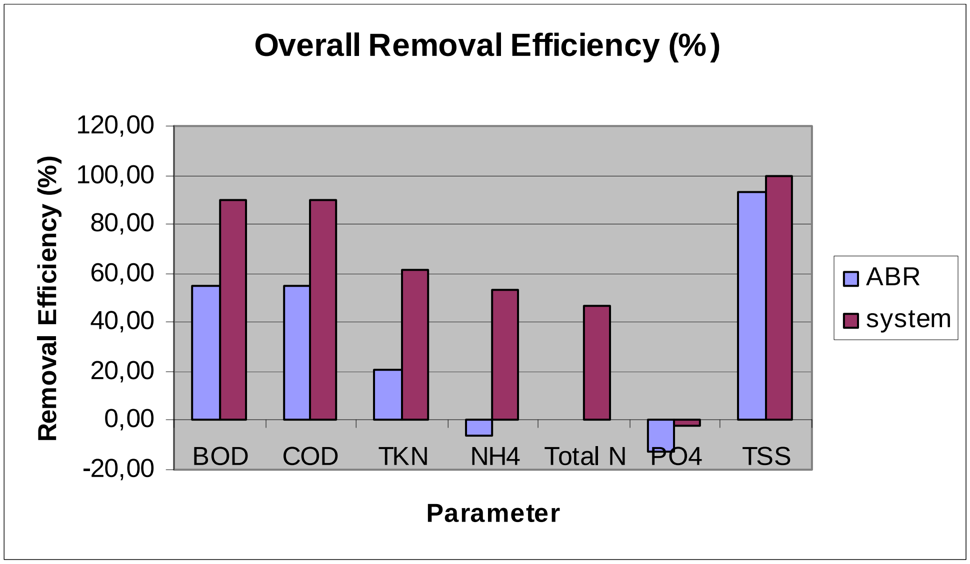

Figure 4-27: Overall removal efficiency (%) in the ABR and in the system

4.2 Discussion

As mentioned earlier, results of samples analyzed during winter were not significantly different. Results showed the enhancement and development of biological process in both ABR and AS during the experiment period. Removal efficiencies had increased gradually then stabilized. Also, effluent quality was getting better and better till it stabilized.

Removal efficiency was not affected by the change in temperatures; results showed the same performance of the treatment plant during the hot and wet weather flow. So, changing of temperatures effect could be ignored.
Also, as mentioned earlier, effect of sand filter tertiary unit on removal efficiency could be ignored except for TSS and FC.

Results of Ein Sinya pilot plant were compared to those in research mentioned above and with international and local standards to test if the effluent quality meets the requirements for reuse or not.

4.2.1 Operational parameters for Ein Sinya WW treatment pilot plant

BOD_5 removal efficiency had increased in ABR; this explains the low values of OLR and volumetric COD loading rate entering Aeration Tank and assures good ABR removal efficiency of organic matter.

All operational parameters except F/M ratio are within acceptable limits, which assure good performance of the treatment plant.
F/M ratio didn't reach desired values to the fact that approximately 65% of BOD_5 load was removed in ABR and entering Aeration Tank with low values.

No need for emptying excess sludge, Sludge Volume values stay within acceptable range. This is because of the fact mentioned above that high percentage of organic load and suspended solids had been removed in ABR. This could be an advantage of this combined system due to the fact that there is no sludge management plan or strategy in Palestine, and excess sludge represents major environmental problem.

From previous tables shown above, figures and results, desired operational parameters for Ein Sinya Wastewater Pilot Plant at HRT = 2.5 day for ABR and HRT = 30 hours for AS could be summarized as follow:
For ABR:

- OLR = 0.16 ± 0.05 kg COD / m^3 .day

For Activated Sludge System:

- OLR = 0.16 ± 0.09 kg COD / m^3 .day
- MLSS = 2850 – 3100 mg / l
- S.V. = 400 – 450 mg/l

- S.V.I. = 0.14 – 0.15 ml / mg
- F/M = 0.01 – 0.03 day^{-1}

4.2.2 Organic removal

4.2.2.1 BOD_5 removal

Results for samples taken during November to January showed a kind of stability in removal efficiency (%) and effluent quality (mg/l) for both ABR and AS. System removal efficiency and effluent characteristics are better than those obtained from Al-Bireh WWTP.

System effluent values meet international and local standards for reuse in irrigation.

4.2.2.2 COD removal

The ABR removal performance in Ein Sinya is comparable with other ABR systems implemented in South Africa by (Pillay et al., 2004) and modified ABR in England by (H. Yu, and G. K. Anderson, 1995). ABR system in Ein Sinya showed average removal efficiency of 54.64% with average effluent concentration of 199 mg/l, and last results analyzed during November to January showed removal efficiency around 65%. ABR system in South Africa showed removal efficiency between 58% and 72% with average effluent concentration of 192 mg/l. Results were approximately similar taking into consideration that HRT and Flow Rate ($Q_{inf.}$) for ABR system in South Africa, 2004 are less than those in Ein Sinya ABR system (22 h, 3.3 m^3 / day and 2.5 days, 10 m^3 / day, respectively). On the other hand, influent COD concentration in South Africa was higher than it in Ein Sinya ABR system (716 and 438 mg/l, respectively).

Modified ABR system in England, 1995 showed variable COD removal efficiencies depending on variable HRT (from 2 h to 10 h) and OLR (from 0.92 kg

COD / m^3.day to 2.43 Kg COD / m^3.day.) Results showed that as long as HRT was maintained, removal efficiency was getting better. Removal efficiency ranged from 83.5% at HRT = 10 h to 52.3% at HRT = 2 h.

Results of Ein Sinya ABR were also compared with results from UASB system implemented in Palestine by (Al-Shayah and Mahmoud, 2008). UASB system showed COD removal efficiency of 58% with average effluent concentration of 493 mg/l at HRT = 4 days. The average organic removal in Ein Sinya ABR system found to be 54%, knowing that last samples showed removal efficiency higher than 60% at HRT= 2.5. It is important to mention that the organic matter influent concentration and OLR for tested UASB in Al-Bireh WWTP are higher than those in Ein Sinya ABR system (1185 mg/l, 0.3 kg COD/m^3.day and 438 mg/l, 0.17 kg COD/m^3.day, respectively).

Comparison between Ein Sinya ABR system and other ABR and UASB systems used for pretreatment should be carried out under the same conditions, operational parameters and the same wastewater characteristics to decide if ABR system could be used in Palestine as a low cost domestic wastewater treatment system or not. Effluent quality in Ein Sinya ABR system or mentioned before systems did not meet the requirements for reuse in irrigation.

AS removal performance in Ein Sinya is comparable with AS removal performance in Al-Bireh WWTP (Zimmo, 2008), the most successive WWTP in Palestine. HRT and OLR for Ein Sinya AS system and Al-Bireh AS system were the same (30 h, 0.09 kg BOD_5/ m^3 .day and 18 – 36 h, 0.05 – 0.14 kg BOD_5/ m^3 .day, respectively). Ein Sinya AS system showed average removal efficiency of 89.57% with extreme values of 13 and 91 mg/l, while AS system in Al-Bireh showed average removal efficiency of 89% with extreme values of 53 and 112 mg/l. So, AS system in Ein Sinya could be better than AS system in Al-Bireh.

Ein Sinya overall removal performance is comparable with ANANOX system implemented by (Garuti et al., 1998) in Italy. Average influent COD concentration in Ein Sinya and Italy were 438 and 598 mg/l, respectively. Last results analyzed during November to January in Ein Sinya ABR system showed removal efficiency around 65% with average COD effluent concentration of 199 mg/l, while ANANOX system showed maximum ABR removal efficiency of 74% with effluent concentration of 152.3 mg/l. Ein Sinya overall system showed average removal efficiency of 89.57% with average effluent of 46 mg/l, while ANANOX system showed overall removal efficiency of 95% with average effluent of 30.7 mg/l. Removal efficiency and effluent quality of Ein Sinya system are very close to those in ANANOX system, to the extent that ANANOX system which was implemented in Italy is a full scale plant.

COD effluent values in the system are acceptable and meet local and international standards for reuse in irrigation.

4.2.2.3 TSS removal

The ABR removal performance in Ein Sinya is comparable with ABR system implemented in South Africa by (Pillay et al., 2004) and UASB implemented in Palestine by (Al-Shayah and Mahmoud, 2008). ABR system in Ein Sinya showed average removal efficiency of 92% with average effluent concentration of 96 mg/l. ABR system in South Africa showed average effluent concentration of 225 mg/l. ABR system in Ein Sinya had better effluent quality than the system in South Africa, to the extent that the influent concentration in Ein Sinya was higher than South Africa (1363, 480), respectively. This could be due to the fact that HRT for Ein Sinya was higher than South Africa (2.5 days, 22 hours), respectively.

UASB system in Palestine by Al-Shayah and Mahmoud, 2008 showed average removal efficiency of 80% with average effluent concentration of 117 mg/l at HRT = 4 days. ABR system in Ein Sinya could be better than UASB system in Palestine in TSS removal efficiency and effluent quality, to the extent that TSS influent concentration in Ein Sinya was higher than UASB (1363, 614), respectively. This could be due to the compartmental system that was used in the ABR system.

The AS removal performance in Ein Sinya is comparable with AS system in Al-Bireh WWTP, Palestine (Zimmo, 2008). AS system Al-Bireh had average removal efficiency of 58% with extreme values of 37 and 369 mg/l. AS system in Ein Sinya had average removal efficiency of 97% with average effluent concentration of 42 mg/l. This could be due to the fact that 92% of TSS concentration is removed in ABR stage before entering AS system in Ein Sinya.

Overall system removal performance in Ein Sinya is comparable with ANANOX system implemented in Italy by (Garuti et al., 1998). ANANOX system showed average ABR and AS effluent concentration of 72.4 mg/l and 11 mg/l, respectively. System in Ein Sinya showed higher effluent concentration in ABR and AS; 96 mg/l and 42 mg/l, respectively. HRT for both systems were approximately similar. On the other hand, influent concentration in Ein Sinya was higher than ANANOX system (1363, 302), respectively. So, Ein Sinya system had removed higher quantity of TSS concentration. This could consider Ein Sinya system better than ANANOX system in TSS removal performance.

ABR effluent quality in Ein Sinya is classified as Low Quality according to Palestinian classification of treated wastewater (Table 2-2), and could not be used for irrigation, as other ABR systems mentioned above.
AS effluent quality in Ein Sinya is classified as Medium Quality according to PS.

Overall system effluent quality after tertiary unit is classified as High Quality according to Palestinian classification of treated wastewater (Table 2-2) with an average value of 6 mg/l and could be used for irrigational purposes.

4.2.2.4 Total Dissolved Solids (TDS)

According to Table 2-4, where all TDS concentrations were measured to be less than 1200 mg/l, effluent could be used for irrigational purposes for all uses mentioned in Table 2-4, except for discharge to the sea.

4.2.3 Total nitrogen removal

Analysis showed that the Total Nitrogen removal efficiency is 46.5% on average, which indicates that nitrification and denitrification were achieved in the system. NO_3^- effluent values are below 50 mg/l. Effluent could be used for irrigational purposes (dry fodders, green fodders, garden plays, forests, fruit trees…etc).. 46.5% Total Nitrogen removal may be considered relatively low percentage compared to desired values (80 – 90 %) in other countries and standards. Values for typical strength domestic wastewater as determined by Metcalf and Eddy, 2003 are shown below:

Table 4-6: Typical Composition of Domestic Wastewater

Parameter	Average Concentration (mg/l)	Typical Range (mg/l)
Ammonia nitrogen	25	12-50
Nitrate + Nitrite	0	0
Organic Nitrogen	15	8-35
Total Nitrogen	40	20-85

In Ein Sinya WWTP, results showed that average total nitrogen is 105 mg/l comparing to 40 mg/l for typical strength domestic wastewater mentioned in the table above. Also, minimum value for influent Total Nitrogen in Ein Sinya WWTP is higher than the upper limit mentioned in the table. So, 46.5% removal efficiency means that 49 mg/l of Total Nitrogen are removed (0.49 kg Total N/ Day). This quantity is larger than quantities removed in other treatment plants, and is considered as satisfactory Total Nitrogen quantity removal.

Total nitrogen consists of Total Kjeldal, Nitrite and Nitrate

Total Nitrogen = TKN + NO_3^- + NO_2^-

TKN = NH_4^+ + Organic Nitrogen

NO_3^- and NO_2^- influent concentration assumed to equal zero. So, influent total nitrogen concentration equals influent TKN concentration.

The ABR removal performance of NH_4^+ in Ein Sinya is comparable with ABR system implemented in South Africa by (Pillay et al., 2004) and UASB implemented in Palestine by (Al-Shayah and Mahmoud, 2008). ABR system in Ein Sinya showed increasement in NH_4^+ concentration by 6.54% in average, with average effluent concentration of 30.71 mg/l. ABR system in South Africa also showed an increase in NH_4^+ concentration. UASB system in Palestine showed average removal efficiency of 5% with average effluent concentration of 56 mg/l at HRT = 2 days. While at HRT = 4 days, UASB showed slight increase in concentration by -0.4%.

AS removal performance of NH_4^+ in Ein Sinya is comparable with AS system in Al-Bireh WWTP (Zimmo, 2008). AS system in Ein Sinya showed average removal efficiency of 53.52% with average effluent concentration of 13.4 mg/l. NH_4^+ removal occurred in AS by nitrification process, where NH_4^+ converted to NO_3^- by nirtosomonas bacteria. AS system in Al-Bireh showed average removal efficiency of 43% with extreme values of 4 mg/l and 36 mg/l. AS system in Ein Sinya showed better removal efficiency and effluent quality than AS system in Al-Bireh.

Overall system in Ein Sinya is comparable with ANANOX system by (Garuti et al., 1998) implemented in Italy. Average NH_4^+ influent concentration in Italy was 51.1 mg/l which higher than average influent concentration in Ein Sinya (28.83 mg/l). ABR system in Italy showed increasement in NH_4^+ concentration. Effluent concentration of ABR was 64.3 mg/l. AS system in Italy showed average removal efficiency of 80%. ANANOX system had better removal efficiency than Ein Sinya system. This could be due to the fact that aeration system for AS system in Italy was continuous, while in Ein Sinya, AS system operated as Sequence Batch Reactor (SBR); aeration system operated for only six hours per day (intermittent aeration system).

The ABR removal performance of TKN in Ein Sinya is comparable with UASB system implemented in Palestine by (Al-Shayah and Mahmoud, 2008). ABR system in Ein Sinya showed average removal efficiency of 21.03% with average effluent concentration of 73.6 mg/l. Since ABR has no removal of NH_4^+, removal of TKN concentration was according to the removal of organic nitrogen that forms a part of TKN. TKN influent concentration in UASB was 78 mg/l. UASB system in Palestine showed average removal efficiency of 16% and 12% at HRT = 2 and 4 days, respectively, and effluent concentration of 65 and 68 mg/l. ABR system in Ein Sinya could be better than UASB system for TKN removal efficiency.

AS removal performance of TKN is comparable with AS system in Al-Bireh WWTP (Zimmo, 2008). AS system in Ein Sinya showed average removal of 61.44% with average effluent concentration of 35.94 mg/l. AS system in Al-Bireh showed average removal efficiency of 30% with extreme values 17 mg/l and 51 mg/l, respectively.

After nitrification process occurred in AS system, effluent is recirculated to the third section of ABR system to achieve denitrification process; converting NO_3^- to

N_2 in order to complete total nitrogen removal process. Average effluent concentration of NO_3^- was (24.36 ± 9.14) mg/l. International standards states that NO_3^- concentration must not exceed 50 mg/l in order to reuse treated wastewater for irrigational purposes. So, effluent could be used for irrigational purposes.

4.2.4 PO_4^{-3} removal

The ABR removal performance in Ein Sinya is comparable with ABR system implemented in South Africa by (Pillay et al., 2004) and UASB implemented by (Al-Shayah and Mahmoud, 2008) in Palestine. ABR system in Ein Sinya showed an increase in PO_4^{-3} concentration by 9.34 %. ABR system in South Africa showed no removal of PO_4^{-3}. UASB system in Palestine showed increase in PO_4^{-3} concentration by 2%. So, all the above mentioned systems had no removal of PO_4^{-3}.

AS removal performance in Ein Sinya is comparable with AS system in Al-Bireh WWTP (Zimmo, 2008). AS system in Ein Sinya has small Phosphorous removal efficiency of 1.73%. While Al-Bireh AS system showed 28% removal efficiency.

This Pilot WWTP is not intended for biological removal of Phosphorous. If Phosphorous removal is important and needed, chemical precipitation could be used.

4.2.5 Fecal Coliform removal

The ABR removal performance in Ein Sinya is comparable with ABR system implemented in South Africa by (Pillay et al., 2004) and UASB implemented in Palestine by (Al-Shayah and Mahmoud, 2008). ABR system in Ein Sinya showed 2.36 log average removals of pathogen indicators. While ABR system in South Africa and UASB system in Palestine showed only 1 log average removal of pathogen indicators. However, the bacteriological characteristics of the ABR effluent is not satisfactory for reuse purposes in irrigation as fecal coliform concentration is higher than standard values.

AS removal performance in Ein Sinya is comparable with AS system in Al-Bireh WWTP (Zimmo, 2008). AS system in Ein Sinya showed approximately 3 log average removals of pathogen indicators. While AS in Al-Bireh showed 4 log average removals of pathogen indicators.

Overall system in Ein Sinya showed an average 4.72 log removals of pathogen indicators without UV disinfection unit.

4.2.6 Dissolved and heavy metals removal

Results show that dissolved and heavy metals effluent values are below limits recommended by PSI (except for potassium). This assures the appropriateness of this combined system (ABR and AS) as a new and low cost technology.

4.2.7 Overall removal efficiency

Results showed excellent overall removal efficiency. Effluent values met local and international standards and requirements for reuse in irrigational purposes.

As previous research about ABR system had shown, ABR system in WWTP had good removal efficiency of COD, BOD_5 and TSS. However, ABR effluent quality is not good enough to be used for irrigational purposes. Besides, Nitrogen and Phosphorous levels are higher than desired, i.e. negative nutrients removal in ABR was observed. Also, ABR effluent quality doesn’t achieve human health and environment protection.

4.3 Energy consumption cost

Table 4-7 below shows the energy consumption cost for Ein Sinya WWTP.

Table 4-7: Calculation of energy consumption cost

Equipment	**hp**	**No. of operated hours**	**Cost / m3 (ILS)**
Air blower	1.5	6	0.46
Lifting Pumps	1	1	0.05
Mechanical Screen	0.5	1	0.025
Filter Feed Pumps	0.5	2	0.048
Total			**0.58**

$$\text{Cost/m}^3 = (\text{hp X } 0.746 \text{ X No. of operated hrs. X price of KWH}) / Q$$

Table above shows that cost of treating 1 m^3 is 0.58 ILS. Comparing this value with that in Al-Bireh WWTP which was calculated to be 0.65 ILS/m^3 (Zimmo, 2008), Ein Sinya WWTP has lower energy consumption cost with similar removal efficiency and better effluent quality.

A performance evaluation study was conducted by (Al-Sa'ed and Zimmo, 2004) for contact stabilization system at Birzeit University. That study showed that energy consumption for the mentioned system was 0.86 ILS/ m^3, which is higher than energy consumption at Ein Sinya wastewater pilot plant.

CHAPTER FIVE

Conclusions and Recommendations

5.1 Conclusions:

- Operational parameters for ABR were found to be: 0.16 ± 0.05 kg COD /m^3.day for OLR.
- Operational parameters for AS were found to be: 0.16 ± 0.05 kg COD /m^3.day for OLR, 2850 – 3100 mg/l for MLSS, 400 – 450 mg/l for S.V., 0.14 – 0.15 ml/mg for S.V.I. and 0.01 – 0.03 day^{-1} for F/M.
- ABR has good removal efficiency of BOD_5 (55% in average), COD (55% in average) and TSS (93% in average), but effluent cannot be used for irrigational purposes due to low nutrients removal, high human health hazards and potential environmental pollution.
- ABR showed good resistance for shock organic loadings; especially for TSS i.e. some samples had very high influent concentrations.
- Overall system removal efficiency is high; 89.5% in average for BOD_5 and COD, 97.5% in average for TSS, 46.5% in average for Total N, 61.5% in average for TKN, 53.5% in average for NH_4^+, and 4.72 log pathogen removal for FC. Effluent quality satisfies the use for irrigational purposes (dry fodders, green fodders, gardens, play grounds, parks, industrial and cereal crops, forests and fruiting trees).
- The system has low sludge production rate. Sludge disposal in Palestine is problematic, due to the lack of sludge management policy or plan. This could provide a solution for sludge disposal by minimizing the amount of sludge produced from wastewater treatment plants.
- The system has low power energy consumption; i.e. cost / m^3 is relatively low (0.58 NIS/ m^3).

- This system could introduce innovative solutions; especially in low sludge production rate with potential expansion by modular design for decentralized wastewater management in rural areas.

5.2 Recommendations:

- Comparison between ABR system and other systems used for pretreatment should be carried out under the same conditions and same wastewater characteristics.
- ABR could not be used as secondary treatment unit for treating domestic wastewater. A post-treatment is needed.
- System needs optimization before considering it as innovative low cost system.
- Further investigation is needed to optimize the system before adapting as innovative low cost solution for wastewater management.

REFERENCES

Al-Sa`ed, R. and Mubarak, S., 2006. ***Sustainability assessment of onsite sanitation facilities in Ramallah-Albireh district with emphasis on technical, socio-cultural and financial aspects,*** Manage. Environ. Quality: An Int. J. 17(2), 140-156.

Al-Sa'ed, R. and Zimmo, O., (2004) ***Process Performance Evaluation of the Contact Stabilization System at Birzeit University***, Int. J. Environment and Pollution, 21(5).

Al-Shayah, M. and Mahmoud, N., (2008) ***Start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage***, Bioresource Technol., 99(16), 7758-7766.

Bejarano, J. R., (2005) ***Effect of Operational Variables on Nitrogen Transformation in Duckweed Stabilization Bonds***, Taylor & Francis Group plc, London, UK.

Beychok, M. R., (1971) ***Performance of Surface-aerated basins***, Chemical Engineering Progress Symposium Series, 67 (107), 332-339.

Caicedo, J. R., Steen, N. P. and Gijzen H. J. (2003) ***The effect of Anaerobic Pre-treatment on the Performance of Duckweed Stabilization Ponds,*** Cartagena Colombia.

Choi, E. and Rim, J. M., (1999) ***Completion and Inhibition of Sulfate Reducers and Methane Producers in Anaerobic Treatment***, Water Science Technology, 23, 1259-1264.

Garuti, G., Giordano, A. and Pirozzi, F., (2001) ***Full Scale ANANOX System Performance***, South African Water Research Commission, 27(2).

Greenberg, A. E., Clesceri, L. S., and Eaton, A. D. (1992) ***Standard Methods for the Examination of Water and Wastewater,*** 18th Edition

Heduit, A., Duchene, P. and Sintes L. (1990) ***Optimization of Nitrogen Removal in Small Activated Sludge Plants***, Water Science Technology, 22(3), 123-130.

Issa, K. (2004) ***Economic Value of Water Used for Domestic in West Bank – Palestine***, Palestinian Water Authority.

Lettinga and Hulshoff Pol L. W. (1991) ***UASB-Process Design for Various Types of Wastewater,*** Water Science Technology, 24(7), 87-107.

Metcalf and Eddy, Inc (1991) ***Wastewater Engineering Treatment, Disposal, and Reuse***, Third Addition.

Nayef Tomaleh, Chief Operator of Al-Bireh WWTP.

Palestine Standards Institute (PSI).

Palestinian central Bureau of Statistics Web Site, (PCBS), 2008.

Palestinian Water Authority (PWA) (2003), ***Wastewater Management Plan,*** Technical Directorate, Research and Development Department.

Palestinian Water Authority (PWA) (2008). ***Water Supply and Consumption Report***.

Pillay, F. S., Lalbahadur, T., Rodda, N., Holder, F. and Buckly, C. A., (2004) ***The Anaerobic Baffled Reactor (ABR): An Approriate Technology for On-site Sanitation.***

Samhan, S., Al-Sa`ed, R., and Mahmoud, N., 2007. ***Removal of pathogenic microorganisms in pilot-scale UASB-septic tanks and Albireh urban wastewater treatment plant in Palestine,*** Water International 32(5), 538-544.

The Free Encyclopedia, www.wikipedia.org.

Van Haandel, A. C. and Marais, G. R. (1981) ***Nitrification and Denitrification in the Activated Sludge Process***, Research Report No. W39, Department of Civil Engineering, University of Cape Town.

Vismara, R. (1998) ***Depurazione Biologica, Teoria e Processi***, Edited by Biblioteca Scientifica Hoeple (in Italian).

WESI, Bir Zeit University, Adelphi Research, Berlin, Germany and ENEA, Bologna, Italy, January 2004, ***Prospects of Efficient Wastewater Management and Water Reuse In Palestine.***

William, P., Barber, David, C. and Stuckey (1999), ***The Use of the Anaerobic Baffled Reactor (ABR) for Wastewater Treatment: a Review***, Water Research, 33(7).

Yu, H. and Anderson, G.K. (1996) ***Performance of Combined Anaerobic Reactor for Municipal Wastewater Treatment at Ambient Temperature***, Resources, Conservation and Recycling, 17(4).

Zimmo, O., (2008) ***Monitoring and Evaluation of Al-Bireh WWTP Report***, Civil Engineering Department, Faculty of Engineering, Birzeit University.

ملخص

نظام الصرف الصحي في فلسطين هو من أهم القضايا الحاسمة والتي تحتاج للمناقشة، حيث أن المحطات العاملة مثقله وهذا يعني أنها لا تعمل ضمن المعايير المطلوبة. 54.7% من القرى والمدن الفلسطينية ليس لديها أنظمة صرف صحي وتعتمد على الحفر الامتصاصية للتخلص من المجاري (مركز الإحصاء الفلسطيني، 2006)، مما قد يتسبب بمشاكل صحية وبيئية. وحتى بعض المناطق الريفية التي لديها أنظمة صرف صحي فأنها تعني نقص في تدريب الكوادر القادرة على إدارة تلك الأنظمة. ولهذا السبب فيجب ايلاء الاهتمام للمناطق الريفية لبتم تنفيذ خطة صرف صحي لامركزية من اجل تحقيق إدارة مستدامة للصرف الصحي في فلسطين.

تعتبر المياه من الموارد النادرة والثمينة في فلسطين حيث بلغ العجز المائي 50 مليون متر مكعب، وبلغت نسبة الاستهلاك للأغراض الزراعية نسبة 70% من مجموع العام للاستهلاك. ولهذا السبب وللتعامل مع الطلب المتزايد، فقد أصبح من الضروري البحث عن مصادر بديله، وكان احد هذه البدائل استخدام مياه الصرف الصحي التي يتم معالجتها للأغراض الزراعية. هناك الكثير من البحوث التي تمت في فلسطين لحل هذه المشكلة خلصت احدها إلى اقتراح معالجة هذه المياه في المناطق القاحلة شبه الصحراوية وكانت محطة عين سينيا لمعالجة مياه الصرف الصحي احد النتائج العملية لتلك التوصية، لجمع ومعالجة المياه الواردة من مخيم الجلزون وعين سينيا وجفنا وبيرزيت.

يهدف هذا البحث إلى دراسة جدوى ومدى ملائمة معالجة مياه الصرف الصحي مقارنة بأنظمة شبيهه خاصة بالتجمعات السكانية الصغيرة والكبيرة، كما وتهدف إلى الاستفادة من النتائج لحل مشكلة مياه الصرف الصحي غير المتحكم بها في الضفة الغربية. وقد تم الافتراض أن تكلفة معالجة المياه باستخدام نظام مفاعل القواطع اللاهوائي Anaerobic Baffled Reactor (ABR) ويتبعه نظام الحمأة المفعلة Activated Sludge system (AS) سيكون ذا جدوى اقتصاديه مقارنة بأنظمة الصرف الصحي الأخرى بحيث يمكن حل مشكلة المجارى غير المتحكم بها في محافظة رام الله وبالتالي يمكن تعميم هذه النتائج على جميع مناطق الضفة الغربية.

وقد أظهرت النتائج أن كفاءة إزالة الأكسجين المستهلك بيوكيميائيا Removal Efficiency of Biochemical Oxygen Demand (BOD) قد بلغت 54.63% في نظام ABR مع تركيز 117ملغم/لتر، وبلغت كفاءة إزالة الأكسجين المستهلك بيوكيميائيا BOD_5 في النظام ككل 89.52%مع تركيز 27 ملغم/لتر. وبلغت كفاءة إزالة الأكسجين المستهلك كيميائيا COD 54.64% مع تركيز 199 ملغم/لتر في ABR، بينما بلغت كفاءة إزالة الأكسجين المستهلك كيميائيا COD في النظام 89.57% بتركيز 46 ملغم/لتر. وبلغت كفاءة ازالة Total Kjeldahl (TKN) في نظام ABR 21.03% بتركيز 73.6 ملغم/لتر، وبلغت كفاءة إزالة Total Kjeldahl (TKN) في النظام ككل 61.44% بتركيز 35.94 ملغم/لتر.

وقد ازداد تركيز الأمونيا NH_4 في نظام ABR في الوقت التي بلغت فيه نسبة إزالة الأمونيا في النظام ككل 53.52% مع معدل تركيز 13.4 ملغم/لتر. وبشكل عام لم يتم التخلص من مركبات الفسفور في أنظمة ABR أو النظام ككل. وكان معدل تركيز المواد الصلبة العالقة Suspended Solids (TSS في نظام ABR 96 ملغم/لتر و 6 ملغم/لتر في النظام ككل. نسبة إزالة النيتروجين بلغت 46.45% ،وكذلك تم التخلص من الجراثيم المسببة للمرض بنسبة 2.36 log في نظام ABR في حين بلغت نسبة التخلص في النظام بشكل عام 4.72.