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Application of Combined Integrated Pretreatment Rotating Biological Contactor Followed by Planted Soil Filter for Domestic Wastewater Treatment

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Application of Combined Integrated Pretreatment Rotating Biological Contactor Followed by Planted Soil Filter for Domestic Wastewater Treatment

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Thesis Approval

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Dedication

To my dear parents, wife, daughter and sisters
God bless them all

Declaration

I certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed

Abdalla Adnan Sharief Abu Kishk

Date:

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Abstract

Depletion of water resources including deterioration of water quality in Palestine is a very important environmental theme that requires direct and urgent measures. Average per capita water use is among the lowest in the world (60L/C/D) and the average cost of making water available to the public is among the highest (20 NIS/CM). Moreover, groundwater resources are rapidly deteriorated for different reasons; one is due to the infiltration of untreated wastewater that influencing directly the quality and availability of this scarce and essential resource. Moreover, lack of wastewater management has a direct impact on problems related to public health, marine and coastal pollution in Gaza, deterioration of nature and biodiversity as well as landscape and aesthetic distortion. In spite of the fact that Israel prevent the construction of wastewater treatment facilities it still imposes penalties on the Palestinian Water Authority accusing Palestinians of deteriorating the environment.

Due to water scarcity and high population growth in Palestine 3.75 %, water is becoming an increasingly scarce resource and planners are forced to consider any sources of water which might be used economically and effectively to promote further development.

In this study, the feasibility of using partially submerged rotating contact reactor followed by horizontal subsurface flow soil filter constructed wetland for the treatment of domestic raw wastewater in the study site Langenreichenbach (Saxony), and the feasibility to transfer the technique to Palestine was investigated.

The performance of a rotating biological contactor (RBC) followed by horizontal soil filter (HSF) due to high strength raw wastewater treatment application in the treatment pilot plant Langenreichenbach was the subject of this study. The selection of rotating biological contactor (RBC) to pre- treat the influent of horizontal soil filter constructed wetland (HSF), was due to its proved efficiency of high COD and nitrification removal, while using the HSF as demonstrated tertiary treatment for hygienic removal. In addition, taking in consideration the cost effective of such combination system appealed for developing countries. Effects of major process variables such as COD concentration and loading rate, ammonia concentration and loading rate in addition to constant feeding wastewater flow rate on the rate of COD removal, nitrification and nutrients removal efficiency were investigated. The reduction of parasitical load was also investigated.

The system was operated under three different condition phases (Initial, Phase1 and Phase 2), where the third operation (Phase2) was the targeted phase with 109 L/h feeding rate. HSF was put into operation on 23/6/2006 and the mode at this was continues flow with loading rate (60 L/m^2.d = 14 L/h). HSF adapted to work under phase2 operation conditions where average SS concentration inflow into HSF was at the lowest level during this operation phase.

The results obtained reflected the high purification level achieved within such combination system that the final effluent met the German and Palestinian (Class A) standard for reuse treated wastewater in irrigation purposes.

Recommendations drawn from the results, presented that composite sample must take place to present the raw wastewater influent. However, raw wastewater must be properly pretreated to eliminate the SS and to avoid the excessive sludge at the RBC effluent, as

well as proper and well designed ST must take place after RBC system to eliminate SS to allowable concentration for HSF influent.

ملخص

ان مصادر المياه في فلسطين آخذه في النضوب وذلك بالتزامن مع التدهور الحاصل بجودة المياه الصالحة للشرب والزراعة في فلسطين على السواء، وذلك نتيجة لتسرب المياه العادمة الغير معالجة الى المياه الجوفية.

كذلك يعتبر نصيب الفرد من المياه الأقل حظا بمعدل 60لتر/ فرد/ يوم، ونظرا لقلة توفر المياه جعل معدل اسعارها من الاعلى في العالم(20 شيكل/ متر مكعب) .

وكان مع أرتفاع عدد السكان بمعدل 3.75% سنويا وزيادة الحاجة لتوفر مياه صالحة للشرب والزراعة، فقد عمد أصحاب الاختصاص لاعتماد أية مصادر أضافية ذات قيمة اقتصادية فاعلة. وعليه كان لا بد من دراسة أساليب معالجة للمياه العادمة بطرق بسيطة قليلة التكلفة تتناسب مع الوضع الاقتصادي لدول العالم الثالث وتكون ذات فعالية عالية في المعالجة توفر مصدر مائي اضافي.

ان موضوع هذه الدراسة يتناول اختبار فعالية استخدام نظام الدسك المتحرك الدائري الغاطس جزئيا للمعالجة البيولوجية (RBC) يتبعه نظام الترشيح الافقي في فلتر التربة المزروع بالقصب (HSF) لمعالجة المياه العادمة المنزلية في المحطة التجريبية لاينرشباخ– ألمانيا، من أجل دراستها و استخلاص النتائج و التوصيات للعمل على نقلها الى فلسطين.

ان فكرة استخدام RBC كمعالج أولي للمياه العادمة الغير معالجة يأتي تبعا للفاعلية المطلقة والمثبتة لهذا النظام في معالجة مياه عادمة ذات تركيز (المتطلب الكيميائي للأوكسجين) COD عالي، بينما يستخدم نظام HSF كمرحلة متقدمة في المعالجة الصحية وازالة الكائنات الدقيقة. حيث ان استخدام هذا النظام يعتبر مناسب ومرغوب في دول العالم الثالث نظرا لقلة تكلفته وكذلك فعاليته في المعالجة.

تأثير المتغيرات العملية كتركيز COD وتركيز الأمونيا ضمن تدفق ثابت للمياه العادمة كان هدفا لاختبار فعالية النظام الثنائي في مدى معالجة و ازالة تراكيز COD و الأمونيا.

لقد تم تشغيل النظام ضمن ثلاثة مراحل (المرحلة البدائية, المرحلة الأولى والمرحلة الثانية)،حيث كانت المرحلة الأخيرة (المرحلة الثانية) هي المستهدفة في الدراسة حيث كان معدل تدفق المياه العادمة الى نظام RBC حوالي (109 لتر/ساعة) بشكل ثابت تقريبا و مستمر. تم تشغيل نظام HSF لاحقا بعد ثلاثة اسابيع من عمل المرحلة الثانية حيث كان يستقبل(14 لتر/ساعة) مياه معالجة بشكل ثانوي بيولوجي من RBC.

النتائج التي تم الحصول عليها تشير الى فعالية عالية في عملية معالجة المياه العادمة ضمن النظام الثنائي المدمج، حيث ان المياه المعالجة النهائية تصنف ضمن المواصفات الألمانية و الفلسطينية (صنف أ) مياه عادمة معالجة تستخدم في الري.

وبناءا على النتائج الحاصلة، فقد تمت التوصية على ادخال معالجة أولية لازالة وتقليل المواد الصلبة العالقة قبل دخولها الى نظام RBC لتجنب تكون الحمأة المفرطة في المياه الخارجة من RBC نظرا لوجود معالجة بيولوجية

هوائية. كذلك يوصى بتصميم نظام ترسيب للمياه الخارجة من RBC لتقليل كمية المواد الصلبة العالقة الى أقرب ما يكون للصفر لتجنب حدوث انسداد في فلتر التربة الافقي (HSF).

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List of Abbreviations

LRB	Langenreichenbach
RBC	Rotating biological contactor
SGR	Screen grit removal
HSF	Horizontal soil filter
UASB	Up flow anaerobic sludge bed
CW	Constructed wetlands
SF	Straw filter
ST	Settling tank
MT	Mixing tank
L	Liter
T	Temperature
C	Capita
c	Coarse Materials
W	Week
d	Day
h	Hour
s	Second
r	radius
S	Stage
SD	Standard deviation
rpm	Rotation per minute
p.e	Per equivalent
R^2	Confidence factor
inf	Influent

eff	Effluent
NIS	New Israeli Shekel
CM	Cubic meter
HRT	Hydraulic retention time
OLR	Organic loading rate
SOL	Surface organic loading
ORR	Organic removal rate
Q	Flow rate
V	Volume
t	Time
MPOIC	Ministry of Planning and International Cooperation
PCBS	Palestinian Center for Bureau and Statistics
UFW	Unaccounted for water
EC	Electrical conductivity
COD_{diss}	Dissolved chemical oxygen demand
COD_{tot}	Total chemical oxygen demand
NH_4	Ammonium
DOC	Dissolved organic carbon
DO	Dissolved oxygen
P	Phosphorous
N	Nitrogen
NO_3	Nitrate
TKN	Total Kjeldahl- nitrogen
SS	suspended solids
FC	Fecal coliform

TC	Total coliform
E.coli	Escherichia coli

Chapter One

Introduction & Literatures Review

1.1 General Background

Palestine is semi arid to arid country. The country is divided into six physiographic regions, namely; the Highlands, the coastal Plain, the Dead Sea, the Mediterranean Sea, Al Ghors, and the Desert Region. Due to variability in topographic features of Palestine, the distribution of rainfall varies considerably with location. The average total quantity of rainfall is approximately 2500 million cubic meters per year. Out of the rainfall quantities, it is thought that 5% returns to the sea as surface runoff through the seasonal wadis, 30-40% infiltrates to the groundwater aquifers, and the remaining is lost through evapotranspiration (MOPIC, 1998).

Agriculture is considered one of the major economic sectors in Palestine. Its production contributes more than 30% to the national income. Accordingly, there will be much emphasis regarding the development of irrigated agriculture in Palestine. The actual irrigated area is mainly 500,000 dunums (Ministry of Agriculture, 2003)

Depletion of water resources including deterioration of water quality in Palestine is a very important environmental theme that requires direct and urgent measures. Average per capita water use is among the lowest in the world (60L/C/D) and the average cost of making water available to the public is among the highest (20 NIS/ CM) (Palestinian Hydrology Group, 2002).

Due to water scarcity and high population growth in Palestine 3.75 %, water is becoming an increasingly scarce resource and planners are forced to consider any sources of water which might be used economically and effectively to promote further development (PCBS, 2002)

About 20% of the total Palestinian population in the urban areas is served by a central urban sewerage system, while only 5% of the collected municipal wastewater experienced partial treatment. About 73% of the households in the West Bank have cesspit sanitation and almost 3% without any sanitation system (MOPIC, 1998).

This research was carried out in Langenreichenbach treatment plant and dealt with fixed-film biological contactor that been employed in recent years for treatment of various types of substrates, including municipal wastewater (Grady, 1983; Akunna and Jefferies, 2000; Griffin and Findly, 2000), and followed by constructed wetland that considered as one of the most promising treatment options for municipal wastewater with respect to the decentralized settlements, especially in rural and suburban areas, because this technique is low in cost and maintenance requirements with a good performance. They need more land compared to technical intensive treatment but less space than pond systems (Metcalf & Eddy, 1991).

There are always demands to furthering promotion and development of sustainable, effective and low cost treatment technologies via exchanging experiences and transferring new proper technologies to be applied in Palestine in an effective manner. The study of this demonstrated combined treatment pilot plant would be considered as a good feasibility study for such combination to be transferred after taking into consideration the results and recommendations obtained from this study.

Interest in this type of combination system has arisen because of the following attributes:

- They are low in operating costs.
- They can be sited at the point of wastewater production.
- They can be established by relatively low-level trained personnel.
- They are robust and thus able to withstand a wide range of operating conditions.
- They are environmentally and aesthetically acceptable.
- In the case of HSF, they offer a possibility to create a wildlife habitat.

1.2 Problem Justification

Groundwater resources are rapidly deteriorated by different reasons; one is due to the infiltration of untreated wastewater that influencing directly the quality and availability of this scarce and essential resource. Moreover, lack of wastewater management has a direct impact on problems related to public health, marine and coastal pollution in Gaza, deterioration of nature and biodiversity as well as landscape and aesthetic distortion. In spite of the fact that Israel prevent the construction of wastewater treatment facilities it still imposes penalties on the Palestinian Water Authority accusing Palestinians of deteriorating the environment.

There is a substantial concern about the environmental impacts of domestic wastewater on the local, regional and global scales. It has been shown that observed levels of various wastewater pollutants can threaten human health, vegetation, materials and wild life. In order to limit the negative effects of wastewater pollution, wastewater characteristics and pollutants have to be assessed and various mitigation measures have to be proposed in accordance with the expected level of impact.

Palestinian Water Authority (PWA, 2002) reported that the irrigation is the major consumer of fresh water in West Bank (Figure1.1), leaving people coping with about 60L/C/D average uses due to the exist water shortage. So that there is a substantial concern about water conservation by developing a new source of water for irrigation uses in order to save additional amount of water to meet people demand for domestic purposes without affecting the environment and this is one of the objectives of this study.

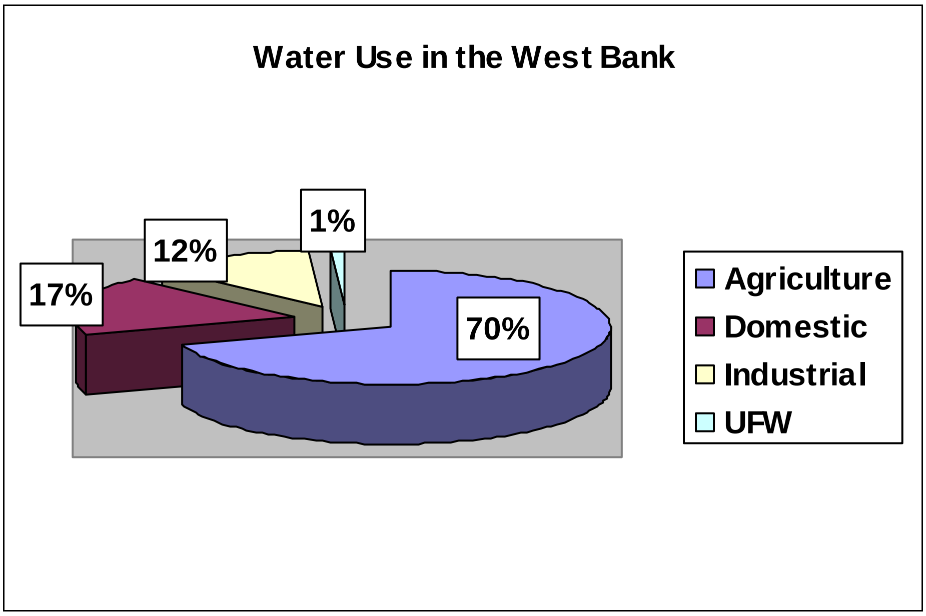

Figure 1.1: Water use in the West Bank (PWA, 2002).

The development of wastewater treatment plants is essential to treat wastewater in general and domestic wastewater in particular. Domestic wastewater includes total water after use and the various waste materials added such as body wastes, kitchen wastes, household cleaning elements, laundry soaps, detergents, solid contents and microorganisms. Such waste materials can cause significant degradation of receiving waters and they may be a major factor in spreading water born diseases.

Design of wastewater treatment facilities is usually based on 15-20 years of project life. The design of an adequate treatment plant that will meet effluent requirements is mainly dictated by influent wastewater properties. Prior knowledge of these properties is essential, and only possible to be obtained during planning stage of the project. These properties could easily change due to variations in time, population, water consumption and socio-economic factors.

In this study, we will investigate the feasibility of using partially submerged rotating contact reactor followed by horizontal flow filter constructed wetland for the treatment of domestic wastewater at the pilot plant "Langenreichenbach", Leipzig- Germany.

The selection of rotating biological contactor (RBC) to pre- treat the influent of horizontal soil filter constructed wetland (HSF), was due to its proved efficiency of high COD and nitrification removal, while using the HSF as demonstrated tertiary treatment for hygienic removal.

Finally; as a society, there is an increasing need for us to view our wastes not as "rubbish", but as "resources". The term "sustainability" means managing our resources so that people and communities can provide for their social, economic and ecological needs without affecting the ability of future generations to do the same.

1.3 Hypothesis of the study

By carrying out this study, an insight into performance of a temperate design combination system in warm and semi arid to arid region will be gained. Moreover, these results will give particular indication of what a “new” technology can achieve in domestic wastewater treatment and, hopefully show great promise for similar adaptations in other institutions. The hypothesis of this study can be stated as:
“***The combination of RBC followed by HSF is an effective method of treating the wastewater and the cost efficiency is proper to be transferred and implemented in Palestine”.***

1.4 Overall Aim and Specific Objectives

This pilot project is a demonstration project that aims to show and give knowledge on how to increase the amount of water available to agriculture by recycling of wastewater and minimizing damages to soil and fresh water resources, human health and environment. The importance of our study is that, such systems will be among the first systems in Palestine. Another aspect is that the system is based on low cost and time consideration, but not low technology, and requires simple operation and maintenance. In addition, the research is specifically aims to achieve the following scientific objectives:

1. To identify physical, biological and chemical pollutant changes during treatment process of domestic wastewater.
2. To evaluate the rotating contact reactor performance for its suitability as pre-treatment for the constructed wetlands.
3. To determine the combination performance for its suitability for irrigation reuse purposes.
4. To prepare a feasibility study to model and implement this system in semi arid to arid region according to recommendations and results obtained from the study.

The aforementioned research objectives can be achieved when answering the following research questions:

- Identify the influent characteristics of RBC in the pilot plant "Langenreichenbach"
- Identify the wastewater characteristics after each module stage of RBC.
- Identify wastewater characteristics after the HSF.
- Identify the removal rates corresponding to organic and nutrient loading rates that the combination achieves reclaimed water guidelines.
- Identify the (best) expected performance of the proposed combination system as one unit.

1.5 Study Area

A pilot-plant system was set up in 2000 by the UFZ Centre for Environmental Research Leipzig-Halle (Germany) in the village Langenreichenbach 45 km to the north east of Leipzig, (Germany, 12° 53' 49" E, 51° 30' 18" N) (Picture1.1). The study site Langenreichenbach (Saxony) has a temperate climate with a mean air temperature of about 10°C and the mean annual precipitation amounts to *400—450* mm (UFZ**,** 2000**).**

Photo 1.1: Bird eye view for the pilot plant in Langenreichenbach, Saxony, Germany.

1.6 Literature Review

Researches and studies in the last few years showed high interest in the low cost, natural and promising technologies seem to be Biological Disk Reactor and Constructed Wetlands due to their purification efficiency. Some selected papers directly related to the topic are summarized in the following pages:

By using different types of water tracers such as; bromide, uranin, eosin, lithium salt and tritiated water for determining the flow characteristics *(Residence Time, Velocity of Flow and dispersion phenomena)* in different three planted soil filter in Germany, (Netter, 1994) in his study "Flow Characteristics of Planted Soil Filters", Found that bromide is the best tracer in such case without any detectable retardation comparing with the other tracers. The results obtained showed that the mean residence time in the soil filter was between 6-40 days with respect to hydraulic load, hydraulic gradient, evapotranspiration and type of soil materials.

Results from various researches in Middle Europe showed a very wide range of nitrogen removal from a few percent to almost complete elimination. But the mechanism for this wide range nitrogen removal is not completely understood. (Platzer and Netter, 1994) provided the factors affecting nitrogen removal in horizontal flow reed beds by evaluating the nitrogen removal at three different treatment plants in order to descript in depth the factors *(Effluent temperature, evapotranspiration, substratum, loading rates and the different types of nitrogen)* affecting nitrogen removal in horizontal flow reed beds. The research results showed that the denitrification was high and the nitrification was limiting factor in most of the plants. It was found that the evapotranspiration is one of the strongest factors supporting nitrification. The influence of the effluent temperature was significantly lower. Investigation on influence of the substratum showed better results for nitrification and denitrification on fine material containing clay.

In their study "Application of Constructed Wetlands for Domestic Wastewater Treatment in an Arid Climate", (Mandi, Bouhoum and N. Ouazzani, 1998) were aiming to assess the efficiency of constructed wetlands for domestic wastewater treatment application in an arid climate in Marrakech, Morocco based on four constructed reed beds in different length dimensions (20, 30, 40 and 50M) that are planted with phragmites australis (Common reed) and where the raw wastewater flow horizontally through these four beds with flow rate of 10 L/S and hydraulic rate varies between 0.86 to 2.16 M^3/M^2/Day. The three researchers concentrated on specific parameters for assessing the constructed wetlands efficiency. Those parameters were as the following; organic load (COD & TSS), nutrients (TKN, NH_4, TP, PO_4), and the parasitical load (helminth eggs). According to the results obtained, the best removal of organic load, nutrient and parasitical loads were obtained at the hot period when this period coincides with reed exponential growth phase. The largest bed (50m) showed a good efficiency at reducing nutrients and helminth eggs due to the lowest hydraulic application rate (0.86 M^3/M^2/Day).

(Harbel, 1999) in his article " Constructed Wetlands: A Chance to Solve Wastewater Problems in Developing Countries", was dealing in details the cooperative arrangements between their institute in Vienna and the developing countries such as; China, Nepal, Mexico, Nicaragua, Kenya, Tanzania and Uganda where they have a great lack of proper wastewater treatment comparing with the developed countries due to their financial situation, more stringent standards, and huge experiences and knowledge with a lot of different systems based on scientific and practical work that led to much more developed wastewater treatment. Promising technology seems to be constructed wetlands was obliged by the institute to solve the wastewater problems in these developing countries due to its their characteristics properties like utilization of natural processes, simple construction, simple operation and maintenance, process stability, cost effectiveness, etc.

(Helland, Kommedal and Bakke, 1999) presented into their study “A Wastewater and Sludge Treatment Process Integrating Biofilms, Wetlands and Aerobic Sludge Digestion for Nutrient Recovery” the efficiency of the Ksnevad wastewater and sludge treatment plant in solving the local pollution problems in a rural community. The study showed that the combination of biofilm reactor with sedimentation, followed by a pond and wetland concept achieved 90% of total nitrogen and phosphorous removal and efficient pathogen removal from the wastewater, and the produced sludge was aerobically digested to achieve by the end of the process stable sludge, nitrified and odor free. It was founded that the total nitrogen in the final product is the same as in the raw sludge but it is converted from organic and ammonia nitrogen to nitrate.

(Mashauri, Mulungu and Abdulhussein, 2000) presented their results obtained from the horizontal flow constructed wetland at the University of Dar Es Salaam to promote and enhancing the use of such low cost, natural and effective technology in treating the wastewater due the lack of investment in wastewater treatment in Tanzania. The horizontal flow constructed wetland was installed at an outlet of waste stabilization pond to treat the effluent from the WSP. The experiments was carried out for a period of 4 weeks at low and high filtration rates (0.27 m/h and 2.3m/h) respectively. The results obtained showed that the removal efficiency was as the following: 80% for the SS, 66% for COD, 91% for the fecal coliform (FC) and 90% for total coliform (TC) achieved at low filtration rate. That means, a proper design, operation and maintenance for the wetlands can provide an efficient and economical instrument for improving the quality of secondary treated wastewater to an acceptable level for reuses application such as irrigation purposes.

(Shrestha, Harbel, Laber, Manandhar and Mader, 2001) discussed the present condition and the application efficiency of the operated constructed wetlands for wastewater treatment in Nepal due to the pollution imposed on surface water by discharging of row sewage into streams, rivers, lakes and other water body, and also due to the lack of plants to treat the row wastewater. The study showed that during the past years, the concept of treating wastewater was unaffordable technologies. But in the last few years and after the improved efficiency of some few operated constructed wetlands, this technology was taken in mind as promising solution for solving the existence problem occurred on surface water. A decentralized two staged- subsurface flow constructed wetlands were constructed at hospital to treat its wastewater and constructed wetlands for treating the greywater and septage. It is resulted that the constructed wetlands due to its efficiency in treating the row sewage and affordability to construct, are pointed as promoted technology for the developing countries.

The performance of a rotating biological contactor (RBC) for the post treatment of the effluent of an up flow anaerobic sludge blanket (UASB) was the study carried out by (Tawfik, Klapwijik, Gohary and Lettinga, 2001). The removal efficiencies of different COD fractions, nitrification and E. coli were investigated at different hydraulic and organic loading rates. The results obtained from this study showed that the best COD fractions removal, nitrifications and E. coli elimination were achieved at the higher hydraulic retention time (HRT= 10h) and with lower influent organic loading rate (95%, 92% and 99.5% respectively). Also the results indicated that the COD removal occurred in the first stage of the RBC while the nitrification removal occurred in advanced stages (second stage).

Reclamation and reuse of water and nutrients at their source was studied by C. (House, Bergmann, Stomp, and Fredrick, 1999) using a combination of simple and less costly technology of constructed wetlands, aquatic and soil filters. The study explained the operation mechanisms of the system for treating the domestic sewage by flowing into the septic tank for pretreatment purposes and then flow to the constructed wetlands, which are combined of vertical aerobic flow with hydraulic loading rate of 40-120 L/M²/Day, and horizontal flow of 7 days detention time in order to provide the necessary environments for nitrification-denitrification, removal of organic materials and phosphorous adsorption reactions. After that the treated wastewater was disinfected by ultraviolet and then flowed into 5 boxes contained different types of soil filters materials in order to test their effectiveness. Also it was flowed into aquatic plant components for removing the low concentration of nutrients remained. The results of improved water quality obtained by this study, promoted to use such simple combined treatment technology in order to protect the quality of the Jordan lack and also creating additional recreational spaces due to reusing water and nutrients.

“Wastewater Treatment Performance of Rotating Perforated Tubes Biofilm Reactor with Liquid Phase Aeration”, was the study carried out by (Kargi and Eker, 2002) to investigate the performance of the proposed system under the effects of the major variables such as feed wastewater flow rate, COD concentration and loading rate, liquid phase aeration on the rate and extent of COD removal. According to results obtained, an empirical design equation was developed to quantify the system’s performance as a function of major process variables.

(Hiras, Manariots, and Grigoropoulos, 2003), evaluated in their study the organic and nitrogen removal in a two stage laboratory scale rotating biological contactor (RBC) in treatment of high- strength municipal wastewater under four recycle ratios operation conditions due to incorporation of anoxic and aerobic units. The anoxic unit was loaded with COD rate of 38-182 g COD/m².d and by oxid-N rate of 0.22-14 g Oxid-N/m².d, and the aerobic unit was loaded with COD rate of 3.4- 18 g COD/m².d and with 0.24-1.8 g NH_4^+-N/m².d. the results obtained showed the the average removal efficiency for COD, BOD5, TSS ad Total-N was, 82%, 86%, 63%, and 54% respectively. Also the results showed the settled effluent of the RBC increased the COD and TSS removal to 94% and 97%. Moreover, it was recognized that the nitrogen removal was improved by increasing the hydraulic loading rate, but in terms to of organic removal, a limited negative effect was recognized. In the other hand, Total-N removal increased up to a ratio of 3 and then decreased.

Chapter Two

Materials & Methods

2.1 Experimental Setup

In order to carry out this research a pilot plant scale system of submerged contact reactor followed by subsurface horizontal flow soil filter constructed wetland technology for treating domestic sewage were for the first time conducted on the field of Langenreichenbach by the UFZ Centre for Environmental Research Leipzig-Halle (Germany).

This research study was carried out between the periods March to September 2006. The study was intend to test the performance of the integrated rotating biological contactor (RBC) and the horizontal soil filter constructed wetlands (HSF) to treat pretreated domestic wastewater for irrigation reuse purposes. However, after detection of insufficient growth amount of biofilms on the rotating discs, the system was altered to receive preliminary treated raw domestic wastewater. The first period of the research extended from the beginning of the practical experimental period until the third week of the research using only the RBC (20/04/2006 to 12/5/2006). The hydraulic feeding rate for the RBC during this phase was almost constant (30 L/h). The second period lasted three weeks by operating only the RBC (12/5/2006 to 29/5/2006) with hydraulic rate ranged between max 100 L/h and min 21 L/h due to some problems related to clogging imposed on the system. The third period was the ideal targeted phase for the research purposes that have been lasted 10 weeks with constant hydraulic feeding rate of 109 L/h to RBC where clogging issues solved by screening the raw wastewater. In this phase the whole combination RBC followed by HSF were in operation. The HSF was supplied with aerobically treated wastewater ranged between (42 L/h to 14 L/h). The study site Langenreichenbach (Saxony) has a temperate climate with a mean air temperature of about 10°C and the mean annual precipitation amounts to *400—450* mm (UFZ**,** 2000).

2.2 Source of Wastewater

The pilot plant system is provided with raw wastewater from dual fewer system of a neighbouring municipal sewage plant for 10,000 population equivalent (p.e.). By gravity, the municipal plant supplies the pilot plant with average 6 CM/day raw wastewater. This wastewater is classified as domestic wastewater since the source is the households.
COD concentration of influent raw sewage was measured biweekly during phase2 research period. The COD concentration ranged between 455 mg/L to 889 mg/ L.

2.3 System Description

The system adopted by this research is a simple one that requires little energy and acceptable due to the economic feasibility, low operation and maintenance requirements. The pilot scale treatment plant consists of a two screen and grit removal (SGR) champers of 3 L capacity each, working as preliminary stage (Annex A-Photo A1). Then sewage outflow from SGR through 1 inch plastic pipe undergoes mechanical secondary treatment in RBC system that consists of three RBC reactors connected in series (Figure 2.1) and (Annex-A Photo A2).

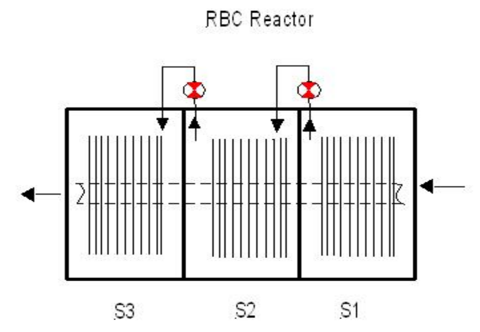

Figure 2.1: Schematic drawing for the RBC reactor system working with three reactor stages connected in series.

Each reactor has a working volume of about 120 L and was equipped with 20 polystyrene (expanded polystyrene) foam disks with a total effective surface of 17.20 m² and rotating at 7.15 rpm. The disk diameter is 0.74 m with a thickness of 0.02 m and they are spaced at 0.02 intervals to minimize surging or short-circuiting, mounted on a steel shaft. The submerged surface amounted to 40% (Figure 2.2).

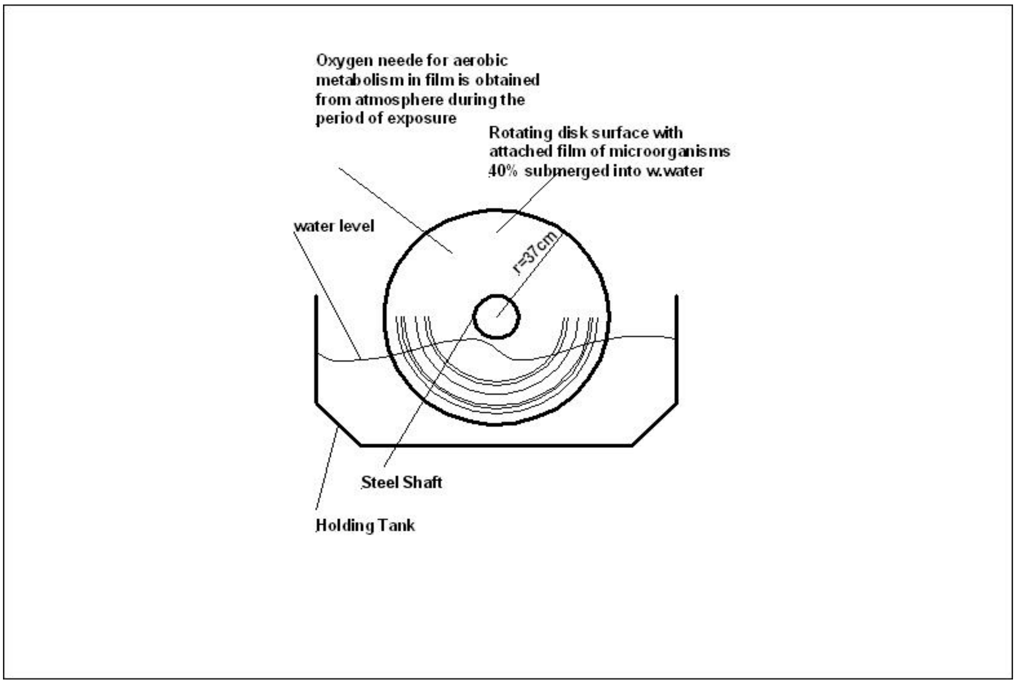

Figure 2.2: Schematic drawing for one single disc.

The RBC troughs were covered (Annex A- Photo A3). This was to reduce the effect of weather on the active biofilm that becomes attached to the disc surfaces (Annex A- Photo A4). A 120L working capacity settling tank was connected to receive the effluent wastewater from the RBC through 50 mm PVC connection pipe to settle down as much as possible of the excessive sludge and suspended solids produced during the biological treatment at the RBC in order to reduce the amount of solids to the minimum allowable volume that flow into the HSF to avoid clogging problems. Another Diploma student integrated into the system to investigate the performance of straw filter (SF) in removing the TSS from raw wastewater in order to develop and dimension new approach of pre-treatment system by such system (Figure 2.3). The idea of integrating this system after the RBC was to benefit from the high TSS produced by the biological treatment occurred in RBC system. The (SF) received treated wastewater directly by 50 mm PVC from the RBC avoiding the settling tank. The wastewater treated by both ST and SF were collected into 40 L working capacity tank named Mixing Tank (MT).

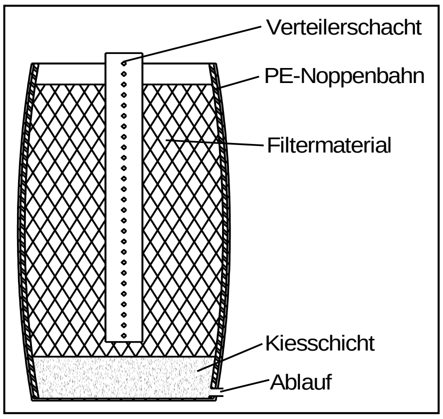

Figure 2.3: Schematic drawing for the straw filter (SF) installed after the RBC in parallel to ST.

A plastic pipe connected to the MT used to suck wastewater from the MT by using peristaltic pump. This pump has a variable speeds; it has peristaltic motor drive, used with pump head and peristaltic tubing. The pump was adopted to supply the HSF with 14 L/h. the water before and HSF pass through black box equipped by pH, EC and DO meters and connected to computer system to provide readings automatically. The final stage of the combination system presented by horizontal soil filters (HSF). The HSF system consists of one coated steel container element measuring a total area of 6.7 m² filled with a mixture of coarse filter material (**c**) expanded clay of 2-4 mm grain size (Fibo Exclay GmbH, Germany) mixed with sand of 0-2 mm grain size (Heinrich Niemeyer GmbH & Co KG, Sprotta, Germany). The effective area of HSF where treatment processes occurred is measuring 5.52 m². This mixture was specially developed for comparative tests to examine the influence of different types of filter materials but with a similar hydraulic transmittance factor. The substrate characteristics are listed in (Table 2.1).

Parameter	**Mixed substrate Sand 0/2 + Exclay 2/4, round**
Abbreviation	**Coarse Material: c**
Grain Size d_{10} [mm]	**0.61**
Grain Size d_{60} [mm]	**2.70**
Total External Porosity Volume%	**50**
Retained Water Fraction Volume%	**11**
Transmittance Factor at 10°C [m/s]	**0.00022**

Table 2.1: Description of physical soil filter materials characteristics used in HSF filling materials (UFZ, 2000).

The height of the main filter layer is 60cm in the horizontal and flow filters (Figure 2.4). All of the soil filters were put into place in such a way as to allow discharge at a height of 20cm above the soil bed. The soil filters were planted with two-year-old *Phraginites australis* with a density of six balls per square meter (photo 2.1). The horizontal soil filters were continuously loaded with peristaltic metering pumps.

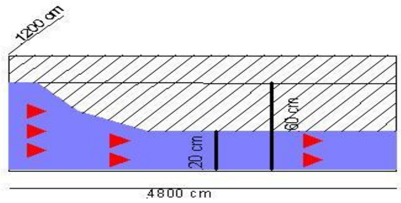

Figure 2.4: Schematic drawing for the cross section of the HSF.

Photo 2.1: Phraginites australis reeds planted with a density of six balls per square meter.

Expected cost for such system with same volume and dimensions to be installed and constructed in Palestinian Territories is about 1800 US$.

2.4 Main Research Periods

The overall research period was 24 weeks. In the first 6 weeks, the efforts were concentrated on system dimensioning and installation processes. In the next 3 weeks, the RBC system was taking place into operation with constant hydraulic load (30L/h) pre-treated wastewater by straw filter (1st operation conditions). However, after the recognition of insufficient amount and growth of Biofilms on the disks during the first operation condition, the RBC system accommodated to receive raw wastewater to enhance Biofilms growth on the disks. The targeted hydraulic load was 100 L/h; however, the obtained hydraulic loading rate was non regular and ranged between 100 L/h to 21 L/h due to clogging and mechanical problems imposed on the system (2nd operation conditions). This operation conditions lasted 3 weeks. The next 12 weeks were the main and final operation conditions (3rd operation conditions) where the RBC system received constant hydraulic loading rate (109 L/h) and the full combination were into operation (RBC and HSF). HSF was into operation in the week number 5 of phase2 (Table 2.2).

Phase	**Initial**	**Pahse1**	**Phase2**	
Duration (week)	3	3	9	
Operated System	RBC & ST	RBC & ST	RBC, ST & HSF	
Flow Rate (L/h)	30	100-21	RBC	HSF
			109	14
Type of Wastewater Influent	Pretreated	Raw wastewater	Raw wastewater	

Table 2.2: Operation planning time

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2.5 Wastewater Sampling

Grab samples for chemical and physical parameters were collected from several points in the treatment line covering the influent and the effluent of each stage. Also samples were collected from the final outflow (Table 2.3.) and (See Annex A- Photo A6). ρH and electrical conductivity (EC) were measured automatically on a daily basis for only the influent and effluent of HSF as last treatment stage. The reason of not measuring EC, DO and ρH at RBC was connected to technical problems. Also the high SS and excessive sludge production at RBC stages disturbed the EC and pH measurements at RBC by the available high tech and high sensitive instruments used in LRB treatment plant for these purposes. Although, the DO was measured manually from time to time to confirm that the DO value is always above (2 mg/l) which is the limited value for DO to enhance effective biofilm growth and metabolism (Von Sperling and Chernicharo, 2005). And the most important is to evaluate the EC and ρH values at the final effluent which is the HSF. Other samples for biological parameters (E. coli and Intestinal nematodes) were collected from the influent of RBC contactor (raw sewage) and HSF influent and effluent at twice for each point during the research period.

All samples were taken according to the recommendations of the standard methods for examination of water and wastewater (American Public Health Association, American Water Works Association an Water Environment Federation, 1998).

Stage	**Parameters**	**Frequency (Number/week)**	**Sample Volume (ml)**
RBC influent	COD, NH4, NO3, TN, P, T, SS, and DOC	1	(2x500)+(2x20) =1040
S1	COD, BOD, NH_4, NO_3, T, and DOC	1	(2x20)= 40
S2	COD, NH_4, NO_3, T, and DOC	1	(2x20)= 40
S3	COD, NH_4, NO_3, SS, T, and DOC	1	(1x500)+(2x20) =540
Settling Tank	COD, NH_4, NO_3, TN, P, T, SS, and DOC	1	(2x500)+(2x20) =1040
HSF influent	COD, DOC, NH_4, NO_3, TN, P, T, SS, and EC	1	(2x500)+(2x20) =1040
HSF effluent	COD, DOC, NH_4, NO_3, TN, P, T, SS, and EC	1	(2x500)+(2x20) =1040

Table 2.3: Sample volume and frequency for physiochemical parameters measured at each stage.

2.6 Wastewater Sampling Points

Seven sampling points with seven plastic valves were installed at the very near and closest place to the influent and effluent of each stage for this purpose (Figure 2.5). It is worthy mentioning here that the values were released for some time and then the representative samples were collected. The samples were collected by using 500 ml and 20 ml bottles (See Annex A- Photo A5).

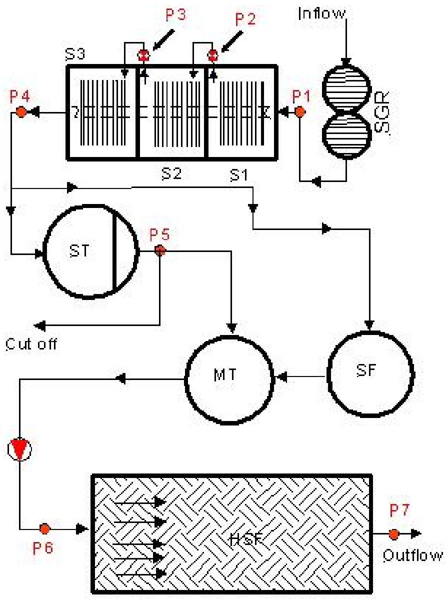

Figure 2.5: Schematic layout drawing for the complete combination system showing flow direction, pipe connections and sampling points.

2.7 Wastewater Analysis

The chemical and physical analysis of the samples conducted at the Centre of the Environmental Research (UFZ), Leipzig-Halle, Germany. Other biological analysis (E. coli and Intestinal nematodes) conducted outside the center.

2.7.1 Chemical Analysis

2.7.1.1 Chemical Oxygen Demand (COD):

Measurements performed by using the reflux method (Acid destruction at 150Cº for 120 minutes). From the diluted sample (10 ml diluted to 50 ml) 2.5 ml filled in the COD-tube. Then the absorbance measured by spectrophotometer at 600nm wavelength according to the standard methods for (American Public Health Association, American Water Works Association and Water Environment Federation, APHA, 1998). Soluble COD was determined by the same procedure using a sample passed through a membrane filter.

2.7.1.2 Biological Oxygen Demand (BOD):

Diluted wastewater was placed in BOD bottle inoculated for a period of five days at temperature of 20˚C. Initial dissolved oxygen and after five days were measured, according to standard methods (APHA, 1998).

2.7.1.3 Ammonia (NH_4):

It was determined by Nesslerization spectrometer according to the standard methods (APHA, 1998). Sample absorbance measured at 425 nm wavelength. In order to measure the nitrogen in the form of ammonium (NH_4^+-N), the obtained ammonium is multiplied by the factor (α)

α = Nitrogen atomic weight/ NH_4^+ Molecular weight
$\alpha = 14/18$
$NH_4^+\text{-N} = (NH_4^+)* \alpha$

2.7.1.4 Nitrate (NO_3):

It was determined by using Cadmium Reduction Spectrometer (HACH) method.
In order to measure the nitrogen in the form of Nitrate (NO_3^--N), the obtained nitrate is multiplied by the factor (β).

β = Nitrogen atomic weight/ NO_3^- Molecular weight
$\beta = 14/62$
$NO_3^-\text{-N} = (NO_3^-)* \beta$

2.7.1.5 Total Nitrogen (TN):

Was calculated as Kjeldahl nitrogen plus nitrate and nitrite nitrogen. Organic nitrogen was calculated as total Kjeldahl nitrogen minus ammonia nitrogen.

2.7.1.6 Total Phosphorous (TP):

TP measurements were carried out using the ascorbic acid spectrometric method, according to the standard methods (APHA, 1995) and measuring absorbance was conducted by spectrometer at wavelength of 800 nm.

2.7.1.7 Total Organic Carbon (TOC):

The method used to determine TOC was the high temperature combustion method (APHA, 1999).

2.7.1.8 Dissolved Organic Carbon (DOC):

0,45 µm - pore – diameter filter used to determine the fraction of TOC which is the DOC that passes through the filter (APHA, 1999).

2.7.2 Physical Analysis

2.7.2.1 Total Suspended Solids (TSS):

It was measured according to standard methods (APHA, 1998) by drying filtered solids at 105˚C oven.

2.7.2.2 ρH:

It was measured for the influent and effluent of HSF automatically by ρH meter connected to computer system.

2.7.2.3 Electrical Conductivity (EC):

EC was measure for the influent and effluent of HSF automatically by EC meter connected to computer system.

2.7.2.4 Temperature (T):

The temperature was determined by digital thermometer instrument for each sample at the location site (Annex A- Photo A8).

2.7.3 Biological Analysis

2.7.3.1 E. coli Analysis:

Escherichia coli (E.coli) were determined in wastewater samples according to the EPA method 600-R-00-013 (EPA 2000) with slight modifications. After membrane filtration (GN-6 Metricel®, Pall Life Science, pore size 0, 45 µm, and diameter 50 mm) of the diluted wastewater samples, the filter papers were incubated on Chromocult® Coliform Agar (CCA, Merck, Germany) at 35°C for 24 hours. Colony forming units of *E. coli* were determined as dark-blue-violet coloured colonies resulting from specific cleavage of a glucuronide complex.

2.7.3.2 Intestinal Nematodes Analysis:

Nematode concentrations were determined according to the modified Bailenger method described in the WHO laboratory manual WHO (1996).

2.8 Calculations

Removal efficiency (%)

This term used to determine the percentage of substrate removed within the system.

$$\% = \frac{(X_{\inf} - X_{eff})}{X_{\inf}} * 100 \qquad (2.1)$$

Where:

% = Removal efficiency.

X_{inf} = Concentration component in the influent (mg/L).

X_{eff} = Concentration component in the effluent (mg/L).

Hydraulic Retention Time (HRT)

In order to calculate the water residence time in the system, the following equation is used;

$$HRT = \frac{C}{OLR} \qquad (2.2)$$

Where:

HRT = Hydraulic retention time (d).

C = COD concentration in the influent (gCOD/m^3).

OLR = Organic loading rate (gCOD/m^3.d).

Flow Rate (Q)

The amount of wastewater flow into the system is measured by the following equation;

$$Q = \frac{V}{t} \qquad (2.3)$$

Where:

Q = Flow rate (L)

V = Volume of the sample (L).

t = Time needed to obtain the required sample volume (h).

Surface Organic Loading (SOL)

To determine the substrate concentration per surface area flow into the system, the following equation is used;

$$SOL = \frac{C * Q}{A_n} \qquad (2.4)$$

Where:

C = COD or NH_4^+-N influent concentration (mg /L).
Q = Hydraulic loading rate (m^3/d).
A_n = Total surface area of all discs in S_n (m^2).

n = Stage number.

2.9 Data Analysis

Statistical analyses for data were carried out using Microsoft Excel 2003 (Microsoft Corporation) software package. With this software most of data analyses (including arithmetic averages, standard deviations, removal equations and correlations between different variables) and graphs were carried out.

Chapter Three

Results & Discussions

3.1 General

In this research two types of wastewater were analyzed. The first type was pretreated wastewater by straw filter pretreatment unit for the first 3 weeks as initial operation phase. After the initial operation, the system was fed with raw wastewater subjected to preliminary treatment to screen and remove coarse solids (Phase1 & Phase2). During phase1, the system was operated 3 weeks by unaccounted flow rate volume due to some mechanical problems related to clogging cases imposed by failure in preliminary system and failure in the peristaltic pump. However, the preliminary system was improved by installing new proper preliminary unit (SGR) that secured constant and continuous flow rate for the 12 weeks of the research period.

Samples and results obtained in the initial and phase1 were considered as experimental results to assess the performance of the RBC under different operation conditions (Table 3.1). The aim of the study was to asses the applied integrated RBC performance to pretreat the influent of the HSF under constant hydraulic loading rate and variable COD concentrations. Therefore the analysis and discussion were concentrated on phase2.

Table 3.1: Basic operation conditions at three stages.

Operation Condition	**Initial**	**Phase1**	**Phase2**
Hydraulic loading rate (L/h)	Constant (30)	Unaccounted (100-21)	Constant (100)
COD tot influent concentration (mg/L)	388-510	490-904	455-889
COD diss influent concentration (mg/L)	250-266	308-523	258-446

3.2 Rotating Biological Contactor (RBC) and Settling Tank (ST) Results

During the three operation condition phases the system was supplied by domestic wastewater from the near by municipal treatment plant in Langenreichenbach. (Table 3.2) summarize the physiochemical characteristics of the influent.

Table 3.2: Domestic wastewater characteristic of RBC influent at three operation phases.

Parameter	**Unit**	**# S**	**Initial Range**	**Initial Average**	**# S**	**Phase1 Range**	**Phase1 Average**	**# S**	**Phase2 Range**	**Phase2 Average**
T	**˚C**	2	14.9-16.5	15.7	3	15.5-23.6	18.7	9	15.5-25.4	21.88
COD_{tot}	**Mg/L**	2	388-510	449	3	480-904	755.67	9	455-889	671.33
COD_{diss}	**Mg/L**	2	250-266	258	3	308-523	384.33	9	258-446	370.11
DOC	**Mg/L**	2	89-102	95.5	3	111-199	140.70	9	76-159	121.56
NH_4-N	**Mg/L**	2	58.4-69.6	64	3	69.4-80.2	74.43	9	48.1-89.2	77.58
NO_3-N	**Mg/L**	2	0.6-0.9	0.75	3	0.3-0.7	0.56	9	0.4-0.9	0.61
TN-N	**Mg/L**	2	67.6-78.2	72.9	3	80.8-100	87.57	9	52.3-103	86.37
SS	**Mg/L**	-	-	-	3	90-484	257.33	6	44.7-238	164.78

RBC system consists of three stage contactors (S1, S2, and S3) each stage consists of 20 rotational discs with total surface area 17.2 m² at each stage. The reactor (S1) mode in this research was continues flow under three different flow rates at three different operation phases, and the discs rotation speed was constant 7.14 rpm. During the targeted operation phase (phase2), the system was fed continuously with 109±3 L/h (2.616 m³/d) raw domestic wastewater from 29-5-2006 up to the end of research period, thus the hydraulic retention time (HRT) about 9±0.3 hours at RBC contactors. Table 3.3 reveals the evolution of wastewater characteristic within the RBC stage reactors (S1, S2, and S3) at operation phase2.

Table 3.3: The evolution of wastewater characteristic of (S1, S2, S3 and ST) effluent at phase2.

	Parameter	**Unit**	**# S**	**Average**	**SD**	**R.E%**	**Cumulative R.E %**
S1	**COD_{diss}**	**mg/L**	9	175.44	23.25	52.6%	52.6%
	DOC	**mg/L**	9	59.44	13.76	51.0%	51.0%
	NH_4-N	**mg/L**	9	69.88	10.91	9.9%	9.9%
	NO_3-N	**mg/L**	9	0.34	0.06	42.2%	42.2%
	TN-N	**mg/L**	9	78.39	13.97	9.2%	9.2%
S2	**COD_{diss}**	**mg/L**	9	96.82	17.53	44.8%	73.8%
	DOC	**mg/L**	9	37.78	11.05	36.5%	68.9%
	NH_4-N	**mg/L**	9	65.4	13.7	6.5%	15.8%
	NO_3-N	**mg/L**	9	0.48	0.27	-39.8%	20.0%
	TN-N	**mg/L**	9	63.22	14.92	7.4%	21.0%
S3	**COD dis**	**mg/L**	9	75.66	13.33	21.9%	79.6%
	DOC	**mg/L**	9	28.56	9.91	24.4%	76.5%
	NH_4-N	**mg/L**	9	48.84	17.13	25.3%	37.1%
	NO_3-N	**mg/L**	9	9.92	7.64	-1967.4%	-1553.9%

	TN-N	**mg/L**	9	63.22	14.92	7.4%	26.8%
	SS	**mg/L**	6	447.33	300.36	-171.5%	-171.5%
ST	**COD_{dis}**	**mg/L**	9	80.94	5.8	-7.0%	78.1%
	DOC	**mg/L**	9	31.3	7.0	-9.7%	74.2%
	NH_4-N	**mg/L**	9	53.1	13.5	-8.7%	31.6%
	NO_3-N	**mg/L**	9	4.4	1.9	5.7%	-61.9%
	TN-N	**mg/L**	9	63.4	12.7	-0.3%	26.6%
	SS	**mg/L**	6	27.1	21.1	96.3%	83.6%

3.2.1 Physiochemical Properties of the System

3.2.1.1 Temperature:

The ambient temperature during phase2 operation is known to be the highest through out the year. Temperature of wastewater is an important parameter affecting the efficiency of aerobic biological removal (Pano and Middlebooks, 1983), since the increase of temperature causing increasing of removal efficiency. The raw wastewater influent temperature ranged between 15.5˚C to 25.4˚C with average wastewater influent temperature in the same period (Phase2) was 21.9 ± 3.1˚C (figure 3.1). The wastewater temperature was measured at each sampling point within the RBC system directly on site from the collected sample. Limited and no recognized difference was found in (S1, S2, S3 and ST) effluent temperatures.

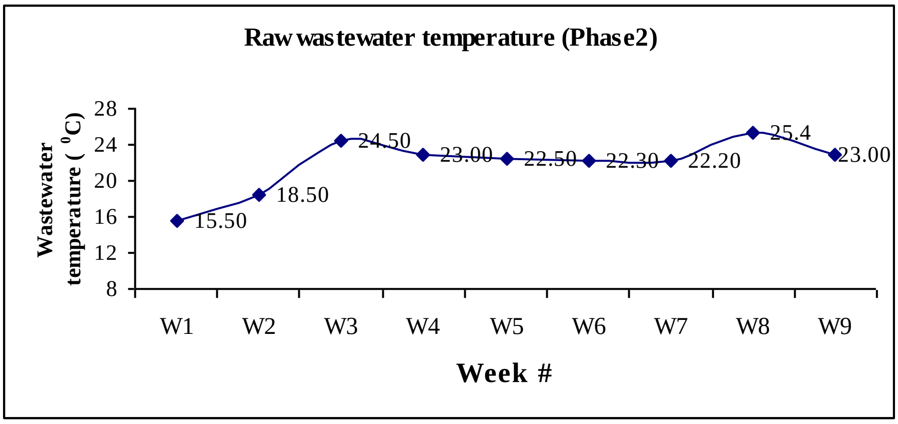

Figure 3.1: Raw wastewater temperature along phase2 experimental period.

Table 3.4: Raw wastewater influent temperature during the 9 weeks sampling (w1… W9) period of phase2.

	W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**Average**	**S.D.**
T˚C	15.50	18.50	24.50	23.00	22.50	22.30	22.20	25.4	23.00	21.88	3.05

3.2.1.2 Suspended Solids (SS):

The suspended solids were measured 6 times during phase2 period. Grab samples were tested biweekly from the influent and effluent of RBC contactor system (Raw wastewater influent to RBC and S3 effluent). Average SS concentration in the influent was 164.78 mg/L. however, significant increase of SS was observed at RBC effluent (S3). The average SS concentration in RBC influent was found 447.33 mg/L. This sharp increase in SS was expected due to the high rotational speed (7.14 rpm), selected to prevent the significant solids accumulation notated in previous studies at lower rotational speed. Aerobic biological COD removal within the RBC reactors, relatively low retention time and troughs internal design that does not allow efficient settling down for the produced solids were also factors affected the increase of SS concentration in the RBCs effluent. The removal efficiency of SS appeared clearly in figure 3.2 where the SS removal efficiency changed sharply from Negative (-171.5%) at RBC final effluent to (96.5%) at ST effluent. Figure 3.3 presented the SS reversal (negative) removal in RBC system. Installing the settling tank (ST) after the RBC contactors was aiming to reduce the SS concentration produced by the biological treatment in RBC and mixed with SS from raw wastewater. The average SS concentration in ST effluent was found to be 16.49 mg/L (See Table 3.5). As mentioned before, the purpose of using ST was to reduce SS to the nearest value to zero, which we did not achieve by the ST. Wastewater temperature and HRT are the main parameters affecting SS removal at ST. According to Smith and Moclyowati model, the SS removal efficiency can be expressed as follows:

$$S_e = S_i\left(\left(\frac{1.18}{T}\right)\ln(t)+\frac{6.5}{T}\right) \qquad (3.1)$$

Where;

S_i: Initial concentration of SS (mg/L).

S_e: Final concentration of SS (mg/L).

T: Wastewater temperature (˚C).

t: Time (days).

For ST design purposes, the best is to increase the HRT at ST in order to achieve the highest SS removal.

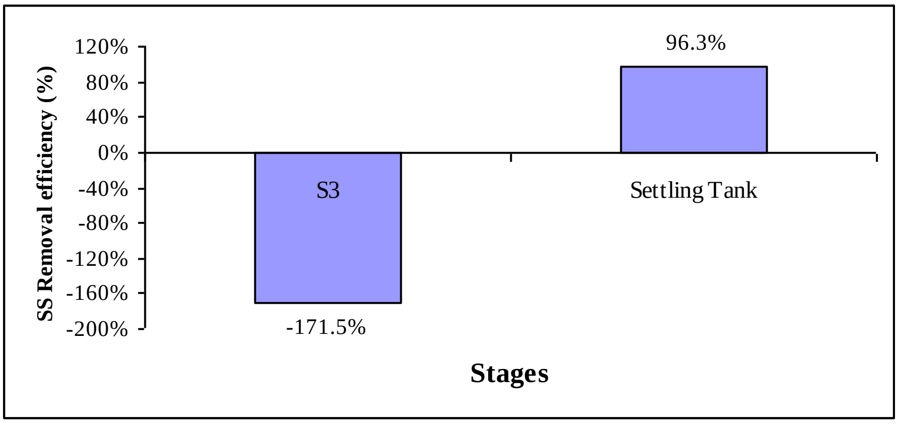

Figure 3.2: SS removal efficiency within RBC final effluent and ST effluent

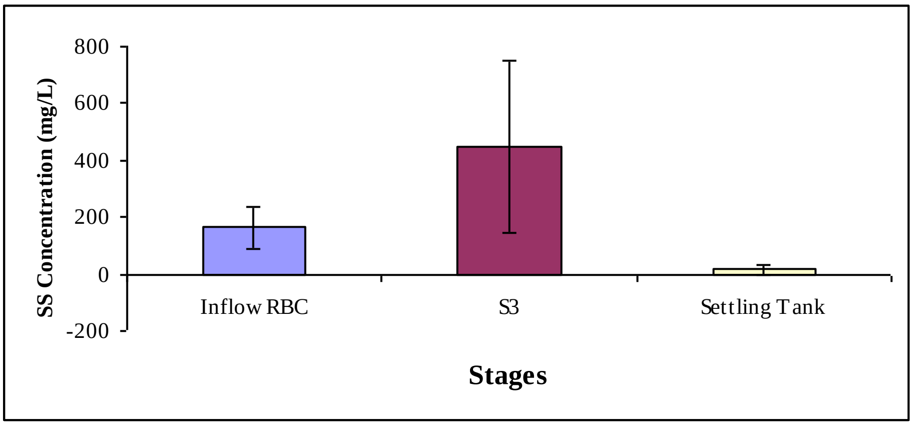

Figure 3.3: SS concentration (mg/L) in RBC contactors influent and effluent (S3) in addition to SS concentration in ST effluent.

Table 3.5: Average SS concentration and removal efficiency at each RBC stage and ST.

Parameter	**Inflow RBC**	**S1**	**S2**	**S3**	**Settling Tank**
Average	164.78	447.33	16.49	45.53	27.07
S.D.	73.76	300.36	18.16	37.19	21.11
%				-171.47%	96.31%

3.2.2 Organic Removal

COD concentration and DOC concentration were two indicators used for organic removal.

3.2.2.1 Dissolved COD removal:

Dissolved COD (COD $_{diss}$) was the best indicator of COD removal among the total COD (COD tot) fractions. According to previous studies (Tawfik, Klapwijk, El-Gohary, and Lettinga, 2001), COD $_{diss}$ removal achieves the lowest rate (56 ± 13.5% to 73 ± 5.8%), while other fractions (Colloidal, Suspended, and Total) achieve the highest removal rates (95.1±3.6% to 95.3 ± 3.4%, 83 ± 10.9% to 92 ± 11.3%, and 73 ± 4.2% to 83 ± 3.2% respectively). Grab sampling was used to measure the COD concentration by weekly throughout this period. Figure 3.4 show the removal efficiency of dissolved COD (COD $_{diss}$) reached an average value of 51.92% at HRT 3 ±0.1 hr and average surface organic loading rate (SOL) 56.29 gCOD $_{diss}$/m^2.d at (S1) (Maximum removal efficiency). While the average removal efficiency recognized at (S2, S3) was 44.8% and 21.9% respectively. In the (ST) the average removal was negative (-7.0%). Figure 3.5 show the COD concentration at each RBC contactor stages and at the ST. The significant COD removal obtained at S1, which can be attributed to the domination of heterotrophic bacteria at a high organic loading rate at S1 (Daigger, Lim, and Henry, 1999), while the removal decreased at S2 and almost diminished at S3, but remain at low level, below 100 mg/L (See Table 3.6). Figure 3.6 shows that during the first three weeks of phase 2 operation conditions (6-19/6/2006), the COD concentration at ST was partially lower than the concentration at RBC contactors effluent (S3). After that date (19/6/2006), the concentration started to increase in ST effluent and no significantly exceeded the concentration in S3. This obtained result was justified as a result of excessive sludge accumulated in ST causing scum accumulation at the top of water surface in the ST (Annex A- Photo A8).

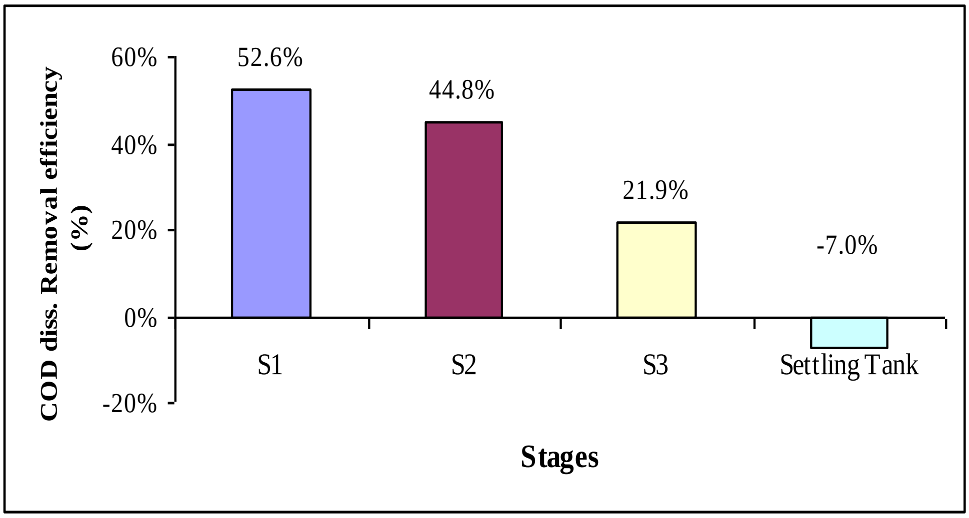

Figure 3.4: COD $_{\text{diss}}$ removal efficiency (%) within RBC contactors and ST.

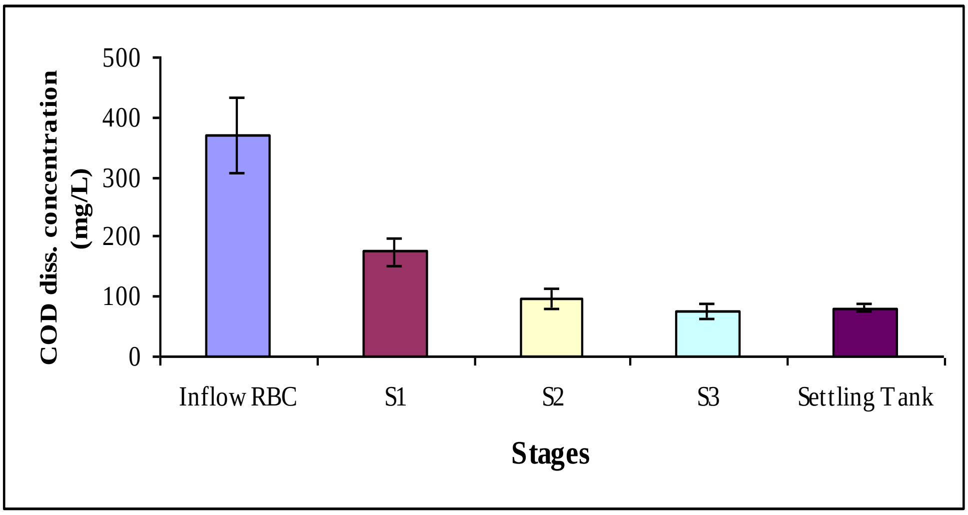

Figure 3.5: COD $_{\text{diss}}$ concentration (mg/L) at RBC contactor stages and at ST.

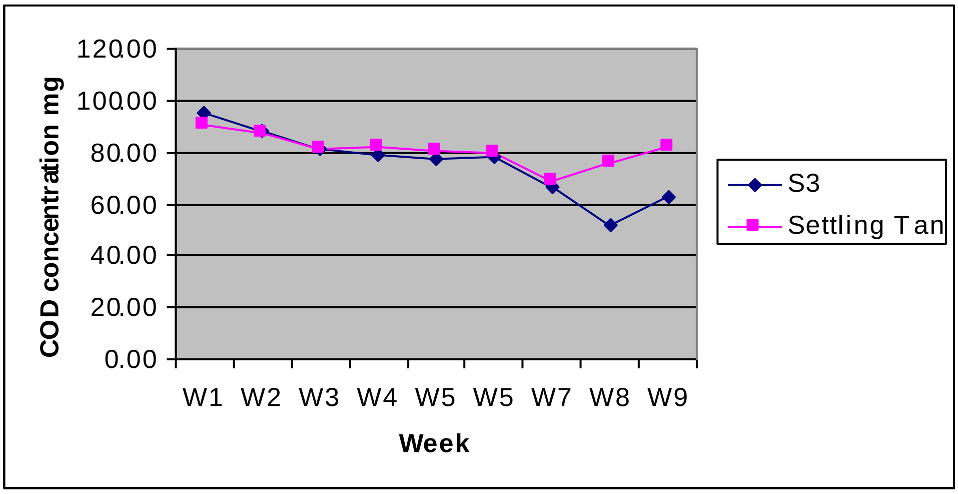

Figure 3.6: COD concentration within RBC effluent (S3) and ST effluent along phase2 research period.

Table 3.6: Average COD concentration and removal efficiency at each RBC stage and ST.

	Inflow	**S1**	**S2**	**S3**	**ST**
Average	370.1	175.4	96.8	75.7	80.9
S.D	62.7	23.2	17.5	13.3	5.8
R.E%		52.6%	44.8%	21.9%	-7.0%

3.2.2.2 Effect of Loading Rate on RBC Performance:

Analyzing each RBC stage alone allows the researcher to study in detail its removal capacity corresponding to the loading rate. In addition to determining the number of stages required to operate the combination under different required effluent characteristics. The effect of the loading rate (in terms of COD) on the RBC contactors system (S1, S2, and S3) performance (as indicated by the corresponding removal rates) presented in figures (3.7, 3.8, 3.9) respectively, where values computed on the basis of feed wastewater characteristics and concentration rate. The COD data in figure 3.7 show a moderate degree of dependence (a correlation coefficient of 0.4233). This may be attributed to the daily and hourly high variations in COD values for the RBC influent (S1 influent). However, the COD data in the figures (3.8, 3.9) do not exhibit similar behavior and show a high degree of dependence (a coefficient of 0.8799 and 0.9849 respectively). So, it should be recommended that a composite sampling must be taking place for the RBC reactors system raw wastewater influent. Mutiple regression analysis carried out for the RBC contactors (S1, S2, and S3) to relate removal rate with loading rate gave the following equations and relationships;

$\mathbf{ORR_1} = 0.2412\mathbf{OLR_1} + 86.177$ $R^2 = 0.4233$ (3.2)
$\mathbf{ORR_2} = 0.7072\mathbf{OLR_2} - 27.249$ $R^2 = 0.8799$ (3.3)
$\mathbf{ORR_3} = 0.7547\mathbf{OLR_3} + 2.5808$ $R^2 = 0.9849$ (3.4)

Where ORR_1, ORR_2, and ORR_3 and OLR_1, OLR_2, and OLR_3 are the organic removal and organic loading rates (mg COD/L) for S1, S2, and S3 contactors respectively. It should be noted that the removal and loading rate in Equations. (3.2), (3.3) and (3.4) are based on the wastewater feed rate (109 L/h). The removal rate for COD was mainly affected by the corresponding loading rate (The removal rate increased with increasing the COD concentration in the influent) and that was approved by (Hiras, Manariotis and Grigoropoulos, 2003).

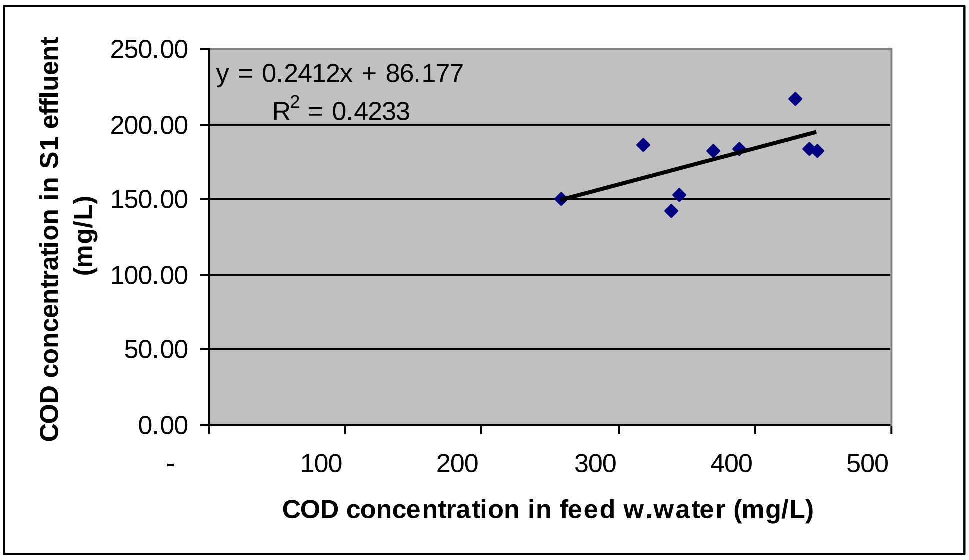

Figure 3.7: COD removal rates vs corresponding loadings (based on feed wastewater characteristics and rate).

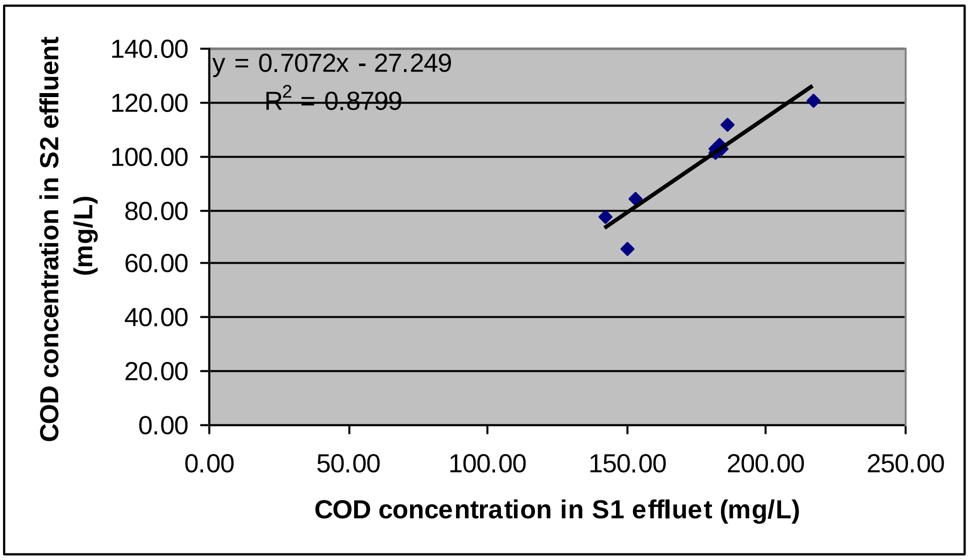

Figure 3.8: COD removal rates at S2 vs corresponding loadings (based on S1 effluent characteristics and rate).

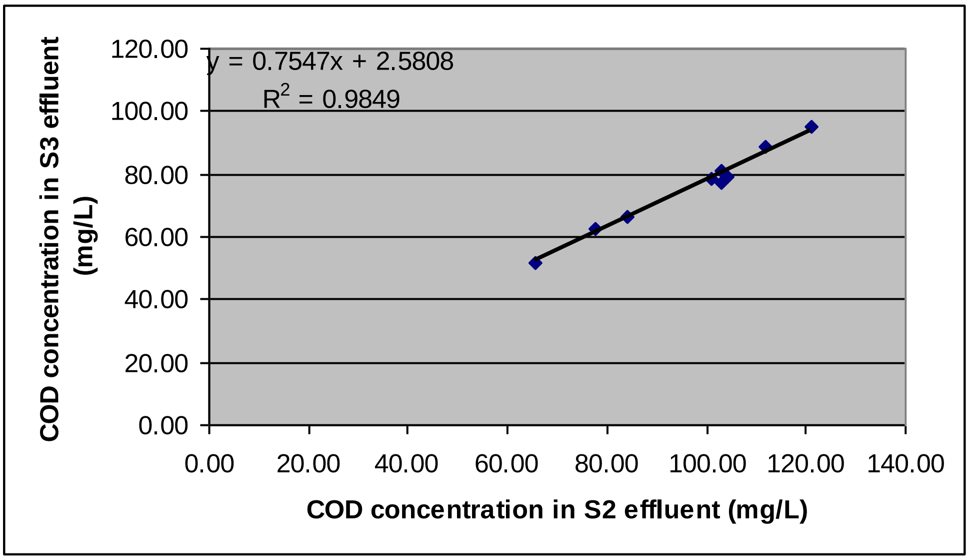

Figure 3.9: COD removal rates at S3 vs corresponding loadings (based on S2 effluent characteristics and rate).

Table 3.7: COD concentration and removal efficiency at each RBC stage corresponding feed wastewater characteristics.

Week #	Inflow	S1	S1 %	S2	S2 %	S3	S3 %
W1	429	217.00	49.42	121.00	44.24	95.40	21.16
W2	318	186.00	41.51	112.00	39.78	88.60	20.89
W3	389	184.00	52.70	103.00	44.02	81.10	21.26
W4	440	183.00	58.41	104.00	43.17	79.00	24.04
W5	446	182.00	59.19	103.00	43.41	77.30	24.95
W6	369	182.00	50.68	101.00	44.51	78.30	22.48
W7	344	153.00	55.52	83.90	45.16	66.50	20.74
W8	258	150.00	41.86	65.70	56.20	51.90	21.00
W9	338	142.00	57.99	77.80	45.21	62.80	19.28
Average	370.11	175.44	51.92	96.82	45.08	75.66	21.76
S.D	62.72	23.25	6.73	17.53	4.48	13.33	1.77

3.2.2.3 DOC Removal:

The average DOC removal efficiency at S1 was found 51%, while the average removal efficiency rate significantly decreased among the following stages of RBC system S2 and S3 (36.5% and 24.4%) respectively (Figure 3.10). However, the average removal efficiency at ST was found negative (-9.7%) means an increase of DOC concentration was obtained in ST. Figure 3.11 shows the average concentration of DOC in the raw wastewater influent, within the RBC contactors system and ST (121.5, 59.5, 37.8, 28.6 and 31.3 mg/L) respectively. DOC average removal degree proportionate with the increase of the influent loading rate at RBC contactors system, while the average concentration slightly increased at ST. the increase of DOC concentration may be attributed to the excessive sludge accumulated in ST causing scum accumulation on water surface, and that was clearly obtained between week 3 and week 4 of phase 2 (19-26/6/2006) (Figure 3.12).

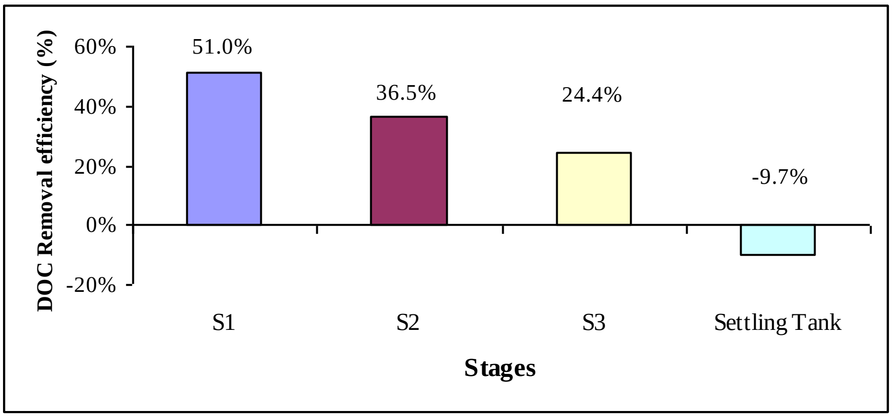

Figure 3.10: DOC removal efficiency (%) within RBC contactor stages and ST.

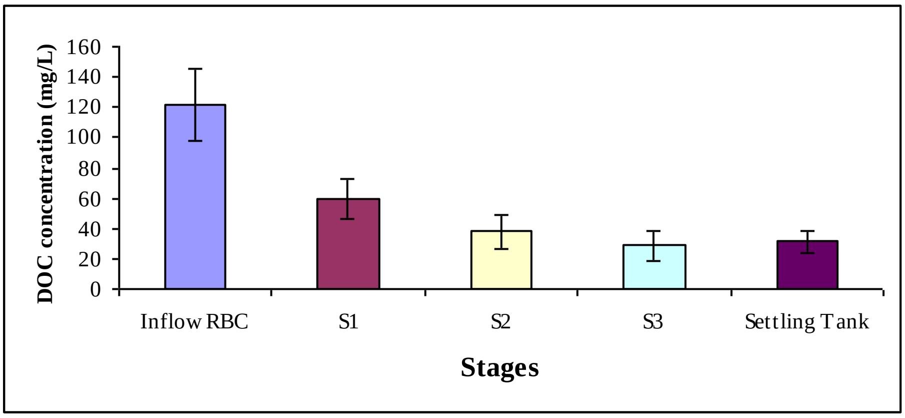

Figure 3.11: DOC concentration (mg/L) at RBC contactor stages and at ST.

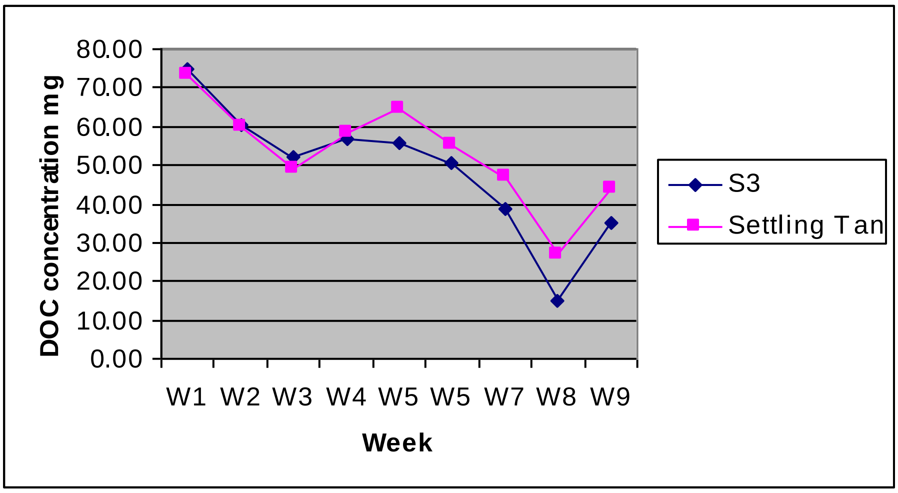

Figure 3.12: DOC concentration within RBC effluent (S3) and ST effluent along phase2 research period.

Table 3.8: Average DOC concentration and removal efficiency at each RBC stage and ST.

	Inflow RBC	S1	S2	S3	Settling Tank
Average	121.5	59.5	37.8	28.6	31.3
S.D.	24.3	13.8	11.1	9.9	7.0
R.E%		51.0%	36.5%	24.4%	-9.7%

3.2.3 Nitrogen Transformation and Removal

Changes in NH_4^+-N, NO_3^--N and TN-N concentrations are major indicators investigated for nitrogen transformation and removal in this study.

3.2.3.1 NH_4^+-N Removal:

Grab sampling was used to measure the NH_4^+-N concentration by weekly throughout this period. Figure 3.13 shows the removal (elimination) efficiency of NH_4^+-N reached an average value of 25.3% at RBC contactors effluent (S3) (Maximum removal efficiency). While the average removal efficiency recognized at (S1, S2) was 9.9% and 6.5% respectively at average NH_4^+-N loading rate 11.79 g NH_4^+-N/m².d at RBC influent. In the (ST) the average removal was negative (-8.7%). Figure 3.14 shows the NH_4^+-N concentration at each RBC contactor stages and at the ST. The efficient NH_4^+-N removal obtained at S3, which can be attributed to the domination of autotrophic bacteria at significantly low organic loading rate at S3 that efficiently removed at earlier stages (S1, S2) (Grady, Daigger and Lim, 1999) (Tawfik, Klapwijk, El-Gohary and Lettinga, 2001). The domination of heterotrophic bacteria at a high organic loading rate at earlier stages (S1, S2) exerted a negative effect on the rate of NH_4^+-N elimination at these stages. (See Table 3.9). Figure 3.15 shows that during the first three weeks of phase 2 operation conditions (6-19/6/2006), the NH_4^+-N concentration at ST was partially lower than the concentration at RBC contactors effluent (S3). However, between the third week and the forth week, the concentration started to increase in ST effluent and slightly exceeded the concentration in S3. This obtained result was justified as a result of excessive sludge accumulated in ST causing scum accumulation at the top of water surface in the ST. Ammonification due to biological decomposition of organic nitrogen could be a main reason.

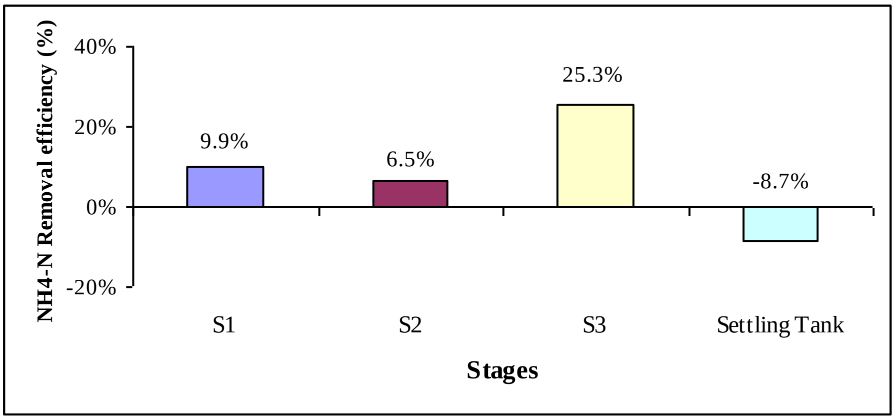

Figure 3.13: NH_4^+-N removal efficiency (%) within RBC contactors and ST.

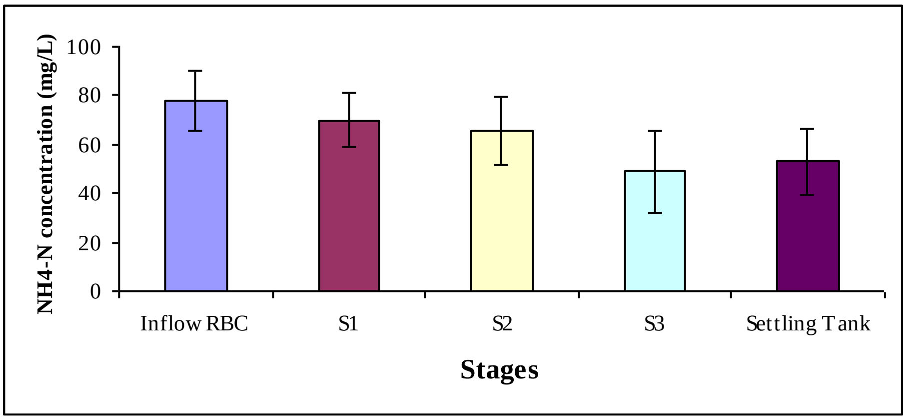

Figure 3.14: NH_4^+-N concentration (mg/L) at RBC contactor stages and at ST.

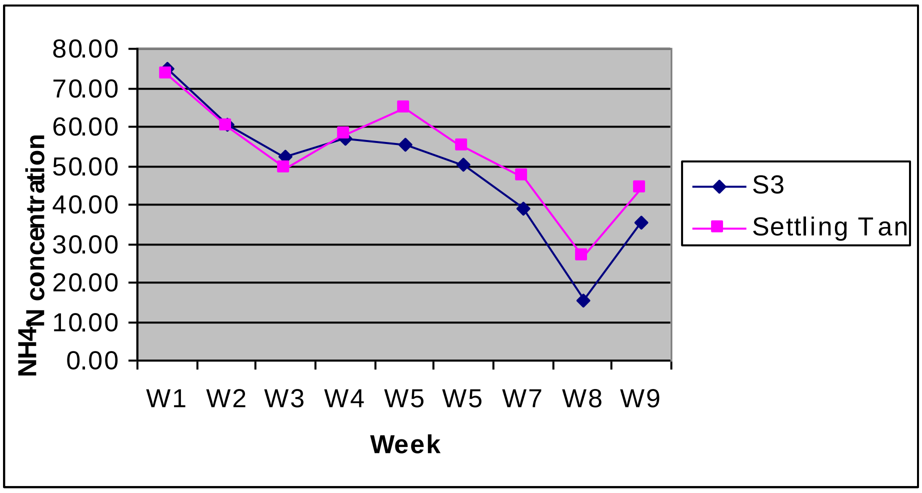

Figure 3.15: NH_4^+-N concentration within RBC effluent (S3) and ST effluent along phase 2 research period.

Table 3.9: Average NH4-N concentration and removal efficiency at each RBC stage and ST.

	Inflow RBC	S1	S2	S3	Settling Tank
Average	77.6	69.9	65.4	48.8	53.1
S.D.	12.2	10.9	13.7	17.1	13.5
R.E%		9.9%	6.5%	25.3%	-8.7%

3.2.3.2 NO_3^--N Removal:

Average NO_3^--N concentration in the raw wastewater influent was low 0.6 mg/L. (Table 3.10) declares that an elimination occurred on NO_3^- -N concentration within the first stage of RBC contactors system then started to increase at the second stage (S1, S2) 0.3 and 0.5 mg/L respectively, while the concentration sharply increased in S3 to 9.9 mg/L. However, (Figure 3.16) shows that the higher reduction rate of NO_3^--N obtained in the ST (55.7%).

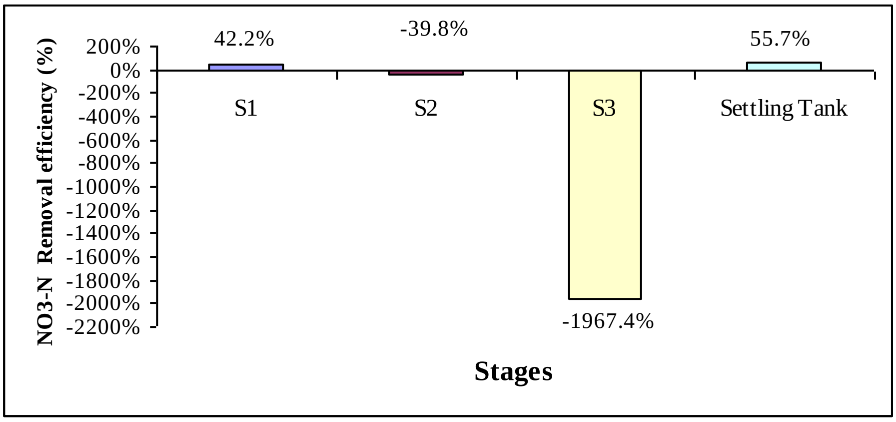

Figure 3.16: NO_3^--N removal efficiency (%) within RBC contactors (S1, S2 and S3) and ST.

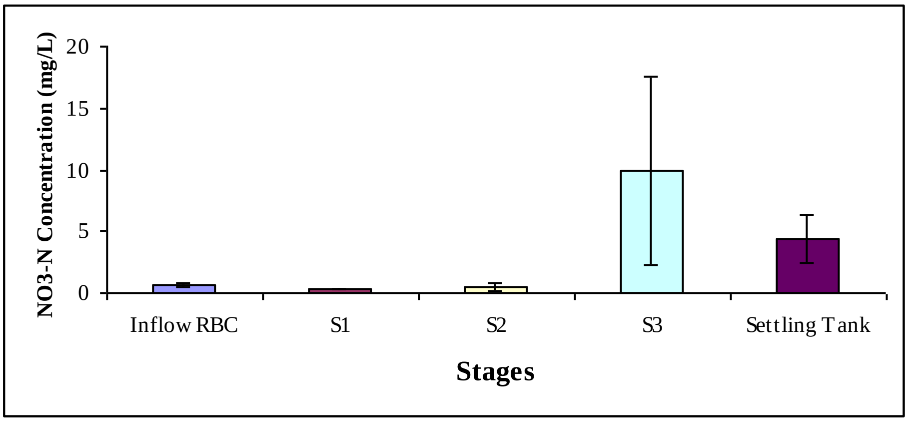

Figure 3.17: NO_3^--N concentration (mg/L) at RBC contactor stages and at ST.

Table 3.10: Average NO_3^--N concentration and removal efficiency at each RBC stage and ST.

	Inflow RBC	S1	S2	S3	Settling Tank
Average	0.6	0.3	0.5	9.9	4.4
S.D.	0.2	0.1	0.3	7.6	1.9
R.E%		42.2%	-39.8%	-1967.4%	55.7%

3.2.3.3 TN-N Removal:

Average TN-N concentration at raw wastewater influent was 86.4 mg/L. Fair reduction rate observed at S1 and S2, while the reduction rate decreased at S3 (78.4, 68.3 and 63.2 mg TN-N/L) respectively (Figure 3.18). No recognition of changes observed on TN-N concentration at ST. The average removal efficiency considered within RBC system and ST was 9.2%, 12.9%, 7.4% and -0.3% respectively (Figure 3.19).

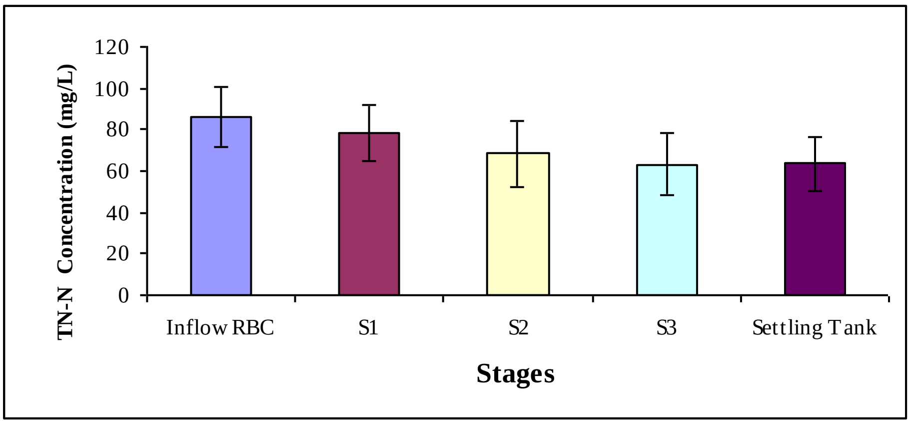

Figure 3.18: TN-N concentration (mg/L) at RBC contactor stages and at ST.

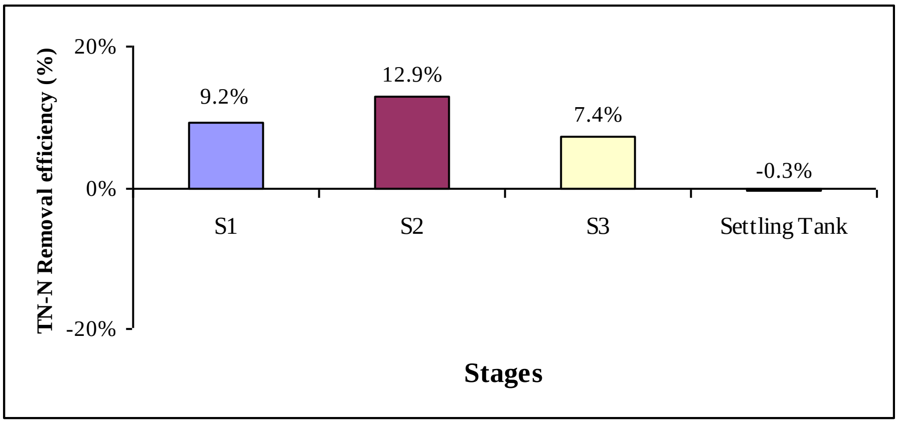

Figure 3.19: TN-N removal efficiency (%) within RBC contactors and ST.

Table 3.11: Average TN-N concentration and removal efficiency at each RBC stage and ST.

	Inflow RBC	S1	S2	S3	Settling Tank
Average	86.4	78.4	68.3	63.2	63.4
S.D.	14.4	14.0	15.7	14.9	12.7
R.E%		9.2%	12.9%	7.4%	-0.3%

3.2.3.4 General Nitrogen Removal:

Comparison of overall treatment efficiencies of TN-N, NH_4^+-N and NO_3^--N within RBC contactors system and ST showed that there was good compatibility among the three parameters removal efficiencies. TN-N concentration was mainly equal to the summation of NH_4^+-N and NO_3^--N concentrations at each stage. NH4+-N eliminated at S1 and S2, while significant autotrophic nitrification occurred at S3 and this could be recognized due to the increase of NO_3^--N concentration at the same stage (figure 3.20).

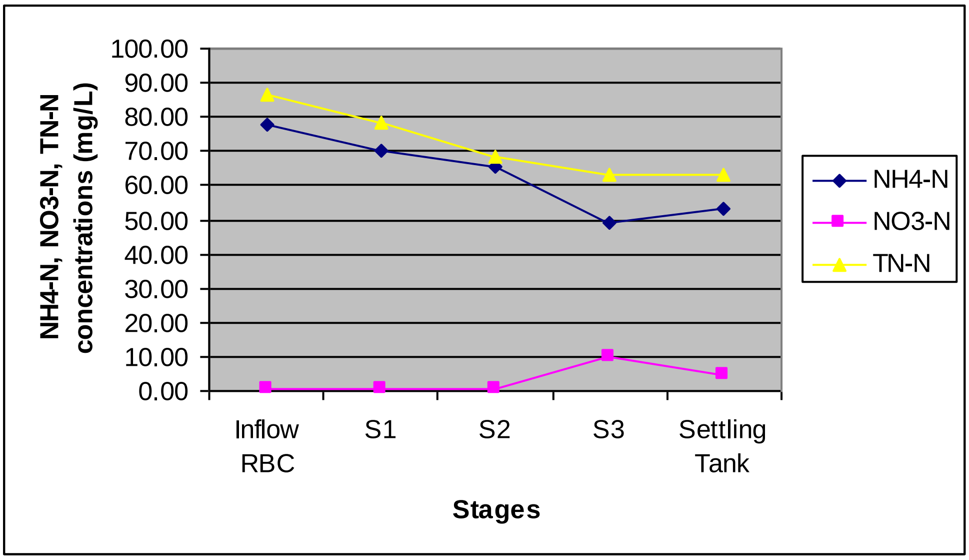

Figure 3.20: Comparison between TN-N, NH_4^+-N and NO_3^--N concentrations (mg/L) at RBC contactor stages and at ST.

3.2.3.5 Effect of Loading Rate on RBC Performance:

Following on analyzing each RBC stage alone to study in detail its removal capacity corresponding to the loading rate that allows to determining the number of stages required to operate the combination under different required effluent characteristics. The effect of the loading rate (in terms of NH_4^+-N) on the RBC contactors system (S1, S2, and S3) performance (as indicated by the corresponding removal rates) presented in figures (3.21, 3.22, 3.23) respectively, where values computed on the basis of feed wastewater characteristics and concentration rate. Moreover, the effect of the loading rate (in terms of COD) on the RBC system performance by the corresponding removal rates of NH_4^+-N presented in figure 3.24. The NH_4^+-N data in figures (3.21, 3.22, and 3.23) show a high degree of dependence (a coefficient of 0.8592, 0.9048 and 0.8847 respectively). The NH_4^+-N data in figure 3.24 exhibited lower degree of dependence but mainly considered high (a coefficient of 0.6663) and that was attributed to the daily and hourly variations in COD values in the raw wastewater influent. So, it should be recommended that a composite sampling must be taking place for the RBC reactors system raw wastewater influent. Multiple regression analysis carried out for the RBC contactors (S1, S2, and S3) to relate removal rate with loading rate gave the following equations and relationships;

$\mathbf{NRR_1} = 0.8273\mathbf{NLR_1} + 5.7272$ $R^2 = 0.4233$ (3.5)
$\mathbf{NRR_2} = 0.1982\mathbf{NLR_2} - 18.367$ $R^2 = 0.9048$ (3.6)
$\mathbf{NRR_3} = 1.1726\mathbf{NLR_3} - 22.805$ $R^2 = 0.8847$ (3.7)
$\mathbf{NRR_4} = 0.0002\mathbf{OLR_4}^{2.1353}$ $R^2 = 0.6663$ (3.8)

Where NRR_1, NRR_2, NRR_3, and NRR_4 and NLR_1, NLR_2, and NLR_3 are the NH_4-N removal and NH_4^+-N loading rates (mg NH_4^+-N /L) for S1, S2, and S3 contactors respectively. OLR_4 is the organic loading rate in raw wastewater influent. It should be noted that the removal and loading rate in Equations. (3.5), (3.6), (3.7) and (3.8) are based on the wastewater feed rate (109 L/h). The removal rate for NH_4^+-N was mainly affected by the corresponding loading rate (the removal rate decreased with increasing the COD concentration in the influent) and these findings were reported by (Hiras, Manariotis and Grigoropoulos, 2003 and Klees and Silverstein, 1992), while no effects of NH_4-N loading rates on removal rate.

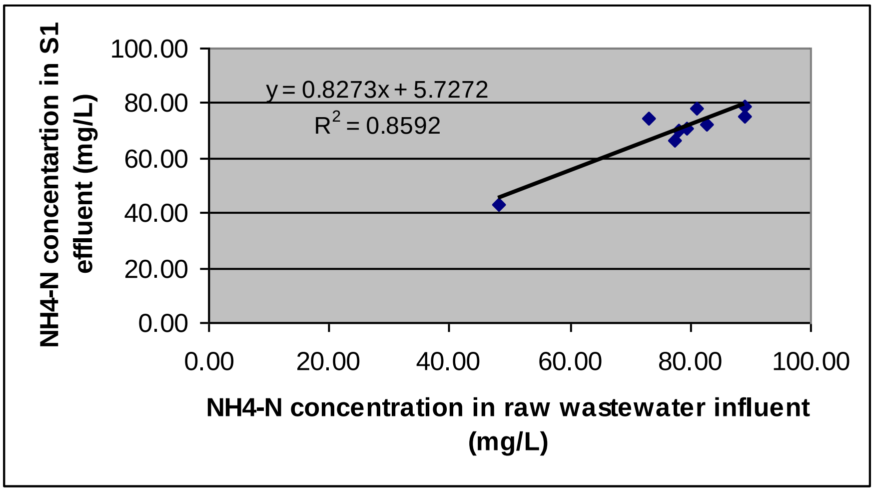

Figure 3.21: NH_4^+-N removal rates at S1 vs corresponding loadings (based on influent characteristics and rate).

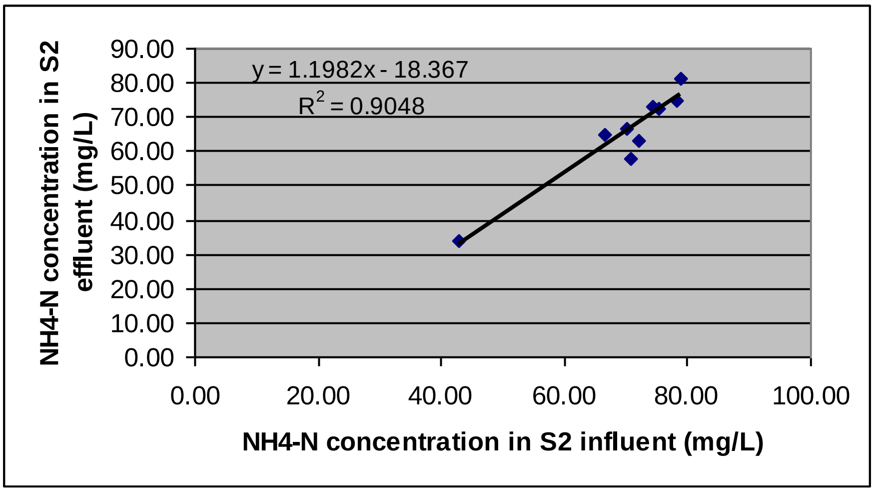

Figure 3.22: NH_4^+-N removal rates at S2 vs corresponding loadings (based on S1 effluent characteristics and rate).

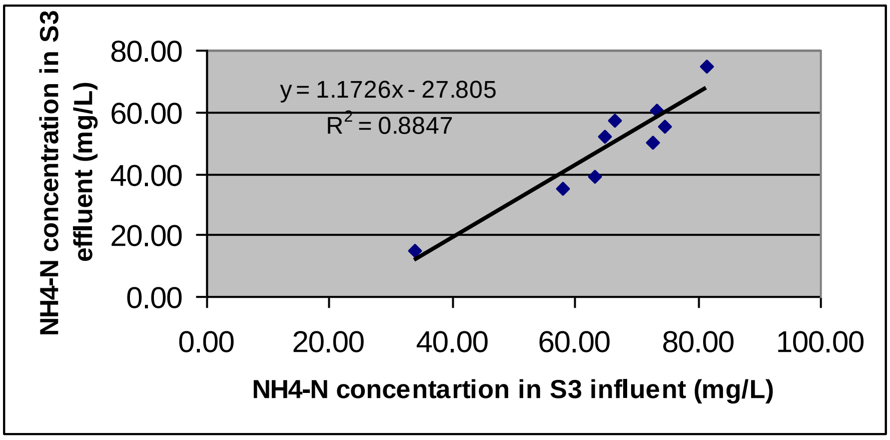

Figure 3.23: NH_4^+-N removal rates at S3 vs corresponding loadings (based on S2 effluent characteristics and rate).

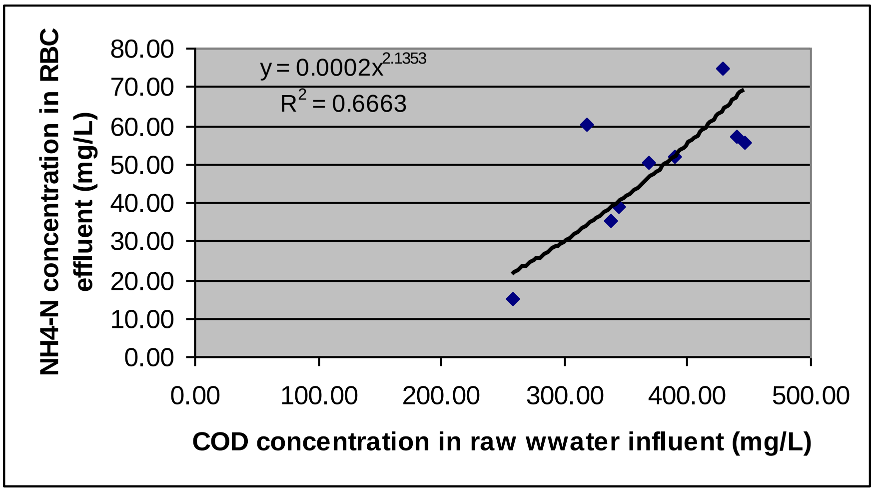

Figure 3.24: NH_4^+-N removal rates at S3 vs corresponding loadings (based on COD concentration in raw wastewater influent).

Table 3.12: NH_4^+-N concentration and removal efficiency at each RBC stage corresponding feed wastewater characteristics.

Sample #	Inflow	S1	S1 %	S2	S2 %	S3	S3 %
W1	89.15	79.05	11.33	81.40	-2.97	74.75	8.17
W2	73.05	74.40	-1.85	73.25	1.55	60.40	17.54
W3	77.25	66.40	14.05	64.80	2.41	52.15	19.52
W4	78.20	70.10	10.36	66.60	4.99	57.00	14.41
W5	81.20	78.10	3.82	74.60	4.48	55.60	25.47
W6	88.90	75.20	15.41	72.70	3.32	50.40	30.67
W7	82.75	72.20	12.75	63.10	12.60	38.95	38.27
W8	48.10	42.80	11.02	33.90	20.79	15.20	55.16
W9	79.35	70.70	10.90	57.95	18.03	35.15	39.34
Average	77.55	69.88	9.75	65.37	7.25	48.84	27.62
S.D	12.22	10.91	5.42	13.74	8.04	17.13	14.76

3.3 Horizontal Soil Filter Constructed Wetlands (HSF)

HSF was put into operation on 23/6/2006 and the mode at this was continues flow with loading rate (60 L/m².d = 14 L/h) and the first sampling obtained after ten days on 3/7/2006 when steady state achieved. HSF adapted to work under phase2 operation conditions. Five grab samples were collected from the HSF influent and effluent along the research period. Table (3.13) reveals the evolution of wastewater characteristic between the ST effluent and the influent of HSF.

Table 3.13: The evolution of wastewater characteristic between ST and HSF influent.

	Parameter	**Unit**	**#**				
ST			**S**	**Average**	**SD**	**R.E%**	**Cumulative R.E %**
	COD $_{diss}$	**Mg/L**	9	80.94	5.80	-7.00%	78.10%
	DOC	**Mg/L**	9	31.30	7.00	-9.70%	74.20%
	NH_4-N	**Mg/L**	9	53.10	13.50	-8.70%	31.60%
	NO_3-N	**Mg/L**	9	4.40	1.90	5.70%	-61.90%
	TN-N	**Mg/L**	9	63.40	12.70	-0.30%	26.60%
	SS	**Mg/L**	6	27.10	21.10	96.30%	83.60%
In-HSF	**COD $_{diss}$**	**Mg/L**	5	79.90	8.06	1.29%	78.41%
	DOC	**Mg/L**	5	28.58	3.74	8.76%	76.48%
	NH_4-N	**Mg/L**	5	44.03	7.76	17.05%	43.26%
	NO_3-N	**Mg/L**	5	4.51	7.80	-2.80%	-652.33%
	TN-N	**Mg/L**	5	50.84	11.42	19.84%	41.16%
	SS	**Mg/L**	3	27.07	21.11	40.56%	83.58%

The data in the previous table show that no significant changes recognized between ST effluent and HSF influent.

3.3.1 Physiochemical Properties of the System

3.3.1.1 Temperature:

The ambient temperature during phase2 operation is known to be the highest through out the year. At hot period, the reed beds seem to be more efficient in reducing organic load, nutrients and parasitical. The hot period coincides with reed exponential growth phase (Mandi, Bouhoum and Ouazzani, 1998). The HSF influent temperature ranged between 20.0˚C to 24.0˚C along the research period with average wastewater influent temperature was 21.8 ± 1.64˚C (table 3.14), while no significant changes recognized in HSF effluent temperature. The wastewater temperature was measured at each sampling point within the HSF directly on site from the collected sample. No significant difference was found between HSF influent and effluent temperatures.

Table 3.14: HSF influent and effluent temperature during the weeks sampling period.

	1	**2**	**3**	**4**	**5**	**Average**	**S.D**
In-HSF	21.0	21.0	20.0	23.0	24.0	21.80	1.64
Out-HSF	20.5	21.0	21.0	22.0	23.0	21.50	1.00

3.3.1.2 Suspended Solids (SS):

SS was measured three times at HSF influent and effluent due to grab samples collected by weekly. According to the filling materials design applied in the HSF, the acceptable concentration of SS in HSF influent is less than 50 mg/L in order to avoid clogging and deterioration. The data in (Table 3.15) exhibited that the average SS concentration in HSF influent was 45.5 mg/L which is remain at low level, below 50 mg/L. The average SS concentration in HSF effluent was 27.1 mg/L, and from (Table 3.14) the removal efficiency was 40.6%.

Table 3.15: Average SS concentration and removal efficiency at HSF.

Sample #	**Inflow HSF**	**Outflow HSF**
1	33.3	7.3
2	87.3	49.3
3	16.0	24.6
Average	45.5	27.1
S.D.	37.2	21.1
R.E%		40.6%

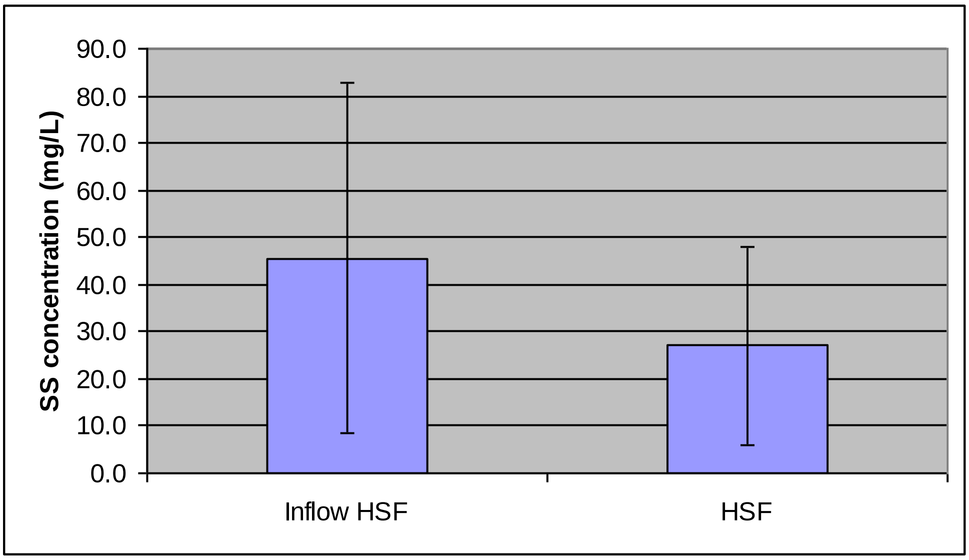

Figure 3.25: SS concentration (mg/L) in HSF influent and effluent.

3.3.1.3 ρH:

ρH value was measured automatically by hourly for HSF effluent throughout the research period. ρH values were found stable, this was reflected through the values ranged between 6.74 and 7.8 with small standard error (data not shown).

3.3.1.4 Dissolved Oxygen (DO):

As well as ρH, the DO was measured automatically by hourly for HSF effluent throughout the research period. Number of DO readings was very huge. The DO average was found 1.82 mg/L with small standard error (data not shown). This concentration is sponsor for prohibiting denitrification process that can take place with absence of oxygen (less than 0.5 mg/l) (Metcalf & Eddy 1999).

3.3.1.5 Organic Removal:

The same organic parameters used in RBC system were used in HSF to follow up the evolution occurred on these parameters within the whole combination. COD and DOC were the two parameters represented the organic parameters. Grab sampling was used to measure the COD and DOC concentration every week throughout this period. Table 3.15 shows the removal efficiency of (COD diss) and DOC reached an average value of 31.06% and 18.47% respectively. From (Figure 3.26) the COD and DOC concentration in the influent was below the level. Most of organic loads consumed in RBC system and this reflected the low removal efficiency.

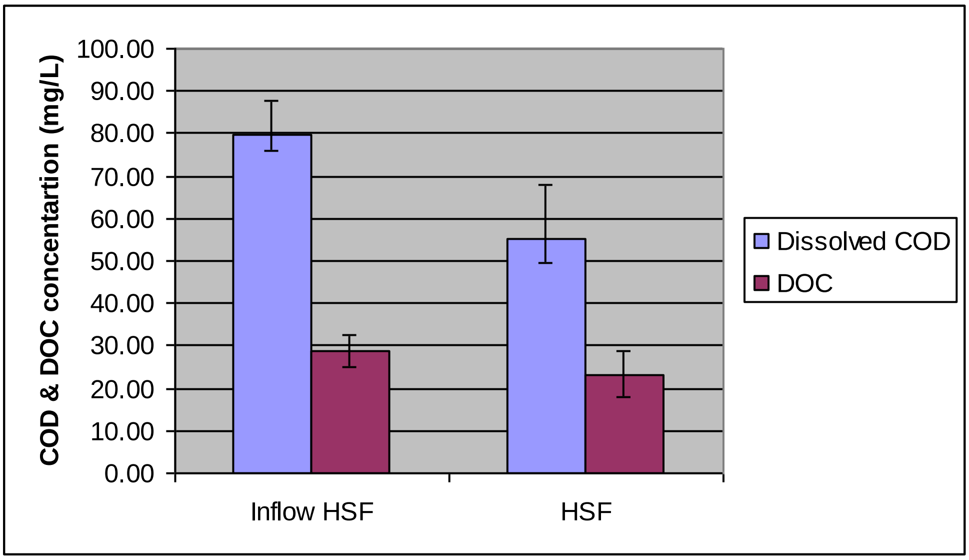

Figure 3.26: COD $_{diss}$ and DOC concentration in HSF influent and effluent.

Table 3.16: Average COD & DOC concentration and removal efficiency at HSF.

Dissolved COD	n	S.D	Average	R.E %
Inflow HSF	5	8.06	79.90	
HSF	5	12.68	55.08	31.06%
DOC				
Inflow HSF	5	3.74	28.58	
HSF	5	5.54	23.30	18.47%

3.3.1.6 Nitrogen Transformation and Removal:

Nitrogen can be eliminated by the chemical adsorption by the soil (Wittgren, 1988). System with horizontal subsurface flow, allow certain activity of nitrification-denitrification considering aerobic and anaerobic zones in the system (Cooper, 1990). Table 3.16 shows that NH_4^+-N and TN-N average removal efficiency was 56.94% and 50.79% respectively and these results were higher than the results obtained by (Mandi, Bouhoum and Ouazzani, 1998). The most is the nitrification phenomenon due to NO3-N negative removal efficiency (-129.08%). That attributed to the oxygen diffused by the roots stimulates the growth of nitrifying bacteria in the rhizosphere (EPA, 1930). Denitrification and , therefore, also elimination of total N, remains lower in this system, most probably because in this relatively new wetland, the development of carbon- rich habitats for denitrification has not yet occurred (Luederitz, Eckert, Lange-Weber, Lange and Gersberg R, 2001).

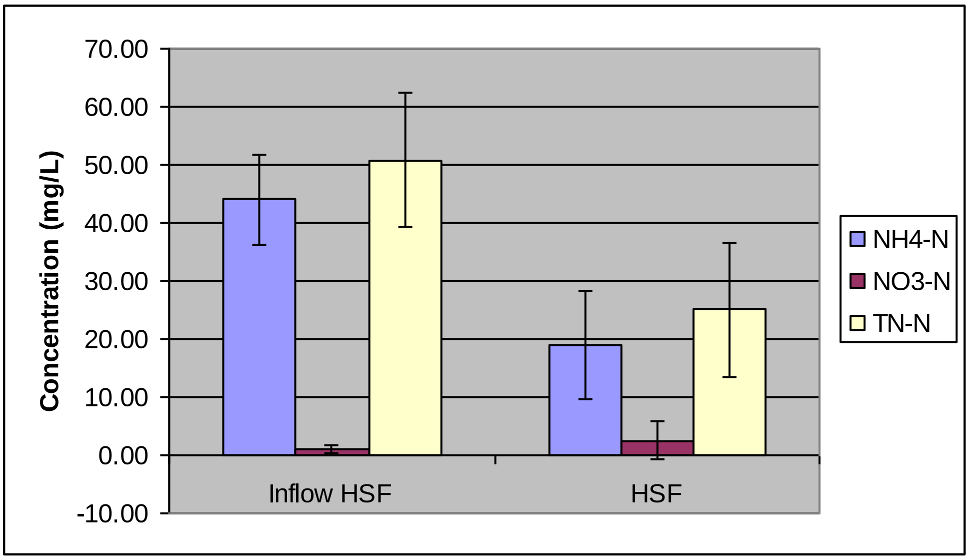

Figure 3.27: NH_4^+-N, NO_3^--N and TN-N concentration in HSF influent and effluent.

Table 3.17: Average NH4-, NO3-N & TN-N concentrations and removal efficiency at HSF.

NH4-N	n	S.D	Average	R.E %
Inflow HSF	5	7.76	44.03	
HSF	5	9.44	18.96	56.94%
NO3-N				
Inflow HSF	5	0.78	1.11	
HSF	5	3.25	2.55	-129.08%
TN-N				
Inflow HSF	5	11.42	50.84	
HSF	5	11.60	25.02	50.79%

3.4 Overall Performance for the Total Combination in Phase2 operation

The previous analyses were taken for each stage alone to have in details the efficiency and evolution occurred on wastewater characteristics at each stage. To have an over view about the complete combination system efficiency, an overall performance in physiochemical and parasitical loads removal was taking place to evaluate the compatibility of the combination. The average combination system (RBC, ST and HSF) influent and effluent quality characteristics and the corresponding removal efficiencies are given in Figures (3.28, 3.29, 3.30, 3.31, 3.32, and 3.33). The optimal removal efficiencies at the final effluent were 85.12% for COD diss, 80.8% for DOC, 75.6% for NH_4^+-N, -325.3% for NO_3^--N, 71.0% for TN-N, and 83.6% for SS. The final effluent characteristic results obtained by this combination exhibited high level purification comparing with other similar in concept (low cost and maintenance) combination results in similar conditions. NO_3^--N removal can take place by the denitrification with the absence of oxygen and that was missing in HSF where denitrification (minimal denitrification occurred) suppose to take place due to the development of carbon- rich habitats for denitrification has not yet occurred (Volker, 2001). Table 3.18 shows the parasitical concentration at the final effluent (E. coli and intestinal nematodes). Two samples were taken for each parameter in two different dates. The first sampling show that E. coli had dropped below 200 MPN/100 ml (165 MPN/100 ml), this is the upper limit for E. coli according to the German standard for irrigation water for crops, likely to be consumed (Bederski, Durr, Lipp, Kuschk, Netter, Daeschlein, Mosig and Mueller, 2005). One month later the E. coli was found in the second sampling test 50 MPN/100 ml. Intestinal nematodes was found (0 Eggs/L) within the two times sampling tests.

Table 3.18: E. coli and intestinal nematodes concentration in raw w.water and in the final effluent.

	Raw W.Water		**Final Effluent**	
Sample #	**E. coli (MPN/100 ml)**	**Nematodes Eggs/L**	**E. coli (MPN/100 ml)**	**Nematodes Eggs/L**
1	2522	0	165	0
2	3290	2	50	0
Average	2906	1	108	0
R.E%			96.3%	100%

Comparing the final effluent quality characteristics with the Palestinian standard for treated wastewater for reuse application in irrigation, the effluent would be categorized as type A (PS, 2003). This class imposes specific effluent quality limit for reuse application in irrigation (<60 mg COD/L, <30 mg SS/L, <1 eggs/L nematodes, and < 200 MPN/100 ml E.coli) that the final effluent did not exceed these concentrations level. The average overall E. coli and nematodes removal efficiency in the final effluent reached 96.3% and 100% respectively. For Nematodes, the removal was constant among the two samples. While the E.coli was improved in the second sample and efficiency increased from 93.4% in the first sample to 98.5% in the second sample. (Bederski, Durr, Lipp, Kuschk, Netter, Daeschlein, Mosig and Mueller, 2005) reported that the concentration of E.coli in the final effluent of vertical soil filter (VSF) followed by HSF (same as the HSF used in our study) was below 200 MPN/100 ml. after 10 months the concentration reduced to 1 log10 to 30 MPN/100 ml.

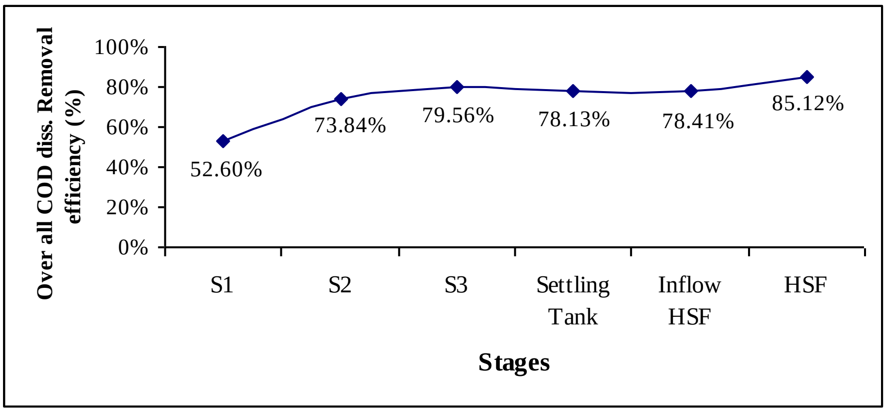

Figure 3.28: Overall cumulative removal (%) for COD $_{diss}$ within the complete combination.

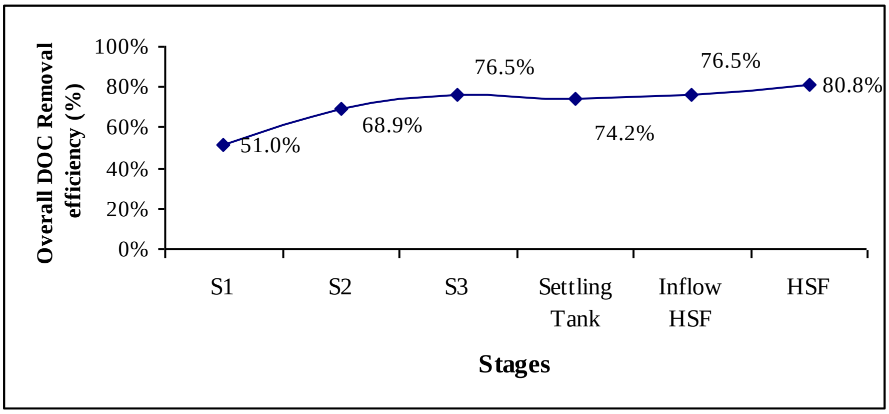

Figure 3.29: Overall cumulative removal (%) for DOC within the complete combination.

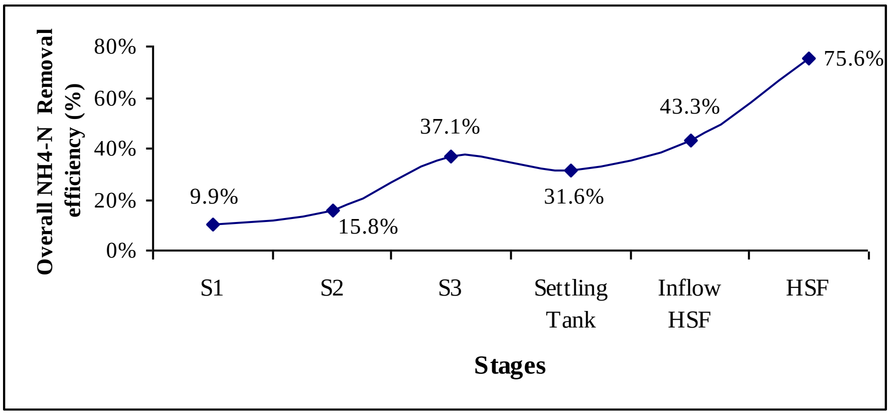

Figure 3.30: Overall cumulative removal (%) for NH_4^+-N within the complete combination.

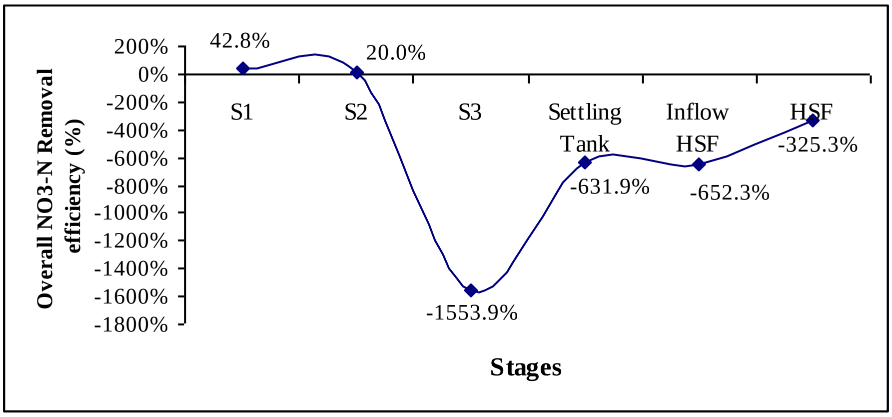

Figure 3.31: Overall cumulative removal (%) for NO_3^--N within the complete combination.

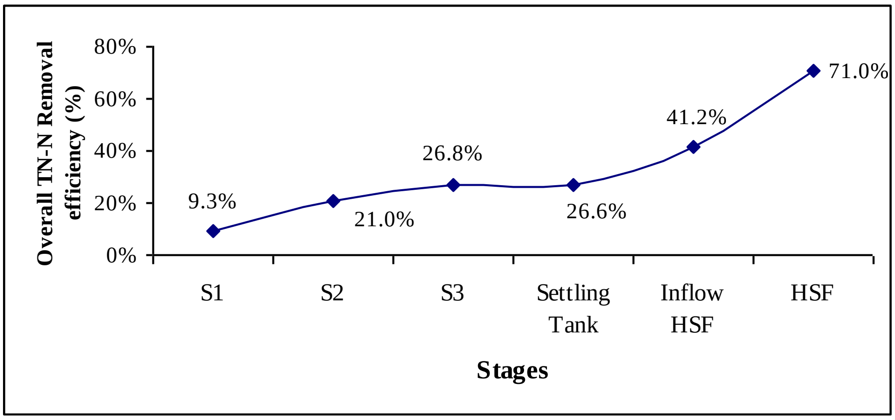

Figure 3.32: Overall cumulative removal (%) for TN-N within the complete combination.

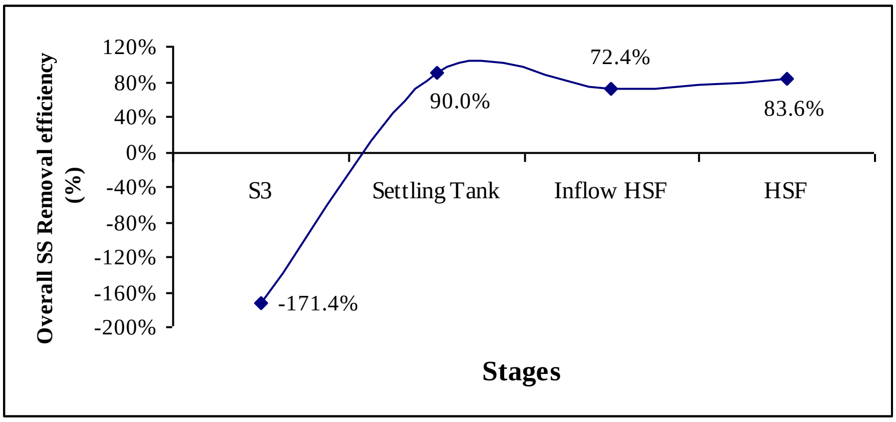

Figure 3.33: Overall cumulative removal (%) for SS within the complete combination.

3.5 Conclusion

The benefits of efficient and reliable aerobic wastewater treatment in many cases can be fully realized only if a proper combination of different stages is available. This system should be simple in construction, operation and maintenance, stable, under shock loads and its energy requirements should be lows. For these reasons we selected a rotating biological contactor (RBC) as an aerobic pretreatment (pretreatment in concept but secondary treatment practice and biological processes occurred) for the post treatment horizontal soil filter constructed wetlands (HSF) for high strength raw wastewater treatment. In our investigations, emphasis was given to the removal of COD diss, pathogenic bacteria and the conversion of NH_4^+-N by nitrification and the conversion of NO_3^--N by denitrification. The results of the investigation revealed that a major part of the dissolved COD and DOC were removed in the first stage of a three- stages RBC system. Nitrification mainly proceeds in the third stage due to the high COD loads prevailing in the first stage of RBC and also proceeds in HSF. The effect of the combination on studied parameters was as follows;

- COD diss removal mainly, took place in S1 as a result of high COD concentration in the raw wastewater and the proper growth of Heterotrophic bacteria in S1.
- Overall average COD removal at the final effluent was 85.12% and that was mostly, similar to the results obtained by vertical soil filter (VSF) followed by HSF combination to treat domestic pretreated wastewater in the same site (UFZ, 2005).

- COD concentration corresponding to COD loading rates within RBC was reflected by the following equations;

  $\mathbf{ORR_1} = 0.2412\mathbf{OLR_1} + 86.177 \quad R^2 = 0.4233 \quad (3.2)$

  $\mathbf{ORR_2} = 0.7072\mathbf{OLR_2} - 27.249 \quad R^2 = 0.8799 \quad (3.3)$

  $\mathbf{ORR_3} = 0.7547\mathbf{OLR_3} + 2.5808 \quad R^2 = 0.9849 \quad (3.4)$

  R^2 value in equation (3.2) was low due to the daily and hourly variations in COD concentration in raw wastewater.
- As well as COD, DOC reduction mainly occurred in S1 (52%) with constant increasing removal rate along the followed stages (80.8% final removal at HSF).
- Low NH_4^+-N elimination observed in S1 (9.9%) and S2 (15.8%), while good nitrification proceeded in S3 (37.1%) and HSF effluent (75.6%).
- NH_4^+-N concentration corresponding to NH_4^+-N and COD loading rates within RBC was reflected by the following equations;

  $\mathbf{NRR_1} = 0.8273\mathbf{NLR_1} + 5.7272 \quad R^2 = 0.4233 \quad (3.5)$

  $\mathbf{NRR_2} = 0.1982\mathbf{NLR_2} - 18.367 \quad R^2 = 0.9048 \quad (3.6)$

  $\mathbf{NRR_3} = 1.1726\mathbf{NLR_3} - 22.805 \quad R^2 = 0.8847 \quad (3.7)$

  $\mathbf{NRR_4} = 0.0002\mathbf{OLR_4}^{2.1353} \quad R^2 = 0.6663 \quad (3.8)$

- Ammonification due to biological decomposition of organic nitrogen took place in ST causing an increase of NH_4^+-N concentration in ST effluent.
- NO_3^--N Denitrified in S1 (42.8%), then the concentration of NO_3^--N increased sharply at S3 (-1553.9%) due to nitrification. A minimal denitrification recognized in HSF due to the development of carbon- rich habitats for denitrification has not yet occurred.
- TN-N mainly, removed in HSF effluent (71% average removal rate).
- ρH value was mainly constant in final effluent (6.74 and 7.8) with small standard error.

3.6 Recommendations

The following recommendations can be drawn from the results presented in this study:

- Due to the daily and hourly variations in COD concentrations, composite sample must take place to present the raw wastewater influent.
- Raw wastewater must be properly pretreated to eliminate the SS and to avoid the excessive sludge at the RBC effluent.
- Proper and well designed ST must take place after RBC system to eliminate SS to allowable concentration for HSF influent.
- Investigation of modified combination (RBC followed by HSF) models under Palestine condition at pilot scale.
- The feasibility of (RBC/HSF) system should be investigated during winter period at lower ambient temperature.
- Making more investigation about nitrogen transformation and nutrient removal to adopt the system for reuse application in agriculture using the nutrients as fertilizers.

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Appendices

Appendix A: Photos of experimental set up

Photo A1: SGR system used as pretreatment stage.

Photo A2: RBC after its first installation.

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Photo A3: Covering the RBC by aluminum papers to reduce the effect of weather on the active biofilm which becomes attached to the disc surfaces

Photo A4: Biofilm attached on rotating discs

Photo A5: Sampling bottles prepared to collect samples from the pilot plant

Photo A6: Sample collected from RBC system.

Photo A7: Temperature measured manually from RBC effluent.

Photo A8: Excessive sludge accumulated in ST.

Appendix B: All samples analysis

All results in the third operation stage (109 L/h) raw wastewater
All Results in mg/L

	6/6/2006 W1	12/6/06 W2	19/6/06 W3	26/6/06 W4	3/7/06 W5	10/7/06 W6	17/7/06 W7	24/7/06 W8	31/7/06 W9	Median	S.D	Average
	Dissolved COD											
Inflow RBC	429.00	318.00	389.00	440.00	446.00	369.00	344.00	258.00	338.00	369.00	62.72	370.11
S1	217.00	186.00	184.00	183.00	182.00	182.00	153.00	150.00	142.00	182.00	23.25	175.44
S2	121.00	112.00	103.00	104.00	103.00	101.00	83.90	65.70	77.80	103.00	17.53	96.82
S3	95.40	88.60	81.10	79.00	77.30	78.30	66.50	51.90	62.80	78.30	13.33	75.66
Settling Tank	90.50	87.40	81.30	82.00	80.40	80.00	69.00	76.10	81.80	81.30	5.80	80.94
Inflow HSF					76.80	90.90	69.80	77.50	84.50	77.50	8.06	79.90
HSF					48.90	77.10	54.70	47.60	47.10	48.90	12.68	55.08
	DOC											
Inflow RBC	159.00	125.40	121.00	132.00	146.30	120.50	113.10	75.80	100.80	121.00	24.33	121.54
S1	84.30	76.20	53.40	58.00	61.10	59.00	53.60	37.10	53.10	58.00	13.76	59.53
S2	56.50	52.90	34.70	36.00	39.20	38.20	32.30	21.10	29.10	36.00	11.05	37.78
S3	46.00	43.10	25.80	26.00	28.40	27.20	23.70	14.90	21.90	26.00	9.91	28.56
Settling Tank	45.70	40.10	26.73	27.00	29.80	29.00	25.00	27.20	31.40	29.00	6.97	31.33
Inflow HSF					27.00	32.70	24.20	26.70	32.30	27.00	3.74	28.58

HSF					29.30	29.20	21.10	18.70	18.20	21.10	5.54	23.30
	NH4-N											
Inflow RBC	89.15	73.05	77.25	78.20	81.20	88.90	82.75	48.10	79.35	79.35	12.22	77.55
S1	79.05	74.40	66.40	70.10	78.10	75.20	72.20	42.80	70.70	72.20	10.91	69.88
S2	81.40	73.25	64.80	66.60	74.60	72.70	63.10	33.90	57.95	66.60	13.74	65.37
S3	74.75	60.40	52.15	57.00	55.60	50.40	38.95	15.20	35.15	52.15	17.13	48.84
Settling Tank	73.45	59.80	49.15	58.20	64.50	55.00	47.10	26.60	43.90	55.00	13.50	53.08
Inflow HSF					52.50	51.60	38.65	35.10	42.30	42.30	7.76	44.03
HSF					26.70	29.10	19.55	13.10	6.35	19.55	9.44	18.96
	NO3-N											
Inflow RBC	0.60	0.45	0.68	0.80	0.86	0.56	0.49	0.40	0.51	0.56	0.16	0.59
S1	0.38	0.35	0.41	0.40	0.39	0.31	0.26	0.26	0.33	0.35	0.06	0.34
S2	0.32	0.32	0.35	0.40	0.34	0.30	1.15	0.54	0.60	0.35	0.27	0.48
S3	2.94	3.24	4.80	5.40	6.83	8.30	24.60	18.80	14.40	6.83	7.64	9.92
Settling Tank	3.21	4.25	5.05	5.30	6.49	5.40	6.60	2.50	0.72	5.05	1.94	4.39
Inflow HSF					2.13	1.39	1.40	0.38	0.27	1.39	0.78	1.11
HSF					8.16	0.66	0.33	1.01	2.60	1.01	3.25	2.55
	TN-N											
Inflow RBC	103.00	84.30	92.80	85.00	86.40	97.90	91.40	52.30	84.20	86.40	14.35	86.37
S1	91.30	84.20	77.90	80.20	87.20	86.90	82.00	44.60	71.20	82.00	13.97	78.39
S2	87.20	79.70	69.50	71.10	57.90	79.60	75.90	35.60	57.80	71.10	15.69	68.26
S3	86.40	73.10	64.40	66.00	63.00	57.80	73.10	33.70	51.50	64.40	14.92	63.22
Settling	85.00	71.90	67.30	65.00	72.30	61.00	56.00	46.70	45.60	65.00	12.71	63.42

Tank												
Inflow HSF					50.00	61.80	62.60	36.50	43.30	50.00	11.42	50.84
HSF					32.90	38.00	28.10	15.50	10.60	28.10	11.60	25.02
	SS											
Inflow RBC	174.00	244.00	154.00				134.00	44.70	238.00	164.00	73.76	164.78
S3	466.00	802.00	812.00				276.00	132.00	196.00	371.00	300.36	447.33
Settling Tank	24.50	44.60	24/ 24				8.70	3.33	1.30	8.70	18.16	16.49
Inflow HSF							33.30	87.30	16.00	33.30	37.19	45.53
HSF							7.30	49.30	24.60	24.60	21.11	27.07
	Temperature											
	15.50	18.50	24.50	23.00	22.50	22.30	22.20	25.40	23.00	22.50	3.05	21.88