Pilot Plant Lebanon
Performance Evaluation of the Wastewater Treatment Plant at UOB Campus

Water resources have become increasingly scarce and insufficient in many arid and semi-arid countries and plans must be made for the development of any additional, effective and sustainable source of water in these areas. This problem is becoming more and more serious with the expansion of urban population and rising life standards, which require an increased coverage of domestic water supply and thus lead to greater quantities of sewage and wastewater. And with the current emphasis on environmental health and water pollution issues, there is further awareness of the need to dispose these wastewaters safely and beneficially. The use of wastewater in agriculture could be an important consideration when its disposal is being planned in these countries. Wastewater reuse will result in the conservation of higher quality water and its application for purposes other than irrigation.

Many Arab countries in the Middle East have included wastewater in their water resources planning such as Jordan and Saudi Arabia which have national policies to reuse all treated wastewater effluents and have already made considerable progress towards this end.

Wastewater services must be developed as to protect the public health of communities, the scarce water resources and the environment from pollution. This approach should provide wastewater services that are efficient and environmentally responsible and responsive for the problem of water insufficiency.

The Pilot Plant at UOB:

The proposed WWTP, designed by UOB and constructed by EMCO Engineering Ltd., is expected to treat the flows and loads based on the Occupancy and Loading Data as specified below:

1. Average flow: 50-60 m^3/day = 2.1-2.5 m^3/h.
2. Peak flow: 2.1-2/5 m^3/h *3= 6.3-7.5 m^3/h.
3. Typical values for the wastewater characteristics of the UOB sewer system set by EMCO are given in Table1.

Table 1: Average Wastewater Design Quality Parameters (influent) set by UOB and EMCO

Parameter	**Unit**	**Value**
BOD_5	mg/L	270
COD	mg/L	600
TSS	mg//L	400
pH		6 – 9

Source: University Of Balamand: WWTP Master Plan Report

Currently, the wastewater at the University is being discharged in two septic tanks. The average daily flow varies between 100 to 120 m^3/day; this pilot plant treats an average flow of 50 to 60 m^3/day and the remaining flow will be diverted to another similar module of the WWTP that is designed and financed by UOB, and constructed by EMCO. This proposed plant will employ preliminary, secondary and tertiary treatments; and the secondary treatment which is the biological treatment is selected to be of the Extended Aeration Activated Sludge type. The effluent of the biological stage will then be polished in a tertiary treatment stage, and will be stored in an irrigation storage tank and to be finally reused for potential irrigation purposes.

Water flowing from the UOB campus is screened through a rotary screen and then passes to the anoxic tank where it is retained for 130 min and where denitirfication takes place. The denitrified mixed liquor reaches the aeration tank where carbonaceous and nitrogenous biochemical reactions occur. The retention period in the aeration compartment is designed for 27 hrs on average daily flow rate. The mixed liquor is then allowed to settle in the settling tank and the supernatant flows into the chlorination tank. The retention time in the settlement compartment should be at least 3 hrs at peak hourly flow rate. Part of the settled sludge is returned to the first denitirfication tank and the remaining is desludged and stored in the sludge holding tank. The sludge return system from the sedimentation tank will be of continuous operation and the volume of sludge to be returned will be between 0.5 and 1.5 peak flow. Chlorination of the treated wastewater is carried out using liquid sodium hypochlorite solution for a contact time of at least 60 min. After disinfection, water flows into the sand filter and the carbon filter and the effluent is then stored in the irrigation tank. The schematic diagram of the treatment plant is shown in figure1.

Figure 1: Flow Diagram of the Pilot Plant

The treated wastewater from the plant will have an effluent quality in accordance with the hygienic requirements and the standards set by UOB and EMCO are given in Table 2.

Table 2: Typical Values of Effluent Standards set by UOB and EMCO

WWTP effluent	BOD_5 (mg/L)	10
	COD (mg/L)	125
	TSS (mg/L)	10
	pH	6 – 9

Source: University Of Balamand: WWTP Master Plan Report

The emission standards for discharge into surface water and air, that are established by the Lebanese Ministry of Environment (MoE- Ministerial Decision No. 8/1/2001) are provided in table3.

Table 3: Environmental Limit Values for Wastewater Discharge

Parameter	**Value**
pH	6-9
T(ºC)	30
BOD_5 (mg/L)	25
COD (mg/L)	125
TSS (mg/L)	60
TDS(ppm)	2000
Nitrate (ppm)	90

Source: Taken as is from MoE, SPASI, 2001

The monitoring program of the pilot plant will be carried out through several tests conducted on influent and effluent collected from the treatment plant. Accuracy and precision of performance of the plant and operations will be verified by comparison with standard values set by UOB and EMCO and by the Lebanese Ministry of Environment (MoE) to check on and ensure the quality of analytical data produced.

Community Service Program:

The Pilot Treatment Plant constructed at University of Balamand (UOB) Campus in North Lebanon in collaboration represents a modern small-scale treatment plant operating at local Lebanese conditions. As soon as this plant has started, a program of visits or "field days" was organized for members of the community at large including but not restricted to Municipalities, Ministries, NGO's, Engineers and Technicians, Trainees and Students. A major task is to educate the community about the need for and the importance of sewage treatment, and the adoption of environmentally sound practices of recycling; like the reuse of the effluent in irrigation. So the achievement of the objectives for which the Pilot plant was built, is to develop public awareness leading to the acceptance of sewage treatment, and the beneficial recycling of the effluent and the sludge produced.

Geographically, UOB is in the "North Lebanon" region; consisting of the districts of Batroun, Koura, Bcharry, Zghorta, Tripoli, Dinniye and Akkar. Towns and villages and their municipalities are now working with in propagating knowledge and education about the importance and inevitability of the treatment of sewage. These programs, combined with the visits that will be scheduled to the Pilot Plant for municipalities, for university students, and for high school students, will help them to know about the process of wastewater treatment and its efficiency in controlling disease-carrying bacteria in water, and in converting the risky sewage into harmless material to be disposed safely in the environment and its beneficial reuse for irrigation.

In addition, the plant will be contributing to the University Academic programs as a site and setting for the training of students and accomplishment of project- and thesis-research. It's also to be noted that it will provide the students, staff and operators to see how a real WWTP is built and operated and will give them the chance to perform real laboratory testing of the various elements that are normally performed during the operation of wastewater plants. These field days and seminars cannot be just exhibitions. As a university, the prime event would be the presentation of laboratory analytical data produced regularly on samples collected routinely from the treatment plant because theoretical knowledge needs to be scientifically supported by analytical data. For this purpose, a program of sampling is initiated to generate data on certain parameters that indicate monitoring of the progress of the treatment process observance of quality control. And finally, by the time of conducting these visits, it is hoped that the experimental field will be already under cultivation to demonstrate the beneficial recycling of the effluent in crop production. It is of significance to demonstrate how reuse complements and culminates treatment.

Kinetic Parameters:

Effective environmental control in biological waste treatment is based on understanding of conditions governing the growth of microorganisms. Environmental conditions can be controlled by pH and temperature regulation, nutrient or trace-element addition, and oxygen addition or depletion. To ensure that microorganisms will grow, they must be allowed to remain in the medium long enough to reproduce. This period depends on their growth rate, which is directly related to the rate at which they metabolize or use the waste. Assuming that environmental conditions are controlled properly, effective waste stabilization can be guaranteed by controlling the growth rate of microorganisms.

So the dynamic part of this research project is dictated for checking the kinetic parameters of the plant which will be based on Monod kinetics using the mathematical representation of mass balance for both microorganism and substrate. The method of kinetic parameter determination will based on the linearization of mass balance equation with the assumption, that Monod kinetics is applicable for this type of wastewater and treatment technology.

A mass balance equation for substrate (BOD5) at the aeration tank leads to the following equation:

$$r_{su} = \frac{kXS}{K_s + S} = -\frac{So - S}{\theta}$$ **Eq. 1**

$$k = \frac{\mu_{\max}}{Y}$$ **Eq. 2**

Dividing equation 1 by X yield

$$\frac{kS}{K_s + S} = -\frac{So - S}{\theta X}$$ **Eq. 3**

The linearized form of equation 3, obtained by taking its inverse, is

$$\frac{X\theta}{So - S} = \frac{Ks}{k}\frac{1}{S} + \frac{1}{k} \qquad \textbf{Eq. 4}$$

The value of K_s and k can be determined by plotting the term $(X\theta/(S_0\text{-}S))$ versus (1/S).

A mass balance equation for microorganisms at the aeration tank leads to the following equation:

$$\frac{1}{\theta c} = -Y\frac{r_{su}}{X} - k_d \qquad \textbf{Eq. 5}$$

The values of Y and k_d may be determined using Eq. 5 by plotting $(1/\theta_c)$ versus ($-r_{su}/X$).

Where:
Y: Growth yield coefficient
μ_{max}: Maximum specific growth rate, h^{-1}
K_s: Half velocity constant, mg/L
K_d: Endogenous decay coefficient, h^{-1}
r_{su}: rate of substrate utilization
X: microorganism concentration in the aeration tank (mg TSS/L)
S_0: substrate concentration in the influent (mg BOD/L)
S: substrate concentration in the effluent (mg BOD/L)
θ: hydraulic detention time (day)
θ_c: the sludge age (mean cell residence time in days)

Results:

The operations at the plant were launched in December 2007; and testing of influent and effluents started at the end of February 2008. The results of the monitoring program based on the tests carried out are discussed below.

Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD):

Measuring the levels of oxygen demand in wastewater is important because the composition of domestic sewage varies surprisingly little from place to place, although to a certain extent, it reflects the economic status of the society or the studied region. Domestic wastewater contains sufficient amounts of carbohydrates, amino acids, nutrients, fatty acids, surfactants… and this composition is a very well balanced food for microorganisms.

Figures 2 and 3 show the variation of BOD_5 and COD successively, in influent and effluent wastewater. Respective values of both influent BOD_5 and COD didn't exceed that of the design standards set by UOB and EMCO in table1; meaning that the plant won't require an extended period of time and work for each process of wastewater treatment.

Effluent levels also showed to be less than standards set by EMCO and MoE in tables 2 and 3, which allow the reuse of the treated wastewater for irrigation purposes and prove the efficiency of the treatment plant.

The results also reveal a relatively nonlinear variation of both parameters; this can be attributed to the low temperatures at this time of year. And in comparison, COD values are in general higher then BOD values because more compounds can be chemically oxidized than can be biologically oxidized.

Figure 2: Variation of BOD5 Level at the Pilot Plant.

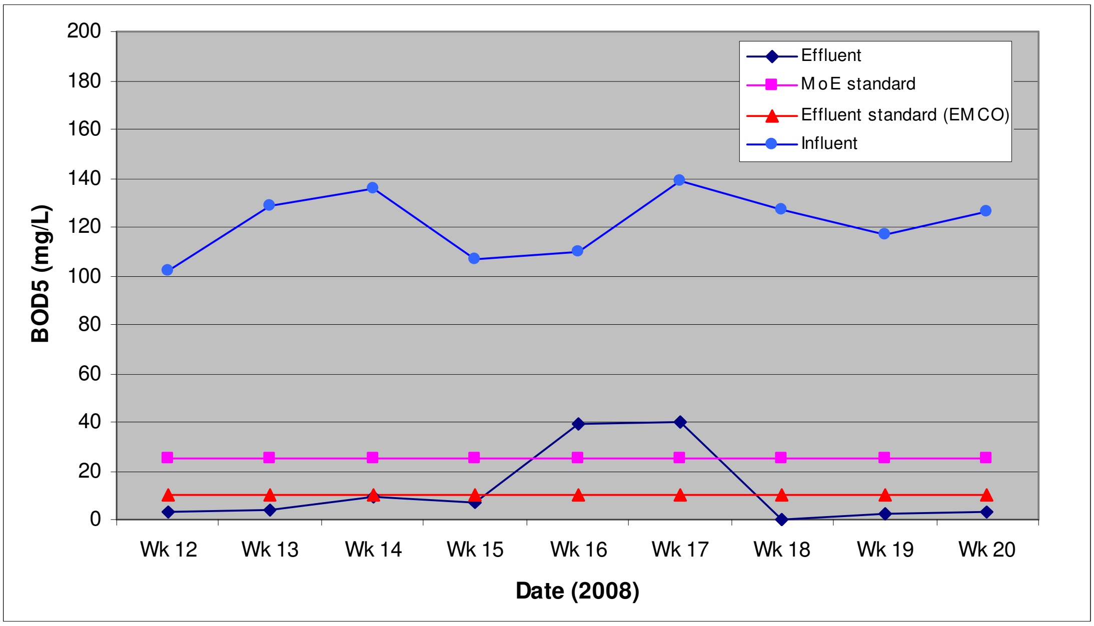
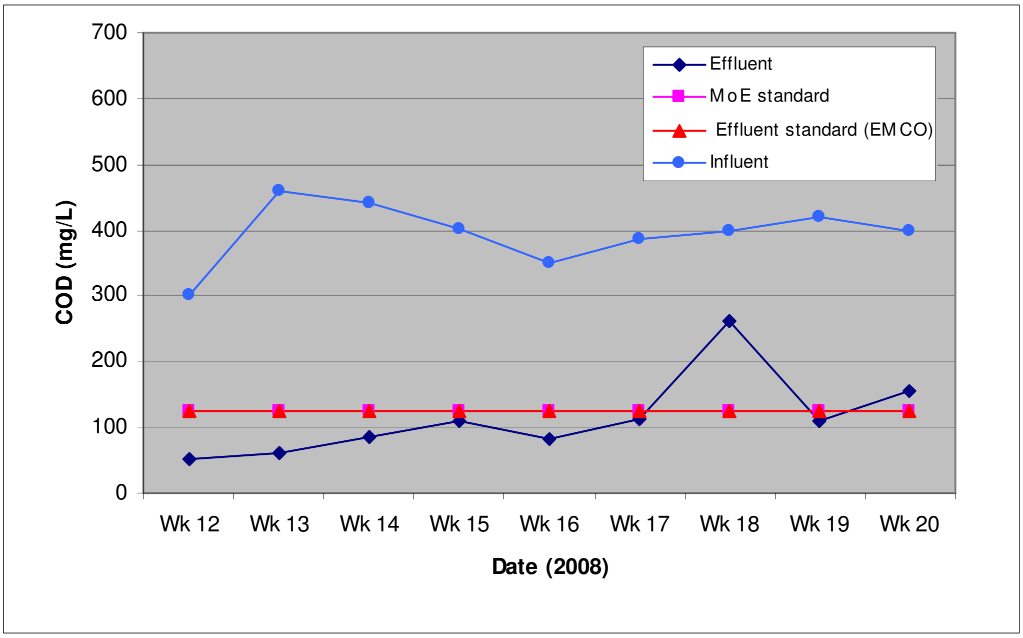


Figure 3: Variation of COD Level at the Pilot Plant.



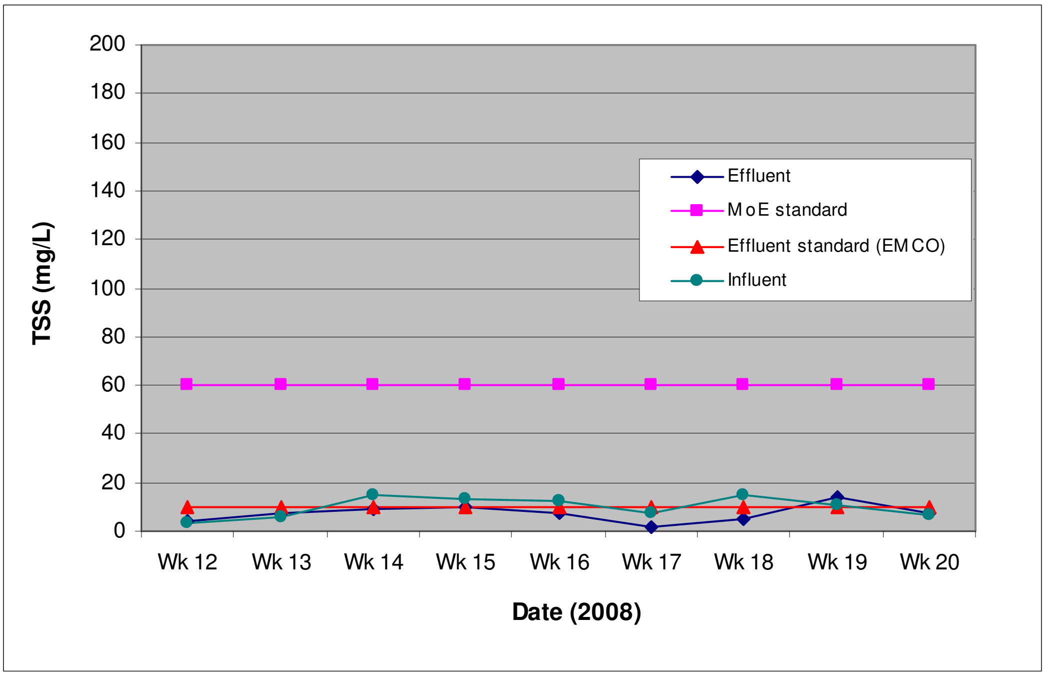
Total Suspended Solids (TSS) and Total Dissolved Solids (TDS):

Determination of suspended and dissolved solids in wastewater is a very important agricultural water quality parameter. Suspended solids affect clarity and turbidity of water. And dissolved solids reflect salinity of irrigation water, which in turn affects the salinity of soil water, and thus plant growth and crop yield.

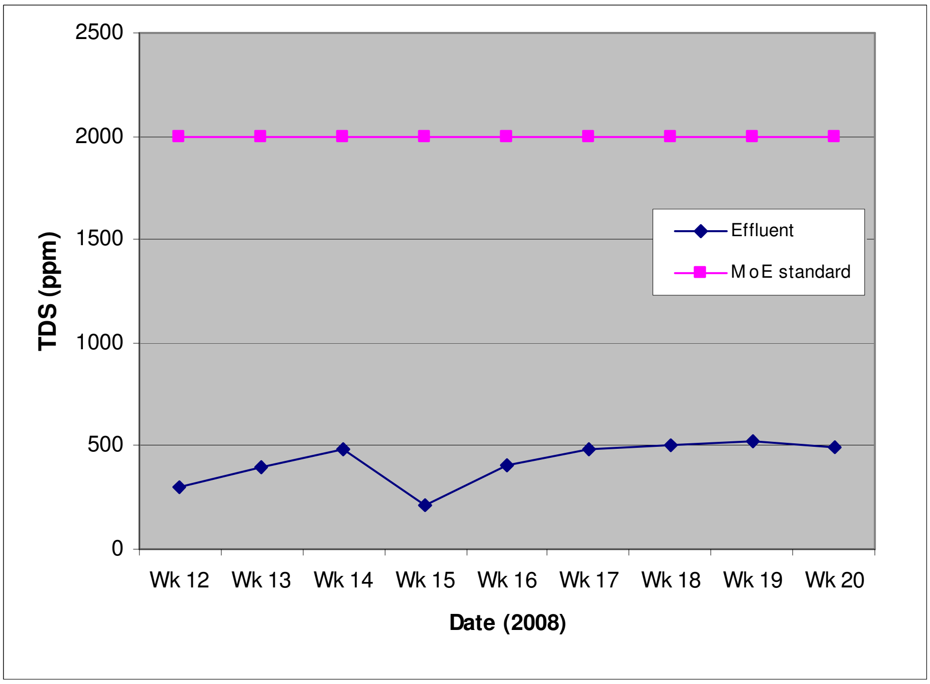
Figures 4 and 5, which show the variation of TSS and TDS at the plant, did not reveal an influent level that exceeded the design standards set by EMCO.

The primary treatment of the influent shows effective in removing suspended matter; this explains the effluent values, which are below the standard.

<u>Figure 4:</u> Variation TSS Level at the Pilot Plant.



<u>Figure 5:</u> Variation of TDS Level at the Pilot Plant.

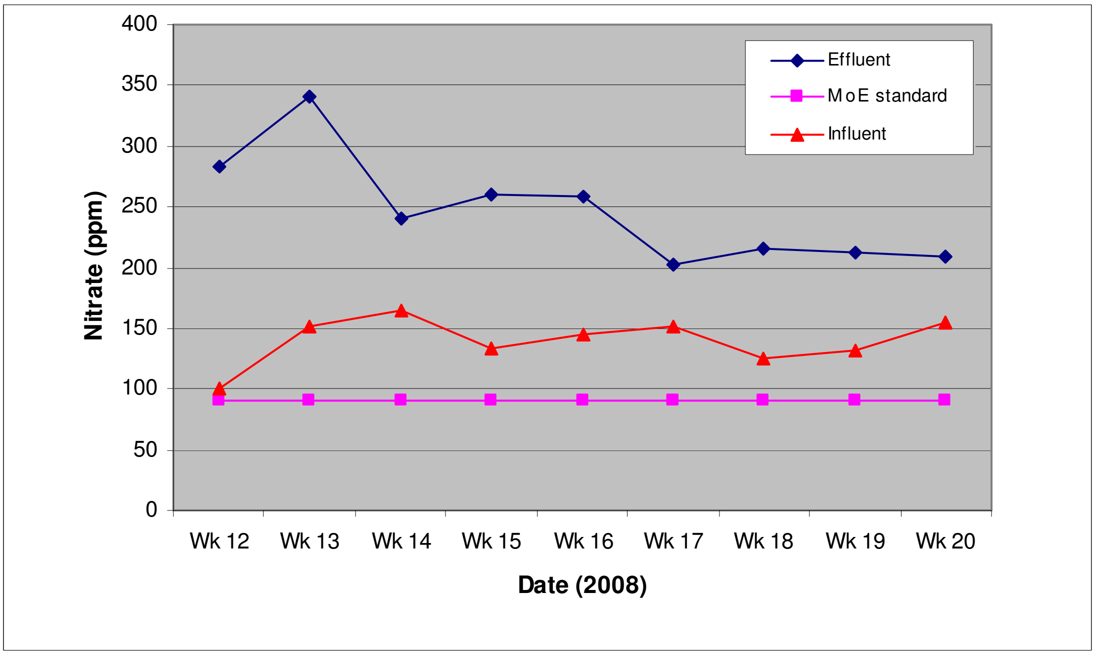


<u>Nitrate NO_3:</u>

Nutrients including ammonia, nitrates, and other nitrogenous compounds are found in domestic sewage; and discharge of these nutrients may cause eutrophication. So in order to avoid these undesirable effects, these must be removed from water; and this

is realized by nitrification followed by denitirfication. To evaluate the efficiency of these processes, nitrate concentrations must be precisely monitored; and figure 6 shows the variation of nitrate concentrations in both influent and effluent wastewater.
The high concentrations obtained in the effluent could be considered normal, since the denitrification process occurs after waste treatment, there may be not be enough organic material left in the waste stream to supply the necessary energy for conversion of nitrate to nitrogen gas.
Nitrogen exists in the influent as organic nitrogen such as proteins, amino acids, amines…and these are decomposed into the inorganic forms of ammonium, nitrites and nitrates. In addition, the university campus is not located in an industrial or agricultural area where high amounts of nutrient-containing fertilizers; all that can explain the relatively moderate nitrate values in the influent.

Figure 6: Variation of Nitrate Concentration at the Pilot Plant.



pH and Temperature:

pH is an indicator of acidity or basicity of water; and the normal range for irrigation water is between 6 and 9. Values outside this range indicate a poor quality of water because low pH values have detrimental effects on soil and plants. Overall, pH and temperature affect several processes in water treatment such as aerobic degradation of organic matter, denitirfication, and disinfection and their rates; stability and solubility of chemicals and suitability of water for beneficial uses are also affected by the variation of these parameters.

Figures 7 and 8 show the variation of pH and temperature in influent and effluent wastewater. pH variation shows to be within the normal range set by MoE which gives the treated water a good quality for irrigation. Temperature values also didn't exceed the standard values but the fluctuations can be explained by the ambient temperature that was varying in the period between February and April.

Figure 7: pH Variation at the Pilot Plant.

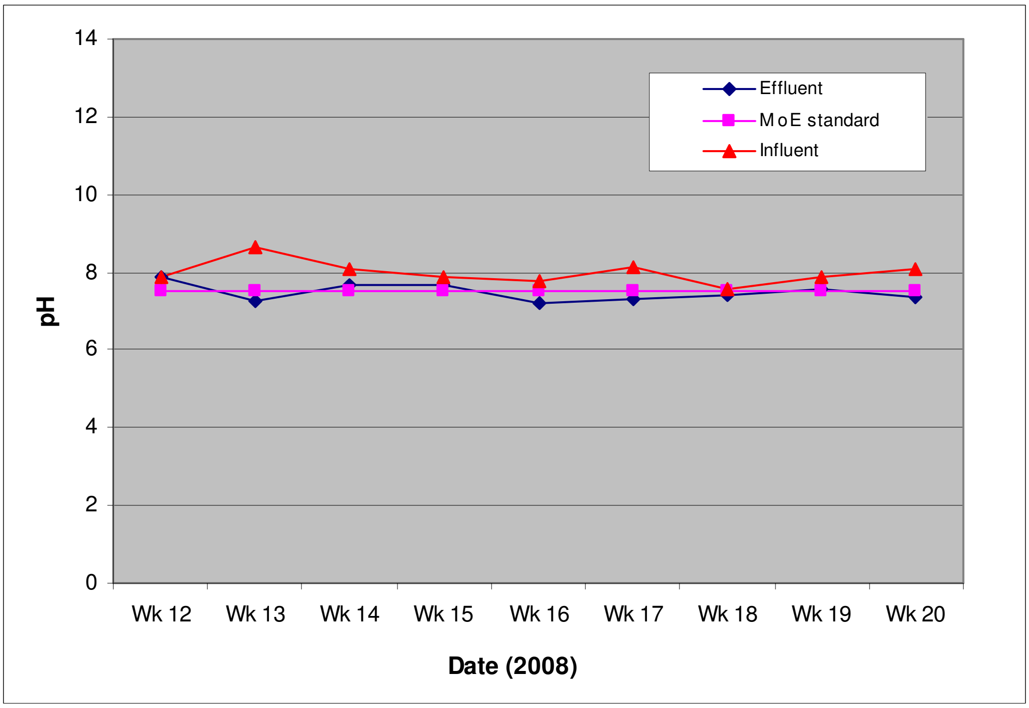
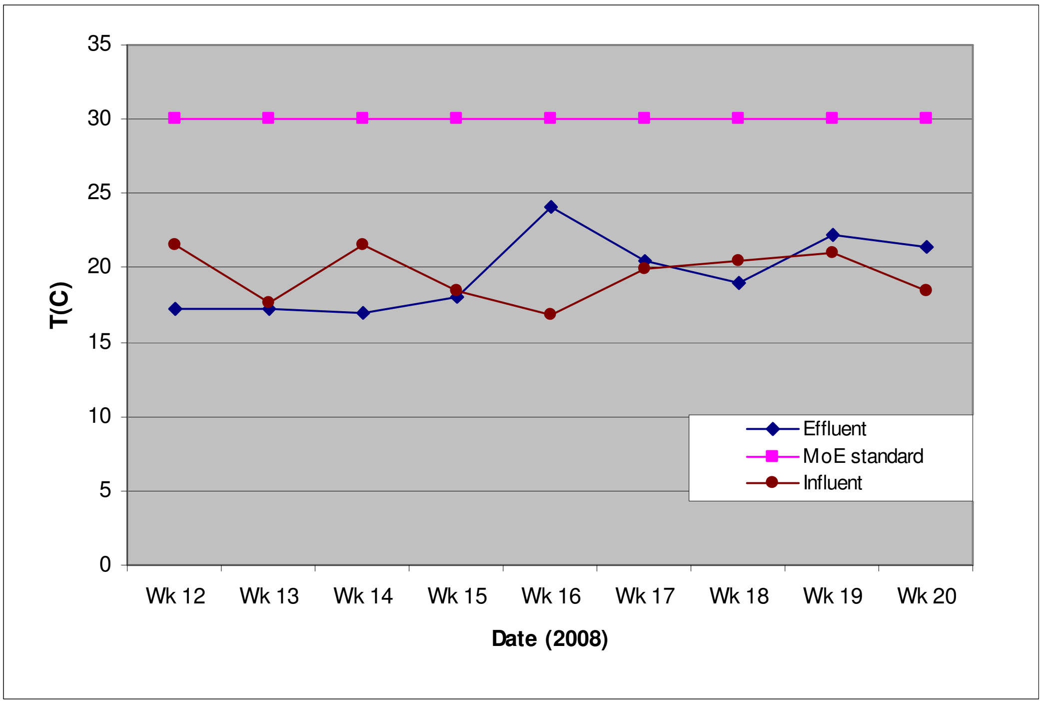


Figure 8: Temperature Variation at the Pilot Plant.



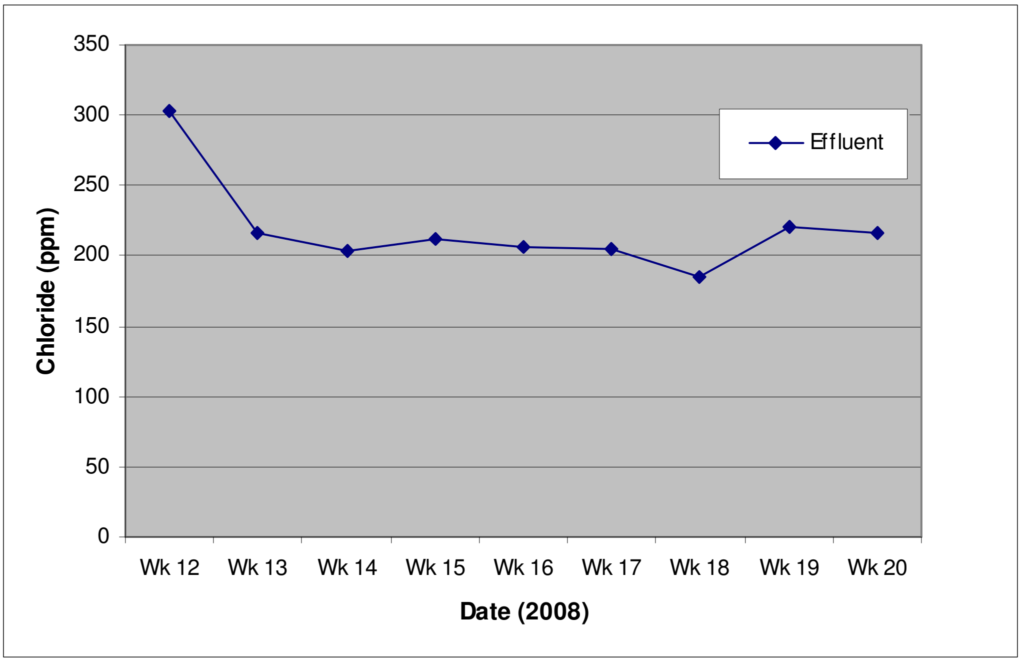
Chlorination:

The principal reason for chlorination of sewage effluent is for disinfection. But sewage treatment cannot completely remove the pathogenic (disease-causing) bacteria which may be present. When effluent may be used for irrigation or recreational purposes, chlorination to kill these harmful bacteria is required; and then dechlorination is necessary to remove the total combined residual chlorine that exists after chlorination.

A chlorine residual of greater than 0.5 ppm must be maintained in the effluent. If the test results are less than that, an increase of the rate of chlorine feed or the strength of solution for disinfection is essential.

Figure9 shows the variation of chloride obtained in the effluent wastewater. The high values can be explained by the normal use of hypochlorite for disinfection followed by dechlorination.

Figure 9: Chloride Variation in the Pilot Plant Effluent.



Statistical Analysis:

In order to evaluate the performance of the pilot plant in a statistical manner, some statistical analysis has been conducted on some major water parameters. All the results obtained for both influent and effluent for BOD5, COD, TSS and NO3 are given in table 4. And the statistical analysis for these parameters shows in table5.

Table4: Influent and Effluent Results for some major parameters.

Date (2008)	Influent				Effluent			
	BOD5 (mg/L)	COD (mg/L)	TSS (mg/L)	NO3 (ppm)	BOD5 (mg/L)	COD (mg/L)	TSS (mg/L)	NO3 (ppm)
Wk12	102	300.0493	3.5	100.88	3	52.4758	4.4185	283.793
Wk13	129	460.321	5.35	150.74	4.1	59.8258	7.5	340.428
Wk14	136	440.657	15	164.6	9.4	84.7414	8.91	240.983
Wk15	107	400.657	13.2	132.76	7	109.336	9.6	260.224
Wk16	110	350.045	12.7	144.97	39	83.1265	7.2	258.85
Wk17	139	387.978	7.8	152.165	40	112.1947	2.044	202.90
Wk18	127	400.134	15	125.25	0.1	263.0725	5.3	215.378
Wk19	117	420.2	10.44	131.48	2.1	110.1184	14.1	213.093
Wk20	126	400.005	6.67	155.287	2.76	154.89	7.36	209.66

Table5: Statistical Analysis for some major Influent and Effluent parameters.

Parameters	Maximum	Minimum	Mean	Standard Deviation
Influent BOD5 (mg/L)	139	102	121.44	13.0682
Effluent BOD5 (mg/L)	40	0.1	11.94	15.8632
Influent COD (mg/L)	460.321	300.0493	395.5085	47.5799
Effluent COD (mg/L)	263.0725	52.4758	114.4201	63.7008
Influent TSS (mg/L)	15	3.5	9.9622	4.2941
Effluent TSS (mg/L)	14.1	2.044	7.3813	3.4287
Influent NO3 (ppm)	164.6	100.88	139.7924	19.3631
Effluent NO3 (ppm)	340.428	202.90	247.2565	44.6124

Kinetic coefficients:

Based on an average wastewater flow of 50 m^3/day, the hydraulic retention time, which is the ratio of reactor volume and flow rate, was calculated to be 1 day. And according to the previous equations given before, the results of their linearization using experimental data achieved are shown in Figures 10 and 11, and the kinetic coefficients are calculated and given in Table 6.

Figure 10: linearization experimental data according to equation 4.

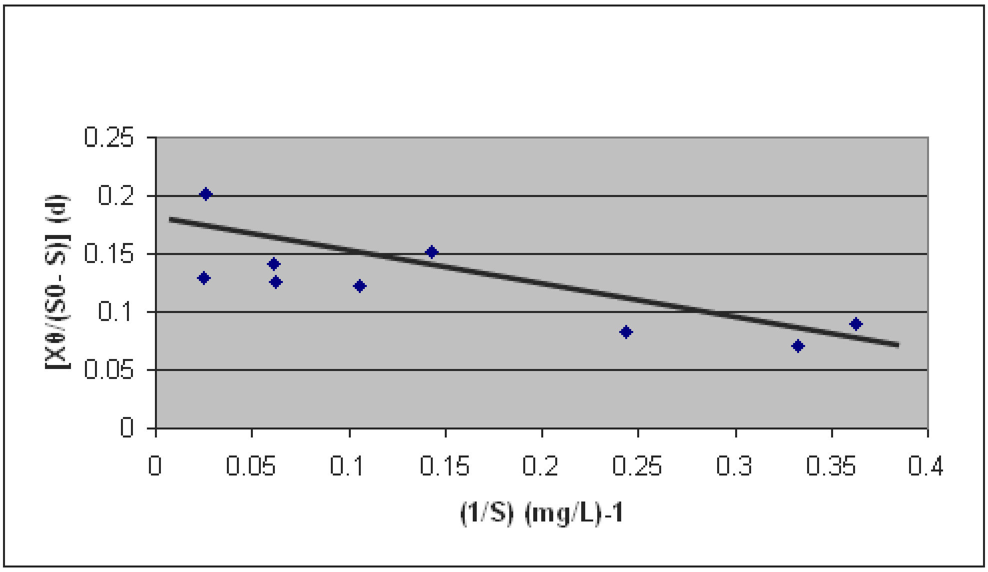
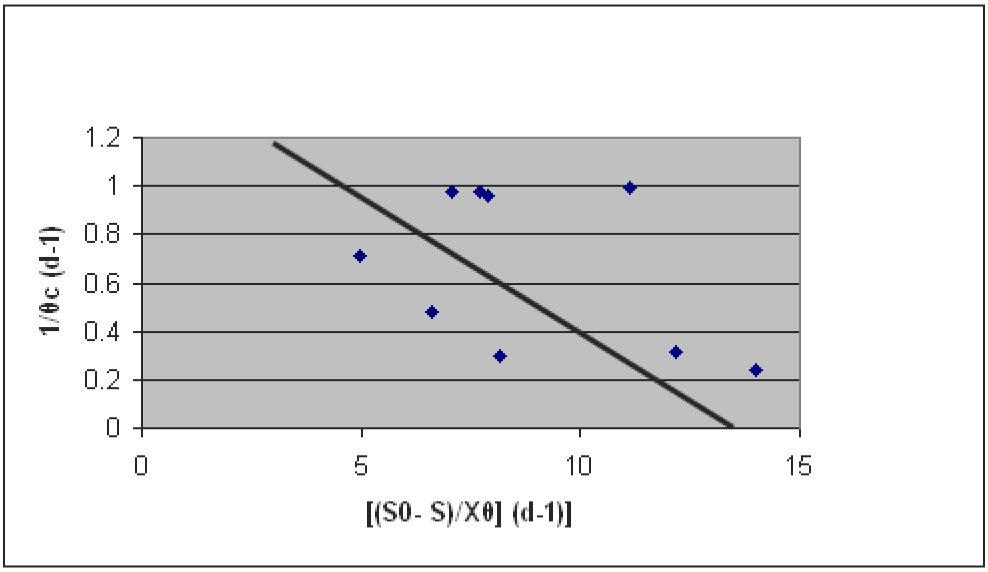


Figure 11: linearization of experimental data according to equation 5.



For Figure 10, the obtained equation is y= -0.28x + 0.18 and for Figure 11, the obtained equation is y= -0.1x +1.4

Table6: kinetic coefficients based on Monod Kinetics (in absolute value).

Parameter	Value
Y	0.1
μ_{max} , d^{-1}	5.555
K_s , mg/L	1.555
K_d , d^{-1}	1.4

Conclusion:

According to the results obtained and statistical analysis for the major parameters (BOD_5, COD, TSS and nitrate), and to the comparison of these values with the standards set by EMCO and the Lebanese MoE, the Pilot Pant at UOB Campus was found to operate properly and normally, which allows the use of the treated water in potential irrigation applications or activities.

References:

- EMCO Engineering Ltd. –Operation and Maintenance Manual (O & M Manual)
- FAO -1992 -Irrigation and Drainage paper 47–Wastewater Treatment and Use in Agriculture
- Frank R. Spellman, Ph.D -1999 –The Science of Environmental Pollution
- K. Karaa, F. Karam, N. Tarabey - 3rd WASAMED Workshop on "Non-Conventional Water Use" -Cairo,6-11 December 2004 – Wastewater Treatment and Reuse in Lebanon: Key policies and Future Scenarios
- MEDAWARE –PART F: water policy and institutional environment – Development of Tools and Guidelines for the Promotion of the Sustainable Urban Wastewater Treatment and Reuse in the Agricultural Production in the Mediterranean Countries
- Metcalf and Eddy -1991 –Wastewater Engineering: Treatment, Disposal and Reuse –McGraw-Hill International Editions –Third Edition
- Dr Najib Nicolas Georges –February 2006 –Master Plan For The Wastewater Treatment Plan For The University of Balamand
- Sven Erik Jorgensen -2000 –Principles of Pollution Abatement – Pollution Abatement for the 21st Century