



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Public Works

Optimization of Sand Filtration Characteristics for Waste Water Treatment

A Thesis submitted in partial fulfilment of the requirements of the degree of
Master of Science in Civil Engineering
(Public Works)

by

Mazen Mohamed Nagib Ahmed Kamal Tawfik
Bachelor of Science in Civil Engineering
(Public Works)
Faculty of Engineering, Ain Shams University, 2019

Supervised By

Prof. Tarek Ismail Sabry,

Professor of Public Works, Faculty of Engineering, Ain Shams University.

Dr. Ahmed Shafik El Gendy,

Assistant Professor of Construction and Architectural Engineering, School of
Sciences and Engineering, The American University in Cairo.

Dr. Sayed Ismail Ahmed,

Assistant Professor of Public Works, Faculty of Engineering, Ain Shams
University.

Cairo - (2019)



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Public Works

Optimization of Sand Filtration Characteristics for Waste Water Treatment

by

Mazen Mohamed Nagib Ahmed Kamal Tawfik

Bachelor of Science in Civil Engineering

(Public Works)

Faculty of Engineering, Ain Shams University, 2019.

Examiners' Committee

Name and Affiliation	Signature
Prof. Osama Fathy Mahmoud Professor of Public Works, Al Azhar University.	
Prof. Mohamed El Hussieny Abdel Rahman Professor of Public Works, Faculty of Engineering, Ain Shams University.	
Prof. Tarek Ismail Sabry Professor of Public Works, Faculty of Engineering, Ain Shams University.	

Date: 17 January 2019

Statement

This thesis is submitted as a partial fulfilment of Master of Science Degree in Civil Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Mazen Mohamed Nagib Ahmed Kamal Tawfik

Signature

.....

Date: 17 January 2019

Researcher Data

Name	:	Mazen Mohamed Nagib Ahmed Kamal Tawfik
Date of birth	:	22-02-1992
Place of birth	:	Saudi Arabia
Last academic degree	:	Bachelor of Science
Field of specialization	:	Civil Engineering
University issued the degree	:	Ain Shams University
Date of issued degree	:	2013
Current job	:	Civil Engineer

Thesis Summary

Improving sanitation systems and treatment technologies that allow for safe discharge into agricultural drains and unrestricted irrigation, must be through solutions that requires reduced environmental impact, lower capital cost and simplified operational procedures for wide application in secluded and rural communities with small populations.

This research work is primarily an investigation of the optimum slow sand filter design configurations, for refining the produced effluent quality of the partially treated wastewater to allow for the reuse in the unrestricted irrigation and decrease the load on the surrounding water bodies. Experimental work has been carried on by the variation of design parameters, and correlating with the effluent quality in terms of pollutants removal efficiencies and effluent passage, locating the optimum variables thereafter.

The work has been done on two phases, the first is aimed to locate the optimum design variables for the slow sand filter, in terms of effective size of the sand media, infiltration rate and filtration depth. Where the second phase is aimed to test two low-cost locally-available filter packing material to be mixed with the previously chosen sand media, to serve as an indicator for future studies and research.

It has been observed that the optimum design parameters for the slow sand filtration (SSF) unit that follows the decentralized wastewater treatment compact units, is utilizing sand media with effective size (D_{10}) = 0.8~1.2 mm, Infiltration rate of $2.68 \text{ m}^3/\text{m}^2/\text{d}$ & filtration depth of 90 cm, will result in pollutants removal efficiency of 63%, 59% & 76% for COD_{tot} , COD_{sol} & TSS concentrations respectively. It has also noticed that when mixing the sand media with a sponge packing material from polyurethane foam, will yield a removal efficiency more than the one resulted from the sand media alone.

Key words: Wastewater treatment, decentralized systems, compact units, rural communities, slow sand filter, packing material.

Acknowledgment

I would like to express my sincere gratitude to my research advisors Prof. Tarek Ismail Sabry, Dr. Ahmed El Gendy and Dr. Sayed Ismail Ahmed for their patience and forbearance. Without their continuous support, this research would not have been progressed above various obstacles and setbacks.

Thank you.

March 2019

Table of Contents

CHAPTER 1	14
1.1 GENERAL	14
1.2 SANITATION SYSTEM IN EGYPT	14
1.3 PROBLEM DEFINITION	15
1.1 RESEARCH OBJECTIVES	15
1.2 CHAPTERS DESCRIPTION	16
1.2.1 CHAPTER 1: INTRODUCTION	16
1.2.2 CHAPTER 2: LITERATURE REVIEW	16
1.2.3 CHAPTER 3: EXPERIMENTAL WORK	16
1.2.4 CHAPTER 4: RESULTS	16
1.2.5 CHAPTER 5: DISCUSSION	17
1.2.6 CHAPTER 4: CONCLUSION	17
CHAPTER 2	18
2.1 GENERAL	18
2.2 CENTRALIZED VERSUS DECENTRALIZED	18
2.3 WASTE WATER TREATMENT STAGES	19
2.4 DECENTRALIZED SYSTEMS	20
2.4.1 SEPTIC TANKS	21
2.4.2 MODIFIED SEPTIC TANKS	22
2.4.3 BAFFLED REACTORS	22
2.4.4 UP-FLOW ANAEROBIC FILTER	23
2.4.5 UPFLOW SEPTIC TANK / ANAEROBIC BAFFLED REACTOR (USBR)	24
2.4.6 ZERO ENERGY COMPACT UNIT (ZECU)	25
2.4.7 DISCUSSION ON THE DECENTRALIZED ANAEROBIC SYSTEMS	26
2.5 FILTRATION	27
2.5.1 GRANULAR FILTRATION MECHANISMS	28
2.5.2 FILTER MEDIA COMPOSITION	30
2.5.3 MOVEMENT OF A SOLUTION THROUGH SOIL	31
2.5.4 SLOW SAND FILTER	32
2.5.5 BIOFILTERS	35
2.5.6 FABRIC FILTRATION	40
CHAPTER 3	43
3.1 INTRODUCTION	43
3.2 PLANT DESCRIPTION	43

3.2.1	PHASE (1) LOACTION	43
3.2.2	ZECU SYSTEM.....	44
3.3	PHASE (2) LOCATION.....	46
3.3.1	SAND FILTARTION UNIT	47
3.4	FILTRATION MODEL	52
3.4.1	FILTRATION MEDIA	52
3.4.2	INFILTRATION RATE.....	54
3.4.3	FILTRATION DEPTH	54
3.5	WORK PLAN	54
3.5.1	TESTING METHODOLGY	54
3.5.2	RUN (1).....	55
3.5.3	RUN (2).....	56
3.5.4	RUN (3).....	56
3.5.5	RUN (4).....	57
3.5.6	RUN (5).....	57
3.6	SAMPLING	57
3.6.1	RUN (1) SAMPLING PLAN	58
3.6.2	RUN (2) SAMPLING PLAN	59
3.6.3	RUN (3) SAMPLING PLAN	60
3.6.4	RUN (4) SAMPLING PLAN	60
3.6.5	RUN (5) SAMPLING PLAN	61
3.7	TESTING	62
3.7.1	TOTAL CHEMICAL OXYGEN DEMAND (COD _{tot}) & SOLUBLE CHEMICAL OXYGEN DEMAND (COD _{sol}). (mg/L).....	62
3.7.2	TOTAL SUSPENDED SOLIDS (TSS.) (mg/L)	62
3.7.3	TOTAL BACETRIAL COUNT (CFU/100ml)	63
3.8	EGYPTIAN LAW 48/1982 LIMIT	63
CHAPTER 4		64
4.1	INTRODUCTION.....	64
4.2	PHASE (1).....	64
4.2.1	RUN (1).....	64
4.2.2	RUN (2).....	70
4.2.3	RUN (3).....	75
4.2.4	RUN (4).....	81
4.2.5	PRE-SEDIMENTATION.....	85
4.3	PHASE (2).....	86
4.3.1	SAMLING UNDER THE DIRTY SKIN	87
4.3.2	SAMPLING AT THE BOTTOM OF THE FILTRATION COLUMN	92
CHAPTER 5		96

5.1	INTRODUCTION.....	96
5.1.1	GENERAL	96
5.1.2	PHASE (1) SEQUENCE.....	98
5.1.3	PHASE (2) SEQUENCE.....	99
5.1.4	ANALYSIS OF PHASE 1	100
5.1.5	ANALYSIS OF PHASE 2	110
CHAPTER 6		120
REFERENCES.....		123
ANNEX I		131
5.2	INTRODUCTION.....	131
5.3	PROCESS COMPARISON.....	132
5.3.1	SLOW SAND FILTERS	132
5.3.2	FABRIC FILTERS.....	133
5.4	OPERATION COMPARISON	134
5.4.1	FLUX RATE.....	134
5.4.2	REMOVAL PREFORMANCE.....	134
5.4.3	EFFLUNET PASSAGE	134
5.5	ENVIRONMENTAL FOOTPRINT.....	135
5.6	COST ANALYSIS	135
5.7	COMPARISON SUMMARY	137

List of Figures

Figure 1: Waste Water Treatment Stages.....	20
Figure 2: Conventional Septic Tank.....	21
Figure 3: Baffled Reactor.....	23
Figure 4: Up-flow anaerobic filter.	23
Figure 5: USBR system.....	24
Figure 6: Zero Energy Compact Unit (ZECU).....	25
Figure 7: (a) Depth Filtration and (b) Surface Filtration.....	27
Figure 8: Trickling Filter.....	36
Figure 9: Fluidized Bed Reactor	37
Figure 10: Downflow Hanging Sponge reactor	39
Figure 11:Zawyet El-Karadsa WWTP.	44
Figure 12: The ZECU system in Zawyet El-Karadsah WWTP.	45
Figure 13: Schematic labeled diagram for the ZECU system.	45
Figure 14: Zenen Wastewater Treatment Plant.....	46
Figure 15: Holding tank, Mixing & Influent pump.....	47
Figure 16: Sand Filtration Unit (setup in Zawyet El Karadsah WWTP).	49
Figure 17: Schematic drawing for the sand filtration unit following the ZECU system.....	50
Figure 18: Sand Filtration Unit following Primary Treatment, Zenen WWTP.	51
Figure 19: Plastic Packing Material	53
Figure 20: Sponge Packing Material	53
Figure 21: COD _{tot} % removal efficiency through run (1).....	67
Figure 22: COD _{sol} % removal efficiency through run (1)	68
Figure 23: TSS % removal efficiency through run (1).....	68
Figure 24: COD _{tot} % removal efficiency through run (2).....	73
Figure 25: COD _{sol} % removal efficiency through run (2)	73
Figure 26: TSS % removal efficiency through run (2).....	74
Figure 27: COD _{tot} % removal efficiency through run (3):.....	78
Figure 28: TSS % removal efficiency through run (3).....	79

Figure 29: CODsol % removal efficiency through run (3)	79
Figure 30: Results of the 1 st day of run (5) (under the biological skin)	88
Figure 31: Results of 7 th day of run (5) (under the biological skin).....	89
Figure 32: Results of 14 th day of run (5) (under the biological skin).....	89
Figure 33: Results of 21 st day of run (5) (under the biological skin)	90
Figure 34: Results of 28 th day of run (5) (under the biological skin).....	90
Figure 35: Average removal efficiencies through run (5) (under the biological skin)	91
Figure 36: Results of 1 st day of run (5) (at 90 cm filtration depth)	92
Figure 37: Results of 7 th day of run (5) (at 90 cm filtration depth).....	93
Figure 38: Results of 14 th day of run (5) (at 90 cm filtration depth).....	93
Figure 39: Results of 21 st day of run (5) (at 90 cm filtration depth)	94
Figure 40: Results of 28 th day of run (5) (at 90 cm filtration depth).....	94
Figure 41: Average removal efficiencies & recovery ratio through run (5) (at 90 cm filtration depth).....	95
Figure 42: Phase (1) experimental work flow chart.	98
Figure 43: Phase (2) experimental work flow chart.	99
Figure 44: Average % Removal Efficiency of COD _{tot} Concentration for All media (A, B & C) & Filtration Depth (60cm).....	101
Figure 45: Average % Removal Efficiency of COD _{sol} Concentration for All media (A, B & C) & Filtration Depth (60cm).	102
Figure 46: Average % Removal Efficiency of TSS Concentration for All media (A, B & C) & Filtration Depth (60cm).	103
Figure 47: % Recovery Ratio for the Filtration Column over the Run Duration Media A - Infiltration Rate (2, 4 & 6 m ³ /m ² /d) - Depth (60cm)..	103
Figure 48: % Recovery Ratio for the Filtration Column over the Run Duration Media B - Infiltration Rate (2, 4 & 6 m ³ /m ² /d) - Depth (60cm)..	104
Figure 49: % Recovery Ratio for the Filtration Column over the Run Duration Media C - Infiltration Rate (2,4 & 6 m ³ /m ² /d) - Depth (60cm)...	104
Figure 50: % Average Recovery Ratio for the Filtration Column over the Run Duration Media (A, B & C) - Infiltration Rate (2,4,6 m ³ /m ² /d) - Depth (60cm).	105

Figure 51: Relation Between % Removal Efficiency & % Recovery Ratio Media (A, B & C) - Infiltration Rate (2, 4 & 6 m ³ /m ² /d) - Depth (60cm) ..	105
Figure 52: % Removal Efficiency of COD _{tot} versus Time Filtration Depth (60, 90, 120 & 150cm) w/ Sand Media B (0.8~1.2 mm) & IR = 4 m ³ /m ² /d.	107
Figure 53: % Removal Efficiency of COD _{sol} versus Time Filtration Depth (60, 90, 120 & 150cm) w/ Sand Media B (0.8~1.2 mm) & IR = 4 m ³ /m ² /d	108
Figure 54: Relation Between % Removal Efficiency & % Recovery Ratio Media (B) - Infiltration Rate (4 m ³ /m ² /d) - Depth (60, 90, 120 & 150cm)	109
Figure 55: % Removal Efficiency of COD _{tot} versus Time for all Media (B, D & E) at constant Infiltration Rate (4 m ³ /m ² /d) and Filtration Depth (90 cm)	110
Figure 56: % Removal Efficiency of COD _{sol} versus Time for all Media (B, D & E) at constant Infiltration Rate (4 m ³ /m ² /d) and Filtration Depth (90 cm)	111
Figure 57: % Removal Efficiency of TSS versus Time for all Media (B, D & E) at constant Infiltration Rate (4 m ³ /m ² /d) Filtration Depth (90 cm)	112
Figure 58: % DO consumption versus Time for all Media (B, D & E) at constant Infiltration Rate (4 m ³ /m ² /d) and Filtration Depth (90 cm)	113
Figure 59: % Removal Efficiency of Total Bacterial Count (at 22° C) versus Time for all Media (B, D & E) at constant Infiltration Rate (4 m ³ /m ² /d) and Filtration Depth (90 cm)	114
Figure 60: % Removal Efficiency of Total Bacterial Count (at 37° C) versus Time for all Media (B, D & E) at constant Infiltration Rate (4 m ³ /m ² /d) and Filtration Depth (90 cm)	115
Figure 61: Average relation between all parameters for Media (B, D & E) at Infiltration Rate (4 m ³ /m ² /d) and Filtration Depth (90 cm)	116

List of Tables

Table 1: Principal mechanism and phenomena contributing to removal of material within a granular medium depth filter.....	29
Table 2: Filtration unit sand media characteristics.....	52
Table 3: Experimental work programme.	55
Table 4: Run (1) sampling plan.....	58
Table 5: Run (2) sampling plan.....	59
Table 6: Run (3) sampling plan.....	60
Table 7: Run (4) sampling plan.....	61
Table 8: Run (5) sampling plan.....	61
Table 9: Results of 1 st day of run (1).....	65
Table 10: Results of 3 rd day of run (1)	65
Table 11: Results of 5 th day of run (1)	66
Table 12: Result of 7 th day of run (1).....	66
Table 13: Average removal efficiencies & recovery ratio through run (1)....	69
Table 14: Results of 1 st day of run (2).....	70
Table 15: Results of 3 rd day of run (2)	71
Table 16: Results of 5 th day of run (2)	71
Table 17: Results of 7 th day of run (2)	72
Table 18: Average removal efficiencies & recovery ratio through run (2)....	75
Table 19: Results of 1 st day of run (3).....	76
Table 20: Results of 3 rd day of run (3)	76
Table 21: Results of 5 th day of run (3)	77
Table 22: Results of 7 th day of run (3)	77
Table 23: Average removal efficiencies & recovery ratio through run (3)....	80
Table 24: Results of 1 st day of run (4).....	81
Table 25: Results of 3 rd day of run (4)	82
Table 26: Results of 5 th day of run (4)	82
Table 27: Results of 7 th day of run (4)	83
Table 28: Average removal efficiencies & recovery ratio through run (4)....	84
Table 29: Cost comparison between SSF & fabric filter unit.	136
Table 30: Comparison summary between SSF & fabric filter unit.....	137

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the current state of social expansion, many developing countries are facing a challenge in providing adequate & reliable sanitation systems to cope with the increasing load on the treatment facilities, not to mention the need for more economically reliable solutions to increase the probability of installation in small communities & dispersed geographical locations.

The centralized waste water treatment systems are not essentially feasible to construct on small scale communities. Meanwhile, the construction of extensive water networks to connect the dispersed locations to such centralized systems is no longer an option. It has become crucial to invest in the development of decentralized systems that is both feasible to construct & easy to operate. Utilizing such approach will allow for flexible installation & simple operation, in contrast to the centralized systems.

1.2 SANITATION SYSTEM IN EGYPT

The government of Egypt has been witnessing a change in approaching the subject of rural sanitation in the past decade, due to the observed decrease of water quality in the Nile river & branched raw water bodies.

The water supply sector is prioritized higher than the supply sector in most of the previous investment plans, though the investment plans has been increasing to be relocated to the sanitation sector in addition to the supply sector. ⁽¹⁾⁽²⁾ Nonetheless, it is more important to collect all the water supplied through the various networks & construct the required treatment systems for such supply with each intended use. ⁽³⁾

Currently, 85% of rural Egypt does not have sanitation systems ⁽⁴⁾, and households devise informal solutions to treat & dispose waste water in relation to its current financial capabilities. Septic tanks are commonly

utilized as a simple & cheap solution for sanitation. However, smaller communities will simply dispose waste water away from their premises, in other cases service providers & collection facilities for those communities, will tend to take the same approach for disposal where supervision is not existed, thus disposing in waterways & irrigation networks.

Add to that the ground infiltration to the surrounding soil structure, not only from the direct discharge but from the simple limitations of treatment solutions; leakages from septic tanks & collection facilities, all that adds to the degradation of the water quality of the ground water bodies and posing environmental hazard on the surrounding areas.

1.3 PROBLEM DEFINITION

Major part of rural Egypt lack adequate sanitation systems for treating waste water emerging from the areas geographically away from the centralized systems, also continuously discharging raw waste water to water bodies is impacting the water quality & posing an environmental hazard at the raw water sources.

Conventional centralized waste water treatment systems require high cost of construction & complicated operational requirements, making it less adequate to be used for small dispersed communities.

The above has increased the need for low cost & easy to operate decentralized systems for treating waste water, that allow for reuse in unrestricted irrigation, to cope with the expanding social development in such communities.

1.1 RESEARCH OBJECTIVES

The research main objective is focusing on improving the partially treated water quality, either resulting from a low cost compact unit installed in an existing waste water treatment plant, or directly from the plant itself, by improving existing technology and optimizing system performance. The treatment of the waste water will aim for producing an effluent in compliance with the Egyptian law 48/1982 limits for discharge in agricultural drains with low cost sustainable solutions.